Town of Barnstable, Massachusetts

Comprehensive Wastewater Management Plan / Single Environmental Impact Report



Volume 2: Appendices

November, 2020

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208 PLAN

Cape Cod Area Wide Water Quality Management Plan Update



Cape Cod Area Wide Water Quality Management Plan Update
June 2015

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COMMISSION

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http://www.capecodcommission.org/208/appendices

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Cape Cod Water Protection Collaborative

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Cape Cod Chamber of Commerce

Association to Preserve Cape Cod

Working Group Stakeholders

Plan Summary

Updating Section 208

This report documents an update to the 1978 Section 208 Plan for Cape Cod. In a January 30, 2013 letter, the Massachusetts Department of Environmental Protection directed the Cape Cod Commission to prepare an update to the 1978 Water Quality Management Plan for Cape Cod to address the degradation of Cape Cod's water resources from excessive nutrients, primarily nitrogen.

In 1978 the plan identified increasing residential densities and a three-fold summer population influx as the cause of isolated water quality and wastewater management problems. It anticipated that future growth threatened to cause more serious groundwater contamination and increased eutrophication in surface waters. Today, the region is facing the impacts of that growth and working to maintain the environmental integrity that is so vital to the economy of this special place.

Cape Cod has a water problem. The saltwater border that has defined our peninsula is being poisoned by nitrogen. The rapid decrease in the water quality of Cape Cod's marine ecosystems is plain to see. The problem is nitrogen and the largest controllable source is the septic systems used every day.

For over a decade the Massachusetts Department of Environmental Protection (MassDEP), the Cape Cod Commission (Commission) and the Massachusetts Estuaries Project (MEP) at the University of Massachusetts-Dartmouth have worked with the 15 Towns on Cape Cod to research and diagnose the problem. In January 2013 the Commonwealth of Massachusetts used the Federal Clean Water Act and directed the Commission to update the 1978 Section 208 plan for Cape Cod. The designation and direction were accompanied by a short time-frame and a focus on nitrogen.

Massachusetts saw the opportunity to use this approach on Cape Cod as a way to combine the independent efforts underway and develop strategies and investigate new technologies and policies to address the looming environmental and economic crises.

The Commission worked with hundreds of people across the region and filed a draft Section 208 Plan Update in June 2014. MassDEP and US EPA reviewed the draft and it was offered for an extended period of public comment in August that closed in November 2014.

THE PROBLEM

Nitrogen is impacting coastal water quality. About 80% of the nitrogen that enters Cape Cod's watersheds is from septic systems. The conditions it creates destroy animal habitat and result in frequent violations of water quality standards indicated in part by fish kills and diminished shellfisheries. The Cape Cod seasonal economy relies on the water that surrounds the region and the degraded water quality is negatively impacting important economic drivers including coastal property values. Restored coastal water quality is an environmental and economic imperative; however, the current planning and regulatory environment makes it difficult for communities to identify cost effective, implementable solutions.

Plan Summary

TOTAL MAXIMUM DAILY LOADS

HOW MUCH IS TOO MUCH?

A Total Maximum Daily Load (TMDL) is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. TMDL's are technical planning documents and are not, in and of themselves, enforceable documents requiring compliance. Federal, state and local authorities implement TMDL's by incorporating the limit as part of other enforceable legal instruments, such as Massachusetts groundwater discharge permits in the case of some nonpoint sources of pollution or National Pollutant Discharge Elimination System (NPDES) permits in the case of NPDES-regulated point source discharges. TMDL's are useful in quantifying goals for reducing or eliminating pollutants that degrade conditions in a waterbody measured qualitatively as fishable and swimmable by the federal Clean Water Act.

As detailed below, the Commonwealth and the University of Massachusetts School for Marine Science and Technology (SMAST) established the Massachusetts Estuaries Project (MEP) which has been working to determine the maximum amount of nitrogen Cape Cod marine ecosystems can accept without becoming eutrophic.

THE COST OF DOING NOTHING

Cape Cod's water resources drive the regional economy. They attract visitors in the summer months and make the Cape a desirable place to live for year-round and seasonal residents. Continuing and increasing nitrogen loading of Cape Cod's embayment watersheds will further degrade coastal water quality, adversely impacting environmental, economic, and societal norms. The economic impact of doing nothing to restore coastal water quality will be significant, affecting every homeowner in the region.

3VS

The Cape Cod Triple Value Simulation (3VS) model is one resource being developed to consider the broader environmental and societal costs of environmental degradation. As a sustainability assessment tool, the 3VS model applies systems thinking to the problem of nitrogen pollution in Cape Cod embayments. Phase 1 of the model will estimate the potential social, economic and environmental costs of not taking action to mitigate projected increases in nitrogen loadings to Cape Cod embayments. Phase 2 of the model will include a comparison of policy intervention scenarios to evaluate direct and indirect costs and benefits of different potential actions to reduce nitrogen loadings. The 3VS model incorporates data sets from around the country to estimate costs associated with inaction.

Case Study: Three Bays

THREE BAYS: ESTIMATED IMPACT OF NITROGEN ON PROPERTY VALUES

A study evaluating home prices in the Three Bays area in the Town of Barnstable was conducted to test the hypothesis that water quality degradation resulting from nitrogen pollution impacts single-family home sale prices negatively. Single-family properties within 1,000m or about 10 minutes walking distance from the waterfront comprise the study area. The model estimates the impact of water quality – nitrogen levels – on home sale prices, controlling for property attributes, macroeconomic influences, proximity to public beaches, distance to water. The time period of the analysis is between 2005 and 2013.

Initial findings demonstrate a 1% increase in nitrogen is associated with a decrease in single-family home sale prices in the range of 0.407% to 0.807% (average 0.61%), with a 95% confidence level. During the study period the water quality in Three Bays degraded by 15.8%. The above range of estimated decrease translates into a noticeable fiscal impact on the community, both in terms of decrease in sale price and consequent impact on the assessed value.

Case Study: Three Bays cont.

For example, if the discharge of nitrogen into Three Bays waters was lessened resulting in a 3% decrease in total nitrogen level, average single-family home sale prices in the study area would have been $16,774 to $32,957 higher than in 2013. That translates into potential sale value loss (and consequent assessed value loss) in the range of $49 to $86 million in the study site alone (1,000m or ten-minute walking distance to the waterfront). No action in 2015 will bring additional loss of home value to Cape Cod due to degrading water quality from nitrogen.

Cape Cod's environment is linked directly to its economy. The nitrogen problem is a significant threat to both. Continued degradation of the coastal resources on Cape Cod will negatively impact the seasonal and year-round economies, affecting property values for year-round residents and second homeowners, and shifting property tax burdens away from higher value seasonally occupied coastal properties on to middle class year-round residents.

Cape Cod – Defined by Water

UNDERSTANDING THE PEOPLE AND THE PLACE BEFORE CONSIDERING SOLUTIONS

A glacial deposit created Cape Cod as a peninsula with Cape Cod Bay to the north, Nantucket Sound to the south, the Atlantic Ocean to the east, and a significant part of the western coastline bounded by Buzzards Bay. With the construction of the Cape Cod Canal circa 1914, the land mass became surrounded by water. Cape Cod has 560 miles of coastline, nearly 1,000 kettlehole ponds and a sole source aquifer.

LAND USE

Cape Cod's great natural beauty, bountiful recreational opportunities and proximity to major urban areas led to a rapid increase in population over the last half century. The Cape's traditional farming and fishing way of life underwent a slow transformation from the 1870s through the early part of the 20th century as seaside resorts began to attract summer visitors. The advent of rail travel and the adoption of the interstate highway system added to the accessibility and the popularity of Cape Cod. The population began to rise more quickly in the 1950s and even more steeply from the 1970s through the early 2000s, as Cape Cod became a desired location for retirees and second-home buyers. Most of this development was residential with associated commercial, industrial, and tourism-based land uses.

In the past several decades the number of people living year-round on Cape Cod increased, with a concomitant conversion of seasonal homes for year-round use. The 2010 US Census listed about 57,000 seasonal housing units, or approximately one third of the housing stock on Cape Cod. These seasonal homes are much more prevalent in coastal areas than inland on Cape Cod.

Balancing natural and human-built systems remains both a challenge and an opportunity. Open space in more sensitive areas improves the ability of the natural environment to further absorb human impacts as well as counteracting naturally occurring uncontrollable nitrogen loads from atmospheric deposition. Conversely, sprawling patterns of growth tend to increase infrastructure costs and make the delivery of services such as public transit less practical. The location of infrastructure and public facilities, and zoning support and drive land use patterns. The development of infrastructure, from wastewater to telecommunications, will be essential to regional economic growth that doesn't degrade the human or natural environment.

Plan Summary

WATER RESOURCES

MARINE WATER

Watersheds define the jurisdiction of the nitrogen problem.

Cape Cod is defined by and dependent on the marine environment that surrounds it. Nutrients and pollutants from land use development, including wastewater, are conveyed through groundwater to surrounding marine waters with concentrations and directional flows determined by watersheds.

Similar to water supply wells, watersheds to embayments are defined by groundwater flow paths of the aquifer. There are 101 watersheds to the surrounding marine waters. Of those, 53 are watersheds to coastal embayment systems, or partially enclosed coastal areas with varying degrees of tidal restriction. Coastal embayments are located at the margin of the aquifer and are the ultimate receiver of the aquifer's groundwater discharge.

Watersheds to coastal embayments extend from the coastline up to the top of the water table lens, located along the spine of the peninsula. They comprise nearly 79% of the land area of Cape Cod. The remaining land area is comprised of watersheds where groundwater discharges directly to open coastal water such as the Cape Cod Canal, Nantucket Sound, Cape Cod Bay and the Atlantic Ocean. These areas may be important to local nitrogen removal, remediation and restoration efforts given their decreased nitrogen sensitivity.

GROUNDWATER

The hydrogeology of Cape Cod is largely composed of coarse sands with considerable permeability. The travel time for wastewater pollutants from their initial entrance into groundwater to the point when they reach an embayment can be up to 100 years, but is less than 10 years across almost half of the region. This presents the likelihood that wastewater treatment options, once implemented, will result in water quality improvements within 5-10 years in some of its polluted embayments.

The Cape Cod Aquifer is one of the most productive groundwater systems in New England and provides 100% of the Cape's drinking water. It is a sole source aquifer providing drinking water to over 650,000 people during the peak tourist season and is derived from 158 gravel-packed municipal supply wells providing public water service to 85% of Cape Cod, and hundreds of private wells providing service to 15% of Cape Cod in the communities of Sandwich, West Barnstable, Eastham, Wellfleet and Truro. The aquifer is recharged from rain and ultimately conveys that water to the surrounding embayments, if not otherwise captured by wells and groundwater-fed ponds.

The Cape Cod Aquifer is extremely susceptible to contamination from various land uses and activities. The aquifer has been seriously impacted in the past from military activities, gas stations, landfills and other activities. The quality of Cape Cod's community public drinking water supply is generally very good, but over the past 15 years there has been a trend toward some degradation.

PONDS

The lakes and ponds on Cape Cod formed about 12,000 years ago during the last stage of the Wisconsinan glaciation. As glaciers retreated from Cape Cod, large chunks of ice were left behind. As these chunks of ice melted, the landscape above them collapsed, forming large depressions called kettle holes. Where these depressions dip below the groundwater table, they are filled with water and create the hundreds of ponds that exist on Cape Cod today.

Cape Cod has 996 ponds covering nearly 11,000 acres. These ponds range in size from less than an acre to 735 acres, with the 21 biggest ponds making up nearly half of the total Cape-wide pond acreage. Approximately 40% of the ponds are less than an acre. One hundred and sixty six are designated as great ponds of 10 acres or more.

Cape Cod's freshwater ponds are fragile systems especially vulnerable to pollution and human activity. The key nutrient of concern for freshwater ponds is phosphorus. Water quality in Cape Cod ponds is significantly impacted by surrounding development. A comparison of 1948 and 2001 dissolved oxygen concentrations suggest that many of these pond ecosystems are not only impacted, but also seriously impaired.

The fresh water ponds of Cape Cod provide a significant benefit in removing nitrogen as it moves through the watershed. Ponds provide natural attenuation of nitrogen in groundwater and are an important consideration in watershed planning, as they act as "nitrogen filters."

Existing Regulatory and Planning Framework

Water quality goals for the nation, the state, municipalities, districts and specifically for Cape Cod are reflected in a number of laws, regulations and plans, some regulating the problem and others focused more on the regulation of proposed solutions that can be identified in two categories – regulating the problem and regulating the solutions. The federal Clean Water Act and the state Title 5 regulations focus on the problem. The Massachusetts Environmental Policy Act, the Cape Cod Commission Regional Policy Plan and other local ordinances impact the siting of potential solutions on Cape Cod.

REGULATING THE PROBLEM

CLEAN WATER ACT

The US EPA regulates water quality under the Federal Water Pollution Control Act of 1972 and its subsequent amendments in 1977, 1981, and 1987. Collectively these are known as the Clean Water Act. The objective of the act is to maintain and restore the chemical, physical and biological integrity of US waters. The act requires states to establish ambient water quality standards for water bodies based on the need to protect the use(s) designated for that water body.

The Act regulates point sources under the National Pollutant Discharge Elimination System (NPDES) permit program. In most cases, the NPDES permit program is administered by authorized states on behalf of US EPA. Massachusetts is one of a handful of states that is not a delegated NPDES permit state; however, permits are jointly issued by the US EPA and the MassDEP and are equally and separately enforceable by both agencies.

Point Sources

The definition of a point source of pollution as stated in §502(14) of the Federal Clean Water Act is "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged."

The Clean Water Act authorizes US EPA and states to regulate point sources that discharge pollutants into navigable waters of the United States through the NPDES permit program. These "point source" discharges are generated from a variety of residential, municipal and industrial operations, including treated wastewater, process water, cooling water, and stormwater runoff. The NPDES Stormwater Program regulates discharges from municipal separate storm sewer systems (MS4s), construction activities, industrial activities, and those designated by US EPA due to water quality impacts.

Nonpoint Sources

The term "nonpoint source" is defined as any source of water pollution that does not meet the above legal definition of a "point source." Nonpoint sources are typically described as those emanating from precipitation that has picked up natural and human-made pollutants as it moves over and through the ground. The US EPA lists fertilizers,

herbicides, pesticides, oil and grease, sediments and bacteria, and nutrients from "faulty septic systems" as examples of nonpoint source pollutants.

MASSACHUSETTS SURFACE WATER QUALITY STANDARDS

Following the federal law and as prescribed by the Federal Clean Water Act, the Commonwealth of Massachusetts adopted surface water quality standards for individual water bodies. The standards designate the most sensitive uses for which the water body must be "enhanced, maintained, and protected" (whether or not the designated use is currently attained), prescribe minimum water quality criteria necessary to sustain the designated uses and contain the regulations necessary to achieve and maintain the designated use and, where appropriate, prohibit discharges.

Massachusetts divides coastal and marine surface waters into three classes: SA, SB, and SC, in descending order of the most sensitive uses that water body must attain. Additionally the state has special designations of Outstanding Resource Waters, Special Resource Waters, Shellfish (waters), and Warm Water.

IMPAIRED WATERS AND TOTAL MAXIMUM DAILY LOADS

The Clean Water Act, under s.305(b) , requires states to assess the quality of surface waters based on the designated uses biennially (every 2 years) and to develop a list, referred to as the 303(d) list, of impaired waters—those waters that do not meet the designated uses. The most recent impaired waters list for MA, including Cape Cod waters, is the Massachusetts Year 2012 Integrated List of Waters; however, a draft 2014 list is also available. Under §303(d) of the Clean Water Act, states are required to:

- Identify those water bodies that are not expected to meet the Surface Water Quality Standards; and,
- Establish, subject to US EPA approval, for those waters total maximum daily loads (TMDLs) - a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards.

On Cape Cod, state-developed TMDLs are based on technical reports prepared by MEP. TMDLs are formulated by MassDEP and submitted to the US EPA for approval after public comment.

TITLE 5

MassDEP regulates wastewater flows less than 10,000 gallons per day under 310 CMR 15.000: The State Environmental Code, Title 5: Standard Requirements for the Siting, Construction, Inspection, Upgrade and Expansion of On-Site Sewage Treatment and Disposal Systems and for the Transport and Disposal of Septage (typically referred to as Title 5). Most of Cape Cod's development is regulated by Title 5. Only 5of the 15 municipalities on Cape Cod utilize centralized collection and advanced treatment. Title 5 covers such uses as conventional on-site septic systems, alternative systems, such as denitrifying systems (often called "Innovative/Alternative," or I/A, systems), as well as composting toilets and other kinds of systems in use on individual properties or cluster developments. Title 5 presumes residential wastewater flows at 110 gallons per day per bedroom (e.g., Title 5 presumes that a four-bedroom house will generate 440 gallons per day). Non-residential wastewater generation is typically based on use and square footage, or the number of restaurant seats.

MassDEP may identify certain areas as particularly sensitive to pollution from on-site wastewater systems and therefore require the imposition of loading restrictions. These Nitrogen Sensitive Areas (NSAs) include:

- Interim Wellhead Protection Areas and department-approved Zone IIs of public water supplies
- Areas with private wells

- Nitrogen-sensitive embayments or other areas, which are designated as nitrogen sensitive under Title 5 based on appropriate scientific evidence

The nitrogen-loading restrictions in NSAs apply to new construction only and do not affect existing Title 5 systems unless they are deemed to have failed or are required to be upgraded at the time of property transfer. To date, MassDEP has been reluctant to designate NSAs on Cape Cod because they don't solve the problem..

GROUNDWATER DISCHARGE PERMIT PROGRAM

Flows in excess of 10,000 gallons per day are regulated under the state Groundwater Discharge Permit Program. Systems requiring a groundwater discharge permit require significant removal of nitrogen because the Cape Cod Aquifer is designated as a non-degradation resource. Groundwater discharge permits for Cape Cod require an effluent treatment level of at least 10 milligrams per liter of nitrate, which is almost a two-thirds reduction in the amount of nitrogen leaving a septic system. In the last 10 years, groundwater discharge permits for projects located in watersheds to impaired embayments have been held to a "no-net nitrogen" standard by MassDEP. This means that any nitrogen released into the watershed must be "offset" by the removal of nitrogen from an existing source. To date, this typically occurs by connecting a nearby existing development to remove nitrogen via wastewater treatment.

REGULATING THE SOLUTION

COMPREHENSIVE WASTEWATER MANAGEMENT PLANS

Currently, individual municipalities develop Comprehensive Wastewater Management Plans (CWMPs) within town boundaries. These plans include watersheds that are both wholly within town boundaries, and shared with a neighboring town(s). MassDEP considers requests for municipal permits and financing after the state level environmental scoping review is conducted under the Massachusetts Environmental Policy Act (MEPA).

The MassDEP Division of Municipal Services Guide to Comprehensive Wastewater Management Planning outlines the process for development of a CWMP. According to the guidance, "The planning exercise requires a community to perform a needs analysis: identifying problem areas."

CWMPs have traditionally recommended conventional wastewater sewer collection and treatment facilities, which require groundwater discharge permits and sewer construction permits.

MASSACHUSETTS ENVIRONMENTAL POLICY ACT AND OTHER STATE REGULATIONS

Comprehensive Wastewater Management Plans typically require MEPA review prior to state and regional permitting. MEPA review involves scoping proposed projects for their potential environmental impacts, identifying alternatives, and avoiding, minimizing or mitigating environmental impacts. CWMPs are typically filed first as an Environmental Notification Form (ENF) or Expanded ENF with a Draft Environmental Impact Report (DEIR) and released for public comment. At the end of public comment, the Secretary of Energy and Environmental Affairs will issue a Certificate of Adequacy that outlines additional information or analysis that should be conducted prior to the next MEPA filing. The final MEPA filing is a Final Environmental Impact Report (FEIR). Upon the Secretary's issuance of a Certificate of Adequacy for an FEIR, appropriate state agencies and the Cape Cod Commission then commence their regulatory reviews. In addition to MassDEP regulatory review, other state agency permits may include: Massachusetts Natural Heritage and Endangered Species Program; Massachusetts Historical Commission; Massachusetts Division of Marine Fisheries, and others.

REGIONAL POLICY PLAN

The Cape Cod Commission Act (Act) established a Commission regulatory function to review and approve, condition, or deny development projects that exceed Development of Regional Impact (DRI) thresholds. The Act includes a provision that the Commission develop and implement a Regional Policy Plan (RPP) that contains the minimum performance standards (MPS) for its regulatory

review of proposals. The Commission published the first version of the Regional Policy Plan in 1991; it has been updated and revised every five years. All revisions to the RPP are approved as ordinances by the Barnstable County Assembly of Delegates, the regional government's elected legislative body.

A Development of Regional Impact is a proposed development that is likely to present development issues significant to more than one municipality in Barnstable County. Projects are referred to the Cape Cod Commission for review as DRIs by a variety of means.

Municipalities are typically required to file an Environmental Impact Report (EIR) with the MEPA Unit for the development of CWMPs. The Cape Cod Commission Act (§12(i)) requires that the Commission shall review as a DRI any proposed development project for which the Massachusetts Secretary of Energy and Environmental Affairs requires the preparation of an EIR. As a result, the Commission conducts a regulatory review, generally concluding with a written approval decision containing findings and conditions for all CWMPs proposed by Cape Cod towns. CWMPs typically trigger EIR review because they involve construction of a new wastewater treatment and disposal facility with a capacity of 2,500,000 gallons per day, or because they result in construction of one or more new sewer mains 10 or more miles long. CWMPs may also trigger mandatory EIR thresholds for land and wetland alterations, impacts to endangered or threatened species or archeological sites, and other factors.

The Commission's regulatory review of a CWMP is presently guided by the planning guidance and minimum performance standards of the Regional Policy Plan. The pertinent technical sections of the RPP include water resources, open space, natural resources, planning and historic preservation. Some of the requirements are similar to MassDEP requirements, but some are quite different.

The 2009 Regional Policy Plan changed the "no net" policy to reflect the newly adopted TMDLs by MassDEP and US EPA as the critical nitrogen loading limit. The performance standard interprets the adopted TMDL as a "fair share." The fair share is the TMDL equivalent load to be allocated to contributing towns on a per-acre rate using the watershed and sub-watershed area.

LOCAL REGULATION

Local zoning, board of health regulations and conservation commission regulations also often impact the selection and siting of wastewater treatment technologies and approaches.

What Is Being Done?

MASSACHUSETTS ESTUARIES PROJECT

In 2001, MassDEP and the University of Massachusetts School for Marine Science and Technology, in collaboration with the Cape Cod Commission, established the Massachusetts Estuaries Project.

MEP scientists developed models that link nitrogen loading in a watershed to coastal water quality. Inputs into the models include data on coastal water quality, tidal flushing, bathymetry, pond water quality, current and historic eelgrass coverage, water use, wastewater treatment plant performance (if any), landfill monitoring, watershed delineations, sediment nutrient regeneration, and nitrogen attenuation from wetlands, rivers and freshwater ponds. The modeling results confirmed earlier studies identifying on-site septic systems as the major source of nitrogen to coastal embayments.

In response to concerns raised by some Cape Cod communities regarding the validity of the MEP scientific approach, the Barnstable County Commissioners directed the Cape Cod Water Protection Collaborative (Collaborative) to undertake a scientific peer review of the MEP process. In 2011, the Collaborative organized an independent scientific peer review of the MEP methodology for developing appropriate TMDLs for the estuaries and embayments of

Cape Cod, and for the use of that methodology as a basis for wastewater and nutrient management planning and implementation on Cape Cod. The scientific peer review process was independent and objective, and operated externally from the Collaborative and from any other Cape Cod stakeholders.

The peer review panel found the MEP modeling approach to be appropriate and useful for evaluating alternative scenarios and informing nutrient management plans, and also found the MEP to be consistent with existing nationwide TMDL practices. The panel also found that the MEP modeling approach is scientifically credible, and the modeling approach is consistent with current understanding of existing conditions for Cape Cod estuaries, based on available data. The components in the approach are well known and documented. Computation of watershed nitrogen loads is strongly data-driven and quantitatively linked to estuarine nitrogen concentrations.

The MEP partnered with Cape Cod communities to evaluate coastal water quality and develop technical reports recommending water quality targets for nitrogen that MassDEP utilizes to develop TMDLs. Model results are presented in published technical reports, and identify one potential scenario indicating how much nitrogen must be removed from wastewater to meet the water quality target in a particular coastal embayment.

The MEP was estimated to cost $12 million over six years. Funding is broad-based with half coming from the state and the other half coming from local and other agency sources. Barnstable County, through the Cape Cod Commission, provided over $700,000 to the MEP over the last eight years as direct assistance to participating Cape Cod towns. The MEP's regionally consistent methodology provides technical work and documents at significant cost savings over towns undertaking similar work individually.

The MEP developed a rigorous Linked-Model approach that includes components of the various disciplines necessary to understand and project how nonpoint source nitrogen loading in a watershed translates into coastal water quality deterioration. Data input into these models includes: three years of volunteer-collected coastal water quality data, tidal flushing data, bathymetric information for estuaries and freshwater ponds, pond water quality data, current and historic eelgrass coverage, water use information, wastewater treatment plant performance, landfill monitoring data, watershed delineations, sediment nutrient regeneration, and wetland nitrogen attenuation.

Embayments on the southern coast of Cape Cod are typically more susceptible to impacts because the tidal range is generally 1/2 to 1/3 of the range observed in Cape Cod Bay to the north.

As of February 2015, 35 watersheds have completed MEP technical reports, two are in draft form, and four are pending.

The MEP provides specific documentation, based on water quality testing, that many of Cape Cod's watersheds have impaired water quality and ecological damage due to nitrogen loading. Nitrogen from septic systems accounts for approximately 80% of the watershed load, with stormwater and fertilizers accounting for the remainder of the locally-controllable nitrogen load. Atmospheric deposition of nitrogen in rainfall is another source accounted for in the stormwater runoff contribution for the watershed and as direct rainfall on the embayment itself.

The MEP technical reports and TMDLs contain estimates for how much watershed nitrogen needs to be removed to meet the TMDL. Since septic system contributions represent the greatest controllable nitrogen load in Cape Cod watersheds, TMDLs also specify how much wastewater nitrogen from septic systems would need to be removed to meet the TMDL. The average removal rate for septic nitrogen load to meet water quality standards exceeds 50% Capewide.

Plan Summary

CAPE COD COMMISSION

Concurrent with the beginning of our awareness about coastal waters, the Commission adopted a regulatory requirement that development projects within watersheds to water quality impaired embayments should have no-net nitrogen loading. In other words, the amount of nitrogen added by the project must be offset by an equivalent reduction. Several County-appointed committees that reviewed the Commission's regulatory program accepted this requirement as a necessary interim step to halt continued degradation of the Cape's coastal water quality. Over the years, it became increasingly clear to organizations involved in assessing and protecting embayments that a comprehensive effort to link regulatory and scientific activities was necessary to realize solutions for observed coastal water quality problems.

POND AND LAKE STEWARDSHIP

In 2001 a coalition of groups interested in protecting ponds received a $30,000 grant to develop a Cape Cod pond stewardship strategy from the Massachusetts Watershed Initiative, known as the Ponds and Lakes Stewardship (PALS) project. The Cape Cod Pond and Lake Atlas, published by the Cape Cod Commission in 2003, provides a status report on the PALS program. It documents the outreach and education activities leading to the creation of the PALS program, reviews water quality data collected by volunteers during the 2001 PALS Snapshot from over 190 ponds, uses this data to develop Cape Cod-specific indicators of pond impacts, reviews data collected in previous studies, and details further efforts necessary to move pond protection and remediation forward on the Cape.

BARNSTABLE COUNTY HEALTH DEPARTMENT

MASSACHUSETTS ALTERNATIVE SEPTIC SYSTEM TEST CENTER

The Massachusetts Alternative Septic System Test Center opened in 2000 to research and test advanced on-site wastewater treatment systems. The Center is operated by the Barnstable County Department of Health and the Environment (BCDHE) and is located at Joint Base Cape Cod. Although the Center's initial emphasis was on nutrient-reducing technologies, more recently it conducted research on the efficacy of commercial and soils-based septic systems for removal of pharmaceuticals and personal care products. The Center has been instrumental in forming and conducting many internationally recognized standards for both secondary and tertiary wastewater treatment. Ancillary projects include the support of research efforts on wastewater diversion techniques, such as composting toilets and urine diversion, and their efficacy for addressing the nutrient management issues in sensitive watersheds. The majority of the systems tested at the Center are proprietary systems and the efficacies of non-proprietary denitrification strategies are less understood, primarily due to the lack of financial incentives to develop and promote them. It is clear, however, that Cape Cod communities are interested in exploring all options available to reduce nitrogen that enters the groundwater. Through this update of the Section 208 Plan for Cape Cod, funding was provided to the Barnstable County Department of Health and the Environment to investigate non-proprietary means to remove nitrogen by enhancing and/or manipulating soils-based systems.

INNOVATIVE/ALTERNATIVE SEPTIC SYSTEMS PERFORMANCE TRACKING

More than 1,500 innovative/alternative (I/A) septic systems have been installed on Cape Cod in an attempt to reduce the amount of nitrogen discharged into the groundwater. These systems range in their complexity, but all require regular maintenance and monitoring. Since 1999, BCDHE has maintained a database to assist regulators in the task of tracking performance and adherence to maintenance schedules. Regular performance and compliance updates are provided to local regulatory boards. More recently, to aid the public and engineering professionals, the department has created an interactive tool to chart performance of all technologies used within Barnstable County. This tool assists wastewater planners to

develop realistic performance expectations, thus facilitating accurate CWMPs. Occasionally printed compendia of the information are distributed to local boards and commissions. The department also maintains training tools to instruct boards of health regarding the proper application of these technologies.

COMMUNITY SEPTIC MANAGEMENT LOAN PROGRAM

The Barnstable County Department of Health and the Environment initiated the Community Septic Management Loan Program to assist homeowners by defraying the costs of septic system upgrades through provision of 20-year betterments. More recently the program has assisted in providing support for the actual connection costs to centralized systems or combined packaged or cluster treatment systems. Barnstable County administers this program regionally for all Cape Cod towns.

CAPE COD WATER PROTECTION COLLABORATIVE

The Cape Cod Water Protection Collaborative was created by county ordinance in 2005 and exists to offer a coordinated approach to enhance the water and wastewater management efforts of towns, the regional government and the broader community. The Collaborative seeks to protect Cape Cod's shared water resources and to provide access to cost effective and environmentally sound wastewater infrastructure. The Collaborative seeks funding support for Cape communities, establishes priorities, directs strategy, builds support for action, and fosters regionalism.

TOWNS

All 15 Cape Cod towns have engaged to some degree in the process of developing CWMPs over the last 10 years. Several towns are in the MEPA review process. A Cape Cod Commission regulatory review file of comment letters, public hearings and decision documents are available for each town that is undergoing the MEPA/DRI review process for their CWMP. Towns with existing wastewater infrastructure including Barnstable, Chatham, Falmouth and Provincetown, completed wastewater facilities plans prior to or in conjunction with nutrient planning.

Why Hasn't There Been More Progress?

Despite the efforts described above, few communities have implemented nitrogen remediation programs that will meet water quality standards.

COST

Cost has been the major impediment to wastewater plans on Cape Cod. The existing wastewater costs to homeowners are hidden. Most people don't recognize the annualized expense of owning and maintaining a Title 5 system.

More than 30% of the housing stock in the region is seasonal. In some towns that figure is as much as 60%. This creates a peak-flow pricing issue for most towns because facilities are sized for a peak flow which occurs only four weeks a year - the last two weeks of July and the first two weeks of August. Less than 4% of the state's population lives on Cape Cod yet the region is home to 20% of the Title 5 systems.

Towns need to stimulate their tax base in order to afford the wastewater costs necessary to meet water quality standards and, at the same time, the economic development necessary to achieve that result is limited by the problem that needs to be solved. Without additional ability to treat wastewater, towns don't have the capacity for appropriate nitrogen-reducing patterns of growth.

LACK OF LOCAL CONSENSUS

Progress on water quality issues related to wastewater is always challenging. The solutions are generally expensive and it is easy for people not to think about what happens after they flush. Education efforts on Cape Cod have been

successful in identifying wastewater as a problem but more work is necessary for a majority of people to recognize that septic systems contribute most to the problem.

Local planning and zoning were ineffective in preventing sprawled residential development patterns that increase the cost of conventional wastewater solutions.

The politics of wastewater is difficult. On the Cape, towns are the primary fiscal agents involved in building wastewater systems. Appropriations on a municipal level that authorize borrowing require a two-thirds vote of the local legislative body. In the Town of Barnstable that is the Town Council. In the other 14 towns the legislative body is town meeting.

LACK OF ENFORCEMENT

Federal and state enforcement tools are imperfect and rely on permitting dischargers. Current enforcement actions would lead to expensive compliance requirements without necessarily resulting in achieving water quality goals.

The web of federal and state regulations governing wastewater management were created to address the water quality challenges of 40 years ago. While the important goals of those efforts remain applicable, the regulatory scheme driving planning and design efforts to meet those goals is inflexible and poorly suited to solving the problems facing the Cape. The current regulations favor centralized treatment approaches and have no effective means for incorporating alternative approaches into a conventional permit.

REGULATIONS LIMIT OPTIONS AND INNOVATION

The regulatory framework in place was built to solve other problems. Existing regulatory drivers overbuild expensive solutions dependent on point-source technologies to solve a nonpoint source problem. This doesn't account for the unique challenges of Cape Cod as a coastal community with a marine water quality issue caused by nutrients and a relatively low-density development pattern.

This plan highlights the need for modifications to the regulatory approach to reflect the predominance of septic system effluent as the primary problem to be solved and to expand the use of alternative and non-traditional technologies and management strategies necessary to meet the unique circumstances of Cape Cod. State development of a watershed permitting process is the essential step in reforming the regulatory environment to unlock the financial savings and management potential of watershed based solutions that rely on a mix of technologies and approaches. Other regulatory reforms are recommended to create the right incentives for the implementation of 21st century solutions to a problem that has been long developing.

The Cape Cod Model

This update provides a regional analysis of watersheds and the nitrogen problem. The review of local nutrient management planning, consideration of the best available scientific assessments and the collection of all relevant geographic data resulted in a recommended new approach to solving the nitrogen problem with specific strategies for better designed and effective watershed-based solution at lower cost with more community support.

COMMUNITY ENGAGEMENT

The Cape Cod Commission committed to an extensive public engagement process to bring more voices to the table in order to develop consensus around a range of solutions to solve water quality problems. The public participation and engagement process was Cape-wide and included both subregional and watershed specific working groups.

There were a number of challenges associated with the complexity of the task and the short time frame for completion. The challenges included:

- Ensuring a high level of process objectivity,
- Staying on task and on time,
- Coming to agreement on potential solutions,
- Addressing the issue of affordability,

- Creating opportunities for regulatory flexibility, and
- Educating and engaging the broader Cape Cod community.

The process took advantage of existing teams and created new teams to tackle each challenge efficiently and effectively.

EXISTING TEAMS

Existing Cape-wide organizations already working on wastewater and nutrient management issues were enlisted to avoid redundant effort and transfer existing knowledge, expertise and data sets.

Cape Cod Water Protection Collaborative Governing Board and Technical Advisory Committee

The Governing Board of the Collaborative reinstated monthly meetings in May 2013 to follow the Section 208 Plan Update process. The Governing Board has 17-members and approves all expenditures, policies and strategies of the Collaborative. Membership consists of an appointed member from each town in addition to two County Commissioners' appointees.

In addition, the Technical Advisory Committee (TAC) of the Cape Cod Water Protection Collaborative was reformed and re-chartered to look at some of the technical aspects of the Section 208 Plan Update. Specifically, the TAC reviewed and commented on the Water Quality Technologies Matrix and helped to develop and refine a series of one-page fact sheets for watershed stakeholders and community use. The TAC consists of one appointed representative from each town and a MassDEP representative to provide the regulatory, permitting and technical perspectives.

NEW TEAMS

New teams were created, as necessary, to provide overall guidance on the plan's progress and separate subject matter advice. Each team established a timeframe for performance and an agreed upon statement of purpose.

Regulatory, Legal and Institutional Work Group

A Regulatory, Legal, and Institutional (RLI) Work Group, with representation from MassDEP, US EPA, the Cape Cod Commission, and other State and Federal partners, as necessary, addressed the potential need for regulatory reform and other challenges associated with planning and implementation. Increased coordination between local, state and federal regulatory requirements was identified by the Commission as a need moving forward and the group met monthly to discuss this and other opportunities and challenges related to the Section 208 Plan Update.

Advisory Board

A six-person advisory board, which meets monthly, was convened with representation from the four subregional planning areas, along with two ad hoc members. Members have current or prior experience in municipal government and/or experience with other regional-scale issues, such as the groundwater cleanup at Joint Base Cape Cod and regionalizing school districts. The mission of the board is to support the Section 208 Plan Update planning process by providing advice on the overall approach, reviewing draft work product and offering insight on strategic and tactical decision-making.

Finance Committee

A Finance Committee, which meets monthly, was convened with representation from local communities and support from consultants to the Cape Cod Commission for the Section 208 Plan Update. Members include a town administrator, a finance director and a municipal finance committee member. The mission of the committee is to work with the consultants to the Commission to establish a factual basis for discussing issues of affordability, financing and resources related to the Section 208 Plan Update.

Technologies Panel

A Technologies Panel, which met four times over the course of two months, was convened to review, confirm, and

expand upon the matrix of technology options developed through and used in the Section 208 Plan Update process, review the overall planning approach in each watershed, and provide input on a site screening methodology for green infrastructure technologies. The panel consisted of local, national, and international experts on the impact of nutrients in coastal waters, remediation approaches, and emerging technologies.

Monitoring Committee

A Monitoring Committee, which meets monthly, was convened in April 2014. The mission of the committee is to provide advice and guidance on appropriate monitoring protocols for technology efficiency and total maximum daily loads, while identifying a process for consolidating all available monitoring data in a central location and format. Members include representatives from MassDEP, US EPA, academic institutions, non-profit organizations, and other government agencies. Among the roles and responsibilities of this committee are to:

- Establish performance monitoring protocols for technologies that may be a part of watershed permits in the future;
- Establish compliance monitoring protocols for meeting TMDLs in the water body;
- Establish process and structure for consolidating and cooperation of existing monitoring programs and data in to a centralized location; and
- Identify region-wide monitoring needs and develop proposals.

WEB-BASED CAPE-WIDE ENGAGEMENT

In an effort to reach groups not normally associated with wastewater or planning projects in general we employed a web-based Cape-wide engagement project. In conjunction with Emerson College's Engagement Game Lab, the Commission tailored the Community PlanIt platform to create and run CAPE2O, an on-line game-based engagement tool. Two different three-week games saw more than 900 people register and generated more than 6,000 comments and questions on water quality issues. CAPE2O introduced players to the nutrient problems on Cape Cod through different problem-solving perspectives including science, civics, economics and consensus building.

STAKEHOLDER ENGAGEMENT

Subregional Public Meetings

To start the stakeholder process, two meetings were held in each of the four subregions – one in July 2013 to introduce the process and develop the watershed working groups and one in August 2013 to introduce information around affordability of infrastructure and discuss what people on Cape Cod are currently paying for water and wastewater infrastructure. These meetings helped to engage the communities and establish the watershed working groups discussed above. The purpose of the subregional meetings was also to recruit stakeholders.

Watershed Working Groups

Working groups, made up of 15-20 self-selected stakeholders (about 170 people Cape-wide), were associated with each watershed group and subregional group. Each working group consisted of the following general representation: Local Elected Officials, Wastewater Committee Members, Town Professional Staff, Local Business Owners/Operators, Local Environmental Organizations, Civic Group Members, Alternative Technology Interests, Development/Real Estate Community and Interested/Concerned Citizens.

In Fall 2013, each working group met three times in four-hour-long professionally facilitated meetings – once in September to discuss the baseline information in each of their watersheds, including land use, nitrogen related water quality impairments, pond water quality, and existing and proposed infrastructure, once in October to discuss the

range of technologies and approaches that might be used on Cape Cod, and once in December to discuss the process for applying technologies and approaches in each watershed.

Subregional Working Groups

Following the three sets of watershed working group meetings the conversation shifted from discussing the jurisdiction of the problem, at the watershed level, to the jurisdiction of the solution, at the subregional level. In early 2014, watershed working groups were asked to self-select into subregional groups, with representation from each of the watershed working groups and in each of the categories established as part of the watershed working group process.

The structure of the subregional meetings was different from the watershed working group meetings, which had discrete topics associated with each meeting. The subregional meetings were iterative, with a standing agenda that included scenario planning; regulatory, legal, and institutional issues; and implementation. Each subregion met three times in four-hour-long meetings. Meetings included representation from MassDEP and US EPA and were also professionally facilitated.

CAPE-WIDE MEETINGS

On November 13, 2013, the Commission held a Watershed Event to conclude the Cape20 game, award prizes to participants and provide funding to top projects associated with the game. About 120 people attended, including stakeholders and Cape20 players, regulatory agency staff, and members of the public. Speakers included Cape and Islands Senator Dan Wolf, as well as representatives from the US EPA and MassDEP. In addition to discussing the outcomes of the Cape20 game the time was used to begin the discussion around structuring the second half of the stakeholder engagement process – the subregional working group meetings.

On February 6, 2014, the Commission held a day-long Stakeholder Summit to review the work to date and discuss the path toward development of the Section 208 Plan Update. About 270 stakeholders, regulatory agency staff, and members of the public attended the event. Speakers included the State Treasurer, MassDEP Commissioner, CEO of the Cape Cod Chamber of Commerce, representatives from the US EPA and the Cape Cod Commission. The discussion focused on the importance of community involvement in the Section 208 Plan Update planning process and the need to meet water quality goals in Cape Cod's estuaries. Breakout sessions included preliminary conversations on scenario planning, regulatory, legal, and institutional issues, and implementation issues, in order to set the stage for the upcoming Subregional Working Group sessions.

TECHNICAL REVIEW

A WATERSHED APPROACH

A watershed approach looks at the jurisdiction of the problem – all of the contributing sources within a watershed (or the receiving water itself), without regard to political boundaries. A watershed is a geographic area separated from other regions by drainage divides, within which all water flows to a common outlet, such as an embayment. Watersheds do not follow the municipal boundaries separating one town from another. Of the 53 watersheds to coastal embayments addressed in this document, 32 are shared by more than one town. Although wastewater planning has been underway on Cape Cod for more than a decade, the current process has been uncoordinated and in many areas represents only a partial solution to the problem resulting in approval of municipal CWMP's that will not meet water quality standards in shared water bodies.

SOLUTIONS CLASSIFIED AND EVALUATED

This report examines 10 categories and a total of 67 nutrient reduction, remediation, and restoration technologies and approaches. Both conventional and alternative means are represented in those groupings. This

work is embodied in the Water Quality Technologies Matrix and then simplified based on the point of intervention and the scale of the technology or approach.

At what point in the nitrogen cycle the intervention takes place determines if the effort is reducing the nitrogen load at the source or reducing the impact of nitrogen already loaded into the ground water or the affected water body. This report classifies technologies and approaches as Reduction, Remediation, and Restoration interventions.

Technologies and approaches considered can be more or less effective and efficient depending on the scale of use. This report groups them based on Site, Neighborhood, Watershed or Cape-wide applicability. It is important to note that not every technology and approach is appropriate for every watershed. Evaluation of these options with the tools developed as part of the Section 208 Plan Update and detailed below is necessary as a preliminary step placing selected options in a watershed-specific scenario.

INFORMATION AND DECISION SUPPORT TOOLS

The process of collecting and analyzing such a large and comprehensive amount of information and a need to organize and analyze many geospatial data layers simultaneously produced a number of important new information products. These new decision support tools and the supporting databases and methodologies will be available through the Cape Cod Commission's Watershed Team technical assistance program. These tools make complex data sets more easily understood and provide an avenue for increased and informed deliberation at the local and hyper-local planning levels. This will expedite the selection and implementation of watershed solutions.

TWO PERSPECTIVES ON ONE PROBLEM

Implementation of wastewater solutions have failed to garner the 2/3rds Town Meeting votes necessary to appropriate money to build in most communities. Many of the plans have suffered a "death by a thousand cuts." The arguments against tend to fall into three categories: Science, Solutions (proposed strategies and technologies) and Cost.

As noted above, a group of experts was empaneled to review the scientific underpinning of the Massachusetts Estuary Project and approved its use by communities in making directionally correct decisions regarding solutions.

This document outlines a technical review process designed to provide insight into the remaining two categories, Solutions and Cost. The concerns often resulted in polarizing local debates, sometimes discussed in terms of centralized versus de-centralized approaches or traditional solutions versus alternative solutions. One of the key distinctions depends on a considered option's reliance on a permanent physical connection among multiple sources, a collection system. The process outlined in this report grouped points of view associated with these categorizations into two approaches to solving Cape Cod's nitrogen problem: a traditional approach and a non-traditional approach.

Two teams worked independently in the application of agreed upon conditions outlined as follows:

- Both approaches consider the entire controllable load.
- Both start with identified nitrogen reduction targets.
- Both agree that nutrient reduction goals can be adjusted based on a watershed's adoption of certain policies that will reduce or eliminate nutrient loading from certain sources, fertilizer reduction and stormwater management.
- Both approaches illustrate an attempt to solve the problem within the boundaries of the watershed as an environmentally preferable result, when possible.
- As a mutual point of reference, the traditional team evaluated a hypothetical analysis of an "all sewer" scenario and compared it to an "all innovative/alternative septic system" scenario. Neither was a best choice for taxpayers or the environment. This evaluation suggested scenario approaches be targeted and mixed, where appropriate.

Traditional Approach Process

The traditional (collection system) approach considered the greatest controllable source of pollution as a percentage of the whole, aggregated nitrogen in the most efficient grouping of sources, and suggested collection and treatment options.

Starting with the agreed upon nitrogen removal target, the review team applied low barrier technologies and approaches, applying nitrogen reduction credits to the watershed for fertilizer reductions and stormwater management. They targeted and identified nitrogen loads and an appropriate collection system to treat and dispose effluent within the watershed. Next the team adjusted the size of the necessary collection by considering treatment and disposal outside of the watershed. The process illustrates the cost and effectiveness of traditional strategies, potential economies of scale with shared treatment and disposal, and potential limitations to the environmentally preferred option of a watershed-based solution. The traditional approach provides an instructive backdrop for an adaptive management approach to managing nitrogen in watersheds.

Non-Traditional Approach Process

The non-traditional approach started with the premise that collection systems should be avoided or minimized to the greatest extent possible. Although conventional wisdom and practice suggests that economies of scale in the construction of wastewater treatment facilities result in the least expensive and most effective treatment, there is valid concern that the case studies supporting this view are from more urban communities with existing but degraded infrastructure. Cape Cod is missing both of these qualifications, having neither the density characteristics nor the existing infrastructure. The Cape also has an attribute not shared by other communities - its seasonal second home owner economy, which creates a peak-flow problem when building wastewater treatment facilities and creates a situation where facilities are overbuilt for 48 of 52 weeks a year.

Additionally, there are people in every community advocating for wastewater solutions that rely less on structural interventions and favor those that enhance natural systems. The technologies and strategies prioritized in the non-traditional approach also tend to result in less movement of water between watersheds and put a greater emphasis on comprehensive system restoration or improvement.

The non-traditional approach team began with the same nitrogen removal target as the traditional team and applied low barrier technologies and approaches, assigning nitrogen reduction credits to the watershed for fertilizer reductions and stormwater management. It then considered an array of watershed/embayment options, as detailed in the Water Quality Technologies Matrix, consisting of a broad range of innovative and non-traditional nitrogen management strategies to either intercept and treat nitrogen in the groundwater or to assimilate and treat them in the receiving waters.

Watershed practices include permeable reactive barriers (PRBs), constructed wetlands, phytoremediation, and fertigation wells, among others. Embayment treatment practices include, but are not limited to, shellfish bed restoration, aquaculture, floating wetlands, dredging and inlet modifications.

The next step considered alternative on-site options that have been screened for geographic suitability. A number of alternative wastewater source controls were evaluated in this step. These include ecotoilets and I/A septic systems. Ecotoilets are alternative toilets that target the source within the building. These include urine diversion (UD), composting, incinerating, and packaging toilets where the waste materials are collected and temporarily stored before processing. These technologies allow little or no human waste to enter the septic system (only gray water from the shower, laundry and sinks).

Social acceptability issues had the team using these strategies in a targeted way, schools for example.

Plan Summary

Among the actions needed to validate the efficacy of non-traditional approachesare piloting, monitoring and analyzing technology performance.

The non-traditional approach produced a targeted starting point for consideration as part of an adaptive management program in most watersheds.

MONITORING

In order for a broader range of technologies and options to be considered a long-term monitoring program must be established to provide technology specific monitoring protocols as well as an enhanced water quality monitoring program in the degraded water bodies.

ADAPTIVE MANAGEMENT

This recommended approach creates a predictable framework for adaptive management. It will allow communities to move forward in a targeted manner to begin to address marine water quality issues now. The traditional and non-traditional approaches can serve as the outer bounds of an adaptive management plan.

ADAPTIVE PLANNING

Although two independent watershed evaluation strategies were used the results have produced a recommended hybrid watershed planning approach. Included in this approach is the consideration of additional non-nitrogen collection needs in the watershed and expanded options for nitrogen reduction, remediation and restoration efforts producing watershed scenarios vetted by a community engagement process producing an adaptive management plan to be incorporated in a watershed permit.

Conclusion

The qualitative water quality goals of the Clean Water Act are not being met on Cape Cod. We are moving in the wrong direction. There has been no debate about the goal of clean water, but the regulatory drivers are producing point source solutions for non-point source problems. Regulatory enforcement actions based on quantitative measures are clear for point source discharges but not for non-point sources. The resulting dissonance has led to litigation attempting to define nutrient pollution related to wastewater as a point source to access more established enforcement action. The discussion has to move beyond this legal impasse. This update focuses on promoting more efficient and effective non-point source strategies designed to meet the qualitative goals of the Clean Water Act.

An update to the Clean Water Act that promotes and supports a non-point source nutrient control program and provides a clear path to compliance for communities will allow the goals of the Act to be more effectively and efficiently realized. The Commonwealth of Massachusetts has an opportunity to allow an innovative and common sense approach to solving the problem.The biggest controllable source of nitrogen on Cape Cod is subject to existing state authority. This update provides a path toward clean water based on the best information available that will make it easier for the 15 towns on Cape Cod to implement effective solutions without excessive costs.

This Section 208 Plan Update recommends actions to streamline the regulatory process, make complex information more transparent and available to citizens, abate nitrogen-induced costs already impacting the region, provide more support to local community water quality efforts, and eliminate unnecessary costs.

Introduction

As the population of Cape Cod increased over the last several decades, so has the volume of nutrients entering its coastal waters and freshwater ponds. The population of Cape Cod has increased by about 60% since the completion of the 1978 Water Quality Management (WQM) Plan, developed under Section 208 of the Federal Clean Water Act by the Cape Cod Planning and Economic Development Commission (CCPEDC), the predecessor to the Cape Cod Commission (Commission). Development associated with this growth is largely in the form of residences. Wastewater from both older and newer housing stock is predominantly treated by on-site septic systems that do not adequately remove nitrogen. Nitrogen from these systems is released to groundwater which ultimately discharges to the surrounding coastal waters. Excessive nutrients, such as nitrogen and phosphorus, are the documented cause of eutrophication in a majority of Cape Cod estuaries and freshwater ponds. In estuarine systems, nitrogen leads directly to thick mats of algae that replace eelgrass, diminish shellfisheries, and decrease dissolved-oxygen concentrations—occasionally leading to fish and shellfish kills, odor and frequent violations of water quality standards.

Cape Cod has less than 4% of the population of the Commonwealth but 20% of the septic systems. Only 3% of the parcels and 15% of the wastewater that flows on Cape Cod are centrally treated. Wastewater accounts for about 80% of the controllable nitrogen load entering Cape Cod's coastal waters.

This report documents an update to the 1978 Section 208 Plan for Cape Cod. In a January 30, 2013 letter (See Appendix A), the Massachusetts Department of Environmental Protection (MassDEP) directed the Cape Cod Commission to prepare an update to the 1978 WQM Plan for Cape Cod to address the degradation of Cape Cod's water resources from excessive nutrients, primarily nitrogen.

Accompanying the directive was a commitment to provide the Cape Cod Commission with $3,350,000 from the Massachusetts Water Pollution Abatement Trust to fund the update. The Memorandum of Understanding, dated March 21, 2013 (See Appendix B) between the Massachusetts Water Pollution Abatement Trust (Trust), MassDEP and Barnstable County, acting by and through the Commission, stipulates roles, responsibilities, terms and conditions under which the Section 208 Plan Update was completed.

Introduction

After review and acceptance of a detailed budget and work plan, the Trust and MassDEP provided a notice to proceed on the full Section 208 Plan Update on May 7, 2013 (See Appendix C).

The Cape Cod Commission was given 12 months to submit a draft Section 208 Plan Update to MassDEP and the United States Environmental Protection Agency (US EPA), which was fulfilled in June 2014. A 60-day review period was provided to the agencies and a public draft was released in August 2014 for an extensive 90-day public comment period. All of the comments received, along with responses prepared by the Commission, can be found in Appendix D.

Authority

The Cape Cod Commission is, pursuant to the Cape Cod Commission Act (See Appendix E), the regional planning agency for Barnstable County. The Commission is charged with furthering "the conservation and preservation of natural undeveloped areas, wildlife, flora and habitats for endangered species; the preservation of coastal resources including aquaculture; the protection of groundwater, surface water and ocean water quality, as well as the other natural resources of Cape Cod; balanced economic growth; the provision of adequate capital facilities, including transportation, water supply, and solid, sanitary and hazardous waste disposal facilities; the coordination of the provision of adequate capital facilities with the achievement of other goals; the development of an adequate supply of fair affordable housing; and the preservation of historical, cultural, archaeological, architectural, and recreational values."

The purposes and provisions of the Cape Cod Commission Act require that the Commission "anticipate, guide and coordinate the rate and location of development with the capital facilities necessary to support such development;" therefore, the Commission has the power "to establish a process and procedures for siting and developing capital facilities and developments of regional impact which are necessary to ensure balanced growth."

The Cape Cod Commission was created by an act of the Massachusetts Legislature and ratified by the voters of Barnstable County in 1990 in response to the rapid development pressure of the 1980s. The increased pace of development focused attention on the need to manage growth, guide land use, promote balanced economic growth, provide for adequate capital facilities and infrastructure, and protect environmental resources. The Commission has planning, technical and regulatory tools that can be applied to water quality management on Cape Cod. The Commission has independent statutory authority and is a department within the structure of Barnstable County government. The Cape Cod Commission is also the State-designated area wide water quality management planning agency for Barnstable County.

In 1985 the United States Environmental Protection Agency promulgated regulations (40 C.F.R. §130.6) to provide for WQM planning programs, which

"consist of initial plans produced in accordance with §208 and §303(e) of the [Clean Water] Act and certified and approved updates to those plans." As stated in 40 C.F.R. §130.6(e), a State is authorized to update these WQM plans "as needed to reflect changing water quality conditions, results of implementation actions, new requirements or to remove conditions in prior conditional or partial plan approvals."

As described above, the Commonwealth exerted its authority under Section 208 of the Clean Water Act and 40 C.F.R. §130.6 to designate an agency and require an update to address the critical need for nutrient remediation in Cape Cod water bodies by designating the Commission as the responsible agency and directing the Commission to update the 1978 Section 208 Plan in 2013.

The 1978 Section 208 Plan

The 1978 Section 208 WQM Plan (1978 Plan) for Cape Cod described the major water quality and wastewater management problems confronting the region and recommended land use controls, wastewater management, nonpoint source controls and institutional arrangements to improve water quality.

Specifically, the plan identified increasing residential densities and a three-fold summer population influx as the cause of isolated water quality and wastewater management problems. It anticipated that future growth, primarily in more inland areas where most public water supply wells are located and along the shores of the Cape's many inland ponds, threatened to cause more serious groundwater contamination and increased eutrophication of surface waters.

The emphasis of the 1978 Plan recommendations was on providing for the protection of drinking water quality and quantity. The plan recommended that towns establish protective overlay districts for major "Water Resource Protection Areas," within which residential density would be limited and major polluting uses would be prohibited in order to protect groundwater, surface waters, and coastal waters. It was suggested that the most highly protected areas be those that contribute recharge to public drinking water supply wells. Additionally, it was recommended that towns cooperate in regional water supply planning to encourage water supply self-sufficiency and to develop and implement appropriate protection measures.

The 1978 Plan generally concluded that septic systems that comply with Title 5 of the Massachusetts Environmental Code (310 C.M.R 15.00) were an adequate form of wastewater disposal for the Cape's development. At the time, about 90% of the Cape's year round population relied on on-site septic systems and the plan recommended that the majority of the population could continue to rely on this form of disposal over the 20-year planning period. However, the plan did identify isolated sewer service areas and suggested that the towns of Barnstable, Bourne, Chatham, Falmouth, Provincetown,

and Sandwich proceed with Clean Water Act §201 facilities planning and construction to remediate water quality or other Title 5 related issues within their communities.

To accommodate the majority of development that would remain connected to on-site disposal systems, the 1978 Plan recommended that all towns participate in an effort to regionalize septage treatment and disposal, as well as develop on-site system management programs to ensure proper maintenance and strict enforcement of Title 5, including the upgrading of failing systems and proper installation practices supervised by qualified local health agents (CCPEDC 1978).

Environmental Conditions Requiring an Update

Nitrogen enters marine ecosystems from many different sources. For the purpose of this report they are classified as uncontrollable sources, such as the atmospheric deposition of nitrogen, and controllable sources, such as wastewater, fertilizer and stormwater. This update focuses on nitrogen loads from controllable sources. The uncontrollable loads are accounted for in the calculation of the nitrogen capacity for a given waterbody.

Cumulative concentrations of nitrogen in groundwater, which are substantially lower than drinking water standards, have a significant impact on coastal resources. These impacts are due to the incomplete removal of nitrogen from on-site Title 5 septic systems that were found to be adequate for drinking water protection in the 1978 Section 208 Plan.

Since the 1978 Plan was developed, Cape Cod communities have worked closely with Barnstable County, the Commonwealth, and the Massachusetts Estuaries Project (MEP) to identify the causes and degree of impairment in coastal water bodies. Cape Cod knows more now about the sources of coastal water quality degradation, and potential solutions, than was understood in 1978.

Cape Cod's water resources drive the regional economy. They attract visitors in the summer months and make the Cape a desirable place to live for year-round and seasonal residents. Continuing and increasing nitrogen loading of Cape Cod's embayment watersheds will further degrade coastal water quality, adversely impacting environmental, economic, and societal norms. The economic impact of doing nothing to restore coastal water quality will be significant, affecting every home owner in the region.

Cape Cod has recently been the subject of a lawsuit on this issue. The original lawsuit, filed by the Conservation Law Foundation (CLF) against US EPA, asserts that US EPA violated the Clean Water Act and its regulations by failing to regulate nonpoint sources of nitrogen which have degraded the embayments in a manner that has injured the recreational, commercial and aesthetic interests in those waters. This lawsuit was dismissed for lack of standing.

In a refiled suit, CLF has asserted that the US EPA's mandatory annual review of how Massachusetts administers its State Revolving Fund (SRF) has been contrary to law. Specifically, under the Clean Water Act, the US EPA has the authority to grant money to a state's SRF fund for certain types of wastewater management projects subject to certain restrictions on the use of the funds. The US EPA has a duty to review a state's plans and reports concerning the state's use of those funds on an annual basis.

CLF sought an injunction requiring that (1) the US EPA notify the Commonwealth of its noncompliance; and (2) an update to the Section 208 Area Wide Water Quality Management Plan be completed within one year. The US EPA sought and received a stay of this lawsuit until June 1, 2015, pending review and approval of this updated Section 208 Plan.

In November 2014, CLF and US EPA filed a settlement agreement in US District Court requesting an extension of the existing stay of the Section 208 Action from June 1, 2015 to September 15, 2015, a stay of the TMDL Action until September 15, 2015, and a dismissal of both actions upon completion of a series of actions to be completed by US EPA, including the approval of the Cape Cod Section 208 Plan Update.

The time for Cape Cod communities to act is now. Approval of the Cape Cod Section 208 Plan Update by US EPA and implementation of the principles and recommendations set forth will ensure local control over selection and application of technologies and management of water resources into the future.

A New Approach

THE SECTION 208 PLAN UPDATE – PURPOSE, GOALS, AND PROCESS

PURPOSE

The purpose of the Section 208 Plan Update was to develop an integrated water and wastewater management system that includes a series of phased approaches to remediate groundwater and surface water impairments in each watershed.

GOALS

The goals of the Section 208 Plan Update include:

- To provide an unbiased evaluation of technologies and approaches that may be appropriate in each watershed;
- To promote the use of sustainability criteria in decision making;
- To work with State and Federal partners on regulatory changes necessary to implement adaptive management plans, including the permitting of alternative approaches and appropriate enforcement mechanisms;

- To develop cost effective management strategies for implementing pilot projects, targeted watershed plans, and watershed plans for shared infrastructure; and
- To identify ways to measure and control unanticipated growth made possible through the development of wastewater infrastructure.

PROCESS

The process used in this update is watershed-based, includes a focus on both stakeholder engagement and technical evaluation, seeks to maximize the benefits of local planning, considers the full range of traditional and non-traditional strategies, and favors allowing local stakeholders to decide which of a range of options to pursue, instead of mandating a single "optimal" solution. Affordability and ancillary benefits to Cape Cod's economy and society are considered in the proposed range of approaches.

Overcoming these significant challenges to restoring many of Cape Cod's marine ecosystems requires a new approach. The Section 208 Plan Update reflects a new approach with five basic principles.

1. The plan is watershed based. The most effective and efficient solutions are found by beginning with the consideration of solutions within the jurisdiction of the problem.
2. The plan leverages existing local plans by making use of the enormous amount of data and input already collected by Towns as part of their comprehensive wastewater management planning to date.
3. All solutions are considered – everything has to be on the table. The plan takes into account all technologies and strategies that may be successful on Cape Cod. It evaluates each individually and then looks for appropriate places for its use as part of a watershed scenario.
4. The purpose of the plan is to set the parameters for the discussion of solutions on a watershed basis, and **not** to suggest an optimal solution.
5. Cost must be considered as part of every watershed scenario and the impact on individual homeowners must be a primary concern. If a solution isn't affordable, it isn't doable.

The plan outlines a path forward with recommendations for implementation. The recommendations can be organized into four categories: information, regulatory reform, support, and cost. The Plan identifies areas where more information is needed, where more support can be offered, where regulatory reforms are necessary and suggests options for additional financial support.

01 PEOPLE

The Cape Cod Model - People & Process

Section 208 of the Federal Clean Water Act emphasizes public engagement as much as the technical aspects of the regional planning process. The Cape Cod Commission committed to extensive public engagement to bring more voices to the table in order to develop consensus around a range of solutions to solve water quality problems. The public participation and engagement process was Cape-wide and included both subregional and watershed specific working groups. It took advantage of existing teams, such as the Cape Cod Water Protection Collaborative, and created new teams, as necessary, to address the challenges associated with this extensive and time-constrained planning process.

STAKEHOLDER PROCESS

strategies for establishing consensus in a regional planning process

Section 208 of the Federal Clean Water Act emphasizes public engagement as an important part of the regional planning process. The Cape Cod Commission committed to an extensive public engagement process to bring more voices to the table in order to develop consensus around a range of solutions to solve water quality problems.

OBJECTIVE

In order to be successful, the planning process needed to remain objective. The Commission brought in the Consensus Building Institute to provide facilitation in order to build collaboration and agreement among stakeholders.



AFFORDABLE

A basic principle of the Section 208 Plan Update is that cost be considered as part of every watershed solution and the financial impact on individual homeowners be a primary concern.



ON SCHEDULE



To ensure the Section 208 Plan Update stayed on task and was delivered on time the Commission engaged the Cape Cod Water Protection Collaborative Governing Board and created a new Advisory Board. These Boards provided advice on the overall approach, reviewing draft work product and offering insight on decision-making.

FLEXIBLE

To ensure regulatory flexibility in planning and permitting was addressed, the Regulatory, Legal and Institutional Work Group advised on regulatory reform and increased coordination between local, state and federal regulatory requirements. The Monitoring Committee provided advice on monitoring protocols and a process for monitoring data to inform adaptive management.

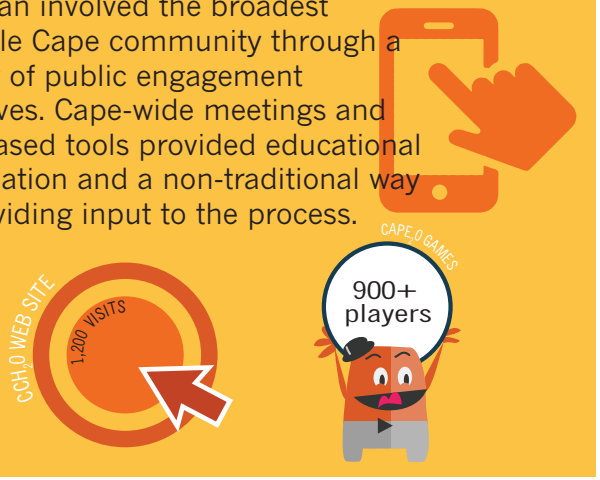
AGREEMENT

The Commission built consensus by working across town lines and identifying solutions at the watershed level. A range of stakeholders was convened at the watershed and the subregional level to consider watershed-based solutions and strategies.



ENGAGING

The Plan involved the broadest possible Cape community through a variety of public engagement initiatives. Cape-wide meetings and web based tools provided educational information and a non-traditional way of providing input to the process.



Process Challenges and Solutions

The Cape Cod Commission (Commission) was given 12 months following the receipt of funds associated with the Section 208 Plan Update to provide a draft document to the Massachusetts Department of Environmental Protection (MassDEP) and the United States Environmental Protection Agency (US EPA). The draft document needed input from individuals Cape-wide in order to address regional concerns and develop consensus around solutions. The challenges associated with the complexity of the task and the short time frame required efficient and effective strategies. The Section 208 Plan Update utilized existing organizations and created new boards and committees (see **Figure 1-1** on following page) to work toward developing solutions to these challenges.

CHALLENGE: HOW TO ENSURE PROCESS OBJECTIVITY

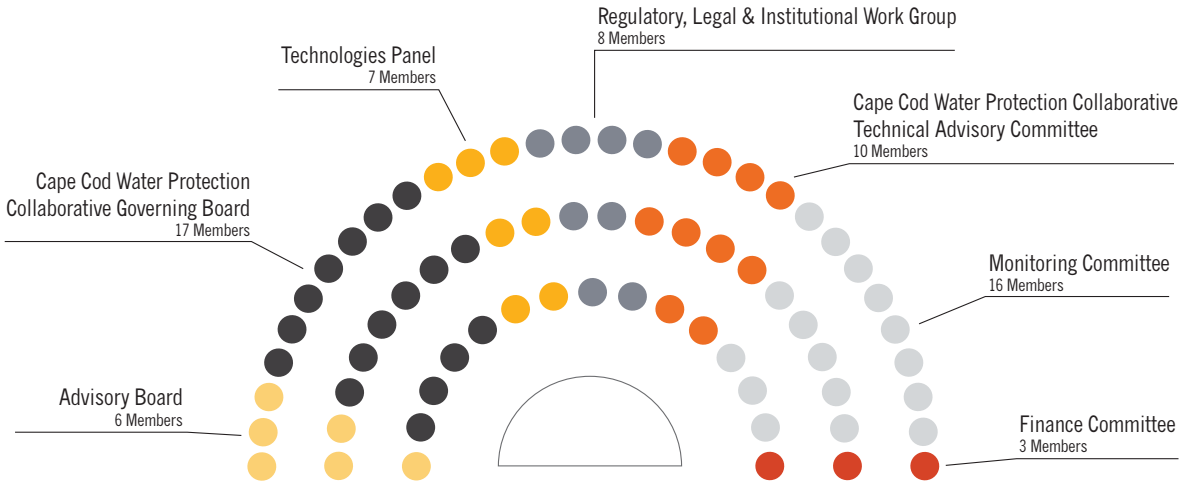
A plan that would address the needs of the region and represent the communities' specific watershed goals and solutions required input from a range of stakeholders with a range of opinions and ideas. In order to be successful, the planning process needed to remain objective.

The Consensus Building Institute (CBI) of Cambridge, MA is an experienced not-for-profit organization focused on negotiation and dispute resolution. As third-party facilitators they work to build collaboration and agreement in complex environments.

The Commission brought CBI on to the project to provide guidance on developing a process for engaging communities in a discussion around watershed impairments and appropriate solutions. Its staff provided third-party facilitation at the watershed, subregional and Cape-wide levels to ensure that all stakeholders were given opportunities to participate and that the Commission effectively responded to concerns and incorporated feedback throughout the process. CBI held all parties involved to a high standard of communication and cooperation in addressing this difficult issue.

Challenges Requiring Solutions

- ☑ Ensuring Objectivity
- ☑ Staying on Task and on Time
- ☑ Reaching Agreement
- ☑ Addressing Affordability
- ☑ Creating Pathway for Regulatory Flexibility
- ☑ Engaging the Broader Public



Section 208 Plan Update Committee Membership

Figure 1-1

CHALLENGE: HOW TO STAY ON TASK AND ON TIME

To ensure the Section 208 Plan Update stayed on task and was delivered on time the Commission engaged an existing team, the Cape Cod Water Protection Collaborative (Collaborative) Governing Board, and a new team, the Section 208 Plan Update Advisory Board.

COLLABORATIVE GOVERNING BOARD

The Collaborative was created by county ordinance in 2005 and exists to offer a coordinated approach to enhance the water and wastewater management efforts of towns, the regional government and the broader community. The Collaborative seeks to protect Cape Cod's shared water resources and provide access to cost-effective and environmentally-sound wastewater infrastructure. The Collaborative seeks funding support for Cape communities, establishes priorities, directs strategy, builds support for action and fosters regionalism.

The Collaborative Governing Board reinstated monthly meetings in May 2013 to follow the Section 208 Plan Update process from start to finish. The Governing Board's 17-members approve all expenditures, policies and strategies of the Collaborative. Membership consists of an appointed member from each town (typically a Selectmen or staff member) in addition to two County Commissioners' appointees. Monthly updates were provided to the Board, which was given a chance to comment and provide feedback. See Appendix 1A for a list of members and their affiliations, as well as meeting information.

208 PLAN UPDATE ADVISORY BOARD

A six-person Advisory Board met monthly and was convened with subregional representation and ad hoc members with regional points of view and experience. Members had current or prior experience in municipal government and/or experience with other regional-scale issues, such as groundwater cleanup at Joint Base Cape Cod and regionalizing school districts.

The mission of the board was to support the Section 208 planning process by providing advice on the overall approach, reviewing draft work product and offering insight on strategic and tactical decision-making. See Appendix 1B for a list of members and their affiliations, as well as meeting information.

CHALLENGE: HOW TO COME TO AGREEMENT ON SOLUTIONS

At the outset, the Commission sought to build community consensus across town lines and identify solutions within the jurisdiction of the problem - watersheds. The most effective and efficient solutions are found by beginning consideration of solutions at this level.

To begin this effort, a chronology of municipal planning efforts was developed for each town. It established what had been done, identified successes and failures to date, and began to illustrate the overlap between communities planning in each watershed. More detail on town planning efforts can be found in Chapter 2.

A premise of the Section 208 planning process is that all solutions must be on the table. The plan takes into account all technologies and strategies that may be successful on Cape Cod, evaluates each individually and looks for appropriate places for use as part of a watershed scenario. The purpose of watershed scenarios is to set parameters for the discussion of solutions on a watershed basis. The watershed scenarios developed represent a range of possible options. They do not suggest an optimal solution, as decisions on how to proceed must be made locally.

To determine appropriate technologies to consider and build consensus on approaches to watershed planning across town boundaries an existing team – the Technical Advisory Committee (TAC) of the Collaborative - and several new teams - the 208 Plan Update Technologies Panel, watershed working groups, and subregional working groups - were utilized.

COLLABORATIVE TAC

The TAC was re-formed and re-chartered to look at some of the technical aspects of the Section 208 Plan Update. Specifically, the TAC reviewed and commented on the suite of technologies identified through the Water Quality Technologies Matrix (Technologies Matrix) and helped to develop and refine a series of one-page fact sheets for stakeholders and community use. These have been incorporated in the online Technologies Matrix, available at: http://capecodcommission.org/matrix. The TAC consists of one appointed representative from each town and a MassDEP representative to provide the regulatory, permitting and technical perspectives. See Appendix 1C for a list of members and their affiliations.

TECHNOLOGIES PANEL

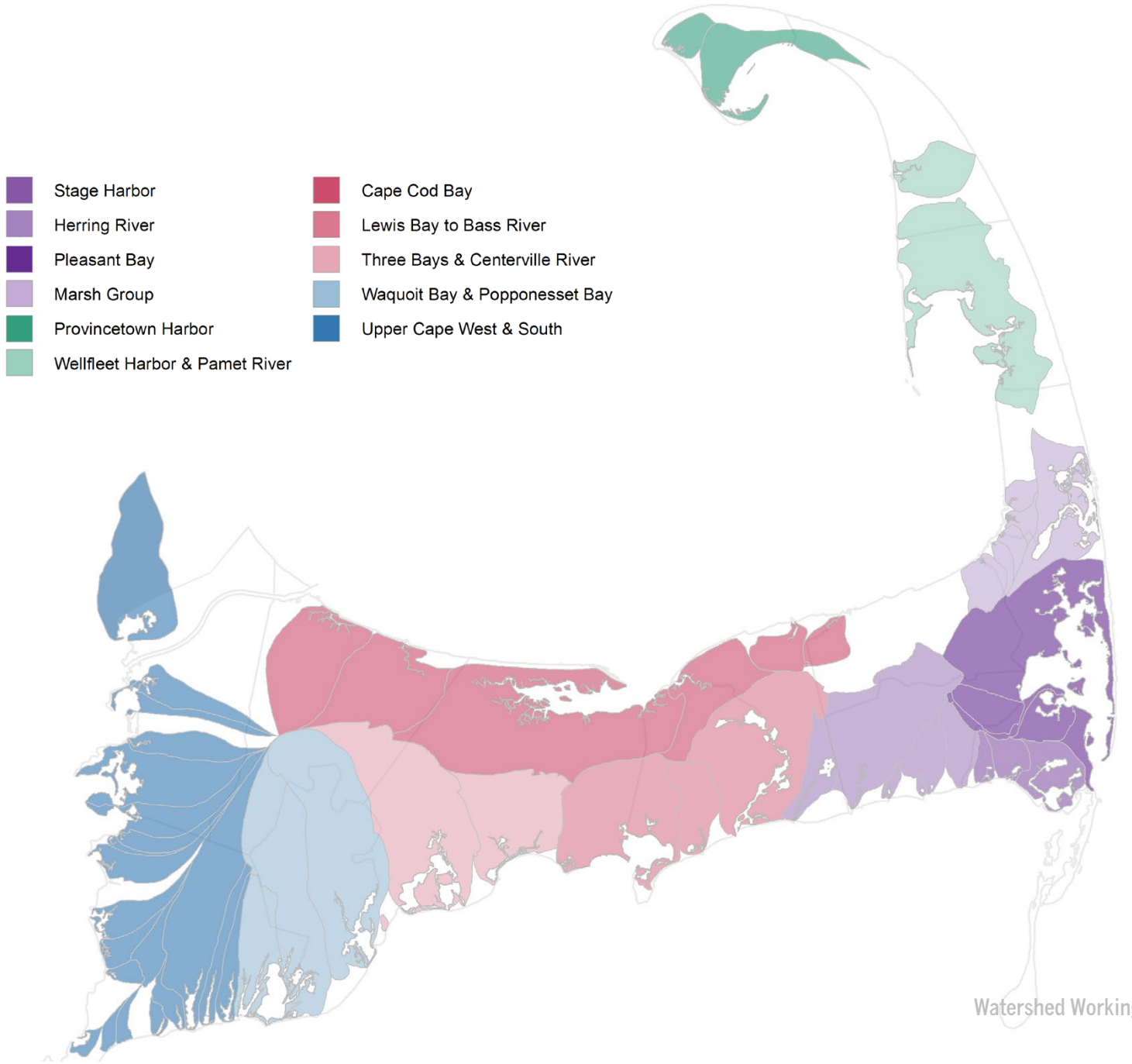
A Technologies Panel, which met four times over the course of two months, was convened to review, confirm, and expand upon the Technologies Matrix, review the overall planning approach in each watershed, and provide input on a site-screening methodology for non-traditional technologies. The panel consisted of local, national, and international experts on the impact of nutrients in coastal waters, remediation approaches, and emerging technologies. See Appendix 1D for a list of members and their affiliations, as well as meeting information.

STAKEHOLDER ENGAGEMENT

For the purposes of planning, the 53 embayment watersheds across Cape Cod were grouped into 11 watershed working groups based on proximity to one another, level of impairment and other hydrogeologic characteristics (see **Figure 1-2** on following page).

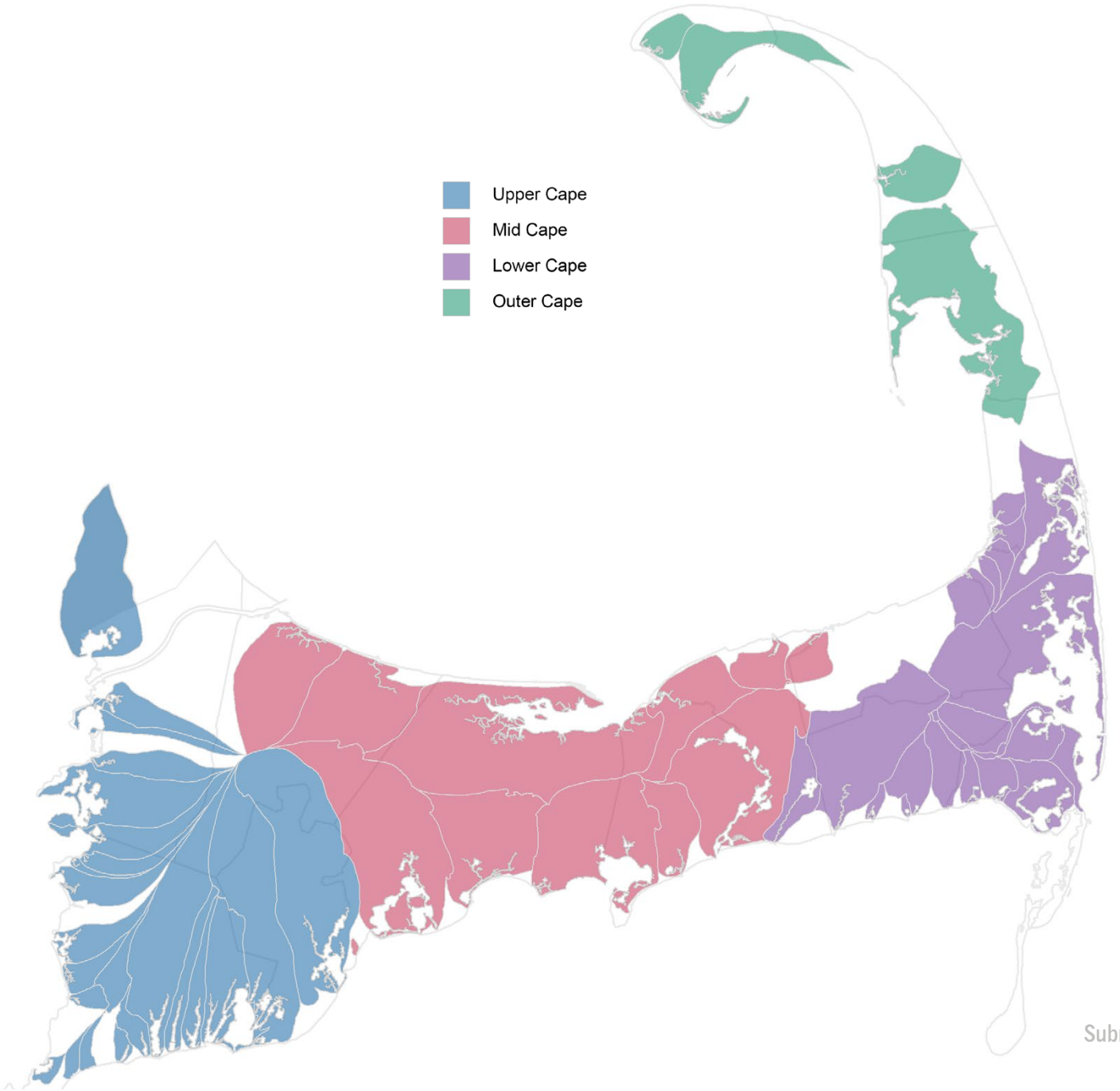
Consistent with the iterative process used throughout development of the Section 208 Plan, the number of watersheds considered in the final plan was reduced from 57 to 53. Four small watersheds are now accounted for within the broader watershed areas to which they contribute.

The watersheds were further organized in to four subregional working groups – the Upper Cape, Mid Cape, Lower Cape, and Outer Cape (see **Figure 1-3** on following page).



Watershed Working Group Boundaries

Figure 1-2



Subregional Boundaries

Figure 1-3

Everyone on Cape Cod is connected in some way to these watersheds. The embayment watersheds make up approximately 79% of the land area on Cape Cod (**Figure 1-4**) and are home to 89% of its residential development and 78% of non-residential development.

Each watershed can be categorized by level of impairment. The scale and diversity of the planning area warranted an extensive and varied group of stakeholders to provide input. **Figure 1-5** shows the watersheds included in each subregion and watershed group along with the general degree of impairment.

Working Groups, made up of 15-20 self-selected stakeholders (about 170 people Cape-wide), are associated with each watershed working group. Each group consists of the following general representation:

- Local Elected Officials
- Wastewater Committee Members
- Town Professional Staff
- Local Business Owners/Operators
- Local Environmental Organizations
- Civic Group Members
- Alternative Technology Interests
- Development/Real Estate Community
- Interested/Concerned Citizens

To start the stakeholder process, two meetings were held in each of the four subregions – one in July 2013 to introduce the process and develop the watershed working groups and one in August 2013 to introduce information around affordability of infrastructure and discuss what residents and business owners on Cape Cod are currently paying for water and wastewater infrastructure. These meetings helped engage communities and identify stakeholders interested in participating in the process.

See Appendix 1E for a full list of the planning areas and the watersheds included in each, as well as the stakeholder group associated with each.

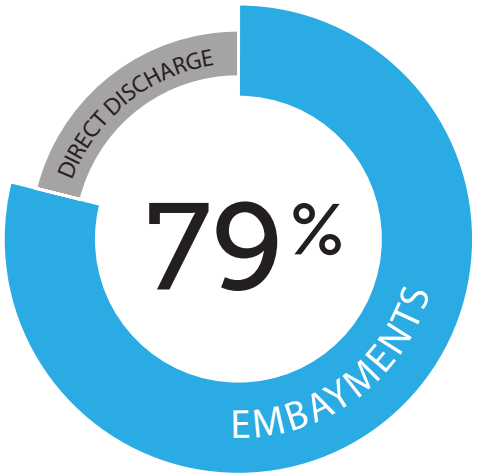
WATERSHED WORKING GROUPS

Each watershed working group met three times in four-hour-long professionally-facilitated meetings in the fall of 2013 - once in September to discuss the baseline information in each of their watersheds, including land use, nitrogen related water quality impairments, pond water quality, existing infrastructure, and proposed infrastructure identified through previous municipal efforts, once in October to discuss the range of technologies and approaches that might be used on Cape Cod, and once in December to discuss the process for applying technologies and approaches in each watershed. See Appendix 1F for a complete list of meeting dates, agendas, and meeting summaries for all of the watershed working group meetings.

SUBREGIONAL WORKING GROUPS

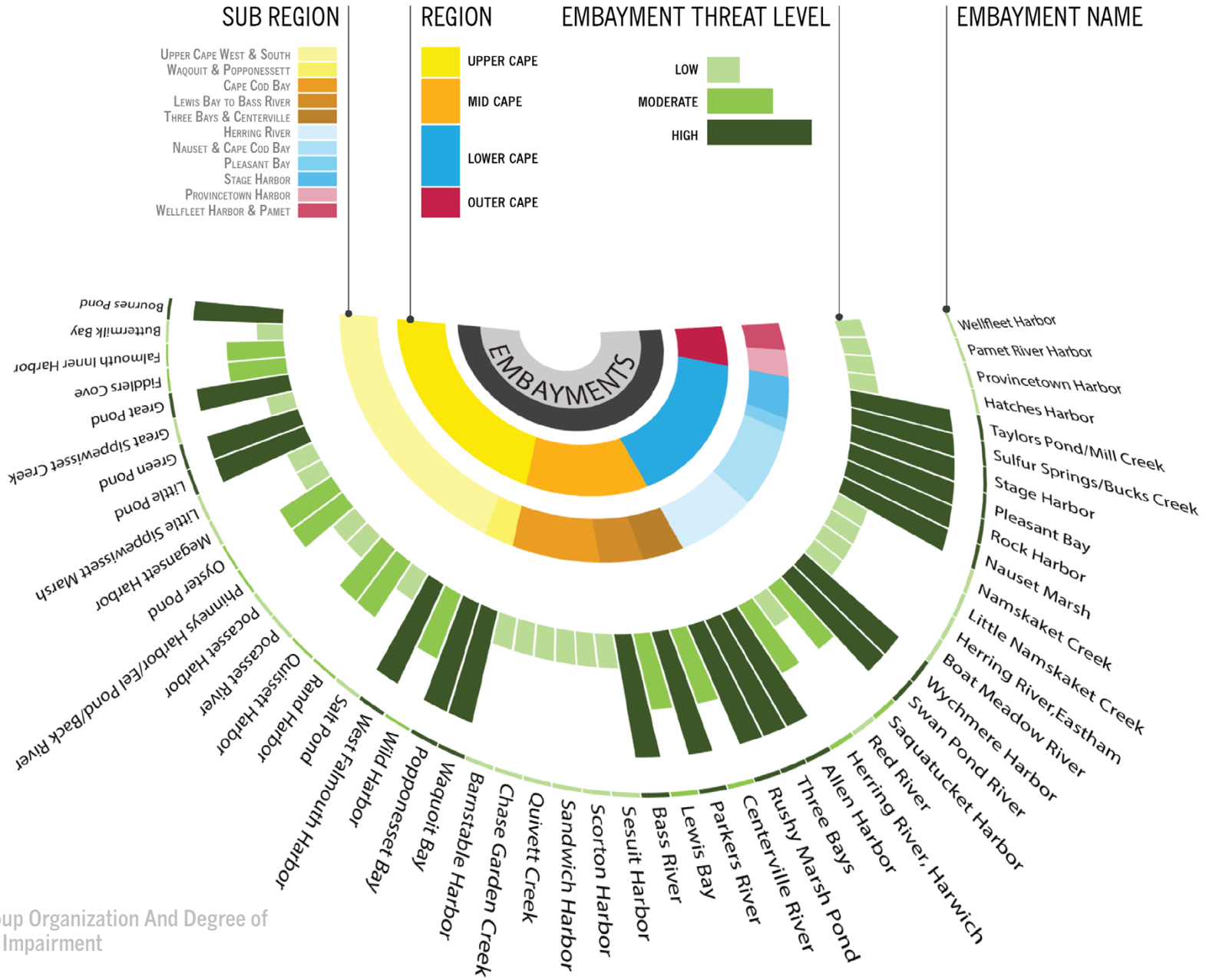
Following the three sets of watershed working group meetings the conversation shifted from discussing the jurisdiction of the problem, at the watershed level, to the jurisdiction of the solution, at the subregional level. In February 2014, the watershed working groups were asked to self-select into subregional working groups, with representation from each of the established categories.

The structure of the subregional meetings was different from the watershed working group meetings, which had discrete topics associated with each. The subregional meetings were iterative, with a standing agenda that included scenario planning, regulatory, legal and institutional issues, and implementation. Meetings included representation from MassDEP and US EPA and were also professionally facilitated by CBI.



Percentage of Cape Cod Land Area that Discharges to an Embayment

Figure 1-4



Working Group Organization And Degree of Embayment Impairment

Figure 1-5

See Appendix 1G for a complete list of meeting dates, agendas, and meeting summaries for all of the subregional meetings.

CHALLENGE: HOW TO ADDRESS THE ISSUE OF AFFORDABILITY

One of the basic principles of the Section 208 Plan Update is that cost be considered as part of every watershed solution and the impact on individual homeowners be a primary concern. If a solution isn't affordable, it's not doable.

In addition to identifying more affordable technologies, it is of the utmost importance to consider how to pay for the needed solutions and identify new resources from the State and Federal Governments to offset the costs.

To help achieve the goals of ensuring affordability for Cape Cod residents and businesses, considering innovative ways to pay for solutions and identifying new resources the Commission established a new team – the 208 Plan Update Finance Committee.

FINANCE COMMITTEE

The Finance Committee met monthly and was convened with representation from local communities and support from consultants to the Cape Cod Commission. Members included a town administrator, a finance director, and a municipal finance committee member. The mission of the committee was to work with the consultants to the Commission to establish a factual basis for discussing issues of affordability, financing, and resources related to the Section 208 Plan Update. See Appendix 1H for a list of members and their affiliations, as well as meeting information.

CHALLENGE: HOW TO ADDRESS THE NEED FOR REGULATORY FLEXIBILITY

The existing regulatory framework was built to solve other problems. Existing regulatory drivers overbuild expensive solutions dependent on pointsource technologies to solve a nonpoint source problem. This approach doesn't account for the unique challenges of Cape Cod as a coastal community with a marine water quality issue caused by nutrients and a relatively low-density development pattern.

To ensure regulatory impediments and flexibility in planning and permitting were addressed the Commission established two new teams – the Section 208 Plan Update Regulatory, Legal and Institutional Work Group (RLI) and the Monitoring Committee.

RLI WORK GROUP

The RLI Work Group had representation from MassDEP, US EPA, the Cape Cod Commission, and other State and Federal partners, as necessary. It addressed the potential need for regulatory reform and other challenges associated with planning and implementation. The need for increased coordination between local, state and federal regulatory requirements was identified by the Commission and the group met monthly to discuss this and other opportunities and challenges related to the Section 208 Plan Update. See Appendix 1I for a list of RLI Work Group members and their affiliations, in addition to meeting information.

MONITORING COMMITTEE

The Monitoring Committee was convened in April 2014 and continues to meet monthly. The mission of the committee is to provide expertise on appropriate monitoring protocols for technology efficiency and total maximum daily loads (TMDLs), while identifying a process for consolidating all available monitoring data in a central location and format. Members include representatives from MassDEP, US EPA, academic institutions, non-profit organizations, and other government agencies. The roles and responsibilities of this committee are to:

- Establish performance monitoring protocols for technologies that may be a part of watershed permits in the future;
- Establish compliance monitoring protocols for meeting TMDLs in the water body;
- Establish a process and structure for consolidating and cooperation of existing monitoring programs and data in to a centralized location; and
- Identify region-wide monitoring needs and develop proposals.

To achieve the benefits of flexible permitting, a plan must remain adaptive in nature. Monitoring the technologies permitted as part of an adaptive management plan is essential to maintaining a flexible regulatory environment

into the future. See Appendix 1J for a list of Monitoring Committee members and their affiliations, as well as meeting information.

CHALLENGE: ENGAGING THE BROADER CAPE COD COMMUNITY

While the number of individuals involved in the effort to update the Section 208 Plan was significant, the broader public still needed to be engaged and educated on water quality issues. In an effort to broaden outreach the Commission developed web-based engagement opportunities and held Cape-wide meetings to provide updates on the problem and process.

WEB-BASED CAPE-WIDE ENGAGEMENT

Cape2O

Between July and December 2013 the Commission ran two online engagement games with the help of the Engagement Game Lab at Emerson College on their Community PlanIt platform (https://communityplanit.org/capecod/). The engagement games, called Cape2O, introduced players to water quality issues on Cape Cod, and touched upon science, civics, economics, our environment and consensus building. The initial game was targeted at seasonal and year-round residents, with the second game targeted at schools. More than 900 individuals registered for the two games, generating more than 6,000 comments and questions on water quality issues. Six local "causes" were awarded $1000 prizes to implement projects on Cape Cod. See Appendix 1K for supporting materials.

www.CCH2O.org

The website www.cch2o.org was developed by the Commission as a portal to raise watershed awareness and enable individuals to better understand various approaches and technologies that may improve water quality on Cape Cod. It was designed to increase the community's understanding of water quality concepts – why water quality problems exist and how they might be improved – through a web-based interactive tool.

Through the website, users are able to locate the watershed in which they live and acquaint themselves with nutrient issues specific to that watershed. The site also provides an opportunity for citizens to examine solutions to water quality problems at individual and community-wide levels. Various links are available to allow users to dig deeper into other web-based tools the Commission has developed and to provide an email address or log in to be updated on the Commission's ongoing efforts.

CAPE-WIDE MEETINGS

On November 13, 2013, the Commission held a Watershed Event to conclude the Cape2O game, award prizes to participants and provide funding to top projects associated with the game. Over 120 stakeholders, Cape2O players, regulatory agency staff, and members of the public attended. Speakers included Cape and Islands Senator Dan Wolf, as well as representatives from the US EPA and MassDEP. In addition to discussing the outcomes of the Cape2O game the time was used to begin the discussion around structuring the second half of the stakeholder engagement process – the subregional working group meetings.

On February 6, 2014, the Commission held a day-long Stakeholder Summit to review the work to date and discuss the path forward toward development of the Section 208 Plan Update. About 270 stakeholders, regulatory agency staff, and members of the public attended the event and speakers included the state treasurer, MassDEP commissioner, CEO of the Cape Cod Chamber of Commerce, representatives from the US EPA and the Cape Cod Commission. The discussion focused on the importance of the community involvement in the Section 208 planning process and the need to meet water quality goals in Cape Cod's estuaries. Breakout sessions included preliminary conversations on scenario planning, regulatory, legal, and institutional issues, and implementation issues, in order to set the stage for the upcoming subregional working group sessions.

See Appendix 1L for all materials related to the Watershed Event and the Stakeholder Summit.

Learning from the Community

Complex environmental problems caused in large part from human interaction with the land and natural environment require complex solutions. Solutions for water quality problems on Cape Cod are not only environmental, but social and political as well. Solving this problem requires cooperation among communities and respect for stakeholder perspectives. Stakeholder feedback maintained that one of the greatest challenges to collaboration in shared watersheds is managing disagreement amongst various interests and multiple municipalities in a shared watershed.

As part of the Section 208 Plan Update, the Commission recommends that guidance on managing disagreement among parties be developed.

> Recommendation S1.1: The Cape Cod Commission shall develop guidance on managing disagreement among parties.

When many people join together to solve a problem, regardless of the approach taken or model used, there will be different points of view and different strategies proposed. Part of the planning effort should include building mechanisms into the process to solve such disagreement.

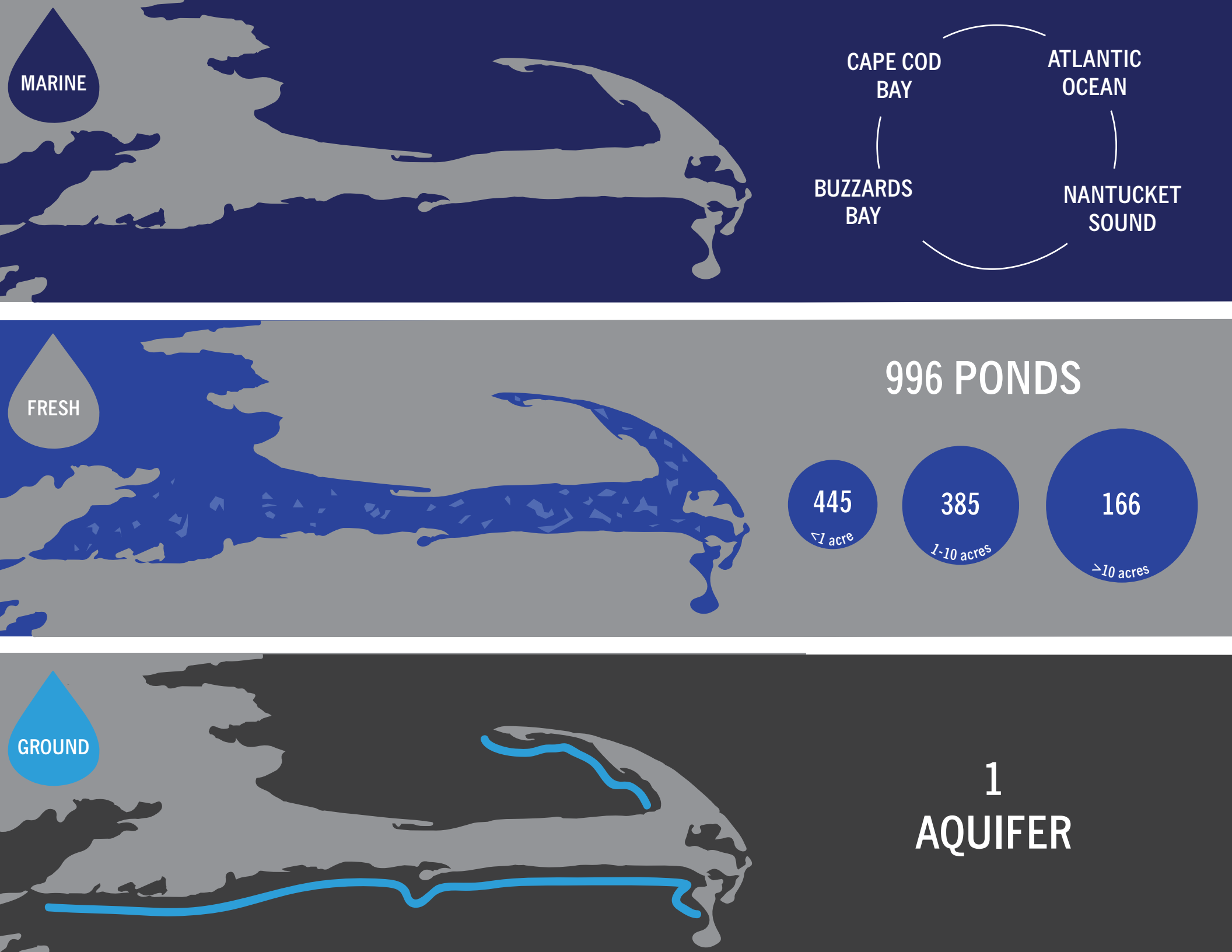
Each party should conduct a self-assessment as part of the terms of their collaboration with a focus on each party's ability to define responsibilities and annual objectives. Agreeing to alternative dispute resolution mechanisms, whether formal or informal, creates that mechanism for managing disagreement as it arises. Agreement to such processes may keep the content of such mediations the responsibility of parties themselves, encourage the exchange of information, help parties to understand differing views, shift the focus to the future, invent solutions that meet fundamental interests of all parties, and increase public trust. The goal of such a process would be a mutually acceptable settlement of all issues raised.

Barnstable County could be considered as a resource for mediation support services. Barnstable County could designate a liaison in each shared watershed to provide support in working through disagreements. These designees could work with town managers, planners or other boards and working groups as a point of contact and provide facilitation service to towns as they implement watershed plans and approaches.

02 PROBLEM

Cape Cod Baseline - People & Place

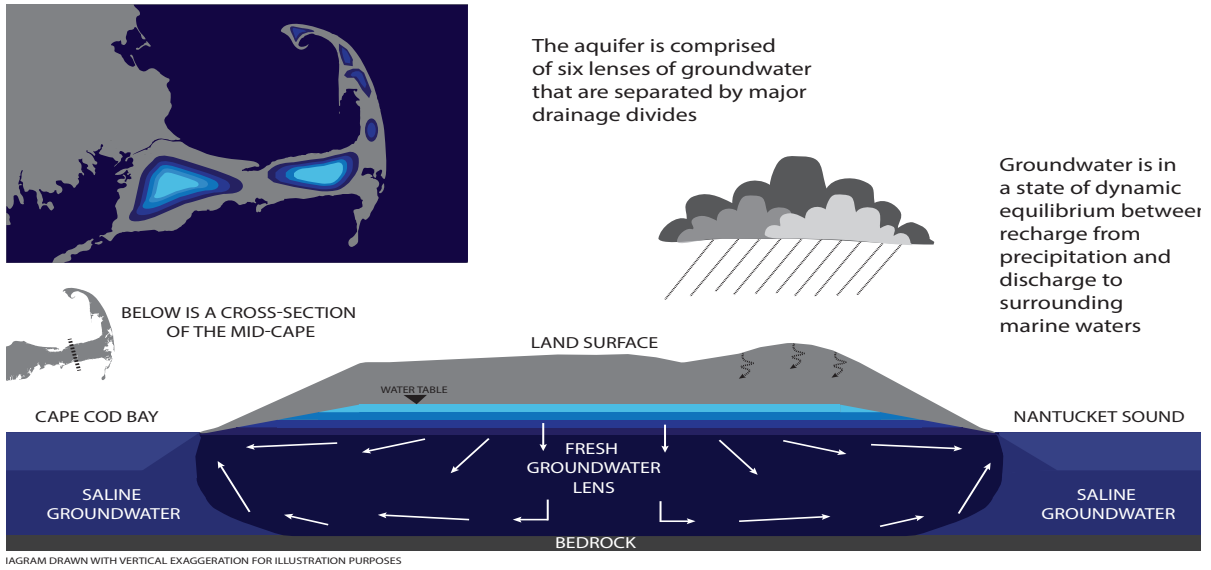
Cape Cod's great natural beauty, bountiful recreational opportunities and proximity to major urban areas led to a rapid increase in population over the last half century. The region is defined by, and dependent on, the marine environment that surrounds it. The intersection of the region's hydrology with its year round and seasonal population presents specific challenges. Increased residential development built to accommodate the rapid influx of people to Cape Cod depended almost exclusively on individual septic systems, which discharge nitrogen to the groundwater. There are101 watersheds to the surrounding marine waters and of those, 53 are watersheds to coastal embayment systems. The coastal embayments are located at the margin of the aquifer and are the ultimate receiver of the aquifer's groundwater discharge.


MARINE
CAPE COD BAY
ATLANTIC OCEAN
BUZZARDS BAY
NANTUCKET SOUND
FRESH
996 PONDS
445
<1 acre
385
1-10 acres
166
>10 acres
GROUND
1
AQUIFER

PHYSICAL SETTING: WATER ON CAPE COD

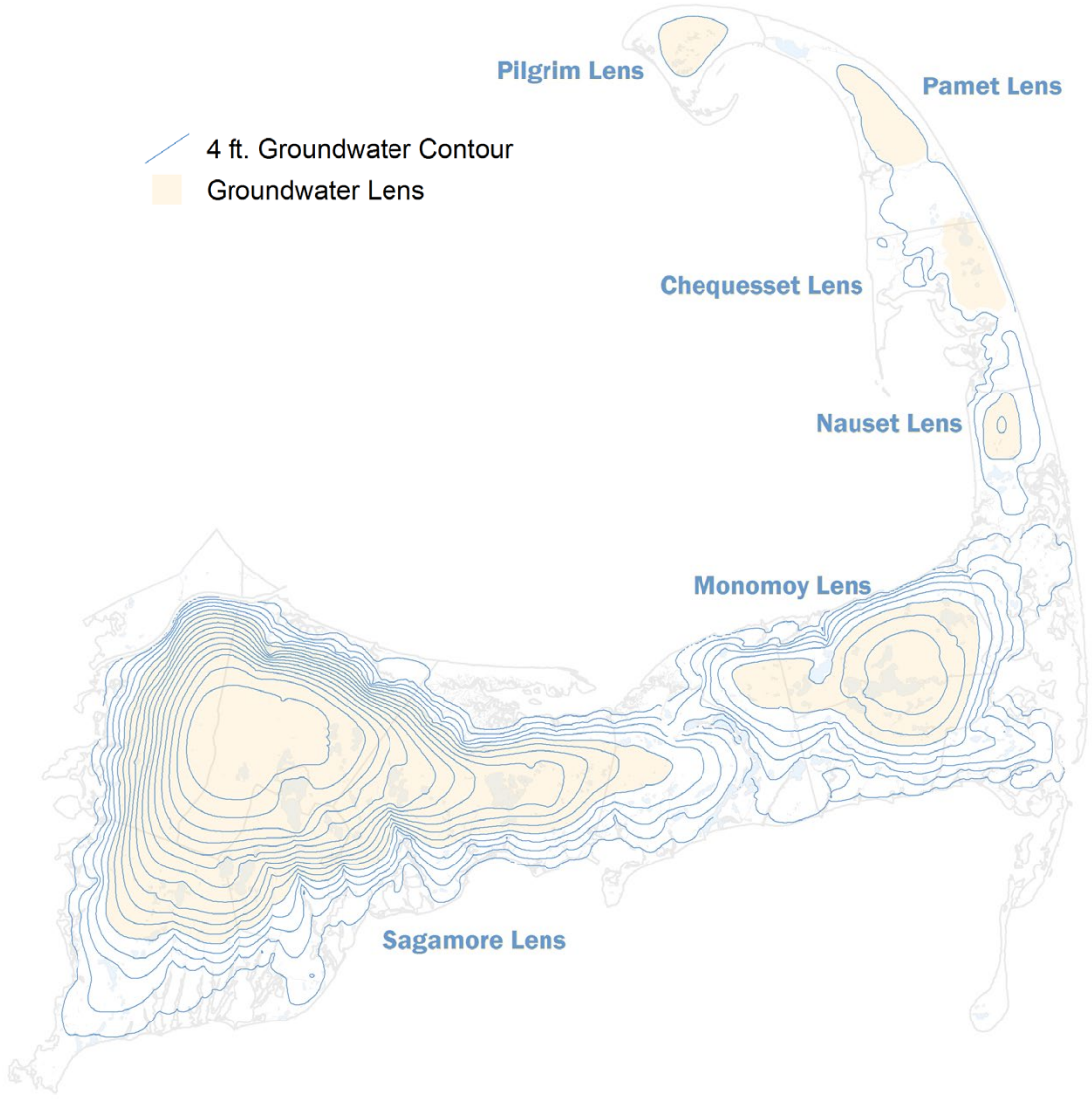
Cape Cod is an iconic peninsula, only 10 miles at its widest point. It is completely surrounded by marine water, including Cape Cod Bay, the Atlantic Ocean, Nantucket Sound, and the Cape Cod Canal. Cape Cod also hosts 996 freshwater ponds covering 11,000 acres of its land area. The fresh water beneath the land is called groundwater.

Cape Cod is a sand and gravel remnant of the last continental deglaciation that occurred 15,000 to 20,000 years ago. The Cape is a series of broad gently sloping outwash plains that are truncated by long linear moraine deposits found along the present day Route 6/Mid-Cape Highway from Sandwich to Orleans and Route 28/ MacArthur Boulevard through Bourne and Falmouth. The glacial deposits are approximately 150 to 900 feet thick from Buzzards Bay to Provincetown and are generally coarse to medium sand, but grade to finer materials at depth. The coarse sands are extremely permeable making for a high yielding groundwater system (**Figure 2-1** illustrates the groundwater system).



Groundwater

Figure 2-1



Water Table Map of Cape Cod

Figure2-2

The groundwater of Cape Cod is bounded at the top by the water table which is ubiquitous across the Cape, a sharp transition zone between fresh and marine water at the shore, and by bedrock below, except for the Outer Cape where freshwater lens floats on top of saltwater.

The groundwater system is recharged solely from precipitation at a rate of 27 inches per year (approximately 60% of precipitation). The groundwater system is in dynamic equilibrium between recharge and discharge to the surrounding marine waters and flows at approximately one foot per day due to gravity. Groundwater located further inland has a greater distance to travel to get to the shore, therefore, the accumulation of recharge over time mounds up. The mounds of groundwater are relatively thin and convex and therefore are referred to as lenses of groundwater.

Six separate lenses comprise the Cape Cod aquifer system: the Sagamore Lens is the groundwater system for the Upper and Mid Cape region, the Monomoy Lens for the Lower Cape and the Nauset, Pamet, Chequesset, and Pilgrim Lens for the Outer Cape. (see **Figure 2-2**).

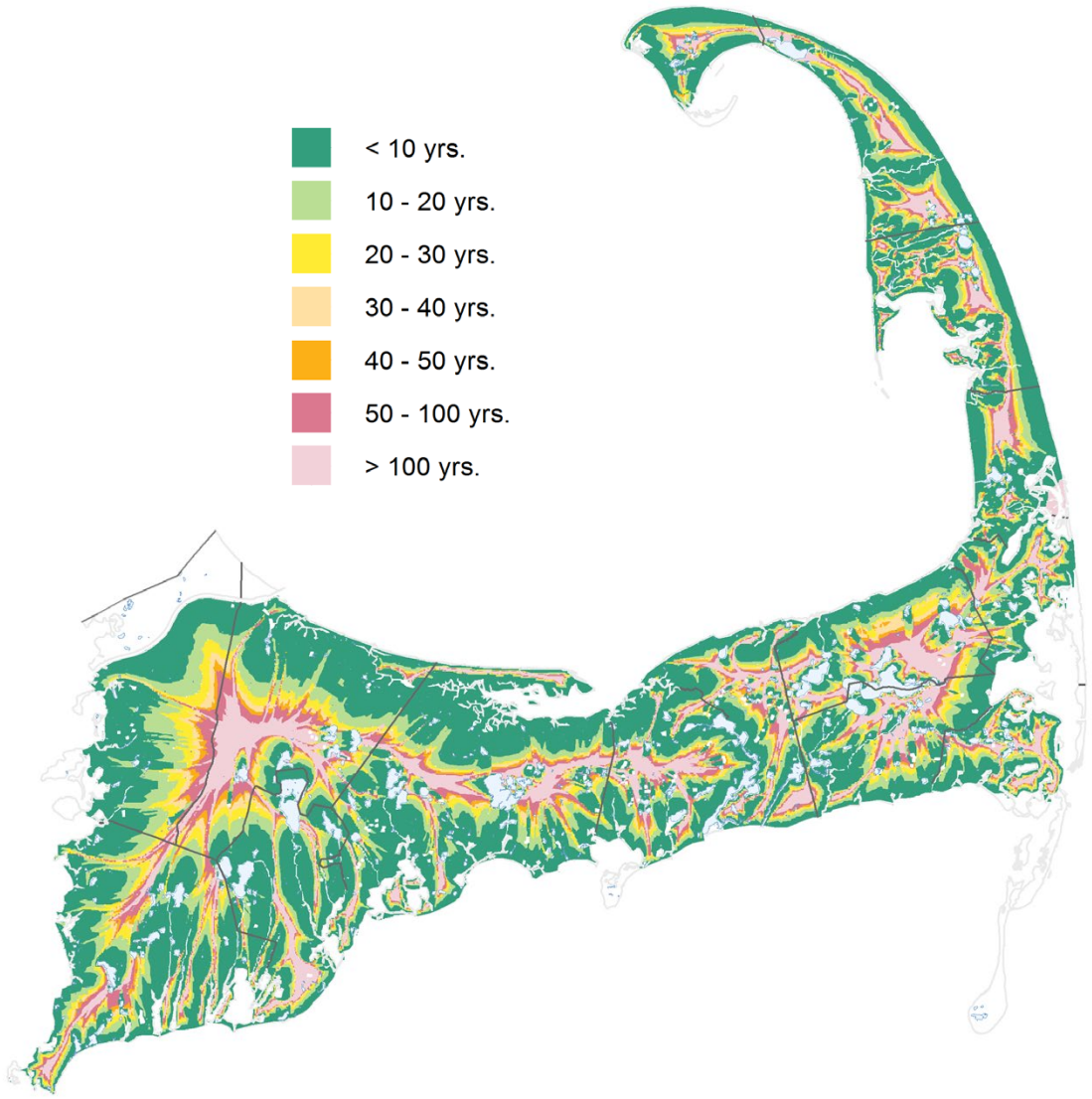
The Cape's groundwater system is directly connected to the fresh and surrounding marine systems. It is susceptible to contamination from various land uses and activities as described in later sections.

Figure 2-3 shows the groundwater time-of-travel areas on Cape Cod, as delineated by the United States Geological Survey (USGS), indicating the years required for a particle to travel from its point of entrance to the groundwater to Cape Cod's coastal embayments.

Travel time is less than 10 years for almost half of Cape Cod's land area. This presents the likelihood that wastewater treatment options, once implemented in these areas, could result in water quality improvements within 5-10 years in some degraded embayments.

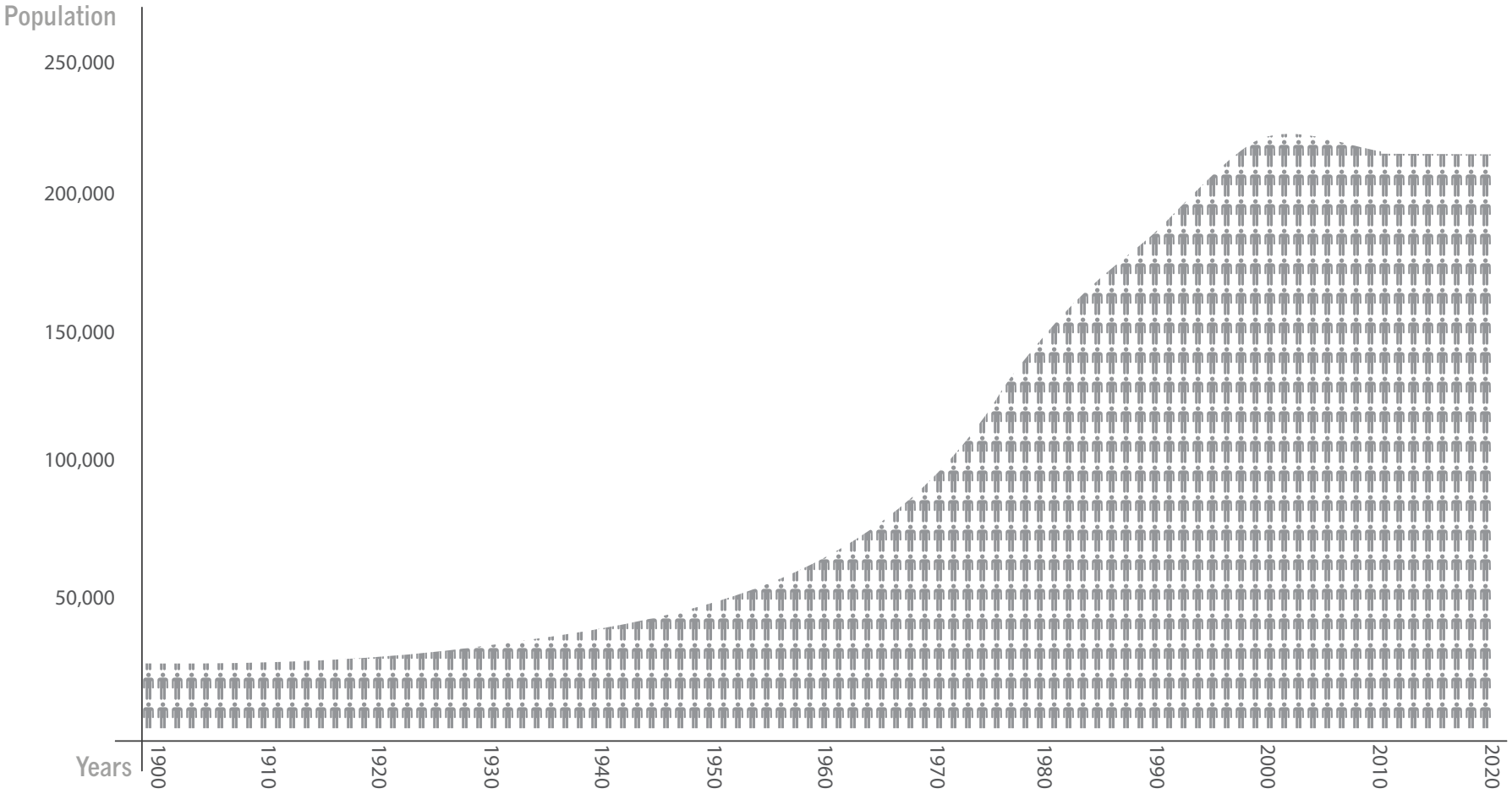
LAND USE: POPULATION, DENSITY, AND SEASONALITY:

Land use on Cape Cod has changed over time due in part to fluctuations in population. The Cape's traditional farming and fishing way of life underwent a slow transformation from the 1870s through the early part of the 20th century as seaside resorts began to attract summer visitors. The advent of rail travel and the adoption of the interstate highway system added to the accessibility and the popularity of Cape Cod.



USGS Time of Travel Map

Figure 2-3



Total Population Barnstable County

Figure 2-4

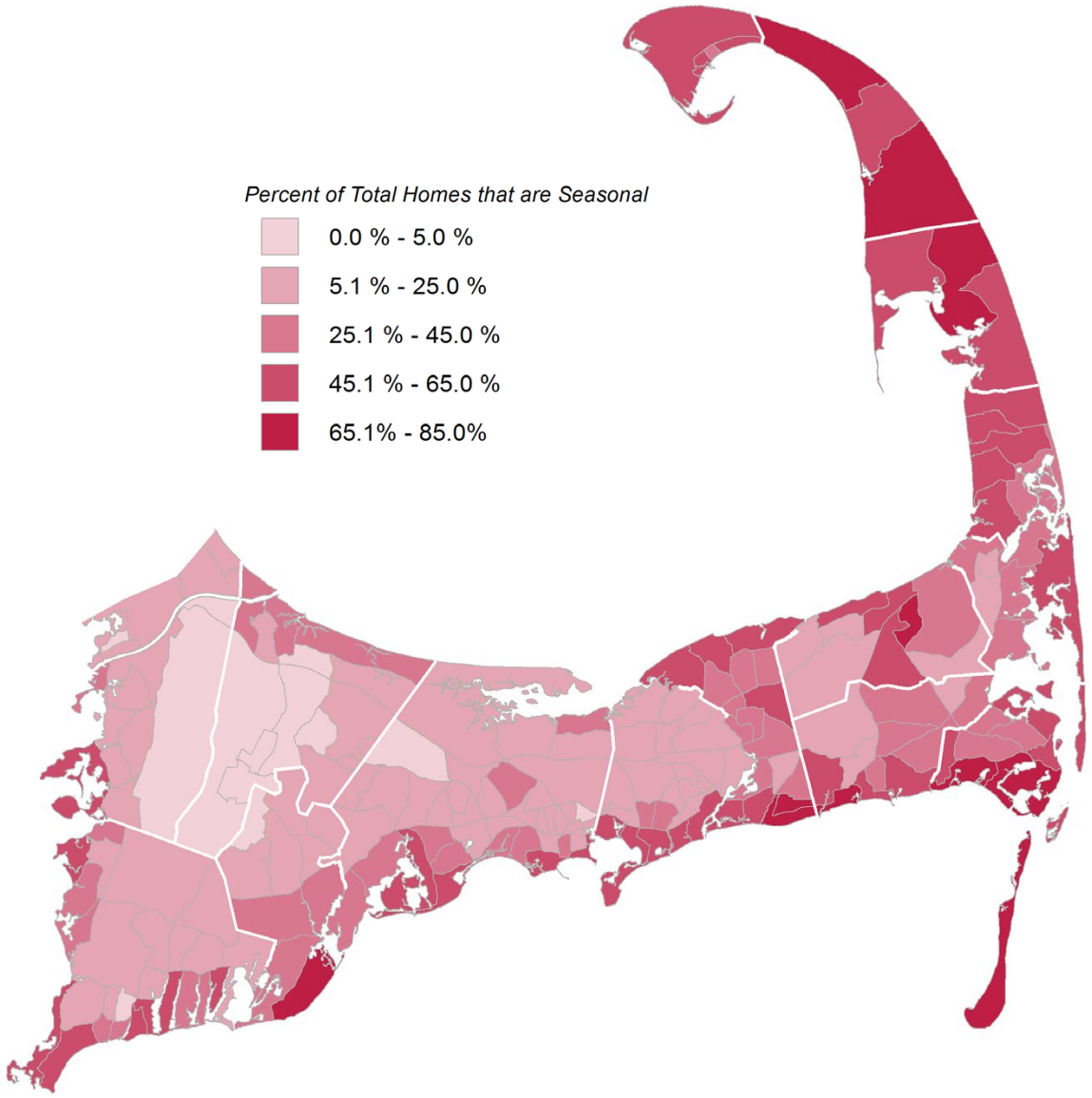
The population began to rise more quickly in the 1950s and even more steeply from the 1970s through the early 2000s, as Cape Cod became a desired location for retirees and second-home buyers (see **Figure 2-4**).

During this time period, the population of Cape Cod swelled 400%. In 1951, just prior to the swell in population, most of the interior of Cape Cod remained open space and the coasts were developed as dense residential areas. By 2012, the interior of the Cape Cod peninsula was consumed by residential units (**Figure 2-5** through **Figure 2-13**). Recently, population decreased from about 227,000 in 2001 to an estimated 215,000 in 2011. The decline is attributed, in part, to the increasingly high cost of Cape Cod real

estate as the market boomed in the last decades of the 20th century, followed by the swift market decline toward the end of the first decade of the 21st century.

These striking changes in population and land use are also apparent in density patterns on Cape Cod. Based on 2010 Census data, the density of human habitation is 582 people per square mile, nearly five times that in 1950 (118 people per square mile). Furthermore, the density in 2010 is far from uniform; people are clustered together in specific areas on the land surface. There are as few as 36 people per square mile in many protected areas, such as the National Seashore on the Outer Cape, state parks and Wellhead Protection Areas. In highly dense areas, such as Hyannis, there are as many as 4,500 people per square mile. The density of housing units mirrors the non-uniformity of human habitation on Cape Cod. Areas such as Falmouth, Barnstable and Provincetown, have larger numbers of people and more housing units per square mile than other parts of the Cape.

There is a seasonality to the population on Cape Cod. In the past several decades the number of people living year-round on Cape Cod increased, with a corresponding conversion of seasonal homes for year-round use. Approximately one third of the housing stock on Cape Cod (57,000 housing units) is dedicated to seasonal use. Seasonal units are non-uniformly distributed over the land and are much more prevalent in coastal areas than inland areas (**Figure 2-14**).



Seasonality

Figure 2-14



Cape Cod Land Use 1951



Cape Cod Land Use 1971



Cape Cod Land Use 1985



Cape Cod Land Use 1999



Cape Cod Aerial Image 1952



Cape Cod Aerial Image 1971



Cape Cod Aerial Image 1984



Cape Cod Aerial Image 2002

Cape Cod Land Use 2012

Figure 2-9



Facing page, from left to right:

Figure 2-5 Cape Cod Land Use 1951
Figure 2-6 Cape Cod Land Use 1971
Figure 2-7 Cape Cod Land Use 1985
Figure 2-8 Cape Cod Land Use 1999

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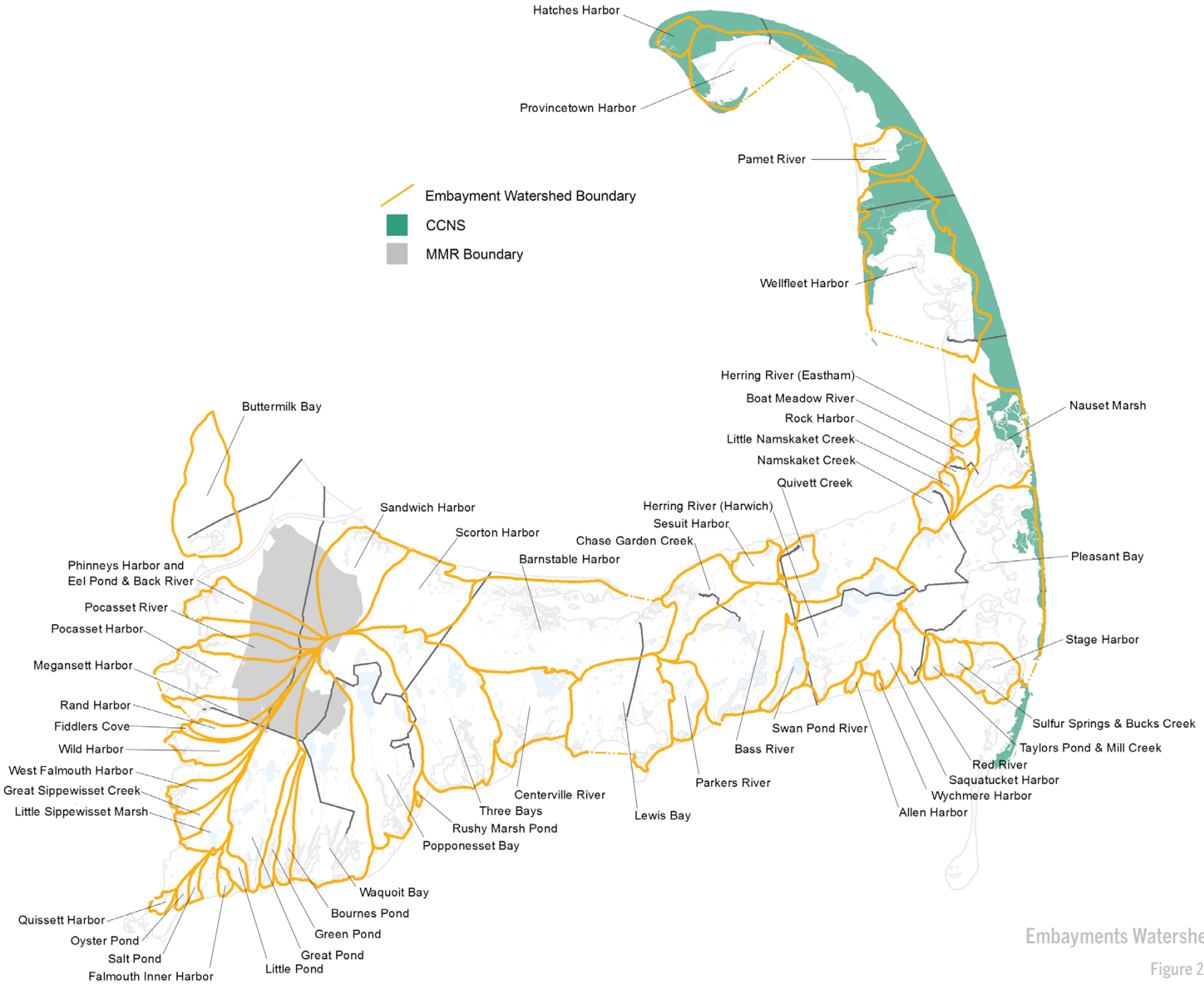
Figure 2-10 Cape Cod Aerial Image 1952
Figure 2-11 Cape Cod Aerial Image 1971
Figure 2-12 Cape Cod Aerial Image 1984
Figure 2-13 Cape Cod Aerial Image 2002

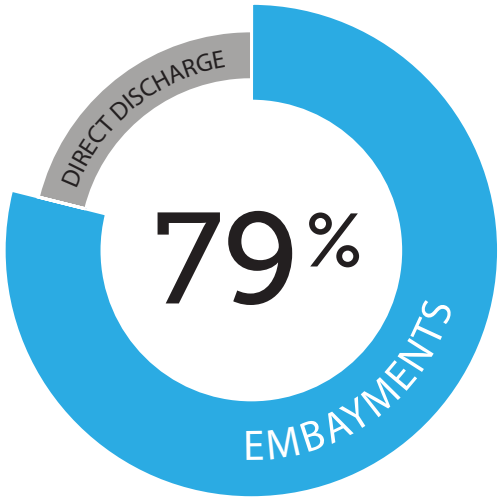


Embayments Watersheds

Figure 2-15

THE INTERSECTION OF PEOPLE AND PLACE

The intersection of the region's hydrology with its year round and seasonal population presents specific nutrient pollution challenges. Increased residential development built to accommodate the rapid influx of people to Cape Cod depended almost exclusively on the construction of individual septic systems. Individual on-site septic systems are documented as the greatest contributing factor to declining estuary and embayment water quality. In the following sections, marine, fresh and ground water systems will be reviewed with specific attention to water quality issues.



Percentage of Cape Cod Land Area that Discharges to an Embayment

Figure 2-16

MARINE WATER

Cape Cod hosts 101 watersheds that drain into surrounding marine waters. A watershed is a geographic area separated from other regions by drainage divides. Within each watershed area, water flows to an embayment or other water body. Fifty-three watersheds on Cape Cod drain into coastal embayment systems. Coastal embayments, partially enclosed coastal areas with varying degrees of tidal restriction, are located at the margin of the aquifer and are the ultimate receiver of the aquifer's groundwater discharge. Embayments are important ecosystems on Cape Cod; they are the primary habitat for shellfish, spawning grounds for fish stocks, and important recreational areas for Cape Cod residents and visitors.

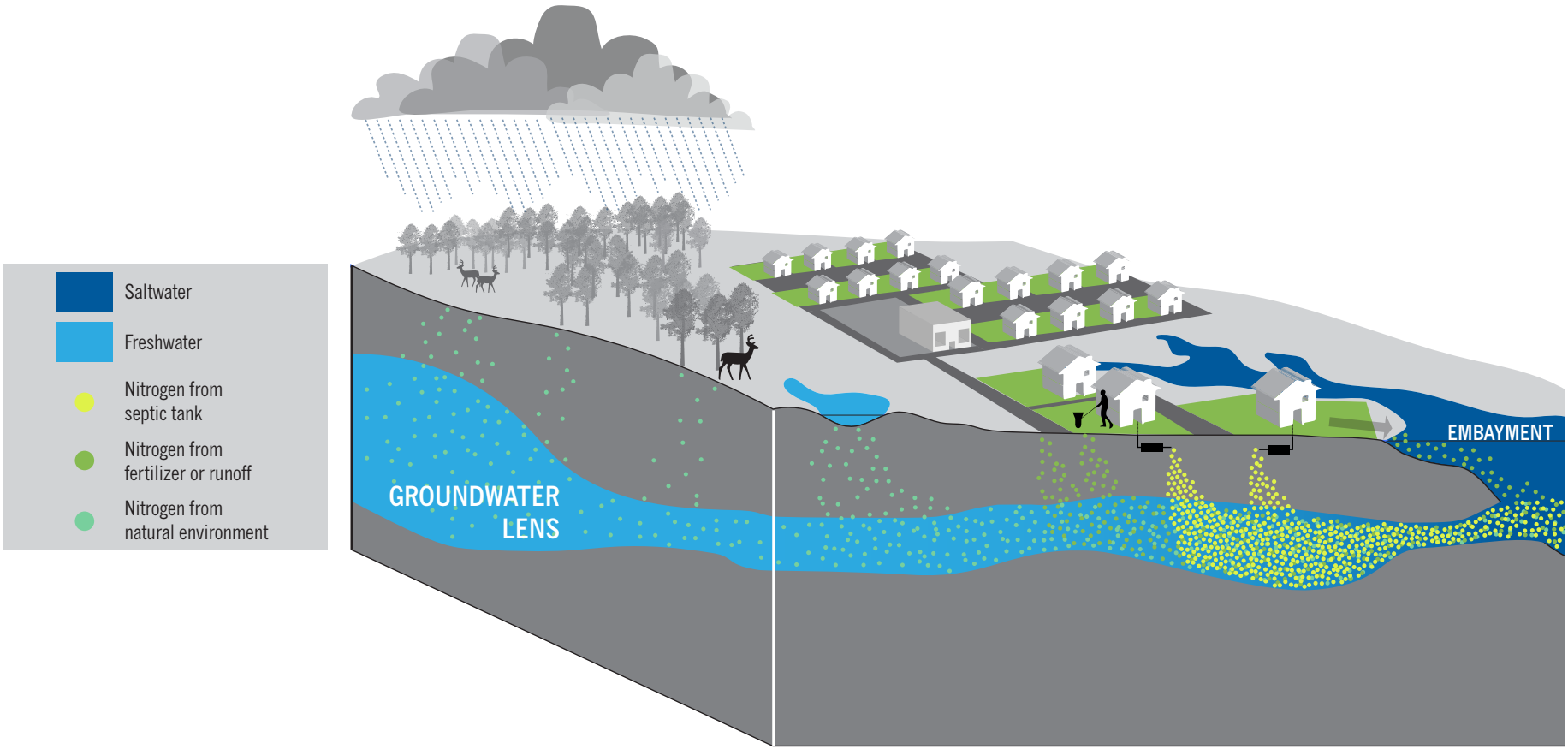
Each watershed, with its associated coastal embayment, extends from the top of the water table lens to the coastline, covering nearly 79% of the land area of Cape Cod (see **Figure 2-15** and **Figure 2-16**). The remaining 21% of Cape Cod is in a watershed where groundwater discharges directly to open coastal water such as the Cape Cod Canal, Nantucket Sound, Cape Cod Bay and the Atlantic Ocean. These are called direct discharge areas and are important areas to consider for potential wastewater discharges since the nitrogen loads do not impact the coastal embayments.

MARINE COASTAL WATER QUALITY

Watersheds are vulnerable to pollutants generated by land uses. Residential development in the last several decades sprawled across Cape Cod, consuming open space and dispersing wastewater throughout the aquifer. Nitrogen, a nutrient in wastewater, stormwater, and fertilizer, percolates into groundwater and ultimately discharges at the coast (**Figure 2-17**). The impact of nitrogen on coastal embayments is a major cause for concern on Cape Cod. Wastewater from septic systems was found to be the primary source of nitrogen overloading the coastal embayments.

In healthy embayment ecosystems, eelgrass is the dominant plant type and survives on sparse amounts of nitrogen. However, when too much nitrogen is added to an embayment, excessive algae is produced, resulting in large algal mats that shade out eelgrass and destroy animal habitat, which eventually leads to a loss of shellfish. This is referred to as the process of eutrophication. In some cases, severe conditions of anoxia have occurred that also result in fish kills and aesthetically unpleasing conditions.

TThe maximum amount of a pollutant that a water body can receive and still meet water quality goals is defined as a Total Maximum Daily Load (TMDL) under the Federal Clean Water Act. As described in guidance from the United States Environmental Protection Agency (US EPA), a TMDL identifies the loading capacity of a water body for a particular pollutant. US EPA regulations define loading capacity as the greatest amount of a pollutant that a water body can receive without exceeding water quality standards. Recent Cape Cod TMDLs have focused on nitrogen.TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass, the leading indicator of ecological health. TMDLs are technical planning documents. Federal, state and local authorities implement



Contributing Nitrogen to Coastal Embayments

Figure 2-17

TMDLs through various legal instruments such as state groundwater discharge permits and National Pollution Discharge Elimination System (NPDES) permits.

Concurrent with the beginning of our awareness about the effect of nitrogen in coastal waters, the Commission adopted a regulatory requirement that development projects within watersheds to impaired embayments must have no-net nitrogen loading. In other words, the amount of nitrogen added by a project must be offset by an equivalent reduction. Several County-appointed committees that reviewed the Commission's regulatory program accepted this requirement as a necessary interim step to halt continued degradation of the Cape's coastal water quality. Over the years, it became increasingly clear to organizations involved in assessing and protecting embayments that a comprehensive effort to link regulatory and scientific activities was necessary to realize solutions for observed coastal water quality problems.

The general science to define critical thresholds and TMDLs advanced considerably over the past two decades. Efforts include defining watersheds, estimating watershed nitrogen loads, collecting water quality data, modeling tidal flushing and evaluating ecosystem interactions between embayment species. One project spearheading these efforts is the Massachusetts Estuaries Project.

MASSACHUSETTS ESTUARIES PROJECT

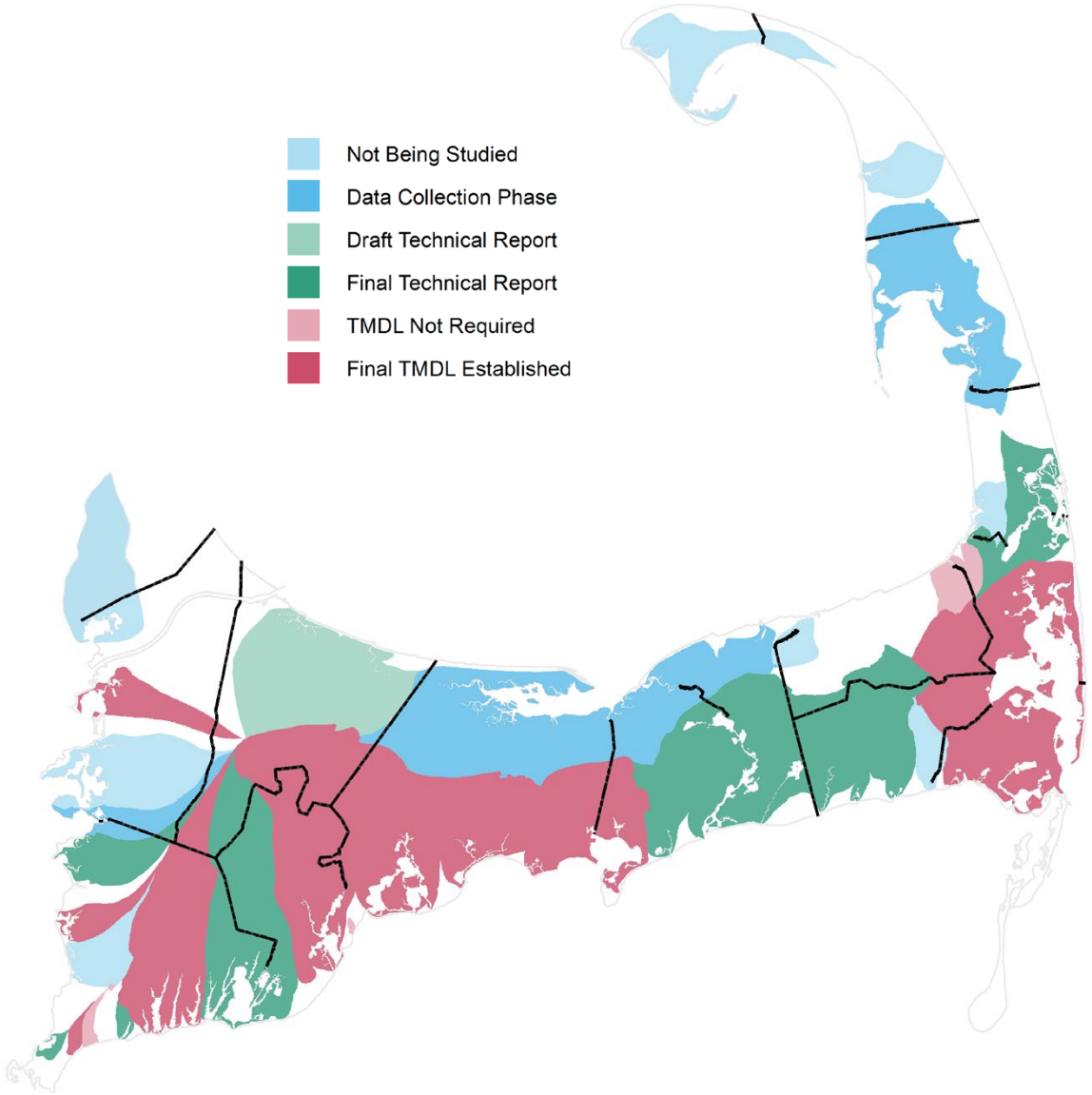
In 2001, the Massachusetts Department of Environmental Protection (MassDEP) and the University of Massachusetts-Dartmouth, School of Marine Science and Technology (SMAST) began the Massachusetts Estuaries Project (MEP). The MEP was estimated to cost $12 million over six years. Funding is broad-based with half coming from the state and the other half coming from local and other agency and non-profit sources. Barnstable County, through the Cape Cod Commission and the Cape Cod Water Protection Collaborative, provided over $700,000 to the MEP over the last eight years as direct assistance to participating Cape Cod towns. The MEP resulted in technical reports and documents that have been approved by state, federal, and county regulatory agencies. The MEP's regionally consistent methodology provides technical work and documents at significant cost savings over towns undertaking similar work individually.

The MEP developed a rigorous linked-model approach that includes components of the various disciplines necessary to understand and project how nonpoint source nitrogen loading in a watershed can result in coastal water quality deterioration. Data input into these models includes: at least three years of volunteer-collected coastal water quality data, tidal flushing data, bathymetric information for estuaries and freshwater ponds, pond water quality data, current and historic eelgrass coverages, water use information, wastewater treatment plant performance, landfill monitoring data, watershed delineations, sediment nutrient regeneration, and wetland nitrogen attenuation.

MEP Report Status and Findings

The MEP provides specific documentation that many of Cape Cod's watersheds have impaired water quality and ecological damage due to nitrogen loading. The results of many technical reports were used to develop federal- and state-approved TMDLs. As of February 2015, 35 watersheds have completed MEP technical reports, two are in draft form, and four are pending. There are 12 embayments not scheduled for study by MEP because nitrogen is not believed to be a critical issue due to tidal flushing, low intensity development, or geomorphology. US EPA approved 12 TMDLs for embayments on Cape Cod. One additional TMDL is currently pending final US EPA approval. MassDEP is drafting additional TMDLs based on MEP technical reports. The results of the technical reports have been adopted as the federal and state approved TMDLs, which makes them the basis for watershed nutrient management. **Figure 2-18** shows the status of the technical reports and TMDLs by watershed.

Although the amount of nitrogen entering the watershed is an important consideration in evaluating the potential impact on coastal embayments, other factors such as tidal range and embayment volume play significant roles. Embayments on the southern coast of Cape Cod are more susceptible to impacts because the tidal range is approximately three feet while the range observed in Cape Cod Bay is nine feet. Therefore, more water is available to dilute and remove nitrogen loads in the Cape Cod Bay embayments than the southern embayments.



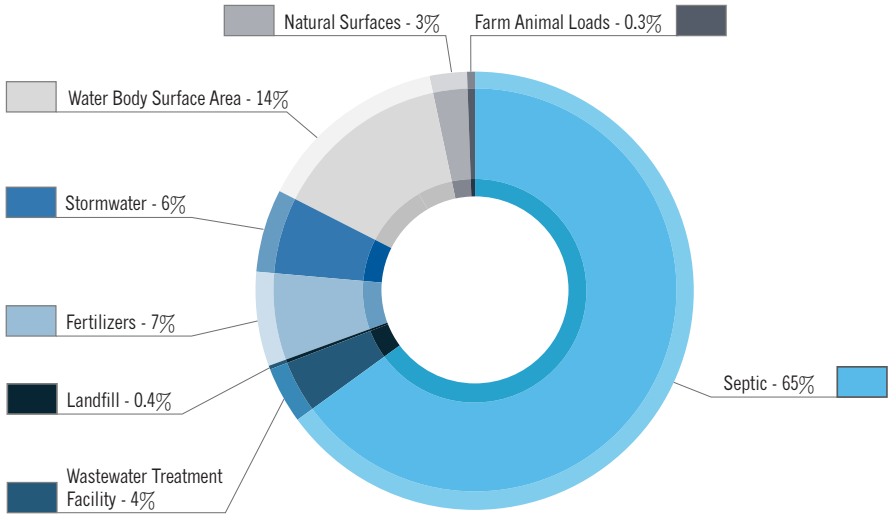
Status of MEP Technical Reports and TMDLs by Watershed

Figure 2-18

MEP Peer Review

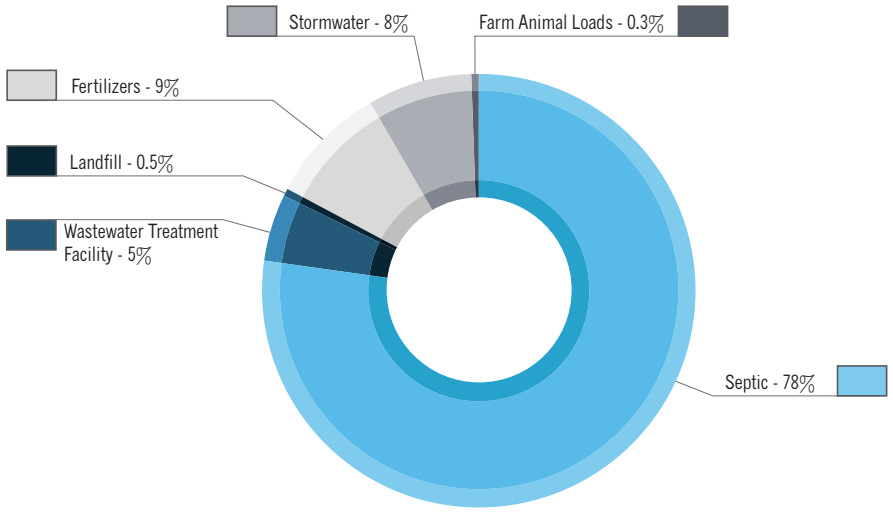
In response to concerns raised by some Cape Cod communities regarding the validity of the MEP scientific approach, the Barnstable County Commissioners directed the Cape Cod Water Protection Collaborative to undertake a scientific peer review of the MEP process. In 2011, the Collaborative organized an independent scientific peer review of the MEP methodology for developing appropriate TMDLs for the estuaries and embayments of Cape Cod, and for the use of that methodology as a basis for wastewater and nutrient management planning and implementation on Cape Cod. The scientific peer review process was independent and objective, and operated externally from the Collaborative and from any other Cape Cod stakeholders.

The peer review panel found the MEP modeling approach to be appropriate and useful for evaluating alternative scenarios and informing nutrient management plans, and also found the MEP to be consistent with existing nationwide TMDL practices. The panel also found that the MEP modeling approach is scientifically credible, and the modeling approach is consistent with current understanding of existing conditions for Cape Cod estuaries, based on available data. The components in the approach are well known and documented. Computation of watershed nitrogen loads is strongly data-driven and quantitatively linked to estuarine nitrogen concentrations. For more information see the MEP Peer Review Executive Summary or the full report of the MEP Scientific Review Panel on the Cape Cod Water Protection Collaborative website (www.ccwpc.org).



Total Nitrogen Sources by Percentage

Figure 2-19



Controllable Nitrogen Sources by Percentage

Figure 2-20

Controllable and Total Loads

The MEP provides specific documentation, based on water quality testing and ecological habitat assessments, indicating that many of Cape Cod's embayments have impaired water quality and ecological damage due to nitrogen loading. The MEP identifies the primary controllable nitrogen sources as wastewater, fertilizer and stormwater. Smaller sources include treated wastewater, landfills and farm animal waste. Septic nitrogen accounts for nearly 80% of the controllable nitrogen load in Cape Cod embayments. **Figure 2-19** and **Figure 2-20** show a Cape-wide breakdown of nitrogen sources for total load and controllable load, respectively.

Some TMDL reports approved by the US EPA include nitrogen loads to natural surfaces and water body surface areas as controllable. The MEP technical reports and TMDL reports approved by the US EPA estimate the total load of nitrogen in a watershed and specify how much needs to be removed to meet the TMDL. Since septic system contributions account for most of the controllable nitrogen load in each Cape Cod watershed, the MEP technical reports and TMDL reports also specify how much septic system nitrogen alone would need to be removed to meet the TMDL. The average reduction rate for septic nitrogen load to meet water quality standards exceeds 50% Cape-wide.

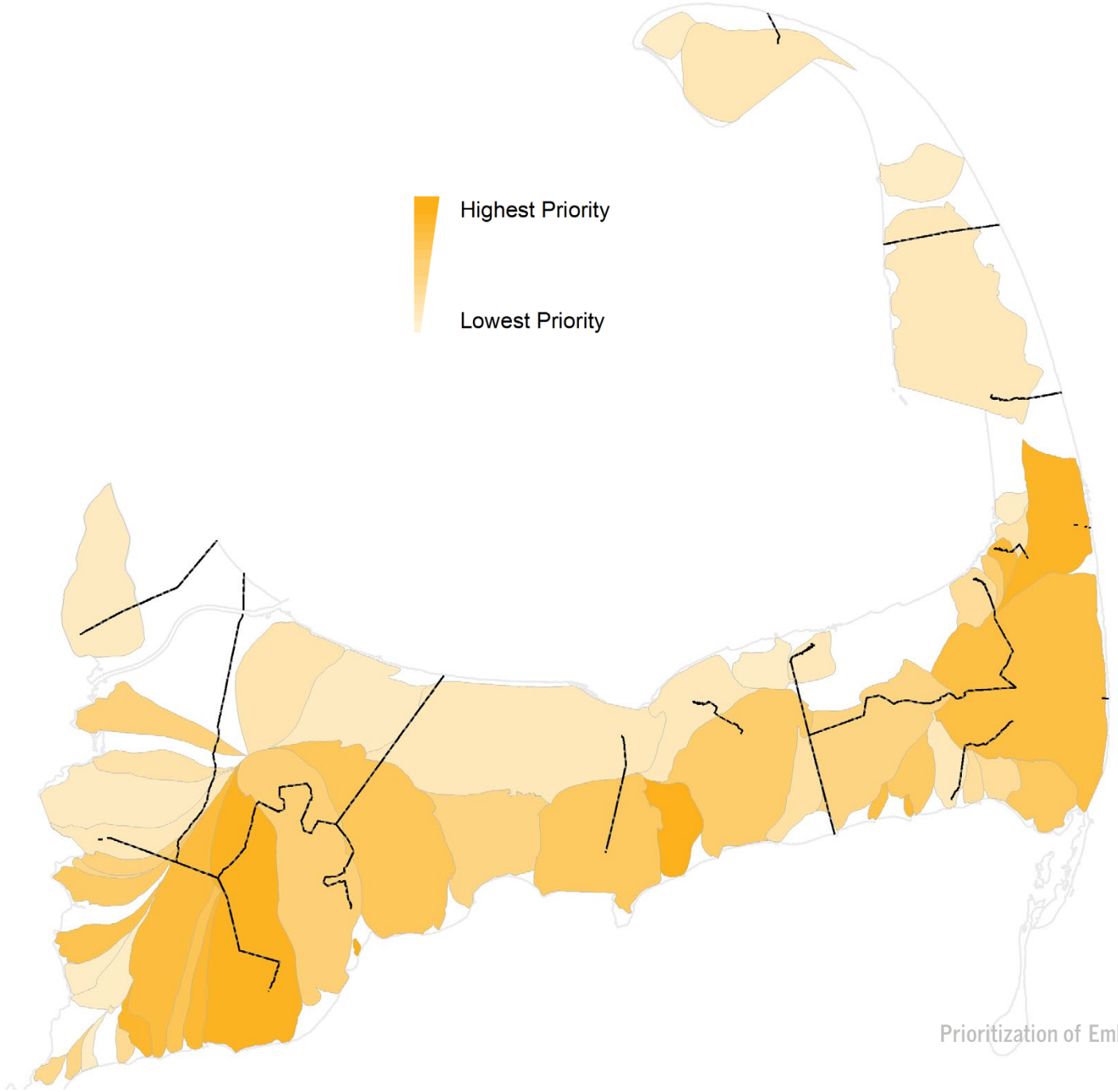
CRITERIA	SCORE	SCORE DEFINITION	DATA SOURCE
Habitat	4	Severe Degradation	Ecological health section of MEP technical reports
	3	Significant Impairment	
	2	Moderate Impairment	
	1	Healthy Habitat Conditions	
% Septic Nitrogen Removal Required after Attenuation	4	Upper quartile (>80%)	Critical nutrient threshold section of MEP technical reports
	3	Upper mid quartile (52-80%)	
	2	Lower mid quartile (35-52%)	
	1	Lower quartile (<35%)	
% Nitrogen Attenuated by Natural Processes	4	Lower quartile (<4%)	Watershed nitrogen load section of MEP technical reports
	3	Lower mid quartile (4-11%)	
	2	Upper mid quartile (11-21%)	
	1	Upper quartile (21-44%)	
Total Nitrogen Load	4	Upper quartile (25,400-85,000 kg-N/yr)	Watershed nitrogen load section of MEP technical reports
	3	Upper mid quartile (9,060-25,400 kg-N/yr)	
	2	Lower mid quartile (2,810-9,060 kg-N/yr)	
	1	Lower quartile (<2,810 kg-N/yr)	
CWMP Status	4	Preferred plan identified but not implemented	Local CWMPs
	3	Alternatives identified	
	2	Needs assessment conducted or MEP technical report completed	
	1	CWMP approved and being implemented	
	0	No CWMP or none anticipated	
Regional Opportunity	3	All municipalities in shared watershed contribute significant nitrogen load to the embayment	MEP nitrogen loads and local water use data
	2	Only one municipality in shared watershed contributes significant nitrogen load to the embayment	
	1	Watershed is wholly within one municipality	
(High ranking and score = higher priority for study)			

Watershed Priority Ranking Criteria

Table 2-1

As a means of identifying a prioritized list of watersheds for study, criteria were established to rank watersheds by subregion (Upper Cape, Mid Cape, Lower Cape, and Outer Cape). Ranking criteria included habitat, total nitrogen load, percent septic nitrogen removal required after attenuation (natural nitrogen reduction), percent nitrogen attenuated by natural processes, CWMP status, and regional opportunities. **Table 2-1** provides details on each of the ranking criteria.

Using the above criteria, watersheds are ranked and prioritized for planning (**Figure 2-21**). All of the embayment watersheds are impacted by nitrogen loading from their watersheds or are at risk for future impairment and should have access to State Revolving Fund (SRF) loans. This prioritization is strictly for planning purposes and not for prioritizing where resources should be made available. Appendix 2A provides specific ratings and scores for each watershed shown in the map. The data used to develop these scores will be updated as new information becomes available.



Prioritization of Embayment Watersheds

Figure 2-21



Ponds

Figure 2-23

FRESHWATER

Lakes and ponds on Cape Cod formed about 12,000 years ago during the Wisconsinan glaciation. As glaciers retreated from Cape Cod, large pieces of ice were left behind. When these pieces of ice melted, the area above each collapsed forming large depressions in the land called kettle holes (**Figure 2-22**). These land depressions dip below the water table, creating the hundreds of ponds seen today.

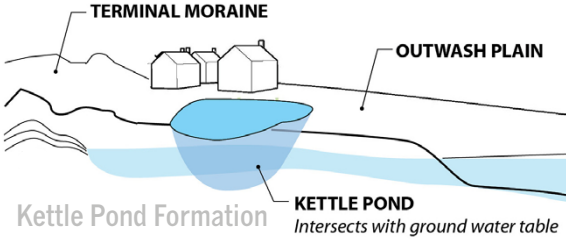


Figure 2-22

Typically, ponds lack a surface water inlet or outlet. Instead, there is a steady inflow and outflow of water between the ponds and the adjacent aquifer, which is why scientists often refer to freshwater ponds as windows into the aquifer. As part of the regional aquifer system, the ponds are directly linked to drinking water and coastal estuaries, as well as any pollutants added to the aquifer.

Cape Cod has 996 ponds covering nearly 11,000 acres (see **Figure 2-23** and **Table 2-2**). These ponds are highly variable in size, ranging from less than one acre to 735 acres, with the 21 biggest ponds making up nearly half of the total Cape-wide pond acreage. Approximately 40% are less than one acre and 166 are designated as great ponds of 10 acres or more (Cape Cod Ponds and Lakes Atlas, 2003).

Freshwater ponds are an important part of the Cape Cod ecosystem. They provide critical habitat for freshwater fish species, including: perch (yellow and white), brown bullhead, pumpkinseed, bass (largemouth and smallmouth), banded killifish, American eel and alewife. Ponds also provide resources for people. Year round and seasonal residents use ponds for recreational activities such as swimming, boating and fishing. Recent property values and sales show that demand for pond-front properties is increasing and use of existing residences is intensifying.

In 2001 the Cape Cod Commission, for a coalition of groups interested in protecting ponds, known as the Ponds and Lakes Stewardship (PALS) project, received a $30,000 grant from the Massachusetts Watershed Initiative to develop a Cape Cod pond stewardship strategy.

The Cape Cod Pond and Lake Atlas, published by the Cape Cod Commission in 2003, provides a status report on the PALS program. The Atlas documents the outreach and education activities leading to the creation of the PALS program and reviews water quality data collected by volunteers during the 2001 PALS Snapshot from over 190 ponds. This data was used to develop Cape Cod-specific indicators of pond impacts. Along with data collected in previous studies, the atlas details further efforts necessary to move pond protection and remediation forward on the Cape. The section on Pond Water Quality below includes a summary of the results and products of the PALS efforts.

LARGEST PONDS

Pond	Town	Acres
Long	Brewster/Harwich	743
Mashpee-Wakeby	Mashpee	729
Wequaquet	Barnstable	654
Great Herring	Bourne	373
Johns	Mashpee	338

DEEPEST PONDS

Pond	Town	Depth (feet)
Mashpee-Wakeby	Mashpee	95
Cliff	Brewster	84
Ashumet	Falmouth	84
Long	Brewster/Harwich	72
Long	Falmouth	66

MOST COMMON NAMES

Name	Number of Ponds with Name
Mill	10
Long	9
Flax	8
Grass or Grassy	7
Round	6
Lily	6

NUMBER OF PONDS BY TOWN

Town	Total	>10 Acres
Barnstable	185	27
Bourne	72	6
Brewster	76	22
Chatham	43	8
Dennis	57	6
Eastham	23	5
Falmouth	143	24
Harwich	62	19
Mashpee	57	9
Orleans	63	4
Provincetown	31	3
Sandwich	63	10
Truro	21	5
Wellfleet	29	7
Yarmouth	71	11
Total:	996	166

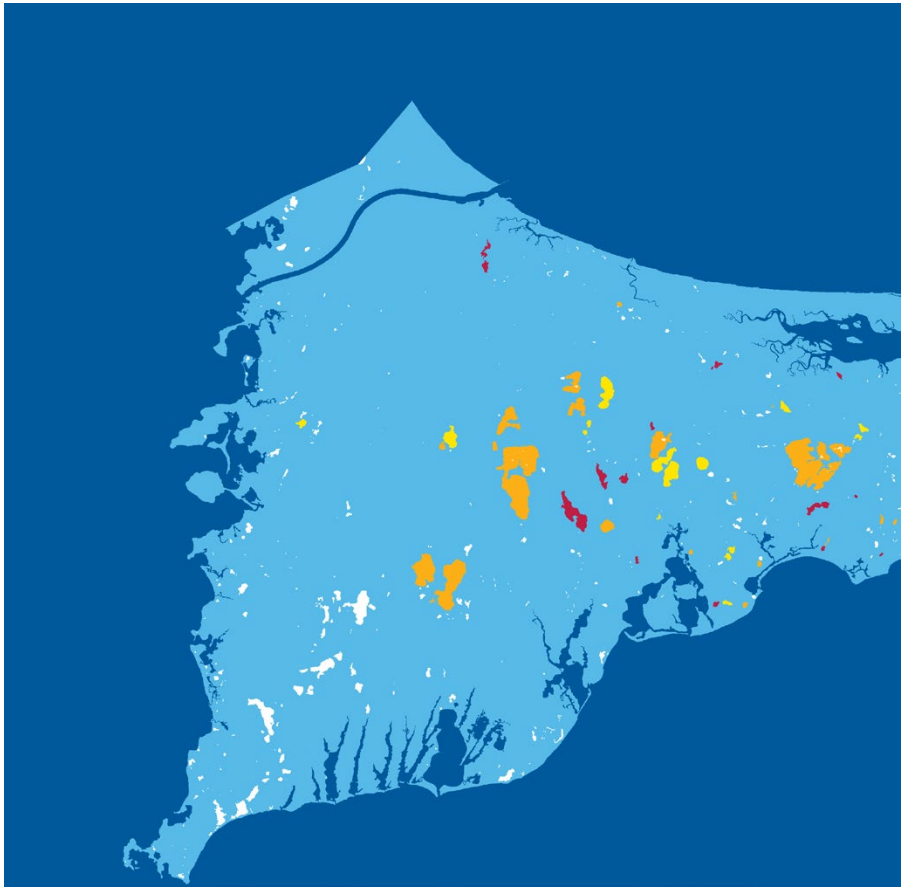
UNIQUE NAMES

Flying Squirrel, Cat Swamp Pond, Widger Hole,Chigger Pond, Pinkwink Pond, Doanes Bog Pond, Canawa Pond.

SOURCES: Cape Cod Commission GIS, Pond and Lake Stewardship (PALS) 2001 Water-quality Snapshot, Massachusetts Department of Fish and Game

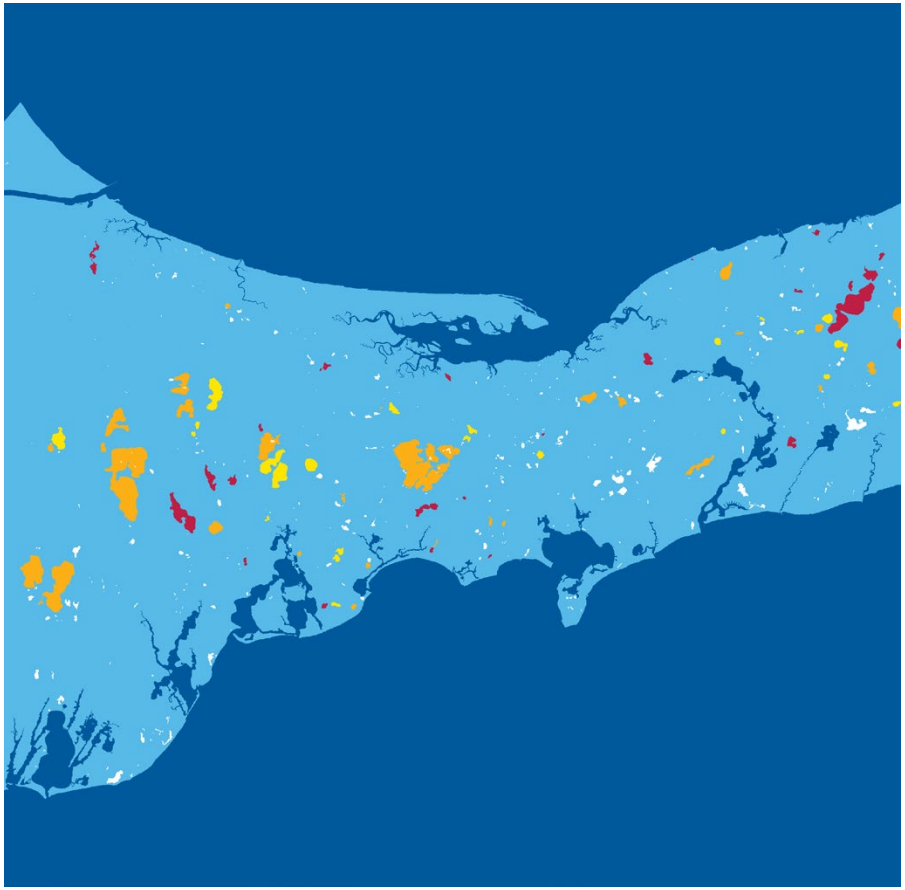
Cape Cod Pond Information

Table 2-2



Upper Cape Pond Trophic Status

Figure 2-24



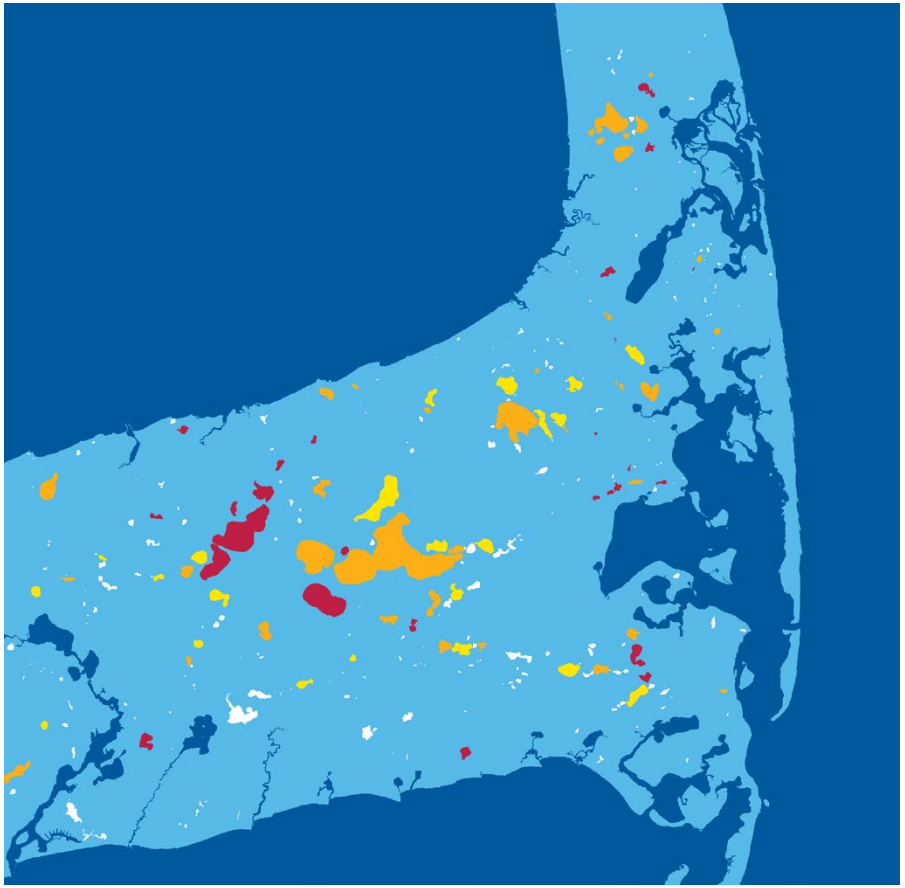
Mid Cape Pond Trophic Status

Figure 2-25

POND WATER QUALITY

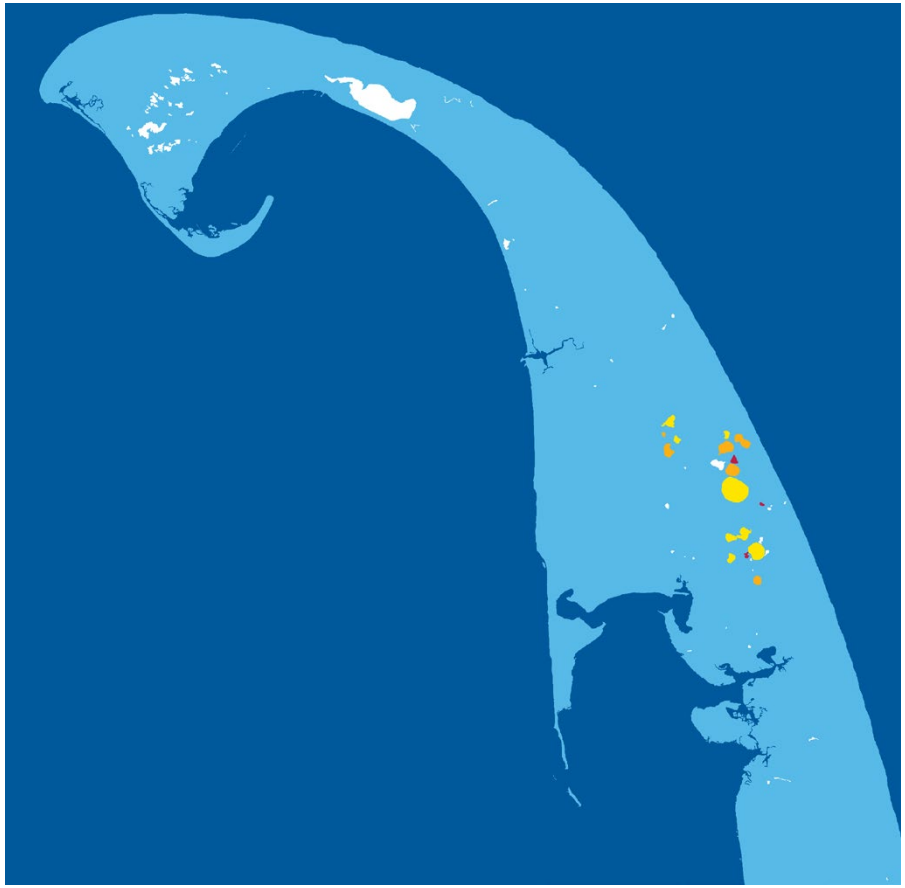
Freshwater ponds are fragile systems and their water quality is significantly impacted by surrounding land development. The soils lack the geological buffering to neutralize acid rain and allow pollutants to drain rapidly. The slow buildup of nutrients from surrounding land use and development impacts ponds through the process of eutrophication, but it can be difficult to detect and abate. The key nutrient of concern for freshwater ponds is phosphorus. Physical impacts to ponds also result from the loss of shoreline buffers as pond front property is developed, lawn area increases, and shorelines erode.

The Massachusetts Department of Environmental Protection established Surface Water Quality Standards (314 CMR 4.00), which are briefly discussed below (www.mass.gov/eea/docs/dep/water/resources/07v5/12list2.pdf). These standards are the basis for listed freshwaters under the 303(d) list for impaired waters. There are 19 fresh water ponds on Cape Cod presently listed on the



Lower Cape Pond Trophic Status

Figure 2-26



Outer Cape Pond Trophic Status

Figure 2-27

2012 Massachusetts Integrated List. Of these, 16 ponds are Category 5 Waters requiring a TMDL. Impairment causes include, but are not limited to, excess algae growth, phosphorous, turbidity, chlorophyll a, Secchi Disk transparency, abnormal fish histology, non-native aquatic plants, mercury in fish tissue, and dissolved oxygen.

A comparison of 2001 dissolved oxygen concentrations from the Cape Cod PALS project with concentrations measured in 1948 suggests that many of these pond ecosystems are not only impacted, but also seriously impaired (see **Figures 2-24** through **2-27**). Based on information in the Pond Atlas, between 74% and 93% of the Cape's ponds are impacted by surrounding development or uses.

Cape Cod Ponds Trophic Status Legend

- Eutrophic
- Mesotrophic
- Ogliotrophic
- Not Interpreted

Based largely on dissolved oxygen information, approximately 45% of all ponds and 89% of the deepest ponds are impaired. The findings suggest that the low dissolved oxygen concentrations observed in the ponds are not "natural" conditions, but are the reflection of 50 years' worth of impacts from surrounding development and land use.

Freshwater ponds play a role in coastal watershed nutrient budgets. They are credited with reducing 50% of the nitrogen load headed toward marine embayments through the process of attenuation. Freshwater ponds are surface water resources that wastewater management plans should include as part of a comprehensive analysis of local water quality. The following provides a general background on the number, condition and significant regional and local efforts to assess and manage these resources.

The annual PALS Snapshot monitoring program has continued every year since 2001 through the continued collaboration of local, county and state university programming and includes a database of over 3,500 samples for 195 ponds in all 15 towns. As part of the overall PALS program, SMAST continues to provide laboratory services at no cost to towns or volunteers for the annual PALS Snapshot of pond water quality. Many towns take advantage of the opportunities presented by the annual PALS Snapshots, and expanded their town monitoring programs. These local efforts and additional funding by the Barnstable County Growth Management Initiative enabled a number of additional lake and pond assessments to be completed in the past decade.

These reports include town wide and pond specific assessments:

- Ashumet Pond, Mashpee (2000)
- Bakers Pond, Orleans (2001)
- Long Pond Brewster (2001)
- Cedar Pond, Orleans (2003)
- Flax Pond, Harwich (2004)
- Orleans Ponds (2006)
- Indians Pond, Barnstable Assessment (2006)
- Harwich Ponds (2007)
- Great Sands Lake, Harwich (2007)
- Barnstable Ponds (2008)
- Lovers Lake and Stillwater Pond, Chatham, (2008)
- Dennis Ponds (2009)
- Brewster Ponds (2009)
- Eastham Ponds (2009)
- Lake Wequaquet, Barnstable (2009)
- Santuit Pond, Mashpee/Barnstable (2010)
- Scargo Lake, Dennis (2011)
- Hinckley Pond, Harwich (2012)

Water quality degradation of Cape Cod lakes and ponds has numerous causes, but most are linked to increased nutrient loads associated with shoreline development. Management strategies identified to lessen future impacts from development include: in-pond restoration using alum or oxygen infusion devices; establishing minimum setbacks for septic systems, roads and lawns; providing natural buffer strips between lawns and ponds; treatment of direct and near shore stormwater runoff; and continued public education. The state prepared a Generic Environmental Impact Report on pond restoration alternatives that is used by towns to streamline permitting of restoration projects. The Cape Cod Regional Policy Plan requires a 300-foot buffer for Title 5 leaching systems from pond shorelines. The 300-foot buffer is used for calculating phosphorus budgets from septic systems because phosphorus is rapidly attenuated in groundwater. If a pond is significantly impacted by surrounding septic systems, a reduction of nutrients through wastewater management may be necessary. Any management plan must include continued sampling and monitoring of conditions within the pond.

Although snapshot water quality data collected over the past decade indicate significant ecological impacts, most ponds still provide the majority of uses that Cape Codders desire. Bacterial testing of ponds has generally indicated healthy conditions for swimming. Fishing and boating are still popular and recent property values and sales show that demand for pond-front properties is increasing.

Regular stocking of deep ponds sustains trout fisheries, but trout generally do not have adequate habitats to make it through a summer due to lack of oxygen in the cold waters of deeper ponds. Increased nutrients generally favor bass fishing, but half of the 18 ponds tested for mercury now have health warnings about consumption of fish tissue.

Actions to correct these ecological impairments will depend on community and state priorities. Active discussion of ecological management strategies for these ponds may lead to refinement of pond users' expectations for habitat and recreation and future TMDLs for ponds.

Despite data gathered by citizen monitoring groups and assessments that document water quality impairment, the state has listed only a few freshwater ponds on the 303d list for impaired waters for nutrients under the Clean Water Act. Additional dialogue is needed between the towns, state and county to evaluate the best use of the information collected and how it should be incorporated into the Commonwealth's clean water program.

GROUNDWATER/DRINKING WATER

The Cape Cod aquifer is one of the most productive groundwater systems in New England. It is a sole source aquifer providing drinking water to a daily summer peak of more than 500,000 people. There are 17 separate water districts or departments across Cape Cod. All together there are 158 gravel pack municipal water supply wells, one surface reservoir and hundreds of private wells. Approximately 85% of Cape Cod is serviced with public water. The remaining 15% rely on private or small volume wells in the communities of Sandwich, West Barnstable, Eastham, Wellfleet and Truro. Since 2000, public community drinking water suppliers have pumped, on average, about 10.7 billion gallons of groundwater per year from Cape Cod's sole source aquifer. Over the last decade, pumping has been fairly consistent, only showing slight variations due to seasonal climatic variations. Studies by the USGS indicate that groundwater pumping is equivalent to approximately 10% of the annual recharge from precipitation.

The Cape Cod Commission analyzed water use data from municipal water suppliers. The total amount of water use was confirmed by comparing 2008 to 2010 data from water suppliers to the total amount reported in the Annual Statistical Reports that suppliers submit to the MassDEP. The results indicate that public water suppliers provide 9.3 billion gallons of water per year to Cape Cod. Applying average water use rates for residential and non-residential uses to parcels served by private wells adds 1.2 billion gallons of water per year for a total of 10.5 billion gallons of water per year. These numbers can be converted to water use in gallons per day (gpd) per residential lot. The average residential per lot water use on Cape Cod is 169 gpd. The average non-residential water use is 586 gpd.

Information about water use is essential to planning for wastewater infrastructure. The amount of water use by parcel is fundamental data that is used to estimate wastewater generation. The MEP convention is that approximately 90% of the water used by a household ends up as wastewater.

DRINKING WATER PROTECTION

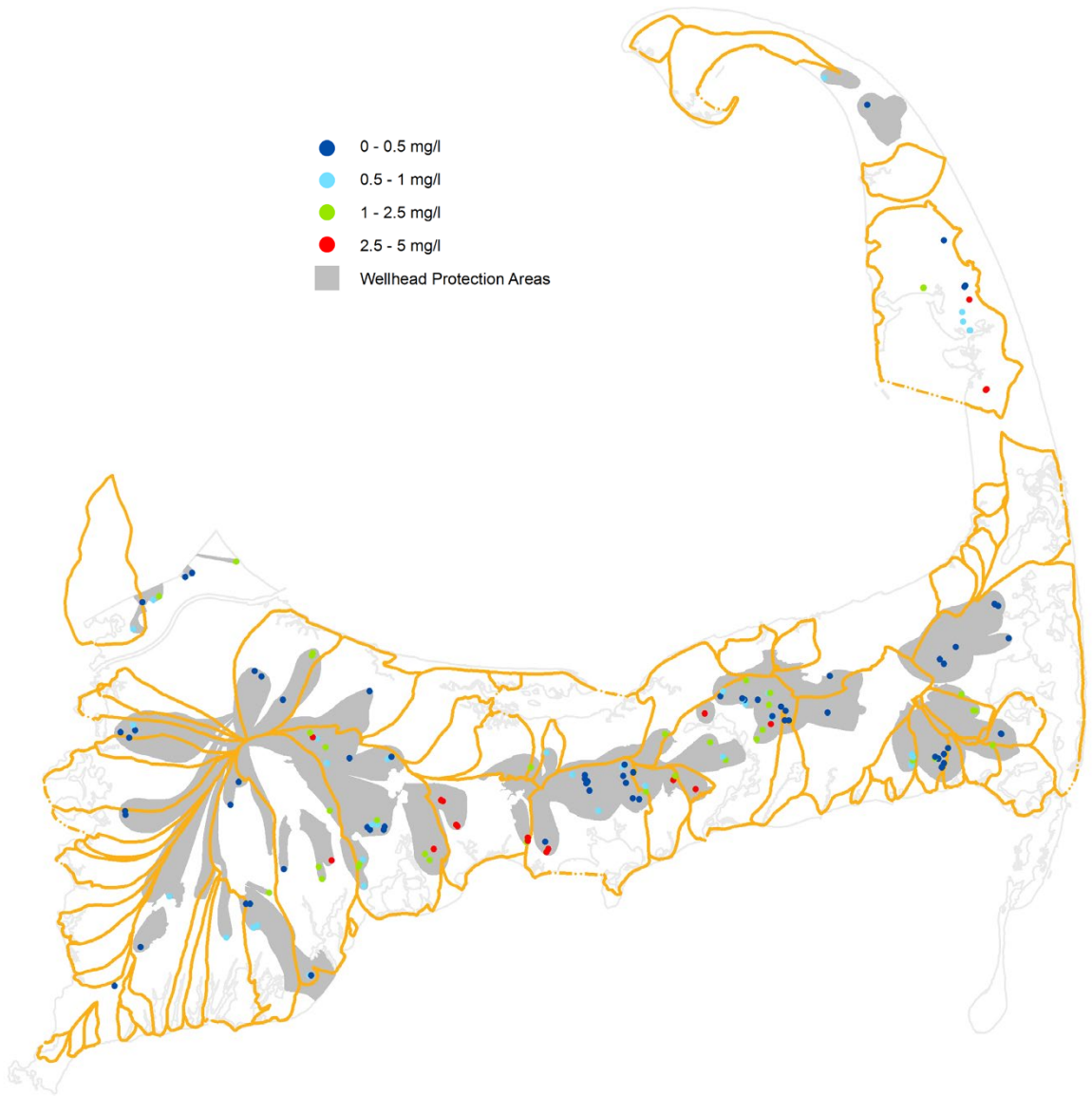
The Cape Cod Aquifer is extremely susceptible to contamination from various land uses and activities. The aquifer has been seriously impacted in the past from military activities, gas stations, landfills and a host of other activities. These examples led to strategies to protect the aquifer at all levels of government and spawned a vigorous industry for the assessment and clean-up of contaminated groundwater. The drinking water of Cape Cod is generally well protected as a result of these activities.

Over the last several decades water planners combined their knowledge of groundwater with policy mechanisms to protect Cape Cod drinking water. Adoption of wellhead protection areas (or Zone IIs) was a major strategy to protect the land area that receives precipitation to recharge the pumping wells. Today each town has zoning and Board of Health bylaws to protect their wellhead protection areas, which are collectively shown in **Figure 2-28**.

In addition, the public embraced acquisition of land for protection of wellhead areas through local, regional and state actions like the Cape Cod Land Bank (later the Community Preservation Act). The Wellhead Protection Area state regulations (310 CMR 22) and Cape Cod Regional Policy Plan (RPP) minimum performance standards prohibit or limit land uses that are potentially detrimental to drinking water quality.

GROUND WATER QUALITY ISSUES

Nitrate, a major component of human wastewater, passes through septic systems virtually untreated and is introduced to the underlying groundwater. Nitrate concentration is often used as an indicator of drinking water quality. A maximum contaminant limit (MCL) of 10 parts per million (ppm) of nitrate for drinking water supplies has been established by the US EPA and adopted by Massachusetts state



Wellhead Protection Areas

Figure 2-28

regulation. The limit was established to protect infants from methemoglobinemia, or "blue-baby" syndrome, a potentially fatal blood disorder that can occur when too much nitrate limits the amount of oxygen in the blood. The RPP established a nitrogen loading concentration of 5 ppm to ensure that nitrate levels in drinking water will not approach the 10 ppm federal standard.

Massachusetts Drinking Water Regulations (310 CMR 22.00) define two types of public drinking water supplies - community and non-community. Community public supply wells include large municipal wells pumping over 100,000 gpd, but also include small volume wells that serve at least 25 year-round residents or at least 15 service connections used by year-round residents. The small volume wells include service to schools, town halls, and community centers mostly located in the Outer Cape that lack large municipal wells. Anything not covered by the definition of community is served by non-community or private wells. Non-community public supply wells fall in to two categories - non-transient and transient. A non-transient non-community public supply well regularly serves at least 25 of the same persons or more for approximately four or more days per week, more than six months or 180 days per year, such as a school. Transient non-community public supply wells serve 25 different persons at least 60 days of the year. Some examples of these types of systems are restaurants, golf courses and community centers. The quality of Cape Cod's community public drinking water supply is generally very good. The percentage of community public supply wells that had nitrate levels at or below 0.5 ppm, which is considered very good, fell from 57% to 42% between 1993

and 2008. Even well protected community public water supply wells have elevated concentrations of nitrate derived from septic systems and other nonpoint sources.

Small volume non-community drinking water wells which are concentrated on the Outer Cape are generally shallower, pump less water and are often closer to septic systems. These non-community public supply wells have shown a greater degradation than the larger and deeper community wells. Since 2000, the number of non-community public supply wells with nitrate concentrations below 0.5 ppm has remained around 35%.

All of the wells exceeding the drinking water limit are located on the Outer Cape where wastewater disposal and private water supply often occur on the same lot. Assessments of private wells in Truro, Wellfleet and Eastham indicate a correlation of high nitrate concentration in relation to housing densities of less than ½ acre (Water Resources of the Outer Cape, 1998). In response to poor water quality, Wellfleet invested in a public water supply system to serve its Central downtown district and Eastham has completed water supply site investigations in two locations as a first step toward a public water system. Eastham voted overwhelming in the spring of 2014 to establish a new Town water system for critical areas of the Town. In February 2015, the Cape Cod Commission approved the town's application to permit the water supply project as a development of regional impact (DRI).

Other Considerations

EMERGING COMPOUNDS: PHARMACEUTICALS AND PERSONAL CARE PRODUCTS

Nitrate can serve as an indicator of other wastewater contaminants, such as disease-causing organisms, solvents, cleaners, petroleum compounds, pharmaceuticals and personal care products (PPCPs) and other emerging contaminants. Emerging contaminants are chemicals or microorganisms that are not commonly monitored or regulated in the environment, but are suspected of having potentially adverse ecological and/or human health effects. They can include hormones, human and veterinary pharmaceuticals, and household products like soaps and lotions, insect repellents, perfumes and other fragrances, sunscreens, and hand sanitizers.

There have been numerous national studies done to investigate and document the occurrence of these emerging compounds in wastewater, surface and groundwater. In 1999 and 2000, the USGS conducted a national stream reconnaissance testing 139 streams in 30 states for 95 organic wastewater compounds (OWCs) (Kolphin et al. 2002). Eighty-two of the 95 compounds were detected in at least one sample and 80% of the streams had at least one OWC detected. In 2000, the USGS sampled 47 groundwater sites across 18 states; 98% of the sites sampled had detections of emerging contaminants, with 46 of the 83 contaminants being found at least once (Barnes et al. 2008).

During 2001, the USGS analyzed 25 ground and 49 surface-water untreated public drinking water supply sources in 25 states. The majority of the samples (96%) showed at least one emerging contaminant. The emerging contaminants were more frequently detected in surface-water than ground-water sources (Focazio et al. 2008). Generally, all of these studies have detected the presence of a variety of organic wastewater contaminants and PPCP's. The detections were more common in the stream samples (86%) and surface water samples than in groundwater (35%). Mixtures of chemicals were common and the concentrations measured were generally at low levels (often less than 1 microgram/liter), just slightly above detection levels.

In June 2004 the USGS and the Barnstable County Department of Health and the Environment sampled wastewater sources and public, semipublic, and private drinking water supplies on Cape Cod that were thought to be affected by wastewater because of previously high nitrate concentrations. Forty-three of the 85 PPCP and organic wastewater contaminant compounds tested for were detected. Thirteen were detected in low concentrations (less than one microgram/liter) in the private and semipublic drinking water supplies and three - an antibiotic, an antidepressant and a solvent - were detected in the public water supply (Zimmerman 2005).

In May 2010 the Silent Spring Institute reported that PPCPs were detected in 75% of 22 public water supply wells sampled on Cape Cod. In general, wells with higher levels of nitrate and higher density land development in

the wellhead protection areas had a greater number of detections than those wells that were better protected by lower density and open space. In a similar study Silent Spring also found detectable traces of PPCP in fresh water ponds and private wells associated with residential development. A recent assessment by the Provincetown Center for Coastal Studies detected traces of PPCP in Nantucket Sound.

Although the ability to detect these emerging compounds at extremely low levels in drinking water has been greatly improved, the human health effects from these low level concentrations are not well documented.

In the absence of better information about the actual occurrence of these compounds and the need to provide a level of protection, MassDEP recently incorporated very stringent performance standards for proposed wastewater discharges in Zone IIs. MassDEP adopted a maximum Total Organic Carbon (TOC) Concentration of 3 ppm. TOC is a surrogate for PPCP in treated wastewater. Some studies documented that PPCP will be adsorbed on to particulates of carbon. It is thought that removing this carbon will provide a level of protection to the underlying aquifer and public supply wells. However, removing TOC to this level requires an extremely high level of treatment, with 20-30% higher capital treatment costs and higher annual operation and maintenance. Investigations into the transport of PPCP have found that the majority of these compounds do not travel very far in the groundwater. In fact, monitoring wells down gradient of existing wastewater disposal sites on Cape Cod have found concentrations of TOC below the 3 ppm concentration.

The US EPA has undertaken national testing of CECs in public water supplies, referred to as the Unregulated Contaminant Monitoring Rule (UCMR). Monitoring for selected CECs is required for water supplies serving over 10,000 connections or by voluntary action. A number of Cape Cod water suppliers have volunteered to have their supplies tested. As data becomes available through the UCMR the US EPA will be able to target more prevalent contaminants for review, research and action.

Although the Section 208 Plan Update is largely focused on the ecological impacts of nitrogen, particular attention will be focused on drinking water areas and wells that have higher levels of nitrogen as an indicator to address emerging contaminants. Additional investigation on the occurrence of emerging contaminants in groundwater will be needed to address the wastewater disposal options for any particular selected site that is located in a Zone II. In relation to the MassDEP TOC requirement to address PPCPs, substantial costs can be saved by avoiding wellhead protection areas and Zone IIs when locating potential wastewater disposal sites.

County Activities

BARNSTABLE COUNTY DEPARTMENT OF HEALTH AND THE ENVIRONMENT

MASSACHUSETTS ALTERNATIVE SEPTIC SYSTEM TEST CENTER

The Massachusetts Alternative Septic System Test Center has been operating since 2000 to research and test advanced on-site wastewater treatment systems. The Center is operated by the Barnstable County Department of Health and the Environment (BCDHE) and is located at Joint Base Cape Cod. Although the Center's initial emphasis was on nutrient-reducing technologies, it has more recently been conducting research on the efficacy of commercial and soils-based septic systems for removal of pharmaceuticals and personal care products. The Center has been instrumental in forming and conducting many internationally recognized standards for both secondary and tertiary wastewater treatment. Ancillary projects include the support of research efforts on wastewater diversion techniques, such as composting toilets and urine diversion, and their efficacy for addressing the nutrient management issues in sensitive watersheds.

The majority of the systems tested at the Center are proprietary systems and the efficacies of non-proprietary denitrification strategies are less understood, primarily due to the lack of financial incentives to develop and promote them. It is clear, however, that Cape Cod communities are interested in exploring all of the options available for

reducing nitrogen that enters the groundwater. Through this process to update the Section 208 Plan for Cape Cod, funding was provided to the County Department of Health and the Environment to investigate non-proprietary means to remove nitrogen by enhancing and/or manipulating soils-based systems. This work is essential in order to assure wastewater planners, managers and the public that all options are properly evaluated. More information on the study and progress to date is available in Appendix 2B.

INNOVATIVE/ALTERNATIVE SEPTIC SYSTEMS PERFORMANCE TRACKING

More than 1,500 innovative/alternative (I/A) septic systems have been installed on Cape Cod in an attempt to reduce the amount of nitrogen discharged into the groundwater. These systems range in their complexity, but all require regular maintenance and monitoring. Since 1999, BCDHE has maintained a database to assist regulators in the task of tracking performance and adherence to maintenance schedules. Regular performance and compliance updates are provided to local regulatory boards. More recently, to aid the public and engineering professionals, the department has created an interactive tool to chart performance of all technologies used within Barnstable County. This tool assists wastewater planners to develop realistic performance expectations, thus facilitating accurate local wastewater planning. Occasionally, printed compendia of the information are distributed to local boards and commissions. The department also maintains training tools to instruct boards of health regarding the proper application of these technologies.

COMMUNITY SEPTIC MANAGEMENT LOAN PROGRAM

The Barnstable County Department of Health and the Environment initiated the Community Septic Management Loan Program to assist homeowners by defraying the costs of septic system upgrades through provision of 20-year betterments. More recently the program has assisted in providing support for the actual connection costs to centralized systems or combined packaged or cluster treatment systems. For more information visit the Community Septic Management Loan Program website at http://www.barnstablecountysepticloan.org/.

CAPE COD COMMISSION

TECHNICAL SERVICES

As the region's planning agency, the Cape Cod Commission supports its regulatory and planning mission with the provision of technical services by professional staff in almost every issue area of the Regional Policy Plan (RPP) for various county, local, state and federal agencies, associations and citizens. In the area of water resources, the Commission staff provides support on water supply, freshwater ponds, coastal water quality, wastewater management and groundwater cleanup. Staff members develop both quantitative and qualitative methods that result in finding cost-effective solutions for common problems shared across the region. Staff members have provided fundamental expertise in the development of local and regional wastewater management planning and in the development of the tools and resources developed as part of the Section 208 Plan Update.

Town Wastewater Planning Efforts

All 15 Cape Cod towns have engaged to some degree in the process of developing Comprehensive Wastewater Management Plans (CWMPs) over the last 10 years. Several towns are in the Massachusetts Environmental Policy Act (MEPA) review process. A Cape Cod Commission regulatory review file of comments letters, public hearings and decision documents are available for each town that is undergoing the MEPA/DRI review process for their CWMP. Barnstable, Chatham, Falmouth and Provincetown have existing wastewater infrastructure and have completed wastewater facilities plans prior to or in conjunction with nutrient planning. The following is a synopsis of the CWMP planning efforts in each town.

STATUS OF CWMPS

BARNSTABLE

The town of Barnstable is working on a town-wide nutrient management plan that will provide the basis of its CWMP. The town completed the MEPA/DRI review process for what is known as the Wastewater Facility Plan (WWFP) in 2007. This included upgrades and expansion of the Hyannis Water Pollution Control Facility (WPCF). The WWFP resolved

wastewater disposal issues relative to wastewater disposal site capacity and identified nine Areas of Concern (AOCs) for sewer hook-up. The DRI approval conditions require an adaptive management plan for monitoring the wastewater facility as it approaches a discharge rate of 3.7 million gallons per day (MGD), prior to attaining its design capacity of 4.2 MGD. The additional 0.5 MGD may require the use of an approved remote disposal site known as the Route 132 site. The DRI conditions also include the scope for the nutrient management plan and provisions for continuing sewer expansion under the WWFP.

The town implemented the upgrades to its present facility and completed a sewer extension project for the Stewart's Creek area in the village of Hyannis.

The town reformulated a Citizen's Advisory Committee (CAC) for wastewater planning and has been working on the nutrient management plan/CWMP. The Alternatives Screening Analysis of the CWMP was submitted as a Draft Environmental Impact Report (DEIR)/Environmental Notification Form (ENF) for joint MEPA/DRI review in May 2012. The Needs Assessment and Alternatives Screening Analysis conclude with five alternative plans, not including the no-action alternative. Each alternative assumes a portion of the town will remain on Title 5 systems, where nutrient removal is not critical, and that remote recharge sites for treated effluent will be needed. The alternatives include a totally decentralized solution; a decentralized solution with some larger facilities; and centralized alternatives with either a single town plant or multiple town plants. Since the Hyannis WPCF is located in a zone of contribution to public water supply (Zone II) and would require expensive total organic carbon (TOC) removal options, the CWMP also includes ocean outfall as an alternative, as well as the alternative of abandoning existing public water supply wells.

The MEPA certificate scope for the Final Environmental Impact Report (FEIR) includes extensive comments and significant additional work. One component of the MEPA certificate is to engage in a targeted watershed approach. The Commission is presently working with Barnstable and Yarmouth to develop a targeted-watershed scope for the Lewis Bay watershed. The Commission and the town have discussed the use of the WatershedMVP to evaluate targeted watershed approaches for Three Bays. The CAC is presently considering the next appropriate steps.

A more detailed chronology of water quality planning efforts in Barnstable is available in Appendix 2C.

BOURNE

The town of Bourne recently completed a targeted wastewater planning effort for the Buzzards Bay downtown area. A portion of the Buzzards Bay area is sewered and up to 200,000 gpd of wastewater is conveyed to Wareham for treatment and disposal. Bourne is limited to this flow through its agreement with the town of Wareham.

The Cape Cod Commission worked with the town of Bourne to develop a wastewater and water supply report for Buzzards Bay. The report provided the town with a detailed assessment of the needs, alternatives, facility siting options, and estimated costs of providing wastewater infrastructure to support the revitalization of the Buzzards Bay area. A copy of the report is available on the Commission's Initiatives webpage. The town voted to approve the report's recommendations to obtain in-house expertise to guide the project and to conduct necessary steps for siting and infrastructure evaluations. In March 2013 the town hired a wastewater coordinator and soon after hired a contractor to determine if either of two identified sites - Queen Sewell Park and land behind the Bourne Veterans Memorial Community Center - is suitable for wastewater disposal. The Queen Sewell Park site was determined to be a suitable site to consider moving forward.

The town of Bourne received a MEP technical report for Phinneys Harbor/Eel Pond and Back River, but reports for other watersheds within its boundaries, including Megansett, Sequeteague, Pocasset, and Buttermilk Bay are not complete or not planned, making it difficult to pursue meaningful wastewater assessments in these areas.

A more detailed chronology of water quality planning efforts in Bourne is available in Appendix 2D.

BREWSTER

In 2009, the Town of Brewster formed a Comprehensive Water Planning Committee (CWPC). The CWPC is charged with coordinating the efforts of the Town staff and consultants and it began the CWMP process in 2009. The town chose to pursue an Integrated Water Resources

Management Plan (IRWMP) because it wanted to closely evaluate drinking water and freshwater pond issues in addition to coastal water quality impairments.

Phase I of the IRWMP was completed in 2011. As a result the town initiated a number of intermediate projects to expand the Town's data and understanding of water quality. In January 2013, Phase II of the IRWMP was issued. The report recommends a number of alternatives for coastal nitrogen reduction in the Pleasant Bay watershed, including innovative/alternative (I/A) and cluster systems, fertilizer reduction, irrigation wells to recycle and reduce groundwater concentrations, permeable reactive-barrier technologies, and alternative toilets (see Chapter 4 for technology descriptions).

The town is continuing its efforts toward drinking water protection through its bylaws and the Brewster Water Protection District of Critical Planning Concern. A number of specific opportunities for stormwater treatment have been identified and conceptual designs have been developed. There are a number of freshwater pond protection strategies that are also recommended.

The town secured funding for Phase III of the IRWMP and began work in June 2013. The goals of Phase III are to:

- Evaluate the Pleasant Bay nitrogen management alternatives identified in the Phase II report and select a preferred plan with recommendations for what Brewster needs to do to restore water quality within Pleasant Bay;
- Finalize recommended stormwater regulations developed in Phase II;
- Encourage proper management of stormwater, septic systems, fertilizers and other potential pollutants that impact Brewster's Ponds (e.g., new regulations);
- Continue with current outreach activities (e.g., website, brochure);
- Facilitate communication between the CWPC, the Cape Cod Commission, the public, and with other town boards and agencies involved in the project.

A more detailed chronology of water quality planning efforts in Brewster is available in Appendix 2E.

CHATHAM

The Chatham CWMP of 2009 is the first town-wide plan on Cape Cod to be completed that incorporates the state and federal total maximum daily loads (TMDLs) to restore coastal water quality for several large coastal embayments. The CWMP/FEIR provides a strategy for wastewater management and reduction of nitrogen loading to restore and protect Chatham's marine embayments, addresses other areas of concern, such as areas experiencing high groundwater, failing systems, and industrial/commercial areas, and includes an adaptive management plan for its implementation.

The prior WPCF in town was built in 1970 and the collection system extended to the Main Street downtown area. Prior to development and implementation of the CWMP this facility served approximately 480 properties.

The CWMP/FEIR details a two-phased implementation program to meet nitrogen TMDLs in Stage Harbor, Pleasant Bay, Sulphur Springs, and Taylors Pond. Phase 1 average annual wastewater flows are projected to be 0.94 MGD. The Phase 2 wastewater flows will be 38 percent more than Phase 1, for an average annual flow of 1.3 MGD over 30 years. The extension of sewers to the remaining part of town will take another 10 years, with an estimated completion date of 2040.

The estimated Phase 1 costs are $210 million (in 2007 dollars) over the initial 20 years. The town has adopted a number of innovative approaches for funding the project and has established a capital facilities plan with the goal of maintaining the tax rate. However, it is acknowledged that modest tax increases will be necessary to meet the costs of the proposed plan. Homeowner charges are estimated at $3,000 to $10,000 for hook-up and $400 for annual operation and maintenance.

The state and the Cape Cod Commission reviewed this 11-year project as a DEIR in 2008 and as a FEIR in 2009. An expanded adaptive management plan scope was part of the conditions of the DRI approval, which included components of implementation progress, Groundwater Discharge Permit monitoring, and monitoring of marine waters for TMDL compliance. The final adaptive management plan was submitted to the Commission two years after the DRI approval.

The town completed the treatment facility upgrade in 2010 and the main sewer trunk line construction in 2012 and is seeking State Revolving Fund (SRF) funding for the next

stage of sewer expansion in to the Stage Harbor watershed system - an area impaired by nitrogen. In 2013 the town signed an agreement with the town of Harwich to further evaluate using a portion of the treatment capacity in Chatham to serve the eastern portion of Harwich, which is part of the shared Pleasant Bay watershed. The potential sharing of the facility is allowed by condition in the DRI approval. Chatham has also been a lead town in the effort to improve circulation in Muddy Creek with a culvert-widening project that would likely reduce nitrogen removal requirements.

A more detailed chronology of water quality planning efforts in Chatham is available in Appendix 2F.

DENNIS

The town of Dennis received MEP technical reports for Herring River, Swan Pond and Bass River. Working through the Dennis Water District, the town completed fundamental portions of a needs assessment that identified a number of areas to be addressed for both nutrients and Title 5 constraints on economic redevelopment in the area of Dennisport. The district filed and passed legislation to become the Dennis Water and Sewer District. The November 2013 special Town Meeting voted to approve funding for a consultant to study previously collected data, identify problems, and recommend possible solutions, along with their costs. The output will be a water quality evaluation and mitigation alternative study for the district and the town to consider as they plan their next appropriate steps for wastewater planning.

A more detailed chronology of water quality planning efforts in Dennis is available in Appendix 2G.

EASTHAM

The town of Eastham completed a town-wide needs assessment in March 2009. The needs assessment concluded that a new public water supply system to protect public health was an overriding concern. In 2013, Town Meeting did not approve the expenditure of funds for either a town-wide water system, at a cost of about $114 million, or a phase 1 water system, at a cost of about $41 million, to serve those areas with the greatest need.

The spring 2014 Town Meeting approved $45.8 million to fund a scaled back version of the full town-wide water system. The system is described as a "backbone with landfill study area service," which will include all the basic elements to allow for expansion to all parts of the town in the future. This backbone will include a single water tower, two wells, with service connecting along major roadways and to the affected areas within the landfill study area. It includes hydrants that will be within 1000 feet of 80% of Eastham structures. The Cape Cod Commission approved this project as a DRI in February 2015.

In addition to pursuing solutions for water supply protection, the town of Eastham is actively pursuing the protection and restoration of its freshwater ponds. The town completed a town-wide assessment and is pursuing in-pond restoration efforts. Alum treatments for Herring Pond and Great Pond are complete and others are under consideration.

Eastham shares the watershed to the Nauset estuary with the town of Orleans and is willing to have further discussions about potential opportunities to share the wastewater treatment facility proposed in the approved Orleans CWMP.

A more detailed chronology of water quality planning efforts in Eastham is available in Appendix 2H.

FALMOUTH

The town of Falmouth completed the MEPA/DRI process for the West Falmouth Harbor WWFP in 2001. The WWFP focused on a necessary upgrade to the existing treatment facility in order to achieve better nutrient-removal rates. The sensitivity of West Falmouth Harbor to nitrogen loading was not well understood when the facility was permitted in the 1980s. The upgrade is now complete and water quality conditions within the groundwater have improved significantly. However, the disposal location has a limited capacity due to sensitivity of the estuary to additional nitrogen inputs.

The Cape Cod Commission reviewed an ENF for the Town of Falmouth Comprehensive Wastewater Management Planning Project for the South Coastal Watersheds in 2007. The ENF included the Needs Assessment Report and Alternatives Screening Report for Little Pond, Great Pond, Green Pond, Bournes Pond, Eel Pond, and Waquoit Bay. This draft CWMP included collection of wastewater in the south coastal areas, generally south of Route 28, treatment at a proposed regionally-shared facility at Joint Base Cape Cod (MMR at the time), and effluent disposal through

injection wells. The town formulated a new internal review committee, the Water Quality Management Committee (WQMC), to evaluate additional alternatives, and in 2012 submitted a draft CWMP/DEIR for joint MEPA/DRI review.

The 2012 draft CWMP/DEIR represented a significant change from the screened alternatives presented in the 2007 ENF. In addition to plans for sewering specific portions of the south coastal estuaries and upgrading the West Falmouth treatment facility and discharge options, the DEIR included specific opportunities for innovative on-site technologies and non-discharging systems, tidal flushing, aquaculture, permeable reactive barrier demonstration projects, and non-structural nitrogen reduction strategies consisting of fertilizer controls and stormwater management.

Through its review, the Commission supported the additional evaluation of Joint Base Cape Cod as a potential shared regional facility for the Upper Cape as one the town's alternatives.

The town received wastewater grant funds from Barnstable County for:

- technical assistance from the USGS and Cape Cod Commission staff to use a groundwater model to evaluate potential wastewater disposal sites;
- detailed hydrogeologic modeling of a likely discharge site, the Falmouth Country Club; and,
- technical assistance through the Cape Cod Water Protection Collaborative.

The town implemented the recommendations of the WQMC and Town Meeting approved $2.77 million to retain an omnibus engineering consultant to oversee design aspects of the entire project and separate expert consulting capacity to prepare feasibility studies for the pilot projects. Spring 2013 Town Meeting appropriated $9 million to provide the design of the Little Pond watershed collection system, necessary facility upgrades, and pilot project implementation.

In January 2014, a MEPA Certificate of Adequacy was issued for the Falmouth South Coast Watersheds CWMP. The certificate details how projects included in the CWMP will come forward as Notices of Project Change in the future. The Commission approved the CWMP as a DRI in February 2014 with conditions to develop an adaptive management plan.

Spring 2014 Town Meeting subsequently approved $50 million to construct a targeted watershed approach for a Little Pond watershed collection system and implement the pilot projects over the next five years, concluding in 2020.

A more detailed chronology of water quality planning efforts in Falmouth is available in Appendix 2I.

HARWICH

The town of Harwich established a water quality management task force to coordinate both fresh and marine water sampling. The task force is responsible for wastewater planning, which consists of developing a CWMP and participating in the Pleasant Bay Alliance.

The Harwich efforts were on hiatus while waiting for the Massachusetts Estuaries Project (MEP) to complete the technical reports for Herring River and several of the south-side embayments. These reports were received by the town in 2010-2012.

The town has since submitted an expanded ENF and anticipates participating in joint MEPA/DRI review with the Cape Cod Commission.

The CWMP includes options for regional infrastructure with the town of Chatham for the East Harwich economic development area of town (part of the shared Pleasant Bay watershed). The town recently signed an agreement with the town of Chatham to evaluate this option.

Harwich is also the lead town in a shared effort to improve circulation in Muddy Creek with a culvert-widening project that will likely reduce nitrogen removal requirements. Design of the culvert is close to complete and construction was scheduled to begin in fall 2015. The project received two federal grants - $3.4 million of Hurricane Sandy Mitigation and Resiliency funding and a $1 million National Coastal Wetlands Conservation grant - and spring 2014 Town Meeting approved the appropriation of an additional $1.75 million.

A more detailed chronology of water quality planning efforts in Harwich is available in Appendix 2J.

MASHPEE

The Mashpee CWMP was scoped through a joint MEPA/DRI review as an ENF in 2001. In 2007, the town submitted its Needs Assessment Report entitled, "Town of Mashpee, Popponesset Bay and Waquoit Bay-East Watersheds Needs Assessment Report." The report documents the significant level of effort that has gone into determining the nitrogen TMDLs for the two subject embayments over the course of six years. Also in 2007, the town completed a technology screening report, which was followed shortly by its draft alternative scenarios and site evaluation report in March 2008.

Mashpee has been engaged in numerous county, state, and federally funded projects, including the 2009 MassDEP Pilot Project and the 2009 Cape Cod Commission TMDL Implementation Project, which were both funded by US EPA. Through these projects, the town ran a number of scenarios through the MEP linked water quality model to evaluate TMDL compliance strategies, including an assessment of cranberry bogs and streams for potential additional natural attenuation. These projects also allowed Mashpee, together with representatives of Barnstable and Sandwich, to participate in the determination of nitrogen allocation for Popponesset Bay for each town and prepare a draft intermunicipal agreement. Mashpee received wastewater grant funds from Barnstable County to model sewer collection systems in the Popponesset watershed and technical assistance from the USGS and Commission staff to use the Sagamore Lens groundwater model to evaluate potential wastewater disposal sites.

The Needs Assessment contains a characterization of the nine operating private sewage treatment facilities, including treatment efficiency and excess capacity. This work allowed the town to focus on three potential wastewater scenarios that were developed in 2012. These options are being reviewed and will be the basis for development of their preferred alternative. The wastewater scenarios include use of the existing private plants at their planned capacity and either three or four subregional plants with consideration of shared town responsibility. Off-site disposal of effluent outside of the impaired watersheds is an important consideration for the plan's approach. The alternatives analysis included consideration of private effluent disposal sites at New Seabury, Willowbend, and others, in addition to the town's transfer facility site.

The town has an appointed seven-member Sewer Commission and an in-house coordinator for wastewater projects as the town proceeds with selecting a preferred alternative. Special legislation filed by the town to convert the Mashpee Water District to the Mashpee Water and Sewer District was signed by the Governor on April 18, 2014 and is pending approval by Mashpee voters. In addition to the needs and alternatives identified, the town is considering the use of the JBCC treatment facility and disposal site as long-term regional solutions.

In April 2014, the Sewer Commission met with Cape Cod Commission staff to begin the discussion around filing its CWMP. The current draft plan includes a significant aquaculture undertaking and an adaptive management approach to achieving water quality goals. In September 2014, the Massachusetts Secretary of Energy and Environmental Affair issued a certificate of adequacy for the DEIR for Mashpee's Comprehensive Watershed Nitrogen Management Plan.

A more detailed chronology of water quality planning efforts in Mashpee is available in Appendix 2K.

ORLEANS

The Orleans CWMP was approved by MEPA and the Cape Cod Commission in 2011 and provides a strategy for wastewater management to achieve reductions of its share of nitrogen loading to restore and protect Orleans's coastal embayments. The CWMP also addresses freshwater ponds and areas with septic system problems associated with frequent pumping, intensity of use and mounded systems. It provides modest capacity for expanded residential housing in the commercial district and includes an adaptive management approach for its implementation.

The CWMP proposes collection of an annual wastewater flow of 0.64 MGD from 2,800 properties to serve 53% of the town. The project would be implemented in six phases over a 15-20 year period of implementation.

The phased sewer plan also accommodates septage and sludge handling and proposes five small package-treatment systems that will hasten nutrient removal for subwatersheds to Pleasant Bay as the plan is phased in. The phased plan also targets nutrient reduction through non-structural elements, including a fertilizer control program, stormwater management, a water conservation

program coupled with a wastewater flow- and load-reduction initiative, enhancement of embayment flushing, and land use controls.

The estimated cost of the CWMP is $150 million (in 2008 dollars) over the 15-20 year implementation period. The average cost to a homeowner is estimated at $2,600 per year. The town has adopted a cost-recovery policy that incorporates property tax assessment to pay for 80% of the costs and relies on betterments for the remaining 20%.

The town asked the Cape Cod Commission staff to participate in reviewing the needs assessment, alternatives assessment, and preferred alternative reports prior to their formal submittal as a DEIR/ENF in 2009. As part of its CWMP process, Orleans took advantage of a Cape Cod Water Protection Collaborative grant to examine potential cost savings that could be realized if the planned Orleans wastewater facility were shared with the towns of Brewster and/or Eastham. The resulting study, entitled "Wastewater Regionalization Study: Orleans-Brewster-Eastham," was released in December 2009. The study identified a potential 6-9% savings in capital costs, and an 18-25% savings in operation and maintenance (O&M) costs resulting from a shared facility.

The town received its MEPA certificate on the FEIR and a DRI approval in 2011. The town has since engaged independent consultants to review the use of alternative sewer collection technologies and the Massachusetts Estuaries Project findings about the Nauset Marsh. The town received significant input from the community as the board of selectmen considers its appropriate next steps.

The Orleans CWMP DRI approval contained several conditions related to the potential of operating the Orleans facility as a shared municipal facility. The Town of Orleans agreed to meet with Brewster and Eastham representatives to discuss potential regionalization options and report to the Commission on the status of those discussions. The DRI decision also directs the Town of Orleans to keep options open for sharing the proposed facility, as well as disposal capacity at the facility, for a finite period of time. The intent of this condition was to create an opportunity for the three towns to pursue a shared facility, while allowing Orleans to proceed with its single town plan in a reasonable time frame.

Another regional issue raised by the Orleans CWMP is that the proposed Orleans wastewater facility will discharge into the Nauset Marsh system, which has assimilative capacity for nitrogen. The Town of Brewster expressed concern about the potential for Orleans to use up this assimilative capacity, leaving Brewster with fewer disposal alternatives as it develops its own management plan. The DRI decision capped the amount of assimilative capacity that may be used by Orleans in order to address this concern.

Funds for design and construction of the Orleans CWMP, or phases within the CWMP, have not yet been appropriated by Town Meeting.

Spring 2014 Town Meeting approved an extension of the three-town agreement with Eastham and Brewster through 2016 to run the Tri-Town Septage Treatment Facility. Town Meeting also approved an appropriation of $1.045 million to fund several projects with a collective purpose to produce information necessary to further shape water quality improvement projects in town. Specifically, the appropriated funds will be used for engineering, planning and hydrogeologic studies necessary for the development of septage, wastewater, groundwater and stormwater management plans needed to maintain and protect the water resources of the town by integrating the CWMP with a new Adaptive Management Plan and components of the Cape-wide Section 208 Water Quality Management Plan.

A more detailed chronology of water quality planning efforts in Orleans is available in Appendix 2L.

PROVINCETOWN

Provincetown completed a WWFP in 2001. The plan dealt with the public health issues of failing septic systems and inadequate infrastructure for its commercial downtown area. The comprehensive plan was approved by state agencies through MEPA and by the Cape Cod Commission through DRI review in 2001. The wastewater facility and phase 1 and 2 areas were subsequently built and are performing well. The plan included a number of innovative aspects, including a lot-by-lot assessment of Title 5 systems, use of the Route 6 median and right-of-way for effluent disposal, combination of force mains, conventional gravity and vacuum sewers, and "checkerboard" sewer areas. The plan included three phases. The town is presently expanding sewers into the Phase 3 area and is upgrading the facility to its planned capacity. During this implementation, the town was able to use measured

wastewater flow to compare to the design capacity and to negotiate the use of that excess capacity for new wastewater flow.

A more detailed chronology of water quality planning efforts in Provincetown is available in Appendix 2M.

SANDWICH

The town of Sandwich has established a water quality committee to oversee water quality and wastewater planning efforts. The committee developed a scope of work for a CWMP and submitted the scope under the Sagamore Lens Natural Resource Damages Assessment, related to past groundwater contamination at the Textron facility at the Joint Base Cape Cod (JBCC). The town received an award of $400,000 t0 conduct its water/wastewater plan and completed a comprehensive needs assessment, as well as an interim wastewater solutions plan to accommodate economic development in the South Sandwich Village Center (often referred to as the Golden Triangle area).

The town spent several years working with a private developer on a development project that included a public-private wastewater component involving the construction of a facility that would accommodate the private project and a certain amount of general public wastewater need. That project will not be completed, but the town is again seeking a private partner to create new economic growth and to potentially participate in infrastructure development.

The town is participating in discussions at JBCC about the potential use of its existing wastewater infrastructure as a regional option for the Upper Cape towns.

A more detailed chronology of water quality planning efforts in Sandwich is available in Appendix 2N.

TRURO

The town of Truro approved funds for a CWMP, acknowledging that protection of private-well drinking water is of paramount importance, and established a water resources oversight committee. The CWMP kicked off in 2012 with a focus on septic systems and stormwater-runoff and their impact on drinking water and embayment water quality. The planning process seeks to assemble existing data, and develop a GIS program to evaluate land and water data, historic septic-system management information and key areas for further analysis and characterization. The committee is in the process of reviewing the phase 1 of the draft water management plan.

A more detailed chronology of water quality planning efforts in Truro is available in Appendix 2O.

WELLFLEET

The town of Wellfleet has an established Comprehensive Wastewater Management Planning Committee that is charged with providing a comprehensive strategy for addressing wastewater treatment and disposal issues for the next 40 years and for the foreseeable build out conditions in town. Along with its consultant, the town completed a draft of its CMWP Needs Assessment and Alternatives Analysis reports in June 2012. The objectives of the CWMP are to protect and enhance the Wellfleet Harbor ecosystem, promote aquaculture-based water quality management solutions, identify low-cost and sustainable remedies, develop least-cost alternatives and, only as a final resort, engage in structured solutions.

The CWMP process allowed Wellfleet to pursue and implement pilot scale ecotoilet and oyster restoration solutions (see Chapter 4 for technology descriptions). Spring 2013 Town Meeting appropriated funds to build a bathhouse at Bakers Field Beach that uses composting toilet technology to reduce the nitrogen load to Wellfleet Harbor. The oyster restoration project is a 2-acre site in Wellfleet Harbor and has a well-structured monitoring component. Water quality monitoring was conducted at the site in 2012 and 2013 and provided necessary data for the town to make informed decisions moving forward.

A more detailed chronology of water quality planning efforts in Wellfleet is available in Appendix 2P.

YARMOUTH

The town of Yarmouth's wastewater committee began its work in 2003. In 2010, the town submitted its CWMP as a DEIR. The draft CWMP targeted areas that would require wastewater collection to restore water quality in the Lewis Bay and Parkers River watershed and deal with the Title 5 constraints on economic redevelopment in the area of Route 28. The town's plan included approximately 125 miles of sewer lines and the collection of 2.75 MGD of wastewater to

be treated at a single facility in the Parkers River watershed. The project would ultimately serve 9,580 properties by 2035. Phase 1 of the plan would begin with the treatment facility and main trunk line sewer to serve Route 28 and portions of the Parkers River and Lewis Bay watershed.

The town submitted its FEIR and received MEPA approval in July 2011, but did not complete the DRI process before going to September 2011 Town Meeting to seek Phase 1 design and construction funds. Phases 1 through 5 were scheduled to be implemented over a 25-year period. The estimated cost of the total plan was $275 million. The first phase had an estimated cost of $55 million. Town Meeting did not approve the expenditure. The town withdrew the CWMP from the DRI review process and is evaluating the next appropriate steps.

Yarmouth officials have been meeting with Cape Cod Commission staff, MassDEP and Barnstable officials to discuss the scoping of a targeted watershed approach for Lewis Bay.

A more detailed chronology of water quality planning efforts in Yarmouth is available in Appendix 2Q.

Existing Wastewater Infrastructure

There are four communities with municipally owned and operated wastewater treatment facilities on Cape Cod. In addition, there are a number of small and privately owned and operated facilities located throughout the region.

What follows is a brief summary of the existing municipal infrastructure, including information on current treatment and disposal capacity. Future analysis of potential expansion capacity of the existing municipal facilities may benefit Cape Cod communities looking for affordable solutions to collect and treat wastewater. The existing infrastructure located in and serving Joint Base Cape Cod is discussed in Chapter 7.

The four communities currently operating municipal wastewater treatment facilities are Barnstable, Chatham, Falmouth and Provincetown.

BARNSTABLE

The Hyannis WPCF, located off Bearses Way in Hyannis, is the primary facility serving the town. It has a permitted capacity of 4.2 MGD that is discharged on-site through open sand beds. In addition to the on-site discharge capacity, the town of Barnstable acquired the "McManus" site on Route 132 in 2002 to potentially accommodate future flows; however, this site is not being used today.

Current operating conditions at the facility treat an average daily flow of 1.46 MGD and a maximum monthly average flow of 1.94 MGD. Treatment performance has averaged 5 milligrams per liter (mg/L) total nitrogen in the treated effluence and the facility has a discharge limit of 10 mg/L. The facility is also equipped with sludge thickening, storage and dewatering facilities sized for the current process conditions.

The town of Barnstable also operates two smaller facilities - the Marstons Mills Wastewater Treatment Facility (WWTF) and the Red Lily Pond Cluster System. The Marstons Mills WWTF is limited to a discharge flow of 42,900 GPD and is intended to service the Barnstable United Elementary School and the Village at Marstons Mills affordable housing development. The Red Lily Pond Cluster System currently serves 17 homes.

CHATHAM

The Chatham WWTF, located on an 80-acre parcel on Sam Ryder Road, recently underwent a major upgrade as part of phase 1 CWMP. The facility has a permitted capacity of 1.0 MGD (annual average) and 2.3 MGD (peak day) and two existing sand beds, which have been in operation for 35 years. The permit requires a discharge limit of 10 mg/L with an annual limit of 9.132 pounds/year, which corresponds to an annual average discharge of 3 mg/L.

The upgrade to the WWTF included several improvements to its sludge processing capabilities. Dewatered sludge is discharged and taken off site for disposal. The site also accepts septage collected from Chatham parcels only.

FALMOUTH

The Falmouth WWTF, located on Blacksmith Shop Road, was upgraded from a lagoon treatment process to include Sequencing Batch Reactors (SBR) and denitrification filters in 2005. The facility is currently permitted with an effluent flow restriction of 0.8 MGD. The permit limits flows to the WWTF to 0.23 MGD inside the West Falmouth Harbor watershed and 0.57 MGD outside the West Falmouth Harbor watershed. On January 10, 2014 the town received a Certificate of Adequacy from the Secretary Of Energy and Environmental Affairs to sewer the Little Pond Service Area and discharge up to 260,000 GPD at a new disposal site is being pursued ("Site 7"), north of the existing beds and outside the West Falmouth Harbor watershed. The town is moving forward with a new effluent measuring system and optimization and improvement to the existing treatment system including the sludge thickening process at the facility.

PROVINCETOWN

The Provincetown WWTF is an advanced secondary treatment plant that is capable of treating a maximum daily flow (MDF) of 650,000 GPD, with discharge to four subsurface disposal beds at six locations along Route 6. Additional upgrades may be required to increase the capacity to allow a MDF of 750,000 in the future, and will occur when required.

Provincetown is currently working to design, permit, expand, and operate its wastewater collection, treatment and disposal systems.

The current sludge management plan includes periodic removal from the SBRs, storage for aeration and mixing, and hauling by a contractor for disposal at a facility in Cranston, RI.

03 POLICY

Regulations

Advancements in the sciences of marine ecosystems and hydrogeology have helped improve understanding of ongoing impairments as well as establish new standards for coastal water quality, but the language and enforcement tools contained in important water quality statutes are imperfect solutions to today's problems.

The Clean Water Act was effective in stopping direct discharge water pollution and Massachusetts Title 5 regulations successfully protect public drinking water supplies from septic system pollution, but neither is well suited to address coastal nutrient pollution on Cape Cod. The Clean Water Act, as applied, does not regulate discharges on Cape Cod and Title 5 allows septic systems with nitrogen levels in effluent that degrades water quality in embayments.

REGULATORY STREAMLINING

The current permitting and regulation framework is a one-size fits all approach with little consideration for shared watershed permitting and regulation across municipal lines. What's recommended provides a necessary evolution of this framework to successfully implement established federal and state water quality goals.

TARGETED



A permitting approach that allows Targeted Wastewater Management Plans reduces upfront planning time, lowers cost and focuses attention where it's needed.

REDUCTION CREDITS



Towns should get credit for what they are already doing. Policies to reduce fertilizer use and stormwater runoff, supported by performance monitoring, should lower watershed nitrogen reduction targets.

WATERSHED PERMIT



Under the watershed permit approach, nitrogen loads are allocated on a watershed-by-watershed basis, as developed through the Waste Treatment Management Agency, or WMA, designations. The watershed permit will list all technology options identified for implementation by stakeholders for the particular watershed, as well as each permittee's specified annual discharge limit.

Regulating the Problem v. Regulating the Solution

Septic systems are the primary wastewater management infrastructure tool on Cape Cod, with limited groundwater discharges from four (Barnstable, Chatham, Falmouth, and Provincetown) publicly owned treatment works (POTWs) and 58 of smaller wastewater treatment works. These discharges are managed by a one size fits all approach with little consideration for shared watershed permitting and regulation across municipal lines. Wastewater management plans with traditional technologies have clear but often lengthy and extensive permitting paths while alternative technologies are often not permitted or their nitrogen reduction performance is poorly understood and not applied to meeting overall watershed nitrogen management goals and standards.

An inescapable conclusion of the Section 208 Plan Update is that the current regulatory scheme is ill suited to result in effective solutions to the water quality challenges of Cape Cod and that reform is necessary for effective and affordable outcomes to be realized. The recommendations

History of the Clean Water Act

The Federal Water Pollution Control Act of 1948 was the first major U.S. law to address water pollution. Growing public awareness and concern for controlling water pollution led to sweeping amendments in 1972, when the law became commonly known as the Clean Water Act.

The 1972 Amendments:

- Established the basic structure for regulating pollutants discharges into the waters of the United States.
- Gave US EPA the authority to implement pollution control programs such as setting wastewater standards for industry.
- Maintained existing requirements to set water quality standards for all contaminants in surface waters.
- Made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions.
- Funded the construction of sewage treatment plants under the construction grants program.
- Recognized the need for planning to address the critical problems posed by nonpoint source pollution.

Subsequent amendments modified some of the earlier provisions. Changes in 1987 phased out the construction grants program, replacing it with the State Water Pollution Control Revolving Fund, more commonly known as the Clean Water State Revolving Fund.

For more information: www2.epa.gov/laws-regulations/history-clean-water-act

that follow suggest a necessary evolution of the tools and established regulatory framework to successfully implement federal and state water quality goals to protect and restore coastal waters, while providing flexibility and certainty in the permitting path for local decision makers.

Regulating the Problem: Existing Regulation and Permitting

FEDERAL REQUIREMENTS AND GOALS

FEDERAL CLEAN WATER ACT

The United States Environmental Protection Agency (US EPA) regulates water quality under the federal Water Pollution Control Act of 1972 and its subsequent amendments in 1977, 1981, and 1987. Collectively these are known as the Clean Water Act (CWA) (see http://www.epw.senate.gov/water.pdf for the full Clean Water Act). The objective of the act is to maintain and restore the chemical, physical and biological integrity of US waters. The act requires states to establish ambient water quality standards for water bodies based on the need to protect the use(s) designated for that water body.

The CWA provides the umbrella for the planning, permitting and financing of water pollution control facilities nationally. As a national tool, it deals in broad strokes with the causes of water quality impairment as they were understood at the time of passage and subsequent amendment of the Act. The law has not been updated to address the diffuse and nonpoint nature of water quality problems experienced on the Cape in mind and, as a result, is an imperfect tool for devising and implementing solutions scaled to Cape Cod.

Clean Water Act Section 208

A cornerstone, but rarely still utilized portion of the CWA is Section 208. This section provides the template for areawide waste treatment management plans, like this one, that form the blueprint for attainment of water quality goals within a given region. Plans prepared pursuant to Section 208 of the Clean Water Act must include, in pertinent part, identification of treatment works necessary to meet anticipated waste treatment needs of the area over a 20-year period; establishment of construction priorities and time schedules for the treatment works; establishment of a regulatory program; identification of those agencies necessary to construct, operate and maintain all facilities required by the plan; identification of measures necessary to carry out the plan, including financing and the economic, social, and environmental impact of carrying out the plan; a process to identify construction activity related sources of pollution and to set forth procedures to control such sources; a process to control the disposition of all residual waste that could affect water quality; and a process to control the disposal of pollutants within such area to protect ground and surface water quality.

Section 208 also requires states, as part of the certification process, to designate one or more Waste Treatment Management Agencies (WMAs). WMAs have specific responsibilities articulated in the CWA, including the ability to build and operate treatment works and technologies outlined in their watershed plan to achieve Total Maximum Daily Load (TMDL) compliance, but also issue bonds and notes to raise revenues to carry out their plan. See Chapter 8 for more information on WMAs.

Point and Nonpoint Source Water Pollution

A “point source” of pollution is defined in §502(14) of the federal Clean Water Act as “any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.” Point sources are regulated by National Pollutant Discharge Elimination System (NPDES) permits.

The term “nonpoint source” is defined as any source of water pollution that does not meet the above legal definition of a “point source.” Nonpoint sources are typically described as those emanating from precipitation that has picked up natural and human-made pollutants as it moves over and through the ground. The US EPA lists fertilizers, herbicides, pesticides, oil and grease, sediments and bacteria and nutrients as examples of nonpoint source pollutants. Septic systems, despite the fact that they introduce nutrients and other contaminants into the groundwater are considered non-point sources of pollution and are therefor not regulated by US EPA.

Regulations and Enforcement

At the present time, there is no federal law that requires the regulation of nonpoint source water pollution in a way that gives rise to enforcement actions. Given the scope of the CWA and the nature of wastewater management on the Cape, US EPA permit requirements do not apply to Cape Cod and the reach of the CWA on Cape Cod is limited to planning and the development of TMDLs for impaired waters.

Cape Cod has recently been the subject of a lawsuit on this issue in the matter of Conservation Law Foundation (CLF) and the Buzzards Bay Coalition (BBC) v. the United States Environmental Protection Agency et al. The original lawsuit asserted that the US EPA violated the Clean Water Act and its regulations by failing to properly regulate nonpoint sources resulting in increased nitrogen levels which have degraded the embayments in a manner that has injured the recreational, commercial and aesthetic interests in those waters. This lawsuit was dismissed for lack of standing, leaving the underlying claims of the plaintiff unresolved by the courts

In a refiled suit, CLF asserted that the US EPA's mandatory annual review of how Massachusetts administers its State Revolving Fund (SRF) has been contrary to law. Specifically, under the Clean Water Act, the US EPA has the authority to grant money to a state's SRF fund for certain types of wastewater management projects subject to certain restrictions on the use of the funds, with the main one being that funded projects be consistent with approved 208 plans. The US EPA has a duty to review a state's plans and reports concerning the state's use of those funds on an annual basis.

CLF sought an injunction requiring that (1) the US EPA notify the Commonwealth of its noncompliance; and (2) an update to the Section 208 Area Wide Water Quality Management Plan be completed within one year. The US EPA sought and received a stay of this lawsuit until June 1, 2015, pending review and approval of this updated Cape Cod area wide water quality management plan under Section 208 of the Clean Water Act.

Subsequently, on November 17, 2014, CLF and US EPA filed a settlement agreement in US District Court requesting an extension of the existing stay of the Section 208 Action from June 1, 2015 to September 15, 2015, a stay of the TMDL Action until September 15, 2015, and a dismissal of both actions upon completion of a series of actions to be completed by EPA, including the approval of the Cape Cod Section 208 Plan Update.

While the lawsuit sought to change this, direct federal regulation of large nonpoint source water pollution is managed today through non-regulatory means, including assistance to states from federal planning and grant programs under the Clean Water Act. Among the non-regulatory strategies this plan tries to leverage are watershed and land use planning, development of voluntary best management practices, technical assistance programs regulatory reform and cost-sharing for implementation of prevention and control measures.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) STORMWATER PERMIT PROGRAM AND MUNICIPAL SEPARATE STORM SEWER SYSTEMS (MS4)

The Clean Water Act authorizes US EPA and states to regulate point sources that discharge pollutants into waters of the United States through the National Pollutant Discharge Elimination System permit program. These "point sources" are generated from a variety of residential, municipal and industrial operations, including treated wastewater, process water, cooling water, and stormwater runoff into drainage systems. The NPDES Stormwater Program regulates discharges from certain municipal separate storm sewer systems (MS4s), construction activities, and industrial activities. The US EPA Regional Administrator may also designate needed stormwater controls for discharge based on waste load allocations that are part of a TMDL that address the pollutant of concern. See 40 CFR §122.26(a)(9)(i)(C) and (D)(relating to discharges that the Regional Administrator determines are a significant contributor of pollutants or contribute to a violation of water quality standards).

On Cape Cod, all communities except Truro and Provincetown are expected to be subject to newly issued regulation under the MS4 permit program.

The Clean Water Act provides that municipal and industrial stormwater permits "shall require controls to reduce the discharge of pollutants to the maximum extent practicable,

including management practices, control techniques and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants" CWA Section §402(p)(3)(B)(iii).

Municipalities not only have to control pollutants to the maximum extent practicable, but also have to effectively prohibit non-stormwater discharges into the system and comply with provisions as deemed by the Regional Administrator or, in states with an approved NPDES program, the State Director.

The definition of MS4s includes but is not limited to: stormwater outfalls, roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, and/or storm drains. The complete definition may be found at 40 CFR §122.26(b)(8).

The Cape communities south and west of Eastham are currently operating under an administrative extension to the 2003 MS4 permit, which remains enforceable and in effect administratively with all of terms and conditions until a new permit is issued. US EPA Region 1 published a 2014 Draft Massachusetts MS4 Permit on September 30, 2014; the comment period for the draft permit closed on February 27, 2015.

The draft Massachusetts MS4 permit has six minimum measures:

- Public education and outreach
- Public involvement
- Illicit discharge detection and elimination
- Construction runoff
- Post construction stormwater management
- Pollution prevention

For more information about the draft permit, see: http://www.epa.gov/region1/npdes/stormwater/MS4_MA.html. In addition, US EPA anticipates issuing a separate small MS4 permit for the Massachusetts Department of Transportation (MassDOT) in the near future.

The 2003 MS4 permit established goals and metrics geared toward improving water quality in water bodies regulated under the Clean Water Act. Municipalities were required to develop, implement, and enforce a stormwater management program designed to control pollutants to the maximum extent practicable in the watershed. The "maximum extent practicable" standard is a flexible goal intended to be met through an iterative process. Municipalities implement their stormwater management programs through best management practices (BMPs), periodically assess the effectiveness of the BMPs, and then make revisions to address ineffective elements of the program, and improve pollutant control.

Presently there are approved TMDLs for nitrogen in many of Cape Cod's coastal embayment systems. The Massachusetts Estuaries Project (MEP) technical reports for Cape Cod watersheds identify MS4 sources as comprising 3%-17% of the controllable watershed nitrogen load, depending on the watershed studied. It has been anticipated that the new permit will contain specific regulations for discharges subject to an approved TMDL to better address specific pollutant problems in regulated water bodies.

For the "Cape Cod Nitrogen TMDL's," the 2014 draft Massachusetts MS4 permit seeks nitrogen reduction through enhanced Best Management Practices for discharges to nutrient impaired waters or their tributaries, with a focus on public education, new development/redevelopment and good housekeeping. For discharges to waterbodies without an approved TMDL, there are still requirements for bacteria, nutrients, solids, chloride, metals and oils and grease. A Nutrient Source Identification Report, which is due on year four from the date of the issuance of the permit, seeks the delineation of potential nitrogen or phosphorus sources, an identification of potential retrofits, one demonstration project by year six, and the tracking of nitrogen or phosphorus reductions through the implementation of structural BMPs.

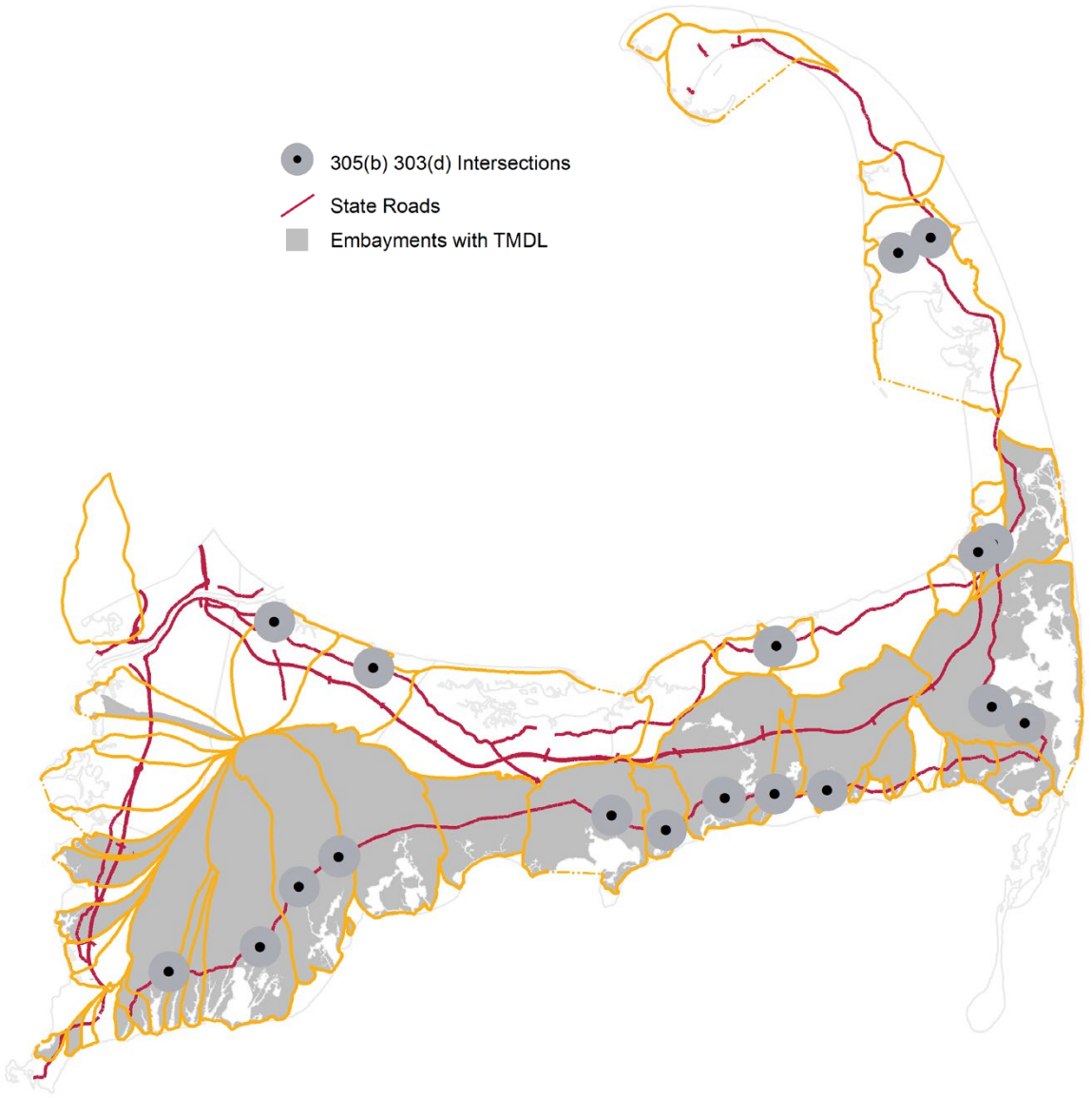
Towns should be prepared to respond to the draft small MS4 general permit soon after its issuance. To seek coverage under the small MS4, towns must file a Notice of Intent (NOI) within 90 days of US EPA's issuance of the final MS4 permit following the public comment period. Requirements for the NOI filing include: the location of the current Stormwater Management Program (website or physical address), status of outfall map, a summary of the status of relevant bylaws/ordinances, identification of the number of outfalls contributing to receiving waters and a summary of the current Stormwater Management Program.

MassDOT is recognized as a regulated entity with a separate individual small MS4 permit anticipated to be released in the near future. State roadways operated by MassDOT in watersheds to impaired water resources also contribute nutrients and other pollutants from stormwater. **Figure 3-1** shows the state roadways that intersect water resources with completed TMDLs for nitrogen, are pending MEP analysis, and/or are listed on §305(b) or §303(d) Integrated List of Waters. See Chapter 7 for specific recommendations for working with MassDOT to improve stormwater management on state roadways.

For more information about the MS4 Permit Program, see http://epa.gov/region1/npdes/stormwater/. Chapter 6 provides a discussion of stormwater utilities as a means of raising stable and adequate revenue to fund stormwater improvements and maintenance.

NPDES AUTHORITY

The CWA allows the US EPA to authorize the NPDES Permit Program to state governments, enabling states to perform many of the permitting, administrative, and enforcement aspects of the NPDES Program. Currently, the US EPA has authorized all but five states to participate in some capacity in the administration and enforcement of NPDES permits. Massachusetts is not a delegated state under the NPDES permit program. NPDES permits are jointly issued by the US EPA and the MassDEP and are equally and separately enforceable by both agencies. Presently, there are various methods used to monitor NPDES permit conditions. According to the US EPA, these include the following:



2012 Integrated List of Waters 305(b) 303(d)

Figure 3-1

- The permit requires the facility to sample its discharges and notify US EPA and the state regulatory agency of its results.
- The permit also requires a facility to notify US EPA and the state regulatory agency when the facility determines it is not in compliance with the requirements of a permit.
- US EPA and state regulatory agencies also send inspectors to companies in order to determine if they are in compliance with the conditions imposed under their permits.

Federal law provides US EPA and authorized state regulatory agencies with various methods of taking enforcement actions against violators of permit requirements. These include the authority for US EPA and state regulatory agencies to issue administrative orders requiring facilities to correct violations and assess monetary penalties. The US EPA and state agencies may also pursue civil and criminal actions that may include mandatory injunctions or penalties, as well as jail sentences for persons found willfully violating requirements and endangering the health and welfare of the public or environment.

To the extent a locally proposed solution results in the need for a NPDES permit, providing the Commonwealth of Massachusetts permitting and enforcement abilities that the majority of the United States currently exercise will enable the locality to pursue the streamlined process that the Section 208 Plan proposes. Delegating such authority to the Commonwealth of Massachusetts in conjunction with its newly produced action plan pursuant to Section 208 is in line with its proposal and it's consideration is recommended as part of this plan.

Recommendation R3.1: The Commonwealth of Massachusetts should seek delegated authority under the Clean Water Act to issue and enforce NPDES permits.

REQUIREMENTS AND GOALS

The lack of direct federal NPDES permitting on Cape Cod means that much of the regulatory load is carried by the Commonwealth of Massachusetts through the Department of Environmental Protection (MassDEP). Wastewater discharges are currently regulated in the Commonwealth through the following means:

- **SEPTIC SYSTEMS:** Regulation of septic systems is delegated by the state to municipalities under the jurisdiction of the Boards of Health in each city or town in accordance with 310 CMR 15.000 (Title 5). The BOH role is to ensure that the systems are installed and maintained according to code.
- **GROUNDWATER DISCHARGES (VOLUMES OVER 10,000 GALLONS PER DAY):** MassDEP issues Groundwater Discharge Permits for facilities that discharge to the ground. At a minimum, these permits require secondary treatment with a nitrogen limit of 10 milligrams per liter (mg/l) before discharging to the ground. Groundwater discharge permits are prominent on Cape Cod.
- **SURFACE WATER DISCHARGES (NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM [NPDES] PERMIT):** MassDEP issues these permits jointly with the US EPA. These permits for discharge to surface waters have end of the pipe effluent limits for pollutants of concern, like nitrogen and phosphorus, which comply with the surface water quality standards.

These permitting processes are part of a set of regulatory programs that, taken together, provide a framework of tools to manage, somewhat imperfectly, the water quality challenges facing Cape Cod. There is no single regulatory program with the scope and authority to successfully manage Cape Cod waters, so these separate programs and tools must be woven together, reformed and used in new ways.

STATE TITLE 5 REGULATIONS ON WASTEWATER FLOWS

MassDEP regulates wastewater flows less than 10,000 gallons per day under 310 CMR 15.000: The State Environmental Code, Title 5: Standard Requirements for the Siting, Construction, Inspection, Upgrade and Expansion of On-Site Sewage Treatment and Disposal Systems and for the Transport and Disposal of Septage (typically referred to as Title 5). Title 5 typically covers such uses as conventional on-site septic systems, alternative systems, such as denitrifying systems (often called "Innovative/ Alternative," or I/A, systems), as well as composting toilets

and other kinds of systems in use on individual properties or cluster developments. Title 5 presumes residential wastewater flows at 110 gallons per day per bedroom (e.g., Title 5 presumes that a four-bedroom house will generate 440 gallons per day, and that one 440 gpd septic system per acre is protective of drinking water quality). Non-residential wastewater generation is typically based on use and square footage, or for example, the number of restaurant seats.

MASSACHUSETTS GROUND WATER QUALITY STANDARDS

Massachusetts Groundwater Quality Standards

Massachusetts applies a number of regulations protective of groundwater, many of which are also protective of surface waters because contaminants affecting groundwater quality, e.g. nitrogen, ultimately discharge to surface waters. Massachusetts Groundwater Quality Standards, 314 CMR 6.00, were rescinded in 2009 because revisions to 314 CMR 5.00 eliminated the need for this regulation.

Primary regulations protective of groundwater include:

- Drinking Water Regulations (310 CMR 22.00)
- Groundwater Discharge Program (314 CMR 5.00)
- Septic System regulations (310 CMR 15.00; Title 5)
- Land Application of Sludge and Septage Wastewater & Sewer Regulations (310 CMR 32.00)
- Supplemental Requirements for Hazardous Waste Management Facilities (314 CMR 8.00)
- Reclaimed Water Regulations (314 CMR 20.00)
- Wetlands Protection Act Regulations (310 CMR 10.00, including the Massachusetts Stormwater Policy and Guidelines)
- Massachusetts Contingency Plan (310 CMR 40.0000)

GROUNDWATER DISCHARGE PERMITS

Flows in excess of 10,000 gallons per day are regulated under the state Groundwater Discharge Permit Program (See 314 CMR 5.00 Groundwater Discharge Permit Program). Systems requiring a groundwater discharge permit require significant removal of nitrogen because the Cape Cod Aquifer is designated as a non-degradation resource. Groundwater discharge permits for Cape Cod require an effluent treatment level of at least 10 milligrams per liter of nitrate, which is almost a two-thirds reduction in the amount of nitrogen leaving a septic system, although not low enough to achieve or maintain marine water quality. In the last 10 years, groundwater discharge permits for projects located in watersheds to nitrogen impaired embayments have been held to a "no-net nitrogen" standard by MassDEP. This means that any nitrogen released into the watershed must be "offset" by the removal of nitrogen from an existing source. To date, this typically occurs by connecting a nearby existing development to remove nitrogen via wastewater treatment.

MASSACHUSETTS SURFACE WATER QUALITY STANDARDS

Following federal law, and as prescribed by the federal Clean Water Act, the Commonwealth of Massachusetts adopted surface water quality standards for individual water bodies. The standards designate the most sensitive uses for which the water body must be "enhanced, maintained, and protected" (whether or not the designated use is currently attained), prescribe minimum water quality criteria necessary to sustain the designated uses and contain the regulations necessary to achieve and maintain the designated use and, where appropriate, prohibit discharges.

Massachusetts divides coastal and marine surface waters into three classes: SA, SB, and SC, in descending order of the most sensitive uses that water body must attain. Additionally the state has special designations of Outstanding Resource Waters, Special Resource Waters, Shellfish (waters), and Warm Water. A brief description of these classes and special designations follows. For more information see M.G.L. c. 21, §27. 314 CMR 4.00: Massachusetts Surface Water Quality Standards.

SA Waters are designated as the highest quality, providing excellent habitat for marine life and for primary and secondary contact recreation. In certain waters, excellent habitat may include seagrass and, where designated for shellfishing, SA waters are suitable for shellfish harvesting without depuration (process of removing impurities). Nearly all of the coastal waters of Cape Cod have been classified as SA.

SB Waters are designated as habitat for marine life and for primary and secondary contact recreation. In certain waters, habitat may include seagrass. Where designated for shellfishing, these waters are suitable for shellfish harvesting with depuration. Several water bodies on Cape Cod have been classified as SB waters, particularly those that are used heavily for shipping and boating.

SC Waters are designated as habitat for marine life and for secondary contact recreation. They may also be suitable for certain industrial cooling and process uses. There is no water body on Cape Cod that has been classified as SC.

Outstanding Resource Waters (ORW) denotes waters that "include Class A Public Water Supplies (314 CMR 4.06(1)(d)1) and their tributaries, certain wetlands as specified in 314 CMR 4.06(2) and other waters as determined by the department based on their outstanding socio-economic, recreational, ecological, and/or aesthetic values." An application to nominate a water body as an ORW must be submitted in accordance with applicable department application procedures and requirements. Areas of Cape Cod that have been designated as ORW include waters within and adjacent to the Cape Cod National Seashore and Areas of Critical Environmental Concern (ACECs). See Appendix 3A for a list of ACECs.

Shellfishing Waters are subject to more stringent regulation in accordance with the rules and regulations of the Massachusetts Division of Marine Fisheries.

Warm Waters are those waters in which the dissolved oxygen and temperature criteria for warm-water fisheries apply. This designation applies only to fresh water bodies.

There is a provision to remove a designated use through a Use Attainability Analysis (UAA) persuant to 40 CFR 131.10(g). The towns of Eastham and Orleans have begun discussions with the state regarding an UAA for Rock Harbor.

IMPAIRED WATERS AND TOTAL MAXIMUM DAILY LOADS

Massachusetts submits a list of the conditions of surface waters to the US EPA every two years in compliance with the Clean Water Act. The "Integrated List of Waters" identifies each water body or segment of a water body as supporting a designated use or as impaired. With the Integrated Report option, US EPA encourages states to use a five-category system for classifying all water bodies (or segments) within its boundaries regarding the waters' status in meeting the state's water quality standards. The categories are listed below in **Table 3-1**. The classification system uses designated uses as the basis for reporting on water quality.

The waters from Category 5 constitute the Section 303(d) list of impaired or threatened waters within the State boundaries. In addition to the 303(d) report, the CWA requires that each state report every two years on the health of all its waters, not just those that are impaired. Information from this report, known as the 305(b) report or "biennial water quality report," has historically been used

CATEGORY/SUBCATEGORY	DESCRIPTION
Category 1	All designated uses are supported, no use is threatened.
Category 2	Available data and/or information indicate that some, but not all, designated uses are supported.
Category 3	There is insufficient available data and/or information to make a use support determination.
Category 4	Available data and/or information indicate that at least one designated use is not being supported or is threatened, but a TMDL is not needed.
Category 4a	A State developed TMDL has been approved by US EPA or a TMDL has been established by US EPA for any segment-pollutant combination.
Category 4b	Other required control measures are expected to result in the attainment of an applicable water quality standard in a reasonable period of time.
Category 4c	The non-attainment of any applicable water quality standard for the segment is the result of pollution and is not caused by a pollutant.
Category 5	Available data and/or information indicate that at least one designated use is not being supported or is threatened, and a TMDL is needed.

Five Category System for Classifying Waterbodies

Table 3-1

to develop the "threatened and impaired waters" list. Most states compile the data and findings from the 305(b) report and add information from other sources, such as the state's report of waters affected by nonpoint sources (CWA §319), to produce the 303(d) list. EPA recommends that states combine the threatened and impaired waters list, 303(d) report, with the 305(b) report to create an "Integrated Report," due April 1 of even-numbered years.

The most recent impaired waters list for Massachusetts, including Cape Cod waters, is the Massachusetts Year 2012 Integrated List of Waters. As of the date of this report, the Massachusetts Year 2014 Integrated List of Waters is still considered draft.

The Clean Water Act, under §303(d), requires states to assess the quality of surface waters based on the intended uses identified in the state Water Quality Standards on a regular basis and to develop a list, referred to as the 303(d) list, of impaired waters detailing those waters that do not meet the intended uses. The Clean Water Act requires all states to submit for US EPA approval every two years on even-numbered years a list of impaired and threatened waters. The states identify all waters where required pollution controls are not sufficient to attain or maintain applicable water quality standards, and establish priorities for development of TMDLs based on the severity of the pollution and the sensitivity of the uses to be made of the waters, among other factors. States then provide a long-term plan for completing TMDLs within 8 to 13 years from first listing.

Under §303(d) of the Clean Water Act, states are required to:

- Identify those water bodies that are not expected to meet the Surface Water Quality Standards from technology-based controls; and,
- Establish, subject to US EPA approval, for those water's TMDLs—the maximum amount of a pollutant from any source and of any kind that a water body can have without violating water quality standards.

On Cape Cod, state-developed TMDLs are based on technical reports prepared by the MEP. TMDLs are formulated by MassDEP and submitted to US EPA for approval after public comment. The TMDLs are utilized as the standards MassDEP and other regulatory authorities use to determine whether their regulations are met as required by the Federal Clean Water Act.

NONPOINT SOURCE MANAGEMENT PLAN

Massachusetts developed a nonpoint source management (NPS) plan in 1988 pursuant to §319 of the Clean Water Act. This plan, updated most recently in 2014, is an integrated strategy for the prevention, control and reduction of pollution from nonpoint sources. As part of the 2014 update, the MA Office of Coastal Zone Management also updated its Coastal Nonpoint Pollution Program 5-Year implementation Plan and 15-Year Program Strategy, and included it in the statewide plan. Federal funds are available for activities such as technical assistance, education, training, technology transfer, watershed restoration and demonstration projects. Only those implementation strategies identified in the management plan are eligible for federal funding. In addition to the NPS Management Plan, in 2006 MassDEP developed a Clean Water Toolkit (also known as the Massachusetts Nonpoint Source Pollution Management Manual) that provides information about the nonpoint source management measures that can be used in Massachusetts. Both the 2014 Massachusetts Nonpoint Source Management Program Plan and the Toolkit can be found at http://www.mass.gov/eea/agencies/massdep/ for more information.

SAFE DRINKING WATER ACT

The US EPA Primacy Agent for the Federal Safe Drinking Water Act is the MassDEP, Division of Watershed Management's Drinking Water Program. On behalf of the US EPA, MassDEP regulates water quality monitoring, new source approvals, water supply treatment, distribution protection and the reporting of water quality data

The Safe Drinking Water Act (SDWA) is the main federal law that protects the quality of drinking water and the rivers, lakes, reservoirs, springs and groundwater wells that are the source of drinking water. The Act authorizes the US EPA to set standards for drinking water quality to protect against natural and human-caused contaminants and to oversee the implementation of those standards on the state, local and water supplier levels. At present, there are standards that regulate 83 different contaminants. Cape Cod was designated a Sole-Source Aquifer under the Safe Drinking Water Act in 1982.

The Act applies to the more than 170,000 public drinking water systems in the country and requires their evaluation by third party analytical laboratories. The Act does not

cover systems that service fewer than 25 individuals or apply to bottled water. There are 17 SDWA regulated public water suppliers on Cape Cod.

DRINKING WATER AND ZONE II WELLHEAD PROTECTION AREAS

Massachusetts' drinking water regulations (310 CMR 22.00) are intended to protect public health by ensuring that all water used for public consumption is safe, fit and pure to drink. The regulations identify contaminants that must be controlled, establish limits on the allowable concentrations of these contaminants and mandate the type and frequency of monitoring required, ensuring compliance with the regulations.

The regulations define a Zone I as "the protective radius required around a public water supply well or wellfield" and a Zone II as "that area of an aquifer that contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated." Zone IIs are also known as wellhead protection areas and all Cape towns have protected them through zoning and Board of Health bylaws. Municipalities identify areas as potential Zone IIs and submit them to the state. Zone I areas are roughly 11 acres large and must be controlled by the public water supplier. Zone IIs are much larger and are subject to protection from the siting of discharges, landfills and other potentially hazardous land uses.

WATER POLLUTION ABATEMENT DISTRICTS

MassDEP may propose the creation of water pollution abatement districts (WPAD) consisting of one or more cities or towns, or designated parts thereof. If MassDEP deems that such a district is necessary for the prompt and efficient abatement of water pollution, it may, after a public hearing, mandate the formation of such a district.

Districts can be proposed by a town or by MassDEP; if it is the latter, a town must take a vote at Town Meeting within 90 days of the nomination. If the town meeting votes against the establishment of a WPAD, MassDEP may hold a hearing with the Water Resources Commission if it finds that the creation of a district is "necessary for the prompt and efficient abatement of water pollution."

Once created, each district is its own independent entity administered by a "district commission." Representatives of the town may comprise the WPAD, but MassDEP may mandate that their agency appoint members (with approval of the Water Resources Commission).

After its creation, the district has one year to present an abatement plan to MassDEP (or a lesser time as established by MassDEP) that contains the source of pollution, the means by which to abate it, and proposed projects for the solution. Once formed, the WPAD may only be dissolved by an act of the Legislature.

The source of authority for WPADs is the Massachusetts Clean Waters Act (M.G.L. c. 21, §§28-30, 32, 35, 36). The Act enables towns to:

- Adopt bylaws/regulations
- Acquire, dispose of and encumber real/personal property (including eminent domain powers)
- Construct, operate and maintain water pollution abatement facilities
- Apportion assessments on the member municipalities
- Issue bonds and notes and raise revenues to carry out the purposes of the district

Member municipalities may then impose assessments on residents, corporations and other users in the district. If a town fails to pay its share, the state may pay it for them out of other funds appropriated to that town.

COMPREHENSIVE WASTEWATER MANAGEMENT PLANS

Currently, individual municipalities develop Comprehensive Wastewater Management Plans (CWMPs) within town boundaries. These plans include watersheds that are both wholly within town boundaries, and watersheds that are shared with a neighboring town. MassDEP considers requests for municipal permits and financing after a state level environmental scoping review is conducted under the Massachusetts Environmental Policy Act (MEPA). MEPA thresholds mandate review for construction and upgrades to wastewater treatment and disposal facilities (MEPA Regulations 301 CMR 11.03 Review Thresholds). Specifically, MassDEP reviews CWMPs under MassDEP "Selection, Approval and Regulation of Water Pollution

Abatement Projects Receiving Financial Assistance from the State Revolving Fund" (310 CMR 44.00). CWMPs have traditionally recommended conventional wastewater sewer collection and treatment facilities, which require a groundwater discharge permit and sewer construction permits. The filing of a CWMP with MEPA typically requires the preparation of an Environmental Impact Report (EIR) which also triggers mandatory regulatory review by the Cape Cod Commission.

The MassDEP Division of Municipal Services Guide to Comprehensive Wastewater Management Planning outlines the process for development of a CWMP. According to the guidance, "The planning exercise requires a community to perform a needs analysis: identifying problem areas including areas with poor soils, areas with failing septic systems and densely developed areas. Different wastewater treatment options including on-site septic systems, decentralized systems, or a centralized community-wide system are also analyzed for applicability in addressing the identified wastewater issues while considering environmental concerns (groundwater recharge, pollution prevention) and costs. Public input is sought throughout the CWMP process."

MEPA AND OTHER STATE PERMITTING REQUIREMENTS

As discussed above, CWMPs typically require MEPA review prior to state and regional permitting. MEPA review involves scoping proposed projects for their potential environmental impacts, identifying alternatives, and avoiding, minimizing or mitigating environmental impacts. CWMPs are typically filed first as an Environmental Notification Form (ENF) or Expanded ENF with a Draft Environmental Impact Report (DEIR) and released for public comment. At the end of public comment, the Secretary of Energy and Environmental Affairs will issue a Certificate of Adequacy that outlines additional information or analysis that should be conducted prior to the next MEPA filing. The final MEPA filing is a Final Environmental Impact Report (FEIR). Upon the Secretary's issuance of a Certificate of Adequacy for an FEIR, appropriate state agencies and the Cape Cod Commission then commence their regulatory reviews (See, 301 CMR 11.). CWMPs typically trigger EIR review because they involve construction of a new wastewater treatment and disposal facility with a capacity of 2,500,000 gallons per day, or because they result in construction of one or more new sewer mains 10 or more miles long. CWMPs may also trigger mandatory EIR thresholds for land and wetland alterations, impacts to endangered or threatened species or archeological sites, and other factors. In addition to MassDEP regulatory review, other state agency permits may include: Massachusetts Natural Heritage and Endangered Species Program; Massachusetts Historical Commission; Massachusetts Division of Marine Fisheries, and others.

Barnstable County Requirements and Goals

CAPE COD COMMISSION

The Cape Cod Commission, the Cape's regional planning agency, was created by an act of the Massachusetts Legislature and ratified by the voters of Barnstable County in 1990 in response to the rapid development pressure of the 1980s. The increased pace of development focused attention on the need to manage growth, guide land use, promote balanced economic growth, provide for adequate capital facilities and infrastructure, and protect environmental resources. The Commission has planning, technical and regulatory tools that can be applied to water quality management on Cape Cod. The Commission has independent statutory authority and is a department within the structure of Barnstable County government.

DRI REVIEW OF MUNICIPAL COMPREHENSIVE WASTEWATER MANAGEMENT PLANS

A Development of Regional Impact (DRI) is a proposed development that is likely to present development issues significant to more than one municipality in Barnstable County. Projects are referred to the Cape Cod Commission for review as DRIs by a variety of means. The Commission is required to review the proposed development and either approve, approve with conditions, or deny the development proposal.

CAPE COD REGIONAL POLICY PLAN

The Cape Cod Commission Act (Act) established a Commission regulatory function to review and approve, condition, or deny development projects that exceed Development of Regional Impact thresholds. The Act includes a provision that the Commission develop and implement a Regional Policy Plan (RPP) that contains the minimum performance standards (MPS) for its regulatory review of proposals. The Commission published the first version of the Regional Policy Plan in 1991; it has been updated and revised every five years.

The initial water resources section of the Regional Policy Plan recognized that many of the Cape's embayments were suffering from water quality impacts associated with nitrogen from septic systems. In the late 1990s the plan's minimum performance standards for development not exceeding a critical nitrogen loading limit and maintaining or improving coastal water quality were interpreted as the "no net" nitrogen load policy. This means that development in a watershed to a nutrient-overloaded system cannot add any more nitrogen to the watershed or that the amount of nitrogen added by the project must be offset by an equivalent reduction.

The "no net" policy may be achieved by (1) providing wastewater treatment for the development or redevelopment and additional treatment capacity for nearby land uses; (2) installation of alternative denitrifying technologies for existing septic systems in the same Marine Water Recharge Area; and/or, (3) an equivalent monetary contribution of $1,550 per kilogram per year of nitrogen towards a municipal or watershed effort that achieves the intent of the "no net" load policy. The implementation of the policy was fairly successful and accepted by the towns and the regulated community. It resulted in increased levels of wastewater treatment from proposed package plants, the construction of package plants with excess capacity to hook in neighboring areas, and hundreds of thousands of dollars in mitigation funds for towns to pursue mitigation and/or CWMP development. Most importantly, it resulted in an acceptance that coastal eutrophication is an important matter for Cape Cod and that better treatment of wastewater is required.

The 2009 Regional Policy Plan changed the "no net" policy to reflect the newly adopted TMDLs by MassDEP and US EPA as the critical nitrogen loading limit. The performance standard interprets the adopted TMDL as a "fair share." The fair share is the TMDL equivalent load on a per-acre rate using the watershed and sub-watershed area. Fair-share nitrogen loads are calculated as the threshold controllable nitrogen load necessary to achieve TMDL compliance in the applicable surface water body, as indicated by the Massachusetts Estuaries Project, apportioned to the project in proportion to the size of the project area relative to the area contributing to applicable surface water body.

DRI project nitrogen loading calculations are reviewed to evaluate how a proponent could best meet the intent of the fair share. The Commission has developed a methodology to assist in calculating a project's nitrogen load and to compare its respective mitigation amount under the fair share.

The Commission's regulatory review of a CWMP is presently guided by the planning guidance and minimum performance standards of the Regional Policy Plan. The pertinent technical sections of the RPP include water resources, open space, natural resources, planning and historic preservation. Some of the requirements are similar to MassDEP requirements, but some are quite different. The pertinent standards from the RPP water resources section are available in Appendix 3B.

JOINT REVIEW PROCESS

As mentioned above, municipalities are typically required to file an EIR with the MEPA for the development of CWMPs. The Cape Cod Commission Act § 12(i) requires that the Commission shall review as a DRI any proposed development project for which the Massachusetts Secretary of Energy and Environmental Affairs (Secretary) requires the preparation of an Environmental Impact Report. As a result, at the conclusion of the MEPA process, the Commission conducts a regulatory review, and issues a written approval decision containing findings and conditions for all CWMPs proposed by Cape Cod towns.

A November 1991 Memorandum of Understanding (MOU) between the Commission and MEPA states that the environmental review processes of the Commission and the MEPA Unit are, in some instances, overlapping and that the environmental review procedures are similar. As

such, the MOU was executed given the extensive overlap of the statutory responsibilities of the Commission and the Secretary with respect to development on Cape Cod, in order to establish a coordinated review process for development projects that are subject to both Commission and MEPA review. The MOU establishes a coordinated voluntary Joint Review Process (JRP) for projects that are subject to MEPA and deemed to be DRIs pursuant to the Cape Cod Commission Act. The seventeen-step process is outlined as an attachment to the MOU. See Appendix 3C for the MOU.

DISTRICTS OF CRITICAL PLANNING CONCERN

The Cape Cod Commission Act provides for the designation of certain areas of critical value to Barnstable County as Districts of Critical Planning Concern (DCPCs).

A DCPC is a planning tool that allows for the adoption of special rules and regulations to protect, preserve, or promote an area, depending on the purpose of the DCPC. Certain local boards and commissions may nominate land within their own municipal boundaries, as well as land in a contiguous town (for example, a town could nominate land in a shared watershed to a nitrogen-sensitive embayment that lies within a neighboring town), as a DCPC. DCPCs may also be nominated by the Cape Cod Commission, the Board of County Commissioners and the Barnstable County Assembly of Delegates. Upon nomination to the Commission, the DCPC is considered by the Commission, which may in turn recommend it to the Assembly of Delegates and County Commissioners for adoption by county ordinance. Ultimately, implementing regulations are adopted and locally enforced by the town(s) to carry out the purposes of the DCPC. With the district designation comes a 12-15 month moratorium on certain development; the development moratorium is limited to specific development proposals as deemed necessary to support the purposes of the nominated district.

In terms of wastewater management or nitrogen control, as one example, a DCPC could be used to specify growth expectations in watersheds that are shared between one or more towns. The DCPC is a very flexible land use planning tool that could have many applications for water quality and growth planning on the Cape.

DCPCs are discussed further in Chapter 7 and a full list of designated DCPCs is available in Appendix 7A.

Other Regulations - Municipal

BOARD OF HEALTH REGULATIONS

Municipalities have authority and responsibility over wastewater flows within their jurisdiction in several ways. Boards of Health have jurisdiction over on-site septic systems and are responsible for enforcing compliance with Title 5 on the local level. Title 5 is a state minimum code, although municipalities may impose stricter standards then those found in Title 5. Under Title 5, Board of health responsibilities include:

- issuing permits and licenses for septic systems, septic installers and sewage haulers;
- controlling lot sizes and setbacks for purposes of siting septic system components;
- conducting inspections of septic systems;
- permitting the use of alternative systems, including denitrifying septic systems; and,
- mandating monitoring of alternative systems where applicable.

Boards of Health are responsible for defining what constitutes a bedroom for the purposes of septic system design flow requirements.

Boards of Health may also promulgate regulations more strict than imposed by Title 5. For example, under Title 5 a leaching field must be located at least 50 feet from a coastal bank, coastal dune, coastal beach, salt marsh, or vegetated wetland bordering on any creek, river, stream, pond, or lake. All Cape towns have increased this setback to 100 feet. Boards of Health may also issue variances and exemptions from certain requirements of local regulations.

In towns with sewers, Boards of Health or Sewer Commissions also promulgate water and sewer regulations. Several Cape Cod towns have implemented nutrient management controls through board of health regulations or general bylaws. Boards of Health have also adopted interim regulations for protection of saltwater estuaries. Some towns have taken steps to address flow-related growth potential through sewer connection regulations. These regulations limit flow to what existed before sewering

or to a small increase. These regulations are "growth neutral" in terms of design flow but do not address non-flow related criteria such as siting and setbacks.

Sewer-connection regulations set limits on the amount of wastewater flow to ensure that the capacity of a planned treatment plant is not exceeded and that TMDLs are met at present and in the future.

CONSERVATION COMMISSION REGULATIONS

WETLANDS PROTECTION

Although the jurisdiction of a local conservation commission is restricted to the delineated wetlands resource area and the 100-foot designated buffer (200 feet if the resource area meets the regulatory definition of a riverfront; 100 feet if it meets the requirement for a certified vernal pool), communities may expand the Massachusetts Wetlands Protection Act "protected interests" to include additional conservation values deemed important to the community. Like with Title 5, the WPA is a minimum code and communities may adopt more stringent wetlands rules for their community. The Massachusetts Association of Conservation Commissioners recommends that communities expand protected interests to include:

- Water quality, including surface water bodies
- Erosion/sedimentation control
- Natural habitat, wildlife habitat, rare species habitat, and wildlife corridors
- Agriculture, aquaculture, and shellfisheries
- Storm damage prevention, including coastal storm flowage
- Prevention and control of pollution
- Recreation

By including these as protected interests, the Conservation Commission has the ability to comment and impose conditions on proposed projects that may threaten resources that are no longer protected due to the elimination of Title 5 criteria.

Conservation Commissions may expand their jurisdiction over proposed projects by changing their bylaws and regulations that concern resource areas and buffer zones. Many Cape towns have established "No Build" and "No Disturb" zones within the 100-foot buffer. In no-build zones, no structures can be placed but some pruning is allowed. In no-disturb zones, no alteration can be made, including disturbing vegetation. Conservation Commissions can also extend jurisdiction by expanding the buffer zone beyond 100 feet.

The Cape Cod Commission has a model bylaw that provides language to extend the buffer zone to 200 feet for riverfronts in concordance with the riverfront amendments to the Massachusetts Wetlands Protection Act. Other language also expands the buffer to 300 feet for coastal plain pond shores, 350 feet for vernal pools, and 300 feet for wetlands that are designated as estimated habitat for rare species by the Massachusetts Natural Heritage and Endangered Species Program and for areas within Areas of Critical Environmental Concern.

Conservation Commissions may have jurisdiction when a septic system is upgraded if the existing system is not located with adequate depth to groundwater or if the leach field is less than the distance required from a wetland resource. If an existing system is repaired or upgraded, the new system must meet the requirements of the 100-foot buffer to the extent possible.

A thorough review of zoning and growth management measures and controls is included in Chapter 7 of this plan update.

LOW-IMPACT DEVELOPMENT

Low-impact Development (LID) is a comprehensive, conservation-based approach to land use planning. LID maintains the pre-development hydrology of a site through the use of natural stormwater best management practices including bio-retention filters, vegetated swales, shared driveways, pervious concrete, green roofs, and other strategies that promote the infiltration, filtering, storage, and evaporation of water on location. To date, none of the Cape towns have implemented comprehensive town-wide LID bylaws. However, several towns have adopted measures to improve stormwater treatment. For example, in 2011 the town of Brewster adopted Chapter 115 (Illicit Discharges bylaw) governing discharges to municipal storm systems. The Town of Dennis adopted a stormwater management bylaw in 2009.

NUTRIENTS FROM FERTILIZERS

Fertilizers are included in the nitrogen loading assessment prepared for each watershed by the MEP. With respect to controllable nitrogen loads, the percentage of unattenuated fertilizer load present in the coastal watersheds of Cape Cod ranges from 2% to 20% with an average of 9%.

MUNICIPAL FERTILIZER MANAGEMENT REGULATIONS

The Massachusetts Department of Agricultural Resources released draft regulations in March 2014 pursuant to M.G.L. c. 128, §2(k) and §65(A), as amended by St. 2012, c. 262. 330 CMR 31.00: Plant Nutrient Application Requirements for Agricultural Land and Land Not Used for Agricultural Purposes seeks to establish limitations on the application of plant nutrients to lawns and non-agricultural turf to prevent pollutants from entering surface and groundwater resources. In addition, the regulations ensure that nutrients are applied to agricultural land in a way that provides for plant growth while minimizing the impacts on water resources. Specific limits are proposed for the application of phosphorus: the application of nitrogen is required to be consistent with the University of Massachusetts Extension guidelines for nutrient best management practices for turf.

Barnstable County, through the regulatory authority of the Cape Cod Commission, designated Cape Cod as a Fertilizer Management District of Critical Planning and Concern, allowing municipalities on Cape Cod to further regulate the use of fertilizer. The Cape Cod Commission developed model regulations for use by the municipalities, which incorporate Turf Management Best Management Practices from the University of Massachusetts Extension, and provide specific nitrogen-related limits. For further information see Chapter 7.

Regulating the Solution: Permitting the Watershed

Changes in statute, regulation and practice will be necessary to provide the tools needed to cost effectively solve the water quality problems identified in this plan. The watershed permit is the central feature of the revised regulatory approach.

WATERSHED PERMITTING

The most important factors in defining the successful achievement of TMDL compliance lie with both the designation of the most effective Waste Management Agencies and redefining the watershed permitting process so that (1) the parties designated are those that can do the job; and (2) the process by which this task is achieved is direct and result-oriented.

The Watershed Permit

In reviewing the permitting process as it currently exists, it becomes clear that the jurisdiction of the solution lies within watershed management. Development of a watershed permit that would be obtained through MassDEP plays a central role in achieving compliance with the TMDL on a watershed-by-watershed basis.

Why is a watershed permit approach needed?

The current regulatory approach may not be conducive for the kinds of local plans expected based on recommendations from the Section 208 Plan Update. Non-traditional mitigation strategies may require a different regulatory approach to ensure that watershed-based nitrogen loading targets are met. Compliance points may differ from traditional end-of-pipe effluent limits. Determinations will need to be made on specific permit goals or limits that apply to the range of alternatives that may be considered as wastewater solutions.

How will the watershed permit work?

MassDEP is still evaluating the details of how a watershed permit will be drafted and implemented, as well as what regulatory and statutory changes could help make a transition to a watershed focus. The following will be considered in the development of this permit process:

- Groundwater discharge permit regulations, which are contained at 314 CMR 5.00, are broad enough to incorporate a watershed approach.

- Permits will be issued for one municipality or multiple municipalities in order to facilitate a focus on watersheds instead of decisions that are driven by town boundaries.
- Consideration of the formation of watershed districts and how to permit them will have to be addressed.
- Water quality targets established through the Massachusetts Estuaries Project, state water quality standards, and applicable total maximum daily loads (TMDLs) will be the foundation of the permit.
- Watershed permits will incorporate an appropriate strategy designed to achieve water quality targets based on the consideration of a variety of treatment approaches.
- Monitoring requirements will be incorporated into the permit and will be tailored to the treatment approaches being proposed to ensure that alternatives are resulting in the required nitrogen reduction or remediation.
- Adaptive management will be incorporated into the watershed plans and permits so that MassDEP can allow communities to try various approaches and determine their effectiveness, accurately monitor and assess their performance, and make any necessary changes to the overall approach needed to achieve the ultimate goal—achieving water quality targets in a timely manner.

What are the components to the watershed permit?

Under the watershed permit approach, the nitrogen load is allocated on a watershed by watershed basis. Approaches to allocating responsibility for nitrogen remediation are discussed in greater detail in Chapter 8, as is the requirement for designation of waste management agencies under Section 208 of the Clean Water Act.

The watershed permit will allocate a portion of the load reduction to each management technique being used in each watershed. The permit will establish standards and expectations for performance, define compliance and will establish the protocol for incremental steps for additional management if the initial measures fail to achieve compliance with the water quality standards. By authorizing and including alternative approaches into a permit, the watershed permit would unlock the savings that can come from properly sited and scaled alternative measures where no such permitting mechanism currently exists.

The permit would also implement a Nitrogen Credit Exchange Program that would be created by the Massachusetts Legislature. It would also reference the Nitrogen Credit Advisory Board which would be created by the Legislature to administer the exchange program. If a permittee cannot meet its specified limit, it must purchase equivalent nitrogen credits. Permittees generate credits when they produce less than their specified annual discharge load.

The general permit would establish the framework for WMAs seeking to offset proposed expansion or new construction by allowing the option of purchasing nutrient reductions generated by nonpoint source BMPs.

It is recommended that MassDEP issue guidance regarding watershed permitting.

Recommendation R3.2:
MassDEP should issue guidance regarding watershed permitting.

FEASIBILITY OF PERMITTING

In pursuing a watershed approach that encompasses the use of non-traditional technologies along with sewering in discreet areas, one issue that must be addressed is the current permitting process. In reviewing the current process it is clear that implementing the comprehensive process proposed in this plan utilizing the current permitting paths is, at its best, a daunting task, and at its worst, next to impossible (see **Figure 3-2**).

The existing permitting for both sewering and the non-traditional technologies as outlined above may require the following permits:

- Municipal Separate Storm Sewer Systems (known as “MS4”) from the Environmental Protection Agency (EPA)
- Groundwater discharge permits from DEP

Existing Permitting for Non-Traditional Technologies



Potential Permits by Technology

Figure 3-2

- Title 5 permits from each town's Board of Health in accordance with 310 CMR 15.00, Surface Water Discharges
- National Pollutant Discharge Elimination System (NPDES) permit from EPA
- An ACOE (Army Corps of Engineers) Section 401 Water Quality Certification that the activity complies with all applicable water quality standards, limitations and restrictions (as a precursor to all federal permits)
- MEPA (Massachusetts Environmental Policy Act) review if it meets the thresholds for review
- Each town Conservation Commission in accordance with the Wetlands Protection Act
- Water Management Act permit from DEP to withdraw over 100,000 gallons/day annually
- DEP and Board of Health approval for use of Innovative and Alternative Technology Systems
- Permits from MassDOT
- Permits from MA Historical Commission
- Approval from the MA Natural Heritage and Endangered Species Program
- Approval form the US Fish & Wildlife Service/ MA Division of Marine Fisheries

A more streamlined process will encourage better planning, enable better intermunicipal cooperation and provide enhanced ability for this plan to be successfully implemented. It is recommended that the watershed permit incorporate and streamline the multitude of permits required to implement a watershed plan.

TITLE 5 DESIGNATION OF NITROGEN SENSITIVE AREAS

MassDEP may identify certain areas as particularly sensitive to pollution from on-site wastewater systems and therefore require the imposition of loading restrictions. These Nitrogen Sensitive Areas (NSAs) include:

- Interim Wellhead Protection Areas and department-approved Zone IIs of public water supplies
- Areas with private wells
- Nitrogen-sensitive embayments or other areas which are designated as nitrogen sensitive under Title 5 based on appropriate scientific evidence

The design flow for wastewater is restricted to 440 gallons per day per acre (gpd/acre) in NSAs and higher levels of nitrogen removal are required. There are exceptions for aggregate flows and systems with enhanced nitrogen removal (typically referred to as Innovative/Alternative or I/A systems). I/A systems are regulated by the state at 310 CMR 15.000. A summary of the DEP approved Innovative/ Alternative systems is located at http://www.mass.gov/eea/agencies/massdep/water/wastewater/summary-of-innovative-alternative-technologies-approved.html. See 310 CMR 15.216 (aggregate flows) and 310 CMR 15.217 (enhanced nitrogen removal) for additional information.

The nitrogen-loading restrictions in NSAs apply to new construction only and do not affect existing Title 5 systems unless they are deemed to have failed or are required to be upgraded at the time of property transfer. Those systems are regulated through the inspection process and the definition of "failing" systems in 310 CMR 15.303 and 15.304. Title 5 has special requirements for repairing failed systems and for the construction of new systems in NSAs.

On Cape Cod, MassDEP has not designated watersheds to embayments that exceed their critical load as "nitrogen sensitive" because the designation would trigger the requirement for new development within the designated area to construct I/A systems. I/A systems are more costly than standard Title 5 systems, and the scenario development work conducted as part of the Section 208 Plan Update demonstrates that even 100% use of I/A systems in many watersheds will not achieve the nutrient reduction levels necessary to meet TMDLs.

MassDEP should consider designating as Nitrogen Sensitive Areas watersheds contributing to waterbodies impaired by nitrogen that are subject to a 208 Plan, whose development primarily relies on on-site septic systems and/or where the water body is listed on the 303(d) list due to nitrogen overloading and modify available remedial actions to allow for appropriate time for waste management agencies to plan. In addition, MassDEP should consider eliminating or amending the regulatory language establishing the presumption that Title 5 systems meet the state water quality standards in situations where it has been established that septic systems contribute to non-attainment.

Recommendation R3.3:
MassDEP should consider designating as Nitrogen Sensitive Areas watersheds contributing to waterbodies impaired by nitrogen that are subject to a 208 Plan, whose development primarily relies on on-site septic systems and/or where the water body is listed on the 303(d) list due to nitrogen overloading and modify available remedial actions to allow for appropriate time for waste management agencies to plan.

Recommendation R3.4:
MassDEP should consider eliminating or amending the regulatory language establishing the presumption that Title 5 systems meet the state water quality standards in situations where it has been established that septic systems contribute to non-attainment.

MODIFIED DEVELOPMENT OF REGIONAL IMPACT REVIEW

The Commission has historically reviewed CWMPs as DRIs pursuant to the Cape Cod Commission Act. In accordance with the Act, in order to approve a DRI, the Commission must find that a proposed project is consistent with any Commission-certified Local Comprehensive Plan (LCP); municipal development bylaws; any District of Critical Planning Concern Implementing Regulations; the Regional Policy Plan; and the probable benefit from a proposed project must be greater than the probable detriment.

The Regional Policy Plan contains over 200 minimum performance standards and best development practices in 12 different issue areas – including land use, economic development, water resources, coastal resources, wetlands, wildlife and plant habitat, open space and recreation, transportation, waste management, energy, affordable housing and heritage preservation/community character. Currently, these MPSs and Best Development Practices (BDPs) are applied during DRI review not only to site-specific individual developments, such as supermarkets and commercial businesses, but also to larger systemic phased projects, such as CWMPs.

The Section 208 Plan Update recognizes the need to modify the existing regulations in order to accommodate the unique nature of wastewater management planning and recommends consideration of alterations to Commission regulations.

The Commission should amend its regulations accommodating for the unique nature of capital wastewater management planning.

Recommendation R3.5: The Cape Cod Commission shall amend its regulations accommodating for the unique nature of capital wastewater management planning.

SPECIAL REVIEW PROCESS

The voluntary Cape Cod Commission/MEPA Joint Review Processed discussed above applies to comprehensive capital planning projects as well as individual parcel developments. CWMPs typically require MEPA review and Commission DRI review and Cape Cod towns have historically elected to participate in the JRP.

Additionally, the Secretary may establish a Special Review Procedure (SRP) for a project that may provide for coordination and consolidation of MEPA review with other environmental or development review and permitting processes (310 CMR 11). An example of an established SRP within Barnstable County is the Herring River Restoration Project in Wellfleet and Truro.

As an alternative to the existing JRP, a Special Review Procedure for Projects designed pursuant to the Section 208 Plan Update should be developed. The SRP should provide a framework for review and implementation of regional wastewater projects and provide flexibility and opportunities for streamlining. Projects could include CWMPs that address nutrient remediation in all watersheds

within a municipality or group of municipalities; Targeted Watershed Management Plans (TWMPs) that address nutrient remediation within a single watershed or a grouping of watersheds, wholly contained within one municipality, or shared by multiple municipalities; and Nutrient Remediation Projects that are individual water quality restoration projects addressing portions of watersheds or municipalities.

A Section 208 Plan Update SRP could contain the following elements:

- **CAPE COD COMMISSION SECTION 208 CONSULTATION:** Municipalities are encouraged to consult with the Commission to ensure coordination between active wastewater planning efforts and the Section 208 Plan Update and to establish consistency between proposed municipal plans and the Section 208 Plan Update with respect to the evaluation of wastewater needs, wastewater management alternatives, and alternatives analyses. Consultation also includes use of Commission decision support tools, such as WatershedMVP, with Commission staff assistance. The Commission would assign a Watershed Team to the specific planning efforts to assist with the decision support tools, permitting of technologies, and financing.
- **WATERSHED ASSOCIATIONS ESTABLISHED:** For projects addressing watersheds shared by more than one town, Watershed Associations could be established. Possible members could include elected and appointed municipal representatives, members of existing water quality advisory committees, representatives from Joint Base Cape Cod or the Cape Cod National Seashore, as appropriate, an expert on traditional wastewater approaches, representatives from the business, real estate and environmental sectors, a Commission representative, and an alternative technology representative. Under current regulations, when establishing a SRP, the Secretary ordinarily establishes a Citizens Advisory Committee (CAC) to assist in reviewing the project. Existing municipal CACs or water quality advisory committees, or a newly formed Watershed Association could be designated as the CAC.
- **WATERSHED MANAGEMENT PLAN DEVELOPED:** Watershed Management Plans should address all water quality planning including remediation of nitrogen, phosphorus, contaminants of emerging concern (CECs), etc. Individual projects identified as CWMPs, TWMPs and other Nutrient Remediation Projects could be eligible for the Section 208 Plan Update SRP. The Project plans should be submitted to MEPA and the Commission simultaneously for expedited review by both entities.
- **PUBLIC HEARING PROCESS:** The citizen engagement process should be expansive and educational and should allow for all public, local, state, regional and federal comment on proposed Projects.
- **FINAL EIR/COMMISSION DRI:** In order to streamline review, a simplified process of submitting one review document that can suffice as a Final EIR and Commission DRI application should be implemented. Upon approval, this document would lead to the Secretary's issuance of a Certificate of Adequacy for the FEIR and the Commission's DRI approval decision.

A recommendation of the Section 208 Plan Update is for the Commission to work with MassDEP and the Secretary of Energy and Environmental Affairs on a Special Review Procedure for Projects designed pursuant to the Section 208 Plan Update, to execute a Memorandum of Understanding between the Cape Cod Commission and the Secretary of Environmental Affairs, and to identify and implement other potential regulatory changes.

Recommendation R3.6: The Cape Cod Commission and MEPA should work together to develop an effective and streamlined process for reviewing projects designed pursuant to the Section 208 Plan Update that are reviewed jointly by both agencies.

SECTION 208 PLAN UPDATE CONSISTENCY REVIEW

A recommendation of this plan is the requirement that all nutrient management planning in the region be subject to review for consistency with the Section 208 Plan Update.

Recommendation R3.7: All nutrient management planning in the region shall be subject to review for consistency with the Section 208 Plan Update.

As outlined below, the consistency review will include, but is not limited to, a review of the planning approach used to ensure consistency with a proposed hybrid watershed planning approach; review and acceptance of a nutrient growth management plan; and a consistency review of the applicable Minimum Performance Standards and Best Management Practices for siting technologies. Specific guidance on the Section 208 Plan Update Consistency Review shall be issued within 90 days of its approval.

Recommendation R3.8: Specific guidance on the Section 208 Plan Update Consistency Review shall be issued by the Cape Cod Commission within 90 days of the 208 Plan Update approval.

Hybrid Watershed Planning Approach

It is recommended that for most watersheds, the most efficient and effective combination of watershed management strategies should include a planning process that integrates prevention, collection, and non-collection strategies. See Chapter 5 for a detailed discussion of the hybrid watershed planning approach.

Review and Acceptance of Nutrient Growth Management Plan

Growth management measures and strategies are an important component in managing nutrient impacts to coastal embayments. As part of the Section 208 Plan Update, the Commission recommends the establishment of a Nutrient Growth Management Plan. A commitment to review and accept or adopt a Nutrient Growth Management Plan shall be a requirement for any watershed plan seeking to realize the benefits related to consistency, and shall be a component of the Section 208 Plan Update Consistency Review. In addition, it is recommended that local plans segregate and present costs to manage nutrient removal from existing development and costs to manage nutrient removal from anticipated new development.

Minimum Performance Standards and Best Management Practices

As part of the Section 208 Plan Update, the Commission recommends MPSs and BMPs for siting technologies should be developed. Compliance with these MPSs and BMPs shall be requirements for any watershed plan seeking to realize certain benefits related to consistency. The MPSs and BMPs shall draw upon updated information in the Technologies Matrix for siting and monitoring technologies and approaches to nutrient management and shall be updated on a regular basis. They will address specific requirements from Section 208 of the Clean Water Act with regard to site selection impacts on water resources and other natural resources, including, but not limited to, impacts from construction and the location of disposal, and their effects on freshwater, saltwater and drinking water resources. Consistency with the MPSs and BMPs shall be a component of the Section 208 Plan Update Consistency Review.

Preserving Capacity for Towns in Shared Watersheds

Where centralized technologies are employed, localities should preserve capacity for treatment and/or disposal by towns in shared watersheds where feasible. Shared systems in higher density areas reduce costs for everyone by bringing more customers online to share costs.

Conducting a Fiscal Analysis of Costs to Taxpayers when Regional Solutions are not Adopted

In the event a municipality determines that it will not pursue available opportunities to design, construct and operate shared infrastructure, they shall conduct and present a fiscal analysis of potential additional costs associated with constructing infrastructure limited to town boundaries.

04 SOLUTIONS

Nutrient Mitigation Technologies & Policies

Cape communities have been aware of decreasing water quality in estuaries and coastal waters for over a decade – but there is little consensus on how to address the problem. Comprehensive wastewater planning at the municipal level is often impeded by concerns about scope and cost, which can lead to failed town meeting votes. The need to identify management options for nutrients beyond traditional collection and centralized treatment approaches became evident. This chapter presents the results of an extensive search for and vetting of alternative approaches for nutrient management on Cape Cod.


Site Scale
Neighborhood
Watershed
Cape-Wide
Reduction
Treatment before disposal to ground
Remediation
Treatment in groundwater
Restoration
Treatment in water body
Title 5
Standard Title 5 Systems
IA
I/A Title 5 Systems
Enhanced IA
I/A Enhanced Systems
Toilets: Composting, Incinerating, Packaging, Urine Diverting
Hydroponic Treatment
Cluster Treatment System: Single- or Two-stage
Satellite Treatment
Nutrient Reducing Development
TDR
Transfer of Development Rights
Constructed Wetlands
Phytoirrigation
PRB
Permeable Reactive Barrier (PRB)
Phytoremediation
Stormwater: Bioretention / Soil Media Filters
N+P
Fertigation Wells: Turf, Cranberry Bogs
Stormwater: Constructed Wetlands
Aquaculture/Shellfish Farming
Coastal Habitat Restoration
Inlet / Culvert Widening
Constructed Wetlands: Floating
Pond and Estuary Circulators
SWR
Surface Water Remediation Wetlands
Pond and Estuary Dredging
Conventional Treatment
Advanced
Advanced Treatment
N+P+K MGMT
Fertilizer Management
Compact and Open Space Development
BMPs
Stormwater Best Managment Practices (BMPs)
Policy

SOLUTIONS

Chapter 4: Nutrient Mitigation Technologies & Policies

Tools for Nutrient Management in Coastal Waters

Cape Codders are closely connected to the water. Whether salt or fresh, water defines Cape Cod and each person's experience with the environment. In the search for solutions to water quality problems, alternative technologies, tools, policies and approaches that may restore water quality in affected water bodies more quickly and cost effectively than traditional methods have been identified. Techniques that may be applied directly within the water body have raised questions about their potential effectiveness, reliability and speed to results.

Water Quality Technologies Matrix

Figure 4.1 (Facing Page)

The technologies and approaches included in the Technologies Matrix address nutrients by means of reduction, remediation, and restoration and are implementable in scales ranging from on-site, to neighborhood, watershed, and Cape-wide.

The Section 208 planning process has provided the opportunity to take an in-depth look at a broad range of techniques for managing nutrients. This chapter examines 10 categories and a total of 67 nutrient reduction, remediation and restoration technologies and approaches. This work is embodied in the Water Quality Technologies Matrix (Technologies Matrix) and then simplified based on the point of intervention, the scale of the technology or approach (site, neighborhood, or watershed) and whether it requires a collection system to remove waste from the property for disposal in another location. The Technologies Matrix includes the breadth of traditional approaches, from on-site (Title 5) systems to centralized treatment facilities, and a diverse array of non-traditional or alternative approaches, ranging from coastal habitat restoration to source-reducing toilets (**Figure 4.1**). The Technologies Matrix is the result of nearly two years of research by Cape Cod Commission staff and consultants, review by a panel of experts, followed by vetting by state, federal, and other stakeholders. **Table 4-1** identifies the technologies and strategies that have been examined.

The Technologies Matrix is conceived as a living compendium of data on nutrient management technologies. The technologies in the Matrix have all shown some promise for being used for nitrogen management; however, many are yet untested on Cape Cod or have been deployed at scales smaller than might be necessary in a watershed plan. It became clear through the research, as well as in questions raised during the many discussions among planning staff, stakeholders, academia and government and private experts, that the Technologies Matrix needs continual refinement as new or more accurate information becomes available through research or from pilot projects on Cape Cod. The actions needed to implement water quality improvements across the Cape will contribute to the body of knowledge about non-traditional nutrient management technologies, allowing us to refine the list of best practices that have proven to be effective in solving water quality problems. It is recommended that the Cape Cod Commission develop a process for annual updates to the Technologies Matrix.

TECHNOLOGY GROUPING	TECHNOLOGY / STRATEGY
Green Infrastructure	Constructed Wetlands - Surface Flow
	Constructed Wetlands - Subsurface Flow
	Constructed Wetlands - Groundwater Treatment
	Hydroponic Treatment
	Phytoirrigation
	Stormwater BMP - Phytobuffers
	Stormwater BMP - Vegetated Swale
	Stormwater BMP - Gravel Wetland
	Stormwater: Bioretention / Soil Media Filters
	Stormwater: Constructed Wetlands
Innovative and Resource-Management Technologies	Aquaculture - Shellfish Cultivated In Estuary Bed
	Aquaculture - Shellfish Cultivated Above Estuary Bed
	Aquaculture - Mariculture
	Phytoremediation
	Permeable Reactive Barriers (PRBs) - Trench Method
	Permeable Reactive Barriers (PRBs) - Injection Well Method
	Fertigation Wells - Turf
	Fertigation Wells - Cranberry Bogs
Waste Reduction Toilets	Toilets: Composting
	Toilets: Incinerating
	Toilets: Packaging
	Toilets: Urine Diverting
Non-Structural Approaches	Fertilizer Management
	Stormwater BMPs
	Nutrient Reducing Development
	Compact and Open Space Development
	Transfer of Development Rights
System Alterations	Inlet / Culvert Widening
	Coastal Habitat Restoration
	Floating Constructed Wetlands
	Pond and Estuary Circulators
	Surface Water Remediation Wetlands
	Chemical Treatment of Ponds
	Pond and Estuary Dredging

TECHNOLOGY GROUPING	TECHNOLOGY / STRATEGY
On-Site Treatment Systems	Title 5 Septic System Replacement (Base Line Condition)
	Innovative/Alternative (I/A) Systems
	Innovative/Alternative (I/A) Enhanced Systems
Treatment Systems	Cluster Treatment System - Single-stage
	Cluster Treatment System - Two-stage
	Conventional Treatment
	Advanced Treatment
	Satellite Treatment
	Satellite Treatment - Enhanced
Collection Systems	Gravity Sewer
	Low Pressure Sewer
	Vacuum Sewer
	Force Main
	Pump Station
	On-Site Pump Station
	STEG - Collection
	STEP - Collection
Effluent Disposal	Effluent Disposal - Infiltration Basins
	Effluent Disposal - Soil Absorption System (SAS)
	Effluent Disposal - Injection Well
	Effluent Disposal - Wick Well
	Effluent Disposal - Ocean Outfall
	Effluent Transport out of Watershed to Recharge, Reuse Facility or Ocean Outfall
Solids Processing	Septage Processing
	Commercial Disposal
	Dewater and Haul to Landfill
	Composting
	Incineration
	Lime Stabilization
	Digestion
	Thermal Drying
	Drying and Gasification

Technologies Included in the Water Quality Technologies Matrix

Table 4-1

Recommendation I4.1: The Cape Cod Commission shall develop a process for annual updates to the Technologies Matrix.

Among the actions needed to validate the efficacy of non-traditional approaches are the piloting of technologies in suitable locations, monitoring water quality and environmental parameters down gradient from a technology, analyzing technology performance and updating the Technologies Matrix as appropriate. Piloting, monitoring and analysis are discussed later in this chapter, along with corresponding recommendations for action. In addition, this plan recommends an annual symposium to present and review new research on these nutrient management techniques. The symposium will support the exchange of research on these tools and provide an opportunity to share experiences on the implementation of pilot projects. New findings may then be incorporated into the Technologies Matrix on a regular basis. A web-based interface will make the data on these technologies available to anyone.

Recommendation I4.2: The Cape Cod Commission shall seek opportunities to sponsor an annual symposium to present and review new research on nutrient management technologies and approaches that coincides with regular updates to the Technologies Matrix.

Catalog of Non-Traditional Technologies

In the pages that follow, summaries of the non-traditional technologies and approaches are presented in an at-a-glance format. This "catalog" of technologies provides a simple method of comparison. Among the features covered in this section are the benefits and performance challenges of a technology, its efficiency in addressing nitrogen, its resilience to sea level rise and whether it rose to the top as a technology for use in developing watershed scenarios on Cape Cod.

Each tool or practice has been categorized according to the scale and the situation in which it best performs. Technologies sorted as restoration are those that address nutrient rich water within an affected water body. Technologies categorized as remediation are those that treat nutrient rich water as it travels through the groundwater, before it reaches a water body. Technologies identified as reduction are those that reduce nitrogen before it enters the groundwater.

As discussed at many of the stakeholder meetings, the Section 208 Plan Update recognizes that while non-traditional technologies hold great promise in managing nutrients in groundwater and water bodies, traditional technologies will also play a significant role in wastewater management. Following the catalog of information presented below, the types and merits of traditional wastewater treatment are reviewed. Traditional wastewater approaches typically do not require piloting to establish performance; consequently, brief summaries of the types of technologies are presented in this chapter to familiarize the reader with the range of methods available.

Detailed performance information may not be available for all technologies at this time. However, a more detailed narrative of each of each technology can be found in Appendix 4A; the most detailed and extensive information can be found in the Technologies Matrix, available in Appendix 4B or on the web at: http://capecodcommission.org/matrix.

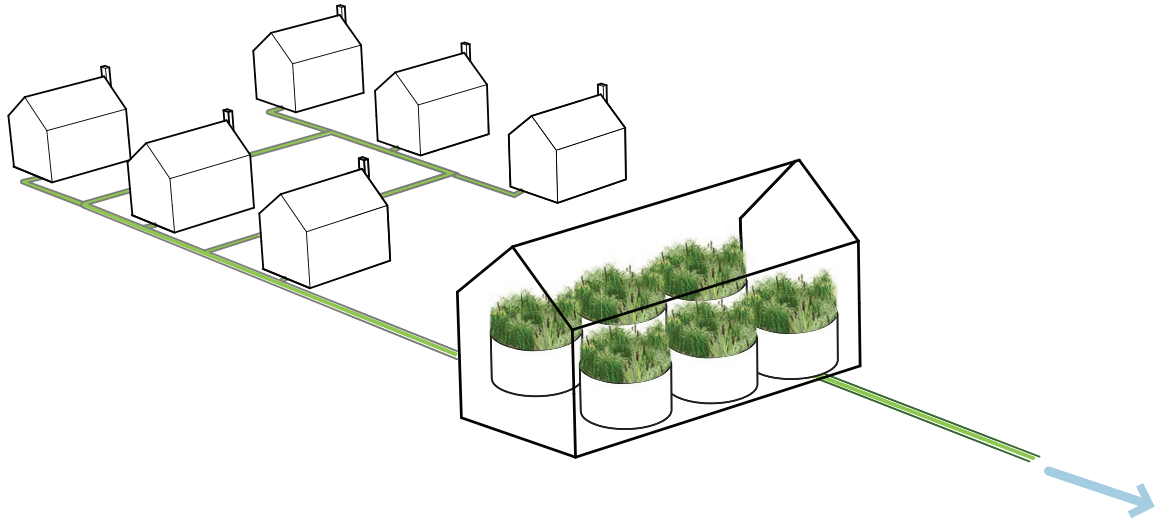


Figure 4-2

Hydroponic Treatment

SCALE: SITE/NEIGHBORHOOD/WATERSHED
APPROACH: REDUCTION

SCENARIO PLANNING: NOT SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

Hydroponic treatment and Photo Bioreactors are natural systems that treat septic tank effluent or primarily treated wastewater. With Hydroponic Treatment, aeration and clarification chambers are combined with constructed wetlands to treat the influent. The wetlands are a series of chambers allowing for microbial communities to engage with and treat the wastewater. Plants are often suspended on racks with their roots systems doing the work. Solids removal is generally onsite, after which water is pumped through the gravel filled cells (similar to subsurface wetlands.) This process transfers more oxygen to the wastewater and completes the pollutant removal process. The wetland effluent can be discharged into a water body or used for open space irrigation after treatment. The wetland effluent can also be discharged into a leach field or similar system for discharge to the groundwater.This technology can also be used for wastewater treatment with primary, secondary, or advanced effluent generally for flows less than 500,00 gpd.

Technology Performance

Nitrogen Removal 58% to 98%

Phosphorus Removal 25% to 75%

$964	$60,136
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
10 years	1 to 10 years
Useful Life	Time to See Results

Hydroponic Treatment

SCALE: SITE/NEIGHBORHOOD/WATERSHED
APPROACH: REDUCTION

SCENARIO PLANNING: NOT SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- Adjacent to housing and development

ECO-BENEFITS

- Promotes Green Space / Conservation / Recreation
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Require high energy and maintenance costs as these systems are generally constructed in greenhouses
- Low phosphorus removal rates

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to more frequent inundation and increased exposure to saline water
- Mobilization of contamination as a result of failure of storage system
- Backflow of saline water into system causing overflows, increased degradation of materials and change in biological processes
- Destabilization of assets as a result of changes in groundwater levels or erosion

CLIMATE RESILIENCE: SOLUTIONS

- Locate infrastructure outside the flood hazard area that is anticipated for the life of the installation
- Select materials and coatings that are able to cope with an increasingly saline environment
- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets)
- Backflow valves on outlets
- Anchoring of buried assets

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Massachusetts Department of Environmental Protection

Fertilizer Management

N+P+K MGMT

SCALE: CAPE WIDE
APPROACH: REDUCTION

SCENARIO PLANNING: SELECTED FOR USE

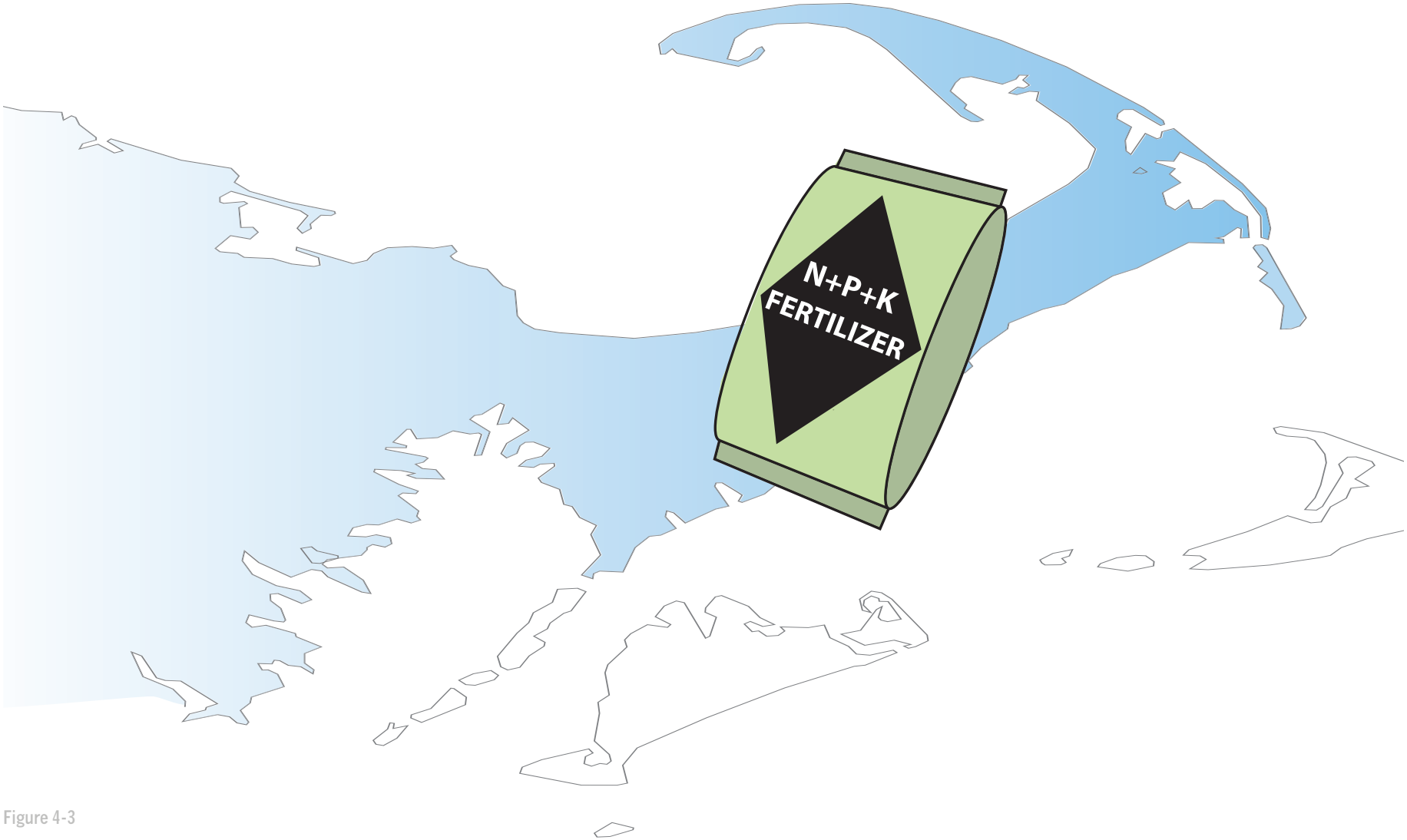


Figure 4-3

Fertilizer Management

SCALE: CAPE WIDE
APPROACH: REDUCTION

SCENARIO PLANNING: SELECTED FOR USE

N+P+K MGMT

DESCRIPTION

This approach relies on managing fertilizer application rates to lawns, golf courses, athletic facilities and cranberry bogs. Residential lawn loading rates could be reduced on existing developed parcels through an intensive public education/ outreach program. This could include a "Cape Cod Lawn" branding program, replacing some turf areas with native vegetation, establishing naturally-vegetated buffer strips on waterfront lots, and reducing application rates. Fertilizer loading rates for new development could be accomplished by reducing lot sizes (cluster development), by restricting lawn sizes and/or by incorporating more naturally-vegetated open space areas. Municipalities could directly reduce fertilizer applications on athletic fields and other properties. Golf courses can significantly reduce nitrogen loading rates by using slow-release fertilizers and reducing application rates in rough areas.Cranberry bog fertilizer exports from the bogs can be reduced using tail water recovery systems. Site-specific assessments are needed to estimate load reductions.

SITING NEEDS

- Fertilizer management does not have specific site requirements.

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity

PERFORMANCE CHALLENGES

- Resulting nutrient removal rates are highly dependent on homeowner / landowner behavior and participation in the program
- Site-specific assessments are needed to estimate load reductions

CLIMATE RESILIENCE: RISKS

- Fertilizer management does not result in significant climate resiliency risks.

CLIMATE RESILIENCE: SOLUTIONS

- Climate resiliency solutions are not needed for Fertilizer Management.

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Board of Health
- Massachusetts Department of Agricultural Resources

Technology Performance



Nitrogen Removal 25% to 75%



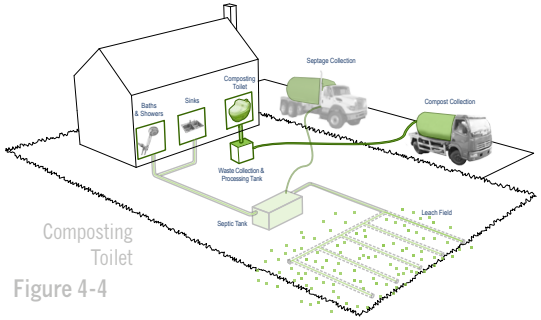
Phosphorus Removal 3% to 10%

$24	$141
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

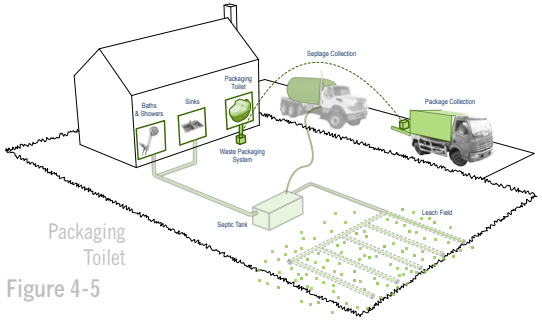
Waste Reduction Toilets

SCALE: SITE
APPROACH: REDUCTION

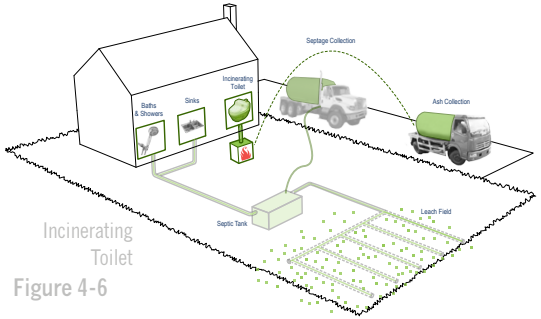
SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING



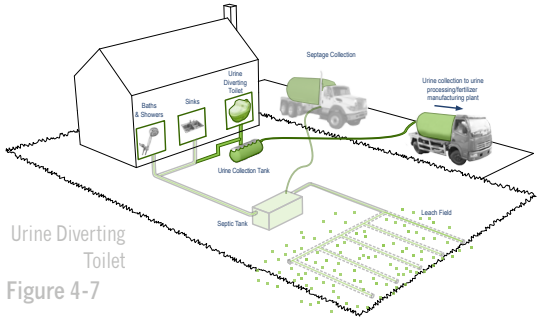
Composting Toilet
Figure 4-4



Packaging Toilet
Figure 4-5



Incinerating Toilet
Figure 4-6



Urine Diverting Toilet
Figure 4-7

DESCRIPTION

A waste reduction toilet is a system which separates human waste from shower, sink and other household water uses. These systems use no or minimal amounts of water. Waste reduction toilets require the installation of a separate toilet(s). Household water uses (i.e. sink and shower uses) continue to flow to the septic system.The four main categories of waste reducing toilets include: composting, incinerating, packaging and urine diverting. Composting toilets capture human waste in a container in the basement where it is decomposed and turned into compost. Incinerating toilets rely on electric power or natural or propane gas to incinerate human waste to sterile, clean ash. Packaging toilets encapsulate human waste in a durable material, stored beneath the toilet, for removal from the site when full. Urine diverting toilets divert urine to a holding tank where it is periodically collected by a servicing company; remaining human waste continues on to the septic system.

SITING NEEDS

- Requires a Title 5 System for ther gray water sources

ECO-BENEFITS

- Improves Energy Savings, Nutrient Recovery, Recycling

PERFORMANCE CHALLENGES

- Resulting nutrient removal rates are highly dependent on homeowner/landowner behavior and participation in the program
- Requires a significant number of citizens to participate to be effective

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to increased exposure to saline water
- Mobilization of contamination as a result of failure of storage system
- Backflow of saline water into system causing overflows, increased degradation of materials and change in biological processes
- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)
- Temporary restricted access to infrastructure to remove waste materials and undertake maintenance. Longer term access restriction may lead to reduced performance or overflow

Waste Reduction Toilets

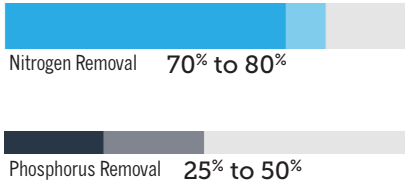
SCALE: SITE
APPROACH: REDUCTION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

CLIMATE RESILIENCE: SOLUTIONS

- Select materials and coatings that are able to cope with an increasingly saline environment
- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets)
- Backflow valves on system
- Anchoring of buried assets

Composting Toilet

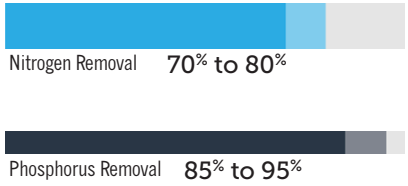


$266	$2,323
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

SPECIFIC PERFORMANCE CHALLENGES

- Requires ongoing maintenance to function correctly
- Requires independent citizens to change systems to be cost effective

Incinerating Toilet

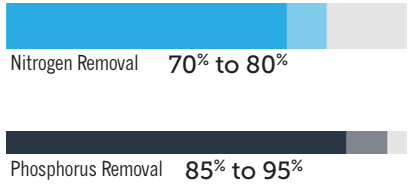


$328	$1,195
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

SPECIFIC PERFORMANCE CHALLENGES

- Incineration process demolishes any nutrients found in human waste - meaning it cannot be used for nourishing soil
- Saves water, but uses more energy
- Still requires septic tank and leaching field for grey water
- The proprietary nature of this technology will impose high fees for waste removal and maintenance

Packaging Toilet

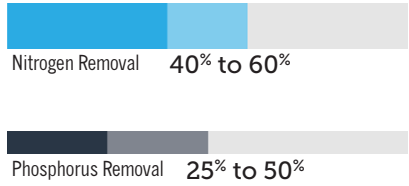


$198	$720
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

SPECIFIC PERFORMANCE CHALLENGES

- Still requires septic tank and leaching field for grey water
- The proprietary nature of this technology will impose high fees for waste removal and maintenance

Urine Diverting Toilet



$333	$2,912
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

SPECIFIC PERFORMANCE CHALLENGES

- Requires company infrastructure to pick up package
- Tight tank for urine storage required.

SPECIFIC POTENTIAL PERMITTING AUTHORITIES

- Municipality (Local plumbing inspector)
- Municipal Board of Health

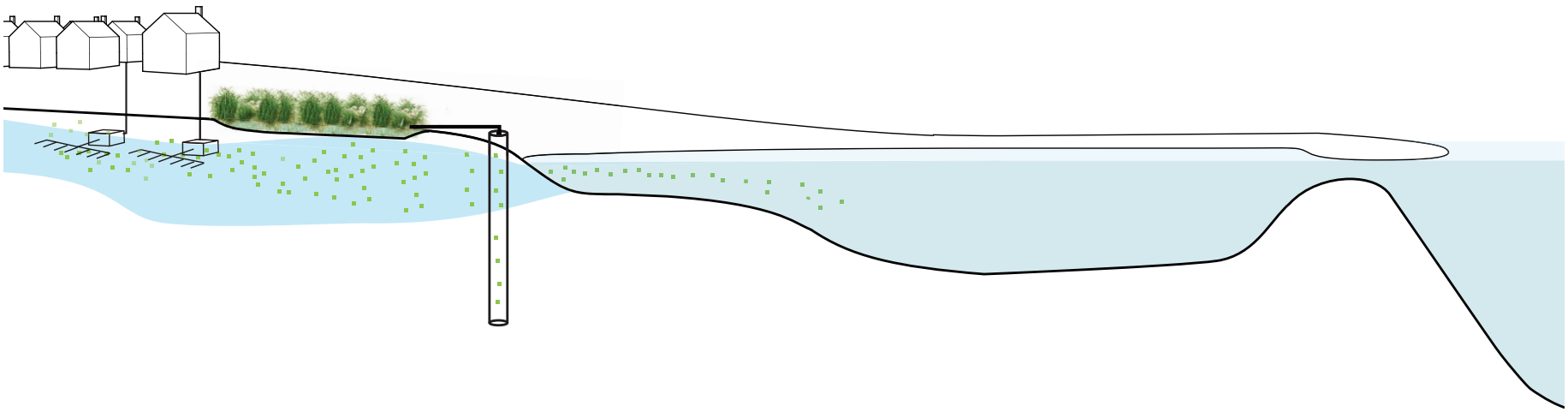


Figure 4-8

Constructed Wetlands Groundwater Treatment

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION
SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

After collecting groundwater with higher nitrogen concentrations, groundwater is treated by pumping water slowly through subsurface gravel beds where it is filtered through plant root zones and soil media. Water flows 3" to 8" under the surface to prevent public exposure to wastewater and mosquito breeding. A combination of horizontal and vertical flow subsurface systems must be utilized to provide total nitrogen removal. These systems occasionally use additional treatment steps to remove nutrients from wastewater. The preferred disposal method is an infiltrator chamber system similar to a leach field but larger in size and designed for overflows. The reclaimed water is generally then discharged to the groundwater. The reclaimed water can also be discharged into a water body or used for open space irrigation after treatment. However, more strict permitting and water quality standards must be met if not discharging to groundwater.

Technology Performance

Nitrogen Removal 85% to 95%

Phosphorus Removal 50% to 90%

$340	$437
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

Constructed Wetlands Groundwater Treatment

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE IDENTIFIED FOR PILOTING

SITING NEEDS

- Undeveloped land > 1 Acre
- Outside all wetlands resource areas
- Outside 100 year flood hazard zone
- Groundwater separation - GW depth > 4 feet
- Not within priority habitat areas
- Not within protected open space
- Benefit if site has clay based soils, has disturbed soils, parcel intersects with 50 to 100 foot Buffer zone, has municipal ownership
- No steep topography

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection

PERFORMANCE CHALLENGES

- Higher maintenance in first few years
- May require carbon source initially
- Can become clogged over time
- Phosphorous removal may decline over time
- May require fencing and security measures
- May attract water fowl which could aggravate N issue
- In addition, on the Cape, these systems may need to be lined to prevent complete infiltration and allow time for N removal rather than just putting N into groundwater

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to more frequent inundation and increased exposure to saline water
- Mobilization of contamination as a result of failure of storage system
- Backflow of saline water into system causing overflows, increased degradation of materials and change in biological processes
- Destabilization of assets as a result of changes in groundwater levels or erosion
- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)

CLIMATE RESILIENCE: SOLUTIONS

- Locate infrastructure outside the flood hazard area that is anticipated for the life of the installation
- Select materials and coatings that are able to cope with an increasingly saline environment
- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets and health of vegetation)
- Backflow valves on outlets
- Anchoring of buried assets
- Project design and species selection to ensure adequate performance in increasingly saline environments

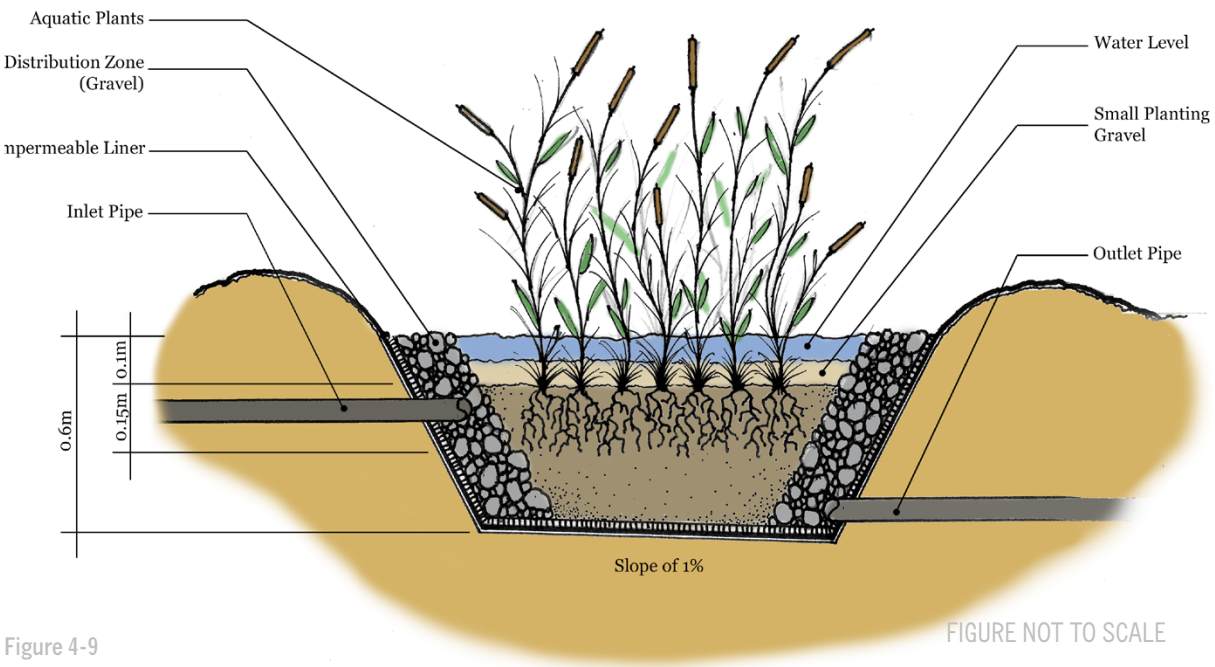


FIGURE NOT TO SCALE

Figure 4-9

Constructed Wetlands Subsurface Flow

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

After primary treatment in a septic tank or WWTF or secondary treatment at a WWTF, wastewater is treated by pumping water slowly through subsurface gravel beds where it is filtered through plant root zones and soil media. Water flows 3-8" under the surface to prevent public exposure to wastewater and mosquito breeding. A combination of horizontal and vertical flow subsurface systems must be utilized to provide total nitrogen removal. The reclaimed water is generally discharged into a leach field or similar system for discharge to the groundwater. The reclaimed water can also be discharged into a water body or used for open space irrigation after treatment. However, more strict permitting and water quality standards must be met if not discharging to groundwater. This technology can be used as an alternative to conventional polishing (i.e. mechanical and/or chemical) of secondary and advanced wastewater treatment.

Technology Performance

Nitrogen Removal 85% to 95%

Phosphorus Removal 50% to 90%

$76	$491
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

Constructed Wetlands Subsurface Flow

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE IDENTIFIED FOR PILOTING

SITING NEEDS

- Undeveloped land > 0.5 Acre
- Outside all wetlands resource areas
- Outside 100 year flood hazard zone
- Groundwater separation - GW depth > 4 feet
- Not within priority habitat areas
- Not within protected open space
- Benefit if site has clay based soils, has disturbed soils, parcel intersects with 50 to 100 foot Buffer zone, has municipal ownership
- No steep topography

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection

PERFORMANCE CHALLENGES

- Higher maintenance in first few years
- May require carbon source initially
- Can become clogged over time.
- Phosphorous removal may decline over time
- May require fencing and security measures
- May attract water fowl which could aggravate N issue
- In addition, on the Cape, these systems may need to be lined to prevent complete infiltration and allow time for N removal rather than just putting N into groundwater

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to more frequent inundation and increased exposure to saline water
- Mobilization of contamination as a result of failure of storage system
- Backflow of saline water into system causing overflows, increased degradation of materials and change in biological processes
- Destabilization of assets as a result of changes in groundwater levels or erosion
- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)

CLIMATE RESILIENCE: SOLUTIONS

- Locate infrastructure outside the flood hazard area that is anticipated for the life of the installation
- Select materials and coatings that are able to cope with an increasingly saline environment
- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets and health of vegetation)
- Backflow valves on outlets
- Anchoring of buried assets
- Project design and species selection to ensure adequate performance in increasingly saline environments

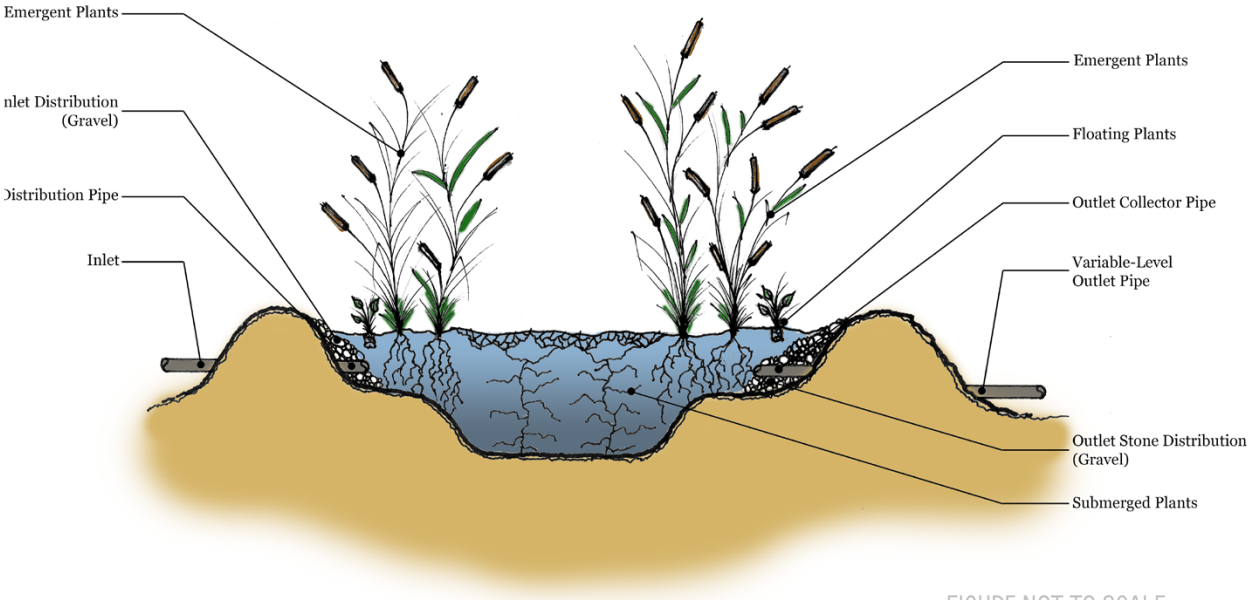


FIGURE NOT TO SCALE

Figure 4-10

Constructed Wetlands Surface Flow

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

After primary treatment in a septic tank or WWTF or secondary treatment at a WWTF, water is fed into a free water surface (FWS) constructed wetland. Free water constructed wetlands closely mimic the ecosystem of a natural wetland by utilizing water loving plants to filter wastewater through their root zone, a planted medium, and open water zones. FWS wetlands are systems where open water is exposed much like in a natural marsh. The reclaimed water is generally discharged into a leach field or similar system for discharge to the groundwater. The reclaimed water can also be discharged into a water body or used for open space irrigation after treatment. However, more strict permitting and water quality standards must be met if not discharging to groundwater. This technology can be used as an alternative to conventional polishing (i.e. mechanical and/or chemical) of secondary and advanced wastewater treatment.

Technology Performance

Nitrogen Removal 80% to 95%

Phosphorus Removal 40% to 60%

$81	$709
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

Constructed Wetlands Surface Flow

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- Undeveloped land > 5 Acre
- Outside all wetlands resource areas
- Outside 100 year flood hazard zone
- Groundwater separation - GW depth > 4 feet
- Not within priority habitat areas
- Not within protected open space
- Benefit if site has clay based soils, has disturbed soils, parcel intersects with 50 to 100 foot Buffer zone, has municipal ownership
- No steep topography

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves management of Flooding / Extreme Events

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- U.S. Environmental Protection Agency

PERFORMANCE CHALLENGES

- Requires larger land area than tertiary treatment
- Disinfection of wetland influent may be required
- May require an NPDES permit
- May require a pilot study, long-term monitoring and reporting
- Vegetation harvesting may need to be performed periodically
- May require fencing and security measures
- May attract water fowl which could worsen N issue
- These systems on the Cape may need to be lined to prevent complete infiltration and allow time for N removal rather than just putting N into groundwater
- May need storage of effluent during non-growing season

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to more frequent inundation and increased exposure to saline water
- Mobilization of contamination as a result of failure of storage system
- Backflow of saline water into system causing overflows, increased degradation of materials and change in biological processes
- Destabilization of assets as a result of changes in groundwater levels or erosion
- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)

CLIMATE RESILIENCE: SOLUTIONS

- Locate infrastructure outside the flood hazard area that is anticipated for the life of the installation
- Select materials and coatings that are able to cope with an increasingly saline environment
- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets and health of vegetation)
- Backflow valves on outlets
- Anchoring of buried assets
- Project design and species selection to ensure adequate performance in increasingly saline environments

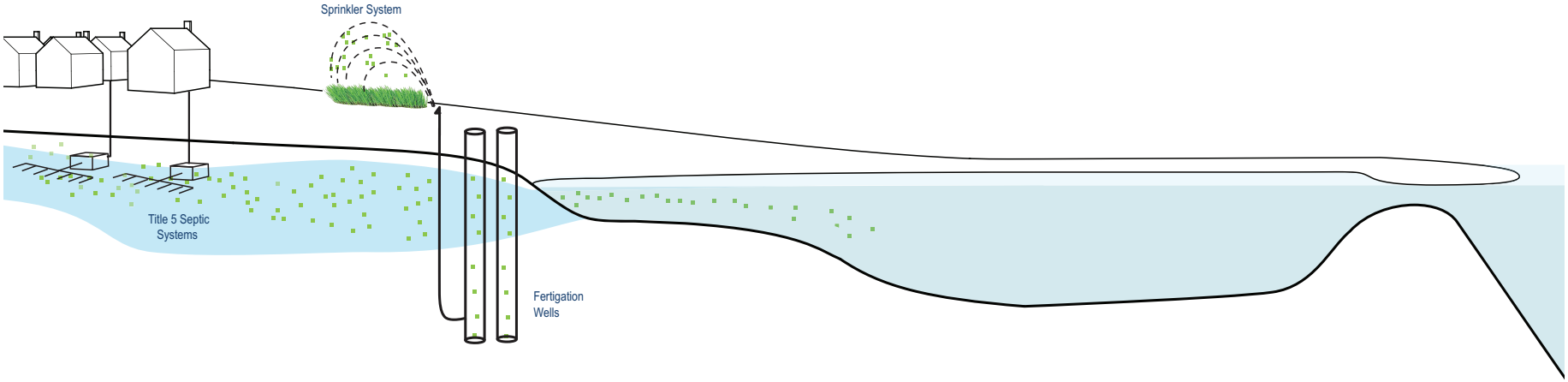


Figure 4-11

Fertigation Wells

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

Fertigation consists of capturing nitrogen enriched groundwater via wells and using it to irrigate plants that use the nutrients. Fertigation wells can capture nutrient enriched groundwater and recycle it back to irrigate and fertilize turf grass areas, and to irrigate crops. Irrigated turf grass areas include golf courses, athletic fields and lawns, while irrigated crops typically include cranberry bogs. Fertigation can reduce nutrient loads to down gradient surface waters while reducing fertilizer costs to the irrigated areas.

Technology Performance

Nitrogen Removal 60% to 80%

Phosphorus Removal 60% to 80%

Turf:	Turf:
$151	$907
Cranberry Bogs:	Cranberry Bogs:
$132	$795
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

Fertigation Wells

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- Fertigation wells should be located down gradient of nutrient source areas such as wastewater treatment plant disposal fields and compact development
- They can also be positioned down gradient of high-density subdivisions where they might capture nutrients derived from both septic systems and residential lawns
- The specific locations, depths and diameters can be optimized using standard hydrogeologic principles

ECO-BENEFITS

- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Turf: Massachusetts Department of Environmental Protection
- Cranberry Bogs: Massachusetts Department of Environmental Protection and Municipal Conservation Commission

PERFORMANCE CHALLENGES

- Seasonal technology potentially requiring several capture wells to capture entire nutrient plume
- Most effective in areas where groundwater contains a "plume" of high concentration of nutrients (i.e. down gradient of a WWTF discharge, etc.)
- Need an area to irrigate for nutrient uptake
- May require monitoring

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to more frequent inundation and increased exposure to saline water
- Inundation leading to saltwater intrusion into groundwater potentially affecting reuse of water (e.g. irrigation)
- Destabilization of assets as a result of changes in groundwater levels or erosion

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets)
- Select materials and coatings that are able to cope with an increasingly saline environment
- Backflow valves on outlets
- Anchoring of buried assets
- Locate technology outside flood hazard area anticipated for the life of the installation

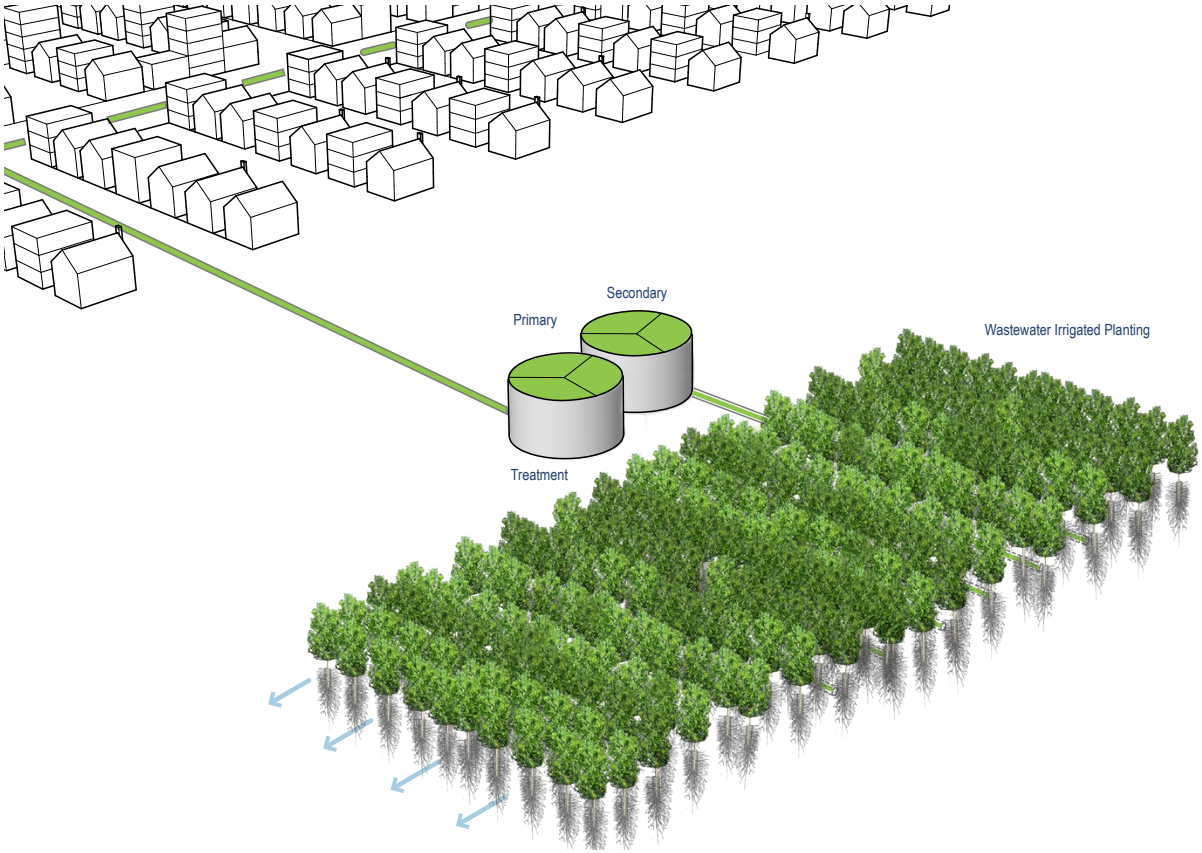


Figure 4-12

Phytoirrigation

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

After secondary treatment, WWTF effluent is irrigated onto plants to remove nutrients and other contaminants. Fast growing poplar and willow trees are typically used. Phytoirrigation requires periodic maintenance and removal of the vegetation being irrigated.

Technology Performance

Nitrogen Removal 50% to 75%

Phosphorus Removal 50% to 75%

$1,899	$14,243
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
10 years	1 to 10 years
Useful Life	Time to See Results

Phytoirrigation

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- Undeveloped open land > 1 acre
- GW depth > 4 feet
- Permeable soils
- Outside all wetlands resource areas
- Outside 100 year flood hazard zone

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection

PERFORMANCE CHALLENGES

- Will likely require meeting stringent and costly water reuse regulations including increased treatment and monitoring requirements
- Plants can only be irrigated during growing season (about 3 months)
- For tree systems, it takes several years before plants are mature enough to uptake the maximum number of gallons per day requiring the effluent be held in holding ponds until the irrigation season

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to more frequent inundation and increased exposure to saline water
- Mobilization of contamination as a result of failure of storage system
- Backflow of saline water into system causing overflows, increased degradation of materials and change in biological processes
- Destabilization of assets as a result of changes in groundwater levels or erosion
- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)

CLIMATE RESILIENCE: SOLUTIONS

- Locate infrastructure outside the flood hazard area that is anticipated for the life of the installation
- Select materials and coatings that are able to cope with an increasingly saline environment
- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets and health of vegetation)
- Backflow valves on outlets
- Anchoring of buried assets
- Project design and species selection to ensure adequate performance in increasingly saline environments

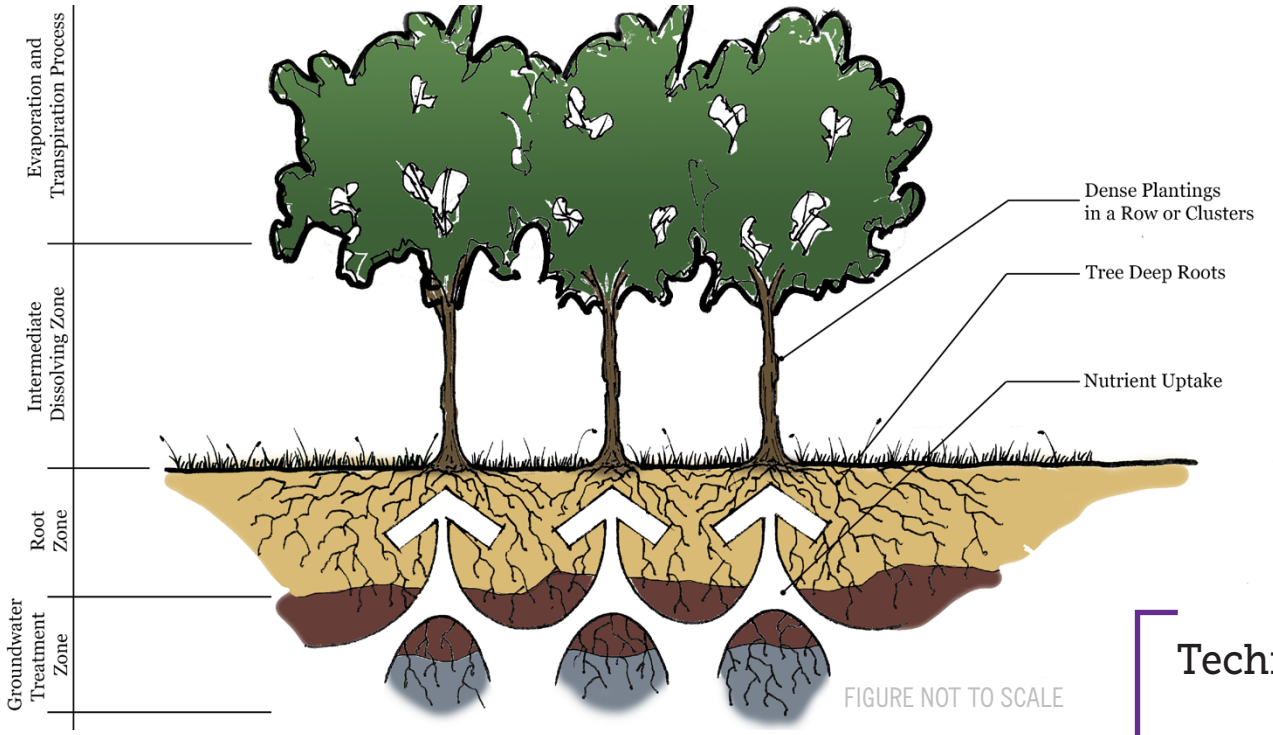


Figure 4-13

Phytoremediation

SCALE: SITE/NEIGHBORHOOD
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE IDENTIFIED FOR PILOTING

DESCRIPTION

Green plants with deep tap roots are planted as a buffer to intercept high nitrogen (nitrogen enriched) groundwater. The plants and microorganisms in their root zone reduce/use the nitrogen, removing it from the groundwater and watershed. Phytoremediation can be used to redirect a plume of nitrogen enriched groundwater or pull it up from deeper in the aquifer, allowing the plants to treat the plume.

Technology Performance

Nitrogen Removal 50% to 90%

Phosphorus Removal 20% to 60%

$228	$1,999
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

Phytoremediation

SCALE: SITE/NEIGHBORHOOD
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- Permeable soils
- Depth to groundwater <10 feet
- Not within priority habitat areas
- Not within protected open space
- Benefit if site is located within a Zone II, has disturbed soils, parcel intersects with 50 to 100 foot wetland buffers, has municipal ownership, necessary nitrogen removal in groundwater filtering through parcel is high

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Licensed Site Professional/Massachusetts Department of Environmental Protection
- U.S. Environmental Protection Agency

PERFORMANCE CHALLENGES

- In year one after planting, no remediation occurs because trees have not reached the groundwater. As the trees get larger and pump more water, nitrogen removal rates increase and plateau
- Plants can only be irrigated during the growing season, requiring use of holding ponds in non-growing season.

CLIMATE RESILIENCE: RISKS

- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor condition and performance of technology (i.e. achieving nutrient removal targets and health of vegetation)
- Species selection to ensure adequate performance in increasingly saline environments
- Preserve areas / buffers to allow migration of salt marsh to higher elevations as MHW rises

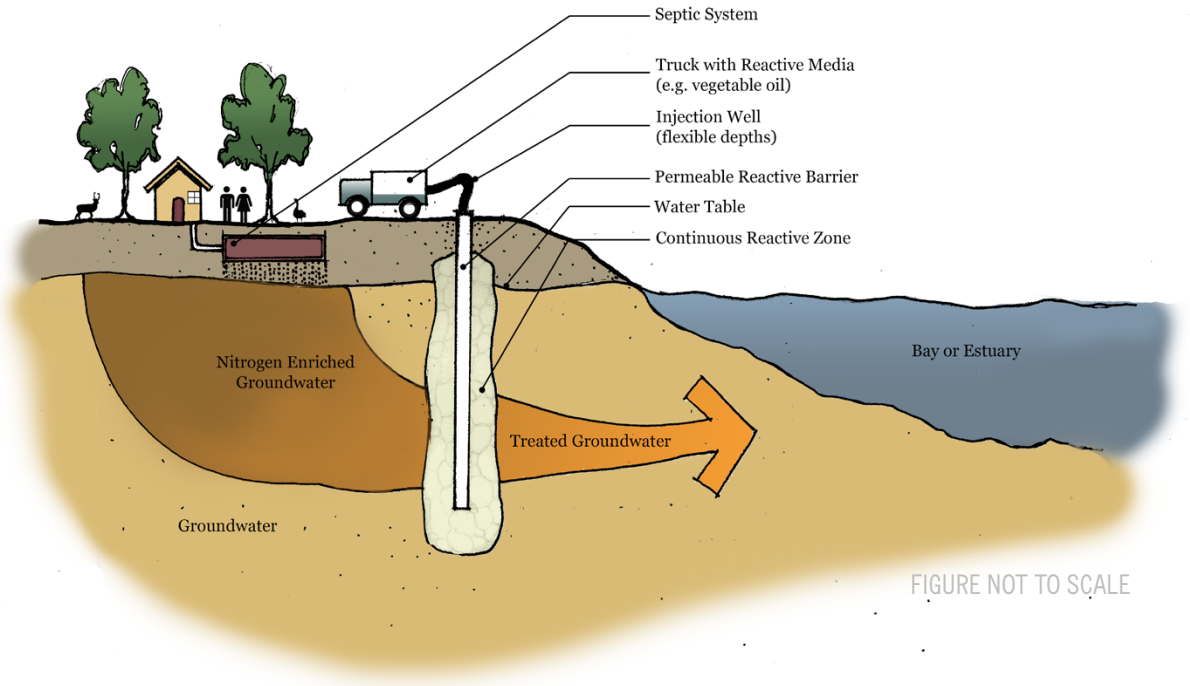


Figure 4-14

Permeable Reactive Barriers (PRBs) Injection Well Method

PRB

SCALE: SITE/NEIGHBORHOOD
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

A permeable reactive barrier (PRB) is an in-situ (installed within the aquifer) treatment zone designed to intercept nitrogen enriched groundwater. Through use of a carbon source, microbes in the groundwater uptake the nitrogen, denitrifying the groundwater. An injection Well PRB system typically uses a series of injection wells to introduce the carbon source (medium) into the groundwater.The injection wells can be installed to depth greater than the PRB trench method. The injection well PRB method can be used in combination with the PRB trenching method described previously. As groundwater flows through the medium, microbes naturally occurring in the groundwater consume the carbon source, as well as oxygen, developing an anaerobic environment. This process releases nitrogen gas to the atmosphere, reducing the groundwater nitrogen load before reaching the estuary.

Technology Performance

Nitrogen Removal 75% to 95%

Phosphorus Removal 50% to 95%

$279	$1,310
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

Permeable Reactive Barriers (PRBs) Injection Well Method

SCALE: SITE/NEIGHBORHOOD
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE IDENTIFIED FOR PILOTING

PRB

SITING NEEDS

- Suitable groundwater flow path (depth to intercept groundwater)
- Generally at least 20 feet of saturated aquifer thickness is desired
- In general, the injection well PRB can be installing areas with steeper topography than a trench PRB
- In general, the injection well PRB can be installing areas where utilities limit the installation of trench PRBs
- Ready access for construction
- Access to sites up gradient or down gradient to allow groundwater monitoring
- Permitting requirements if used in or near wetlands
- Construction cost based on 20-foot spacing between injection wells installed to an overall depth of 40 feet. Deeper installations are possible

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Massachusetts Department of Environmental Protection

ECO-BENEFITS

- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Siting can be limited by wetlands, public utilities and abutter concerns
- Detailed knowledge of local groundwater hydrology needed
- Large projects may require a hydrogeologic investigation and groundwater modeling to estimate effectiveness of PRB
- Permitting requirements may be extensive and time consuming
- Projects may require extensive groundwater monitoring early in the project to quantify nitrogen load reduction
- Projects may require groundwater monitoring near or in embayments as well as monitoring of vegetation and benthic monitoring where groundwater surfaces in the receiving estuary

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to more frequent inundation and increased exposure to saline water
- Inundation leading to saltwater intrusion into groundwater potentially affecting reuse of water (e.g. irrigation)
- Destabilization of assets as a result of changes in groundwater levels or erosion

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets)
- Select materials and coatings that are able to cope with an increasingly saline environment
- Backflow valves on outlets
- Anchoring of buried assets
- Locate technology outside flood hazard area anticipated for the life of the installation

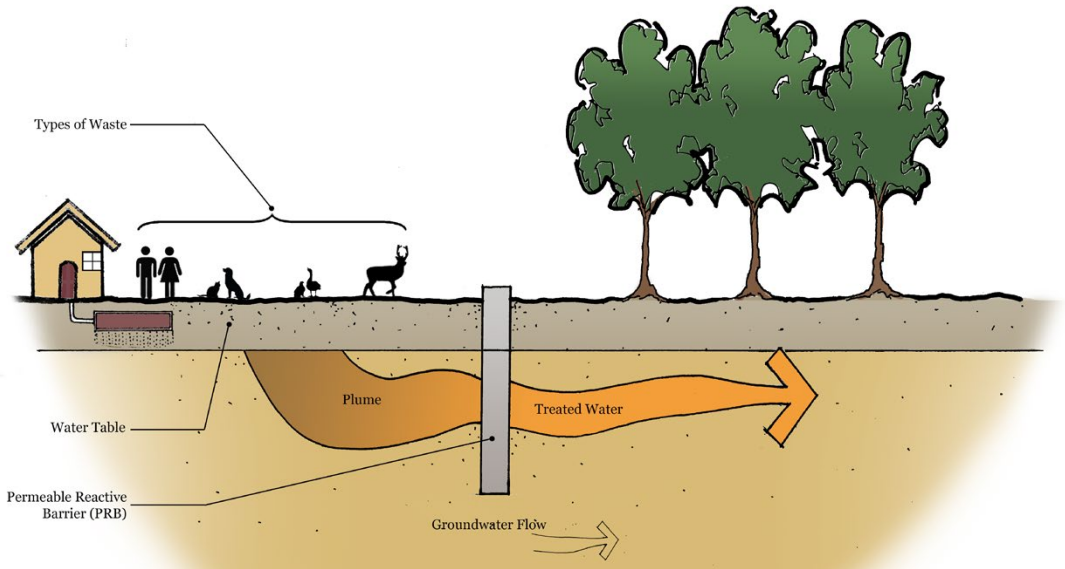


Figure 4-15

Permeable Reactive Barriers (PRBs) Trench Method

PRB

SCALE: SITE/NEIGHBORHOOD
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

A permeable reactive barrier (PRB) is an in-situ (installed within the aquifer) treatment zone designed to intercept nitrogen enriched groundwater. Through use of a carbon source (the PRB medium), microbes in the groundwater uptake the nitrogen, denitrifying the groundwater. The trench method PRB uses large trenching equipment to install a mixture of coarse sand, wood chips, compost and/or other materials (medium) in the trench created by the trencher. The vertical wall can be installed to a depth of 40 feet with a width of 1.5 to 3 feet; PRBs can also be installed in large diameter columns. As groundwater flows through the wall, the medium provides a carbon source for microbes living in the groundwater. The microbes consume the carbon source as well as oxygen, developing an anaerobic environment which releases nitrogen gas to the atmosphere, reducing the groundwater nitrogen load before reaching the estuary.

Technology Performance

Nitrogen Removal 75% to 95%

Phosphorus Removal 50% to 95%

$158	$743
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

Permeable Reactive Barriers (PRBs) Trench Method

SCALE: SITE/NEIGHBORHOOD
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE IDENTIFIED FOR PILOTING

PRB

SITING NEEDS

- Suitable groundwater flow path (depth to intercept groundwater)
- Generally at least 20 feet of saturated aquifer thickness is desired
- Relatively level site
- Ready access for construction
- Access to sites up gradient or down gradient to allow groundwater monitoring
- Limited vegetation, Limited public utilities
- Permitting requirements if used in or near wetlands
- Construction cost based on width of 3 feet width, and an overall depth of 40 feet (using existing trenching equipment - deeper in installations are possible using injection well PRBs described below)

ECO-BENEFITS

- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Massachusetts Department of Environmental Protection

PERFORMANCE CHALLENGES

- Siting can be limited by wetlands, public utilities and abutter concerns
- Detailed knowledge of local groundwater hydrology needed
- Projects may require a hydrogeologic investigation and groundwater modeling to estimate effectiveness of PRB
- Permitting requirements may be extensive and time consuming
- Projects may require extensive groundwater monitoring early in the project to quantify nitrogen load reduction
- Projects may require groundwater monitoring near or in embayments as well as monitoring of vegetation and benthic monitoring where groundwater surfaces in the receiving estuary

CLIMATE RESILIENCE: RISKS

- Degradation of materials and reduced asset lifespan due to more frequent inundation and increased exposure to saline water
- Inundation leading to saltwater intrusion into groundwater potentially affecting reuse of water (e.g. irrigation)
- Destabilization of assets as a result of changes in groundwater levels or erosion

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets)
- Select materials and coatings that are able to cope with an increasingly saline environment
- Backflow valves on outlets
- Anchoring of buried assets
- Locate technology outside flood hazard area anticipated for the life of the installation

Stormwater BMPs

SCALE: CAPE WIDE
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE

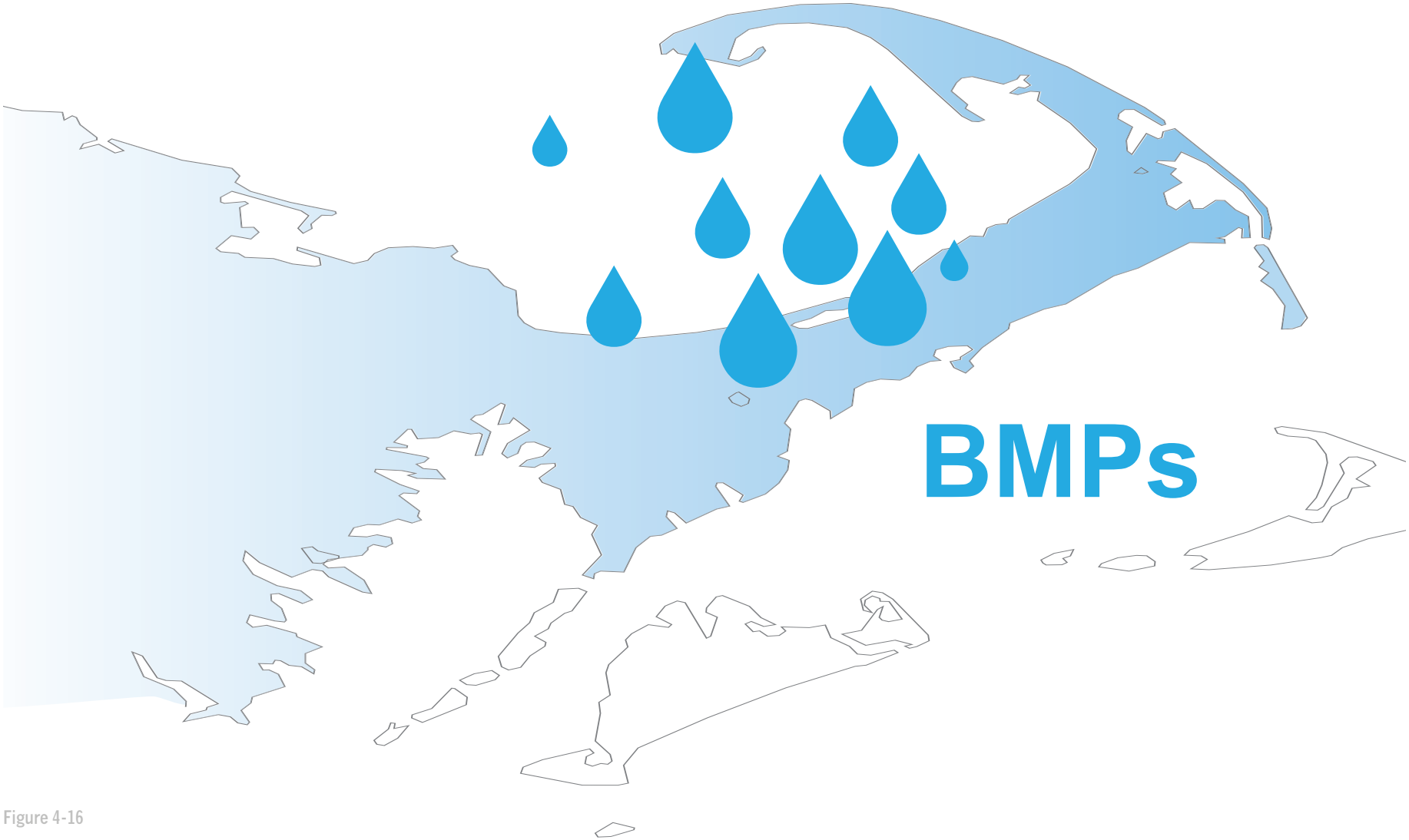


Figure 4-16

Stormwater BMPs

SCALE: CAPE WIDE
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE

DESCRIPTION

Non-Structural Stormwater strategies. These strategies include street sweeping, maintenance of stormwater utilities, education and public outreach programs, land use planning, and IC reduction and control.

SITING NEEDS

- Varies

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Requires the creation and enforce of stormwater regulations and policies

CLIMATE RESILIENCE: RISKS

- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor condition and performance of technology (e.g. achieving nutrient removal targets, health of vegetation)
- Project design and species selection to ensure adequate performance in increasingly saline environments

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection

Technology Performance



Nitrogen Removal 25% to 75%



Phosphorus Removal 1% to 8%

$695	$51,470
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

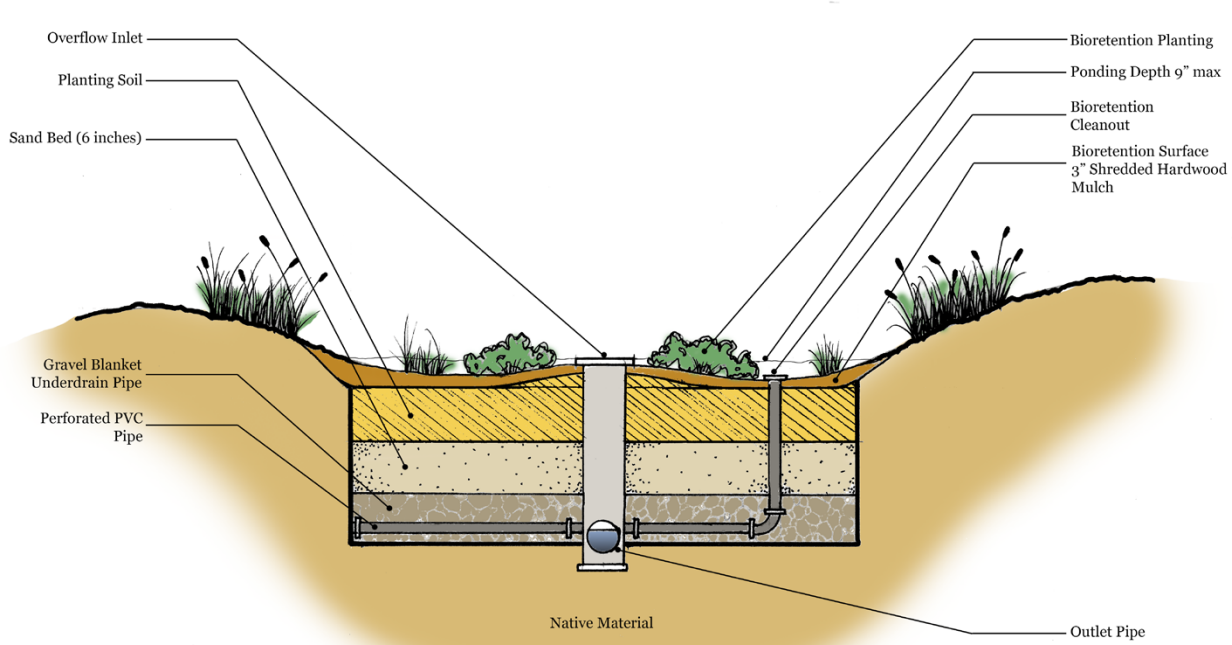


FIGURE NOT TO SCALE

Figure 4-17

Stormwater Bioretention Soil Media Filters

SCALE: SITE
APPROACH: REMEDIATION

SCENARIO PLANNING: NOT SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

Bioretention is the process in which contaminants and sedimentation are removed from stormwater runoff through physical, biological and chemical treatment processes. Stormwater is collected into the treatment area which consists of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. Runoff passes first over or through a sand bed, which slows the runoff's velocity, distributes it evenly along the length of the ponding area, which consists of a surface organic layer and/or groundcover and the underlying planting soil. The ponding area is graded, its center depressed. Water is ponded and gradually infiltrates the bioretention area or is evapotranspired. The bioretention area is graded to divert excess runoff away from itself. Stored water in the bioretention area planting soil exfiltrates over a period of days into the underlying soils.

Technology Performance

Nitrogen Removal 25% to 45%

Phosphorus Removal 20% to 30%

$2,241	$20,912
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

Stormwater Bioretention Soil Media Filters

SCALE: SITE
APPROACH: REMEDIATION
SCENARIO PLANNING: NOT SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- GW depth > 4 feet
- Footprint is greatly scalable

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Open space required for construction

CLIMATE RESILIENCE: RISKS

- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor condition and performance of technology (i.e. achieving nutrient removal targets, health of vegetation)
- Species selection to ensure adequate performance in increasingly saline environments

Stormwater Constructed Wetlands, BMPs

SCALE: CAPE WIDE
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
PHYTOBUFFERS IDENTIFIED FOR PILOTING

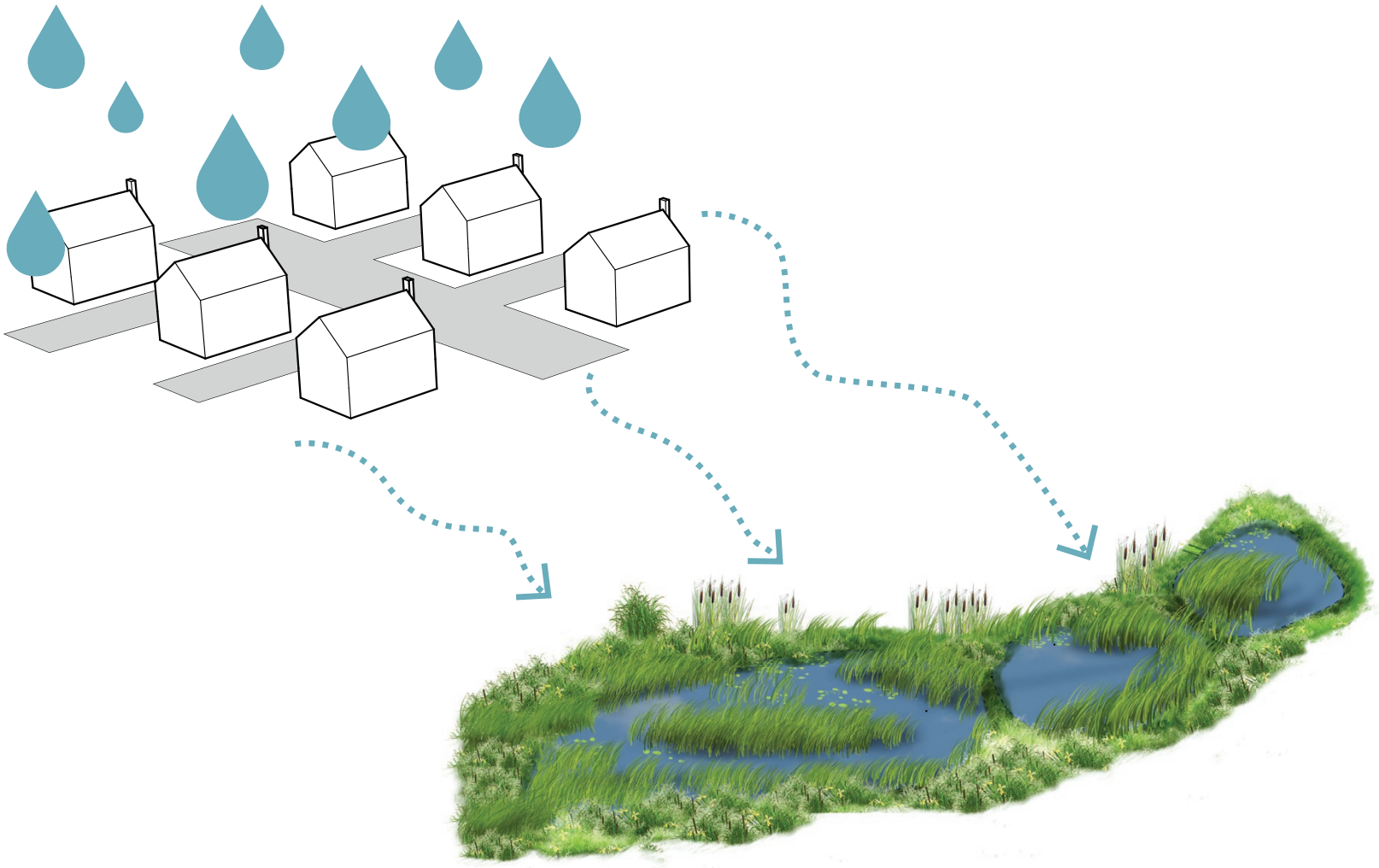


Figure 4-18

Stormwater Constructed Wetlands, BMPs

SCALE: CAPE WIDE
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
PHYTOBUFFERS IDENTIFIED FOR PILOTING

DESCRIPTION

There are several types of structural stormwater BMPs, such as phytobuffers, vegetated swales, and constructed wetlands, which can contribute to nutrient removal. These approaches typically employ an excavated elongated basin engineered to accommodate the requirements of the site, together with components designed to enhance nutrient attenuation. These components may include: a swale to convey runoff; a system of chambers that allow for filtration, sediment settling, aerobic and anaerobic activity; and vegetation for nutrient uptake. Vegetated swales are typically grassed parabolic basins with relatively flat side slopes. Phytobuffers employ fast growing poplars and willow trees to remove nutrients and other contaminants. Constructed wetlands filter stormwater as it flows horizontally through a sediment forebay and a series of gravel-bottomed wetland cells, where algae and microbes grow in abundance. Constructed wetlands can be engineered to mimic natural systems, but designed to improve residence time within anaerobic chambers, allowing for year round nitrogen removal.

SITING NEEDS

- Varies

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Requires the creation and enforcement of stormwater regulations and policies

CLIMATE RESILIENCE: RISKS

- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor condition and performance of technology (e.g. achieving nutrient removal targets, health of vegetation)
- Project design and species selection to ensure adequate performance in increasingly saline environments

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection

Technology Performance



Nitrogen Removal % 25 to 90



Phosporous Removal %1 to 80

$156 to $1,900	$6,483 to $74,143
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Results

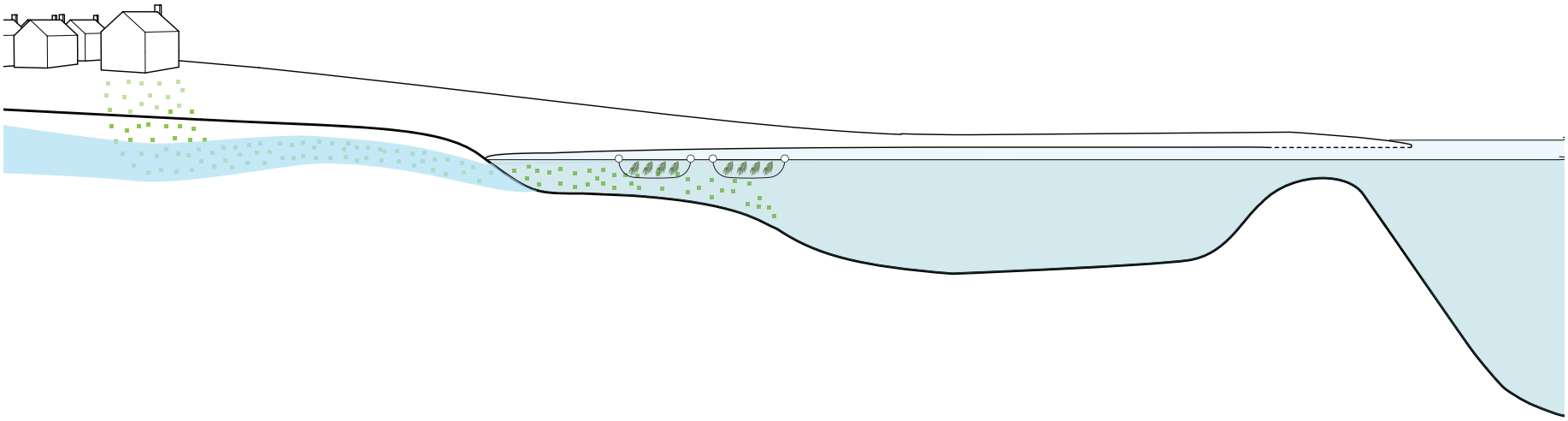


Figure 4-19

Aquaculture Mariculture

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: NOT SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

Seaweed and other marine vegetation remove nitrogen from their environment. The cultivation and removal of the marine vegetation can remove nitrogen from an estuary, reducing the estuary's nitrogen load. Mariculture can become a dual purpose project where seaweed can be harvested for market while there will be a local reduction in nitrogen in the overlying water column during the growth and maturation of the seaweed. This method of aquaculture cultivates marine vegetation such as seaweed to remove nitrogen. Harvesting a portion of the vegetation may be required to remove nitrogen. Mariculture can be used in combination with other types of aquaculture as well as floating constructed wetlands designed for brackish water.

Technology Performance

Nitrogen Removal 8% to 15%

Phosphorus Removal n/a

$61
Removal Cost per kg N
(avg life cycle)

20 years
Useful Life

1 to 3 years
Time to See Results

Aquaculture Mariculture

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: NOT SELECTED FOR USE
IDENTIFIED FOR PILOTING



SITING NEEDS

- Suitable area within estuary to cultivate mariculture

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Growing conditions, aesthetics or navigation may limit applicability
- Seasonal nitrogen uptake coincident with natural cycle and algal blooms
- Requires removal of vegetation in order to take credit for nitrogen removal
- Nitrogen uptake subject to possible disruption due to disease or other
- Growth and harvest monitoring is important to maintain persistence of the benefit

CLIMATE RESILIENCE: RISKS

- Damage to shorelines or subsurface structures from storm events (e.g. wave action)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition and performance of technology (i.e. achieving nutrient removal targets)
- Potential anchoring of structures
- Protective structures to reduce impacts to reefs (e.g. wind walls)

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- Army Corps of Engineers
- Office of Coastal Zone Management
- Board of Selectmen or Aldermen or designee
- Massachusetss Division of Marine Fisheries

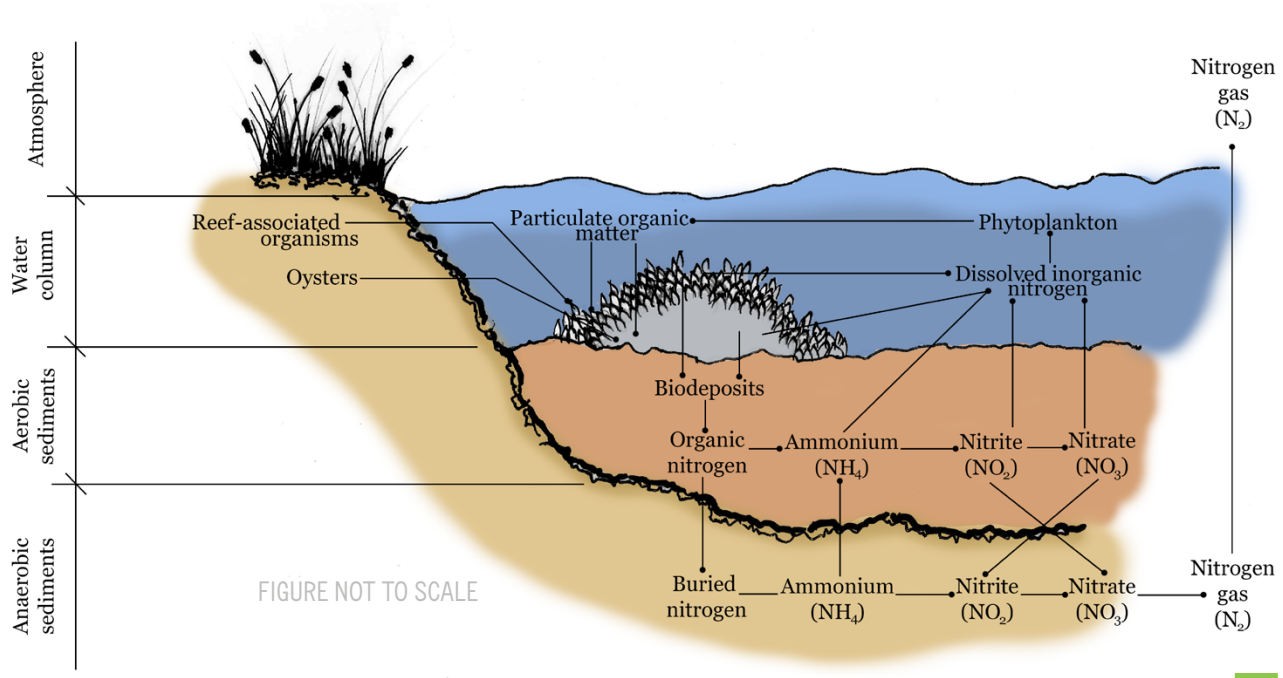


Figure 4-20

Aquaculture Shellfish

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

Shellfish, specifically oysters, remove nitrogen from their environment. The growing and removal of the mature oysters can remove nitrogen from an estuary, reducing the estuary's nitrogen load. Aquaculture can become a dual purpose project where shellfish are harvested for market while there will be a local reduction in nitrogen in the overlying water column during the growth and maturation of the oysters.

Shellfish may be cultivated above or within the estuary bed. The "in-estuary bed" method cultivates the shellfish in the benthic soils of the estuary. Shellfish may also be cultivated above the estuary bed in containters. With either approach, harvesting a portion of the oysters is required to remove nitrogen. Shellfish cultivation may be used in combination with other types of aquaculture (e.g mariculture), as well as floating constructed wetlands designed for brackish water.

Technology Performance

Nitrogen Removal 8% to 15%

Phosphorus Removal n/a

$61
Removal Cost per kg N
(avg life cycle)

20 years
Useful Life

1 to 3 years
Time to See Results

Aquaculture Shellfish

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- Suitable area within estuary to seed and cultivate shellfish

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- growing conditions, aesthetics or navigation may limit applicability

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- Army Corps of Engineers
- Office of Coastal Zone Management
- Board of Selectmen or Aldermen or designee
- Massachusetss Division of Marine Fisheries

- Seasonal nitrogen uptake coincident with natural cycle and algal blooms
- Requires removal of shellfish in order to take credit for nitrogen removal
- Nitrogen uptake subject to possible disruption due to disease or population crash
- Population monitoring is important to maintain persistence of the benefit
- Large concentrations of shellfish can generate waste products, reduce dissolved oxygen levels, and possibly generate ammonia
- Shellfish will undergo rapid growth to a marketable size after which they must be harvested.
- Can require large areas to gain significant nitrogen removal
- If the waterbody is closed for shell fishing, management will be required to prevent the shellfish from getting into the food supply

CLIMATE RESILIENCE: RISKS

- Damage to shorelines or subsurface structures from storm events (e.g. wave action)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition and performance of technology (i.e. achieving nutrient removal targets)
- Potential anchoring of structures
- Protective structures to reduce impacts to reefs (e.g. wind walls)

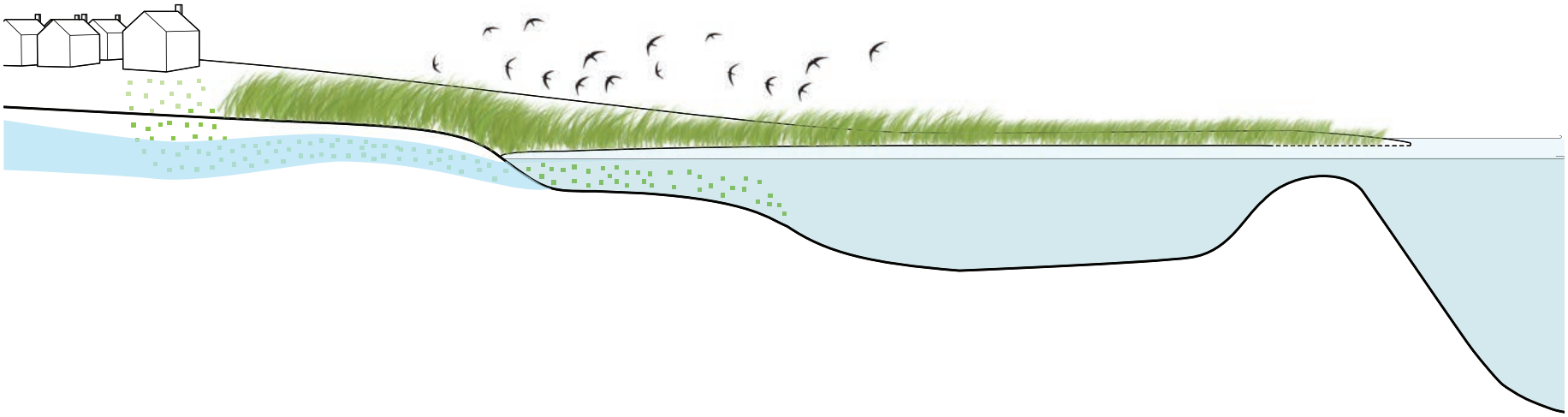


Figure 4-21

Coastal Habitat Restoration

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

Restoration of coastal habitats includes establishing and/or enhancing estuary salt marshes, eel grass beds, as well as shellfish and oyster beds together as an ecosystem.When considering restoration of coastal habitats, implementing these ecosystems jointly should be considered. The installation of riparian buffer zones and Floating Constructed Wetlands should be considered when restoring coastal habitats. Habitat restoration should focus on creating or rehabilitating habitats, including creating communities that are natural to the area.

Technology Performance

Nitrogen Removal 5% to 12%

Phosphorus Removal n/a

$163
Removal Cost per kg N
(avg life cycle)

20 years
Useful Life

0.5 to 3 years
Time to See Results

Coastal Habitat Restoration

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- Site specific requirements based on the characteristics of the estuary
- Suitable substrate in saltwater/ estuarine environments
- Suitable area within estuary to seed and grow shellfish

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

CLIMATE RESILIENCE: RISKS

- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water (surface or ground water)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor condition and performance of technology (i.e. achieving nutrient removal targets and health of vegetation)
- Species selection to ensure adequate performance in increasingly saline environments
- Preserve areas / buffers to allow migration of salt marsh to higher elevations as MHW rises

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- U.S. Army Corps of Engineers
- Office of Coastal Zone Management

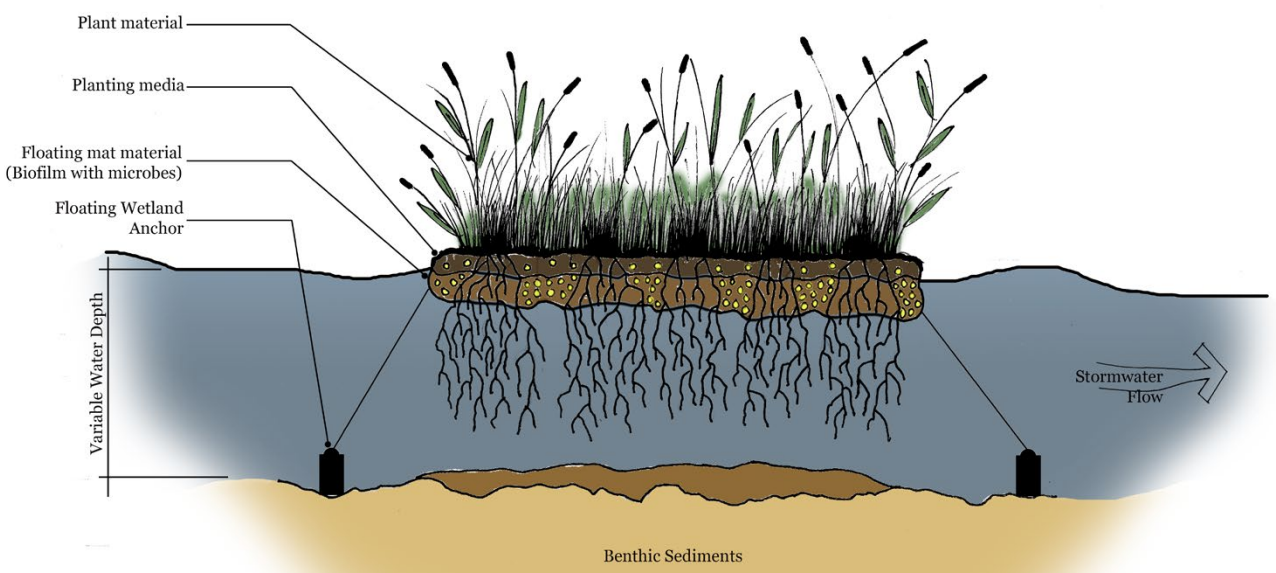


Figure 4-22

FIGURE NOT TO SCALE

Floating Constructed Wetlands

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

FCWs are manmade floating "islands" that act as floating wetlands that treat waters within ponds and estuaries. The islands are made of recycled materials that float on ponds or estuaries, exposing the plant's roots to the pond and estuarine waters. The root zones provide habitat for fish and microorganisms while reducing nitrogen and phosphorus levels. The floating islands can also be designed to allow shellfish and seaweed to grow which can be harvested, offsetting some of the systems costs. Some systems circulate surface water through the island, exposing the water to the root zones of the plants. The islands can be installed with shellfish beds and/or salt marsh grasses potentially assisting with their establishment. The islands are generally stationary and can be installed with walkways to access and maintain the plants growing on the islands. The islands require little O&M and do not need to be removed during the winter months, even if freezing water is a concern.

Technology Performance

Nitrogen Removal 8 to 15

Phosphorus Removal 0.5 to 1

$20	$454
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	0.5 to 3 years
Useful Life	Time to See Results

Floating Constructed Wetlands

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

SITING NEEDS

- Site specific requirements based on the characteristics of the estuary or pond
- A location(s) within the estuary or pond to locate a floating island year around

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Not listed

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- U.S. Army Corps of Engineers

CLIMATE RESILIENCE: RISKS

- Damage to structures from storm events (e.g. wind and wave action)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition and performance of technology (i.e. achieving nutrient removal targets)
- Potential anchoring of structures
- Protective structures to reduce impacts to wetlands (e.g. wind walls)

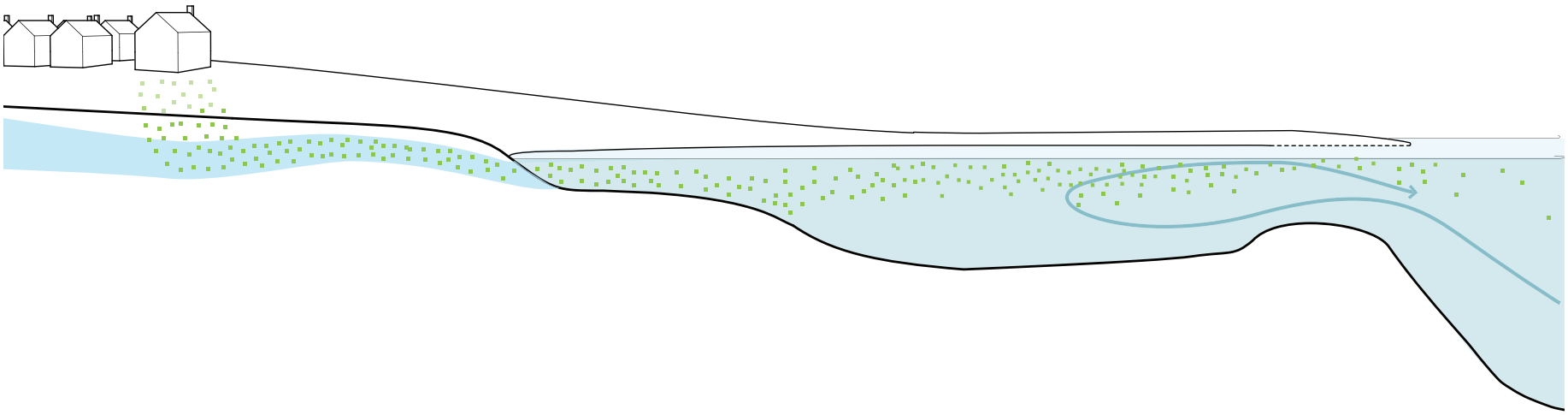


Figure 4-23

Inlet/Culvert Widening

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE

DESCRIPTION

This approach considers re-engineering and reconstruction of bridge or culvert openings to increase the tidal flux through the culvert or inlet. In the right settings, increasing the tidal flux can decrease the nitrogen residence time, lowering the nutrient concentration in the estuary and/or tidal marsh upstream of the widened inlet or culvert.

Technology Performance

Nitrogen Removal 8% to 15%

Phosphorus Removal 0.5% to 1%

$20	$464
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
10 years	0.5 to 3 years
Useful Life	Time to See Results

Inlet/Culvert Widening

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE

SITING NEEDS

- Site specific requirements, based on existing culvert bridge dimensions, hydraulics and other characteristics

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- U.S. Army Corps of Engineers
- Office of Coastal Zone Management

PERFORMANCE CHALLENGES

- Widening a tidal culvert or bridge could increase the depth of flooding during high tides and storm surges in flood prone area and upstream of the structure.
- Disruption of coastal processes must be considered
- Can have significant construction impacts
- Permitting requirements may be extensive and time consuming
- Modeling is required to accurately predict the upstream tidal and coastal process impacts of the culvert/bridge modifications
- Will only return an estuary to a more natural hydrologic regime if the original opening has been restricted

CLIMATE RESILIENCE: RISKS

- Damage to shorelines or subsurface structures from storm events (e.g. wave action)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition and performance of technology (i.e. achieving nutrient removal targets)
- Potential anchoring of structures
- Protective structures to reduce impacts to reefs (e.g. wind walls)

Pond and Estuary Circulators

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: NOT SELECTED FOR USE

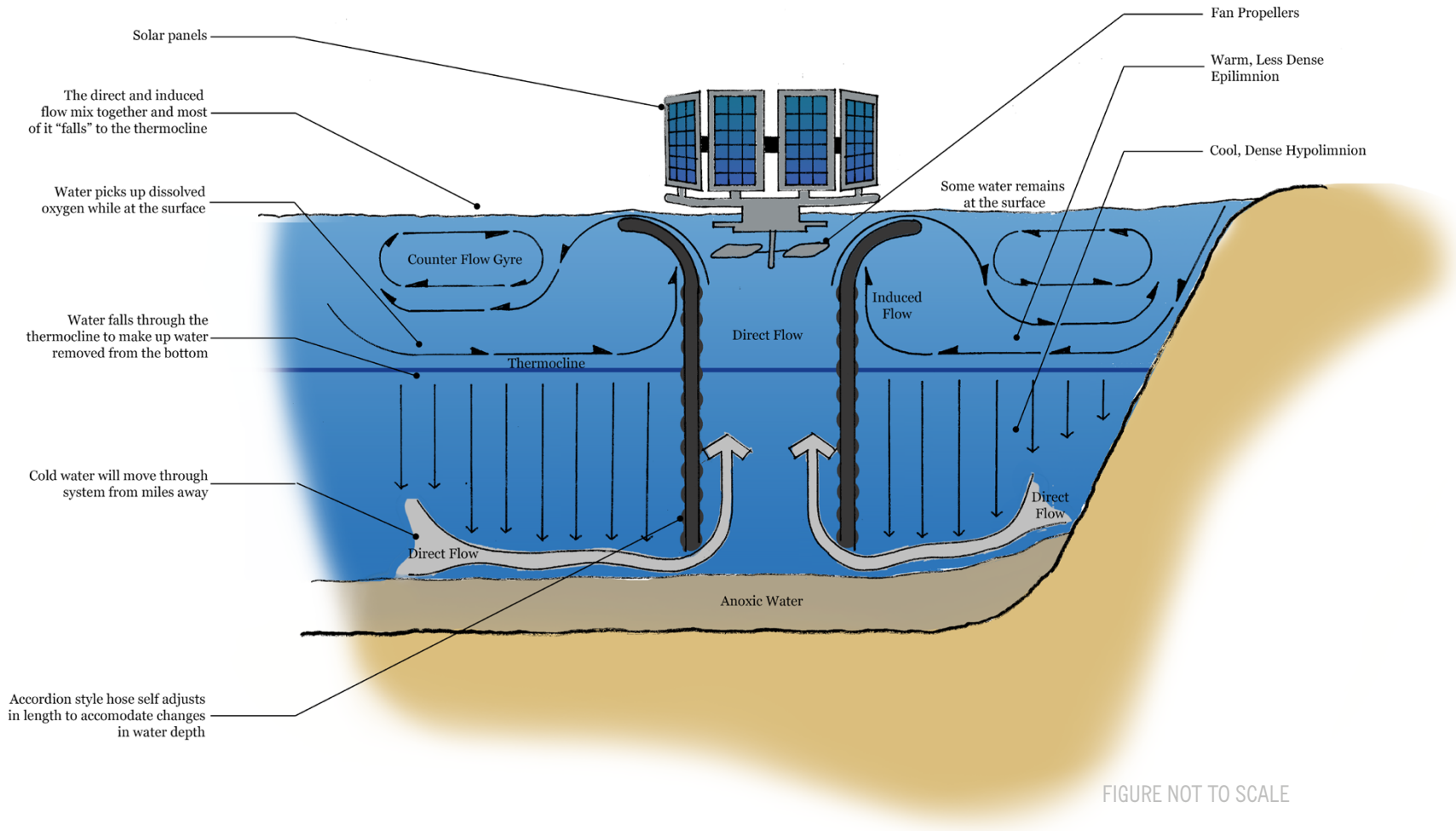


Figure 4-24

Pond and Estuary Circulators

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: NOT SELECTED FOR USE

DESCRIPTION

The circulation of pond and estuary water increases the oxygen concentration while reducing nutrients (nitrogen and/or phosphorus) concentrations, reducing odors, and enhancing fish habitat. The circulation is generally performed mechanically by installing solar or electric powered circulators.

Pond and estuary circulators work by reducing stratification in ponds and estuaries. Anoxic conditions can occur within the lower stratified layers leading to harmful algae blooms, fish kills and odors. Circulators mix these stratified layers, thereby increasing dissolved oxygen concentrations throughout the pond depths.

Technology Performance

10	0.5 to 3 years
Useful Life	Time to See Results

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- U.S. Army Corps of Engineers
- U.S. EPA

SITING NEEDS

- Site specific requirements based on the characteristics of the estuary or pond
- A location(s) within the estuary or pond to permanently locate floating island

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Energy Savings / Nutrient Recovery / Recycling
- Improves Management of Flooding / Extreme Events

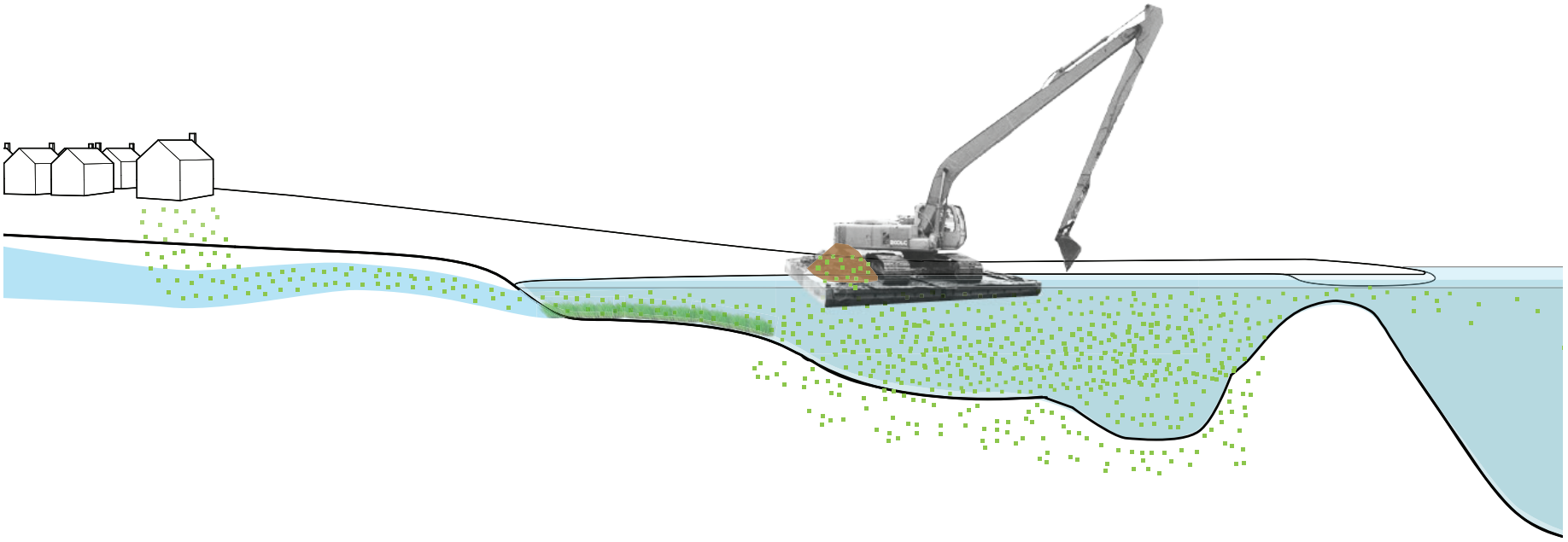


Figure 4-25

Pond and Estuary Dredging

SCALE: NEIGHBORHOOD/WATERSHED

APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE

DESCRIPTION

Lakes, ponds, streams and estuaries store nutrients within their sediments. These sediments tend to accumulate over time. Subsequently, these nutrients can be released into the overlying water column and can become a major source of nitrogen and phosphorus. Dredging and removing these sediments and accumulated nutrients removes the nutrients from the water body and potentially the watershed.

Technology Performance

Nitrogen Removal from sediments removed: 80% to 95%

Phosphorus Removal from sediments removed: 80% to 95%

$7	$7
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
25 years	0.5 to 1 years
Useful Life	Time to See Results

Pond and Estuary Dredging

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Permitting requirements may be extensive and time consuming
- Testing of sediment required
- Dredging can be highly disruptive to biological communities
- Depending on what other contaminants may be present in the sediments, disposal of the sediments may be costly

SITING NEEDS

- Site specific requirements, based on hydraulics and other characteristics

CLIMATE RESILIENCE: RISKS

- Damage to shorelines or subsurface structures from storm events (e.g. wave action)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition and performance of technology (i.e. achieving nutrient removal targets)
- Potential anchoring of structures
- Protective structures to reduce impacts to reefs (e.g. wind walls)

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- U.S. Army Corps of Engineers
- Office of Coastal Zone Management

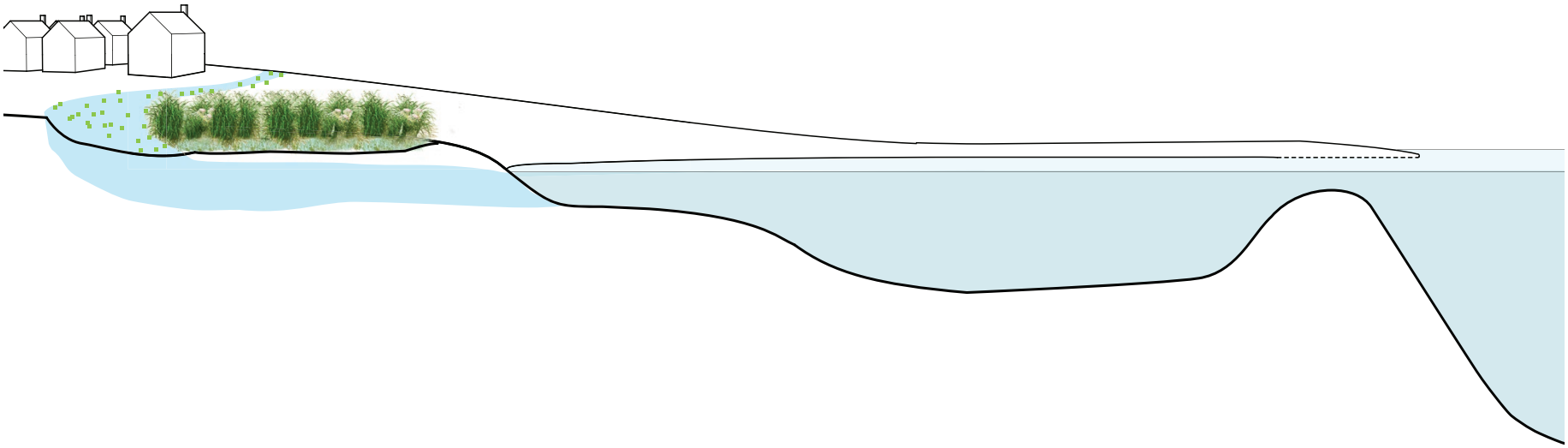


Figure 4-26

Surface Water Remediation Wetlands

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE

DESCRIPTION

Surface Water Remediation Wetlands are constructed to aid in water quality improvements to surface water bodies, usually streams or rivers. Water is directed or allowed to flow naturally through treatment cells containing wetlands. Surface water remediation wetlands are often used in combination with groundwater recharge or potable water reuse systems. Surface water remediation wetlands are generally used with free water surface wetlands due to their larger size, and lower capital and O&M Costs.

Technology Performance

Nitrogen Removal 70% to 95%

Phosphorus Removal 40% to 95%

$1,019	$1,246
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 5 years
Useful Life	Time to See Results

Surface Water Remediation Wetlands

SCALE: NEIGHBORHOOD/WATERSHED
APPROACH: RESTORATION

SCENARIO PLANNING: SELECTED FOR USE

SITING NEEDS

- Site specific requirements, based on hydraulics and other characteristics

ECO-BENEFITS

- Enhances Habitat / Wildlife / Biodiversity
- Promotes Green Space / Conservation / Recreation
- Improves Management of Flooding / Extreme Events

PERFORMANCE CHALLENGES

- Large land area required per amount of nitrogen removed
- Requires existing open space for construction

CLIMATE RESILIENCE: RISKS

- Damage to shorelines or subsurface structures from storm events (e.g. wave action)

CLIMATE RESILIENCE: SOLUTIONS

- Ensure frequent maintenance inspections to monitor asset condition and performance of technology (i.e. achieving nutrient removal targets)
- Potential anchoring of structures
- Protective structures to reduce impacts to reefs (e.g. wind walls)

Permitting

POTENTIAL PERMITTING AUTHORITIES

- Municipal Conservation Commission
- Massachusetts Department of Environmental Protection
- U.S. Army Corps of Engineers
- Office of Coastal Zone Management

Traditional Approaches for Nutrient Management

There are four categories of traditional infrastructure wastewater systems. These include:

- Individual on-site systems with and without enhanced nitrogen removal
- Cluster systems serving up to approximately 30 homes with aggregate wastewater flows less than 10,000 gallons per day (gpd)
- Satellite systems serving from 30 to 1,000 homes (wastewater flows between 10,000 and 300,000 gpd), intended to treat and dispose of wastewater from one area of a community
- Centralized systems that can provide for most or all of a community's wastewater management needs

These traditional approaches are summarized below; more complete discussions of individual treatment techniques can be found in Appendix 4A; the most detailed and extensive information can be found in the Technologies Matrix, available in Appendix 4B and on the web at: http://capecodcommission.org/matrix.

INDIVIDUAL ON-SITE SYSTEMS

The most common infrastructure on Cape Cod is individual on-site systems. These systems include cesspools, non-Title 5 compliant septic systems, Title 5 compliant septic systems, innovative/alternative (I/A) septic systems and enhanced I/A systems. All of these systems work similarly (**Figure 4-27**). Title 5 systems include a septic tank into which wastewater from households and businesses is discharged, and a distribution box from which effluent from the septic tank flows and is distributed to the soil absorption system (SAS), which releases the effluent to the ground. Cesspools do not include a distribution box, leach field, or SAS. The amount of nitrogen removed through denitrifying septic systems is about 40% and can be somewhat enhanced dependent on the soil type and the distance between the discharge and groundwater. Very sandy soils with little organic material, soils common on the Cape, provide less treatment than other soil types.

When estimating nitrogen concentrations being discharged to groundwater, Title 5 compliant systems have a discharge concentration of 26.25 milligrams per liter (mg/L). This concentration includes all denitrification that occurs in the wastewater within the septic system and in the unsaturated soils as it reaches the water table. The Massachusetts Department of Environmental Protection (MassDEP) approves I/A septic systems for 19 mg/L. This value is typically used when estimating nitrogen reduction for nutrient management plans. Enhanced I/A systems may achieve a greater reduction. I/A septic systems may play a significant role in helping to manage nutrients entering the groundwater.

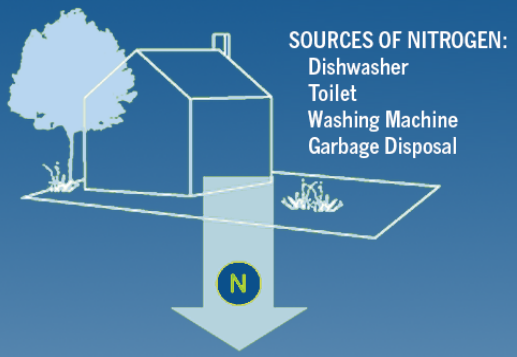
One of the limiting factors in optimizing the performance of I/A systems is variability and inconsistency in maintenance. Outside oversight of I/A systems, potentially at the municipal or county level, could improve performance. Management entities with oversight of private I/A systems can ensure high quality system installation and inspection, maintenance and operation, service provider training and certification, qualified installers and construction inspectors and performance tracking. There are many forms of so-called "Responsible Management Entities" (RME), including public utilities, regional service authorities and county entities, among others. Two US EPA documents – "Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems" dated March 2003, and "Handbook for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems" dated December 2005 – provide useful references for considering management oversight of on-site systems. The establishment of I/A management entities, and the definition of their essential roles and functions, is an area that merits further consideration. Currently, the Barnstable County Department of Health and the Environment (BCDHE) provides a maintenance and monitoring database to assist towns in meeting compliance requirements and the potential to expand this program could be considered.

On-Site Treatment systems

individual on-site systems

Individual on-site systems represent the most common traditional infrastructure on Cape Cod. These systems include cesspools, Title 5 compliant and non-Title 5 septic systems, and innovative/alternative (I/A) and enhanced I/A septic systems and any remaining cesspools.

Wastewater from households and businesses are collected and treated to varying degrees by microbes in these systems. Once treated, the liquid wastewater is discharged, leaving behind small amounts of solid waste.



The soil absorption system (SAS) from a Title 5 system is located at least four feet above the high water table under the discharge area. A Title 5 system has the same general design as a non-Title 5 septic system, but meets MassDEP standards outlined in Title 5 regulations.





of the development on Cape Cod uses septic systems designed for wastewater treatment.

The amount of nitrogen reduction depends on soil type and distance to groundwater. Very sandy soils with little organic material, where are common on the Cape, allow septic system discharges to drain to the water table with less treatment than other soil types.



has standards for maintenance, operation and approval of I/A and enhanced I/A septic systems that nitrogen to 19 and 13 mg/L of discharge.

On-Site Treatment Systems

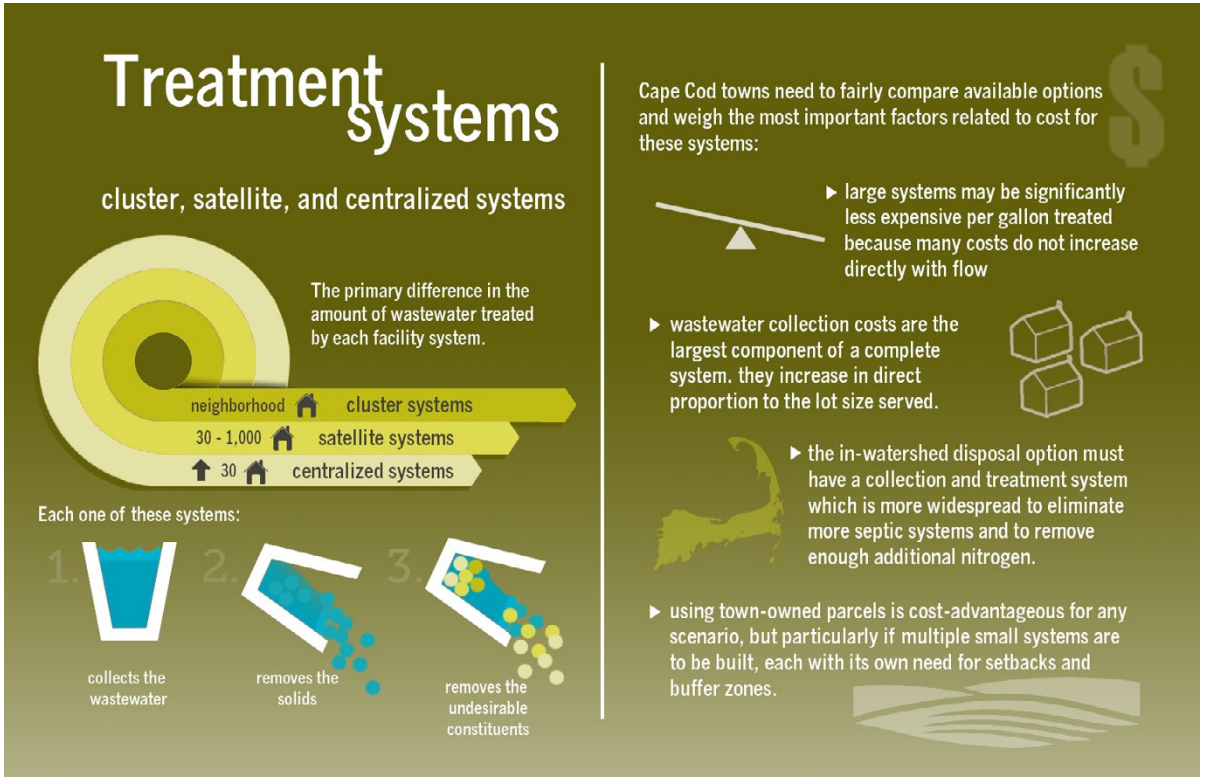
Figure 4-27

CLUSTER, SATELLITE AND CENTRALIZED SYSTEMS

Cluster, satellite and centralized systems all have a series of pipes and sometimes pumps that collect wastewater from multiple households and convey it to a centralized facility for the treatment and disposal of wastewater (effluent) and solids. The primary difference in the facilities is the amount of wastewater each treats. In general, cluster systems treat less than 10,000 gpd, satellite systems treat up to 300,000 gpd and centralized systems treat flows over 100,000 gpd (**Figure 4-28**).

Each of these systems collects wastewater, removes the solids, and through a series of treatment technologies treats the wastewater by partially reducing the undesirable constituents, including nitrogen and phosphorus, prior to discharge to the groundwater, surface water or an ocean outfall. The degree of removal is dependent on the treatment type and degree of treatment designed into the facility. In general, the greater the treatment, the greater the costs to design and build the facility and collection system, operate and maintain the facility, and treat and discharge the wastewater.

The effectiveness of traditional infrastructure can vary and is site-specific. Many wastewater pollutants can be managed with traditional systems, including nitrogen, phosphorus, total suspended solids, biological oxygen demand, pH, suspended metals, total petroleum



Treatment Systems

Figure 4-28

hydrocarbon and pathogens. Traditional systems may be able to remove or manage some contaminants of emerging concern, though which CECs and how well they may be managed is still largely unknown. CECs are addressed in more detail later in this chapter.

Traditional infrastructure generally performs well when operated properly. However, it is possible for these systems to operate below their nutrient reduction potential if not operated properly. Decreases in performance can occur if the design flow is exceeded, the influent contains too much fats, oils or grease, or if the influent contains a compound that compromises the health of the microbes in the system.

ALTERNATIVES FOR EFFLUENT DISPOSAL

Once wastewater is collected and treated at a wastewater treatment facility (WWTF), the treated wastewater (effluent) is generally discharged to surface water or groundwater. There are tradeoffs in selecting sites or approaches for disposing of wastewater, including cost, efficiencies in reducing nutrients in the effluent and thereby meeting total maximum daily load (TMDL) targets and environmental considerations.

Even highly-treated effluent contains some nitrogen. If effluent is disposed of within a watershed with a TMDL as opposed to a location that is not impacted by nitrogen, more septic systems in that watershed must be eliminated or fitted with denitrification systems to meet the TMDL target. If land availability within a town dictates that effluent must be disposed of in public wellhead water supply recharge areas, then a higher level of treatment is needed at sharply increased costs for both capital facilities and operations and maintenance (O&M).

Federal and state laws regulate the dumping of waste into waters of the United States or the Commonwealth. The Massachusetts Ocean Sanctuaries Act of 1990, as amended, (Chapter 132A, §12A-16E, and §18) regulates discharge of wastes, including municipal wastewater, into the Commonwealth's ocean sanctuaries, rivers, and estuaries. As authorized by the federal Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Under this program, new WWTFs on Cape Cod may not discharge effluent to a freshwater body or stream.

The vast majority of WWTFs on Cape Cod are permitted with effluent recharged to the groundwater through beds, fields, or wells designed for specific locations and hydrogeologic site conditions. These conditions include soil characteristics, offset distance between the effluent discharge location and the groundwater layer and the environmental limitations imposed by natural and/or regulatory requirements. See Appendix 4A; Effluent Disposal for more information.

When thinking about siting new wastewater treatment alternatives, effluent disposal can occur at the site of treatment or remotely, depending on the availability of appropriate site conditions. The location of disposal sites may be inside or outside the watershed being served by the WWTF. Effluent transport out of the watershed is a possible option where conditions of the current watershed impose severe limitations or prohibit disposal of wastewater effluent. Looking beyond the borders of a nutrient-sensitive watershed may increase the number of potential disposal sites, may provide overall nutrient-removal efficiencies and may also realize cost efficiencies.

With these considerations in mind, finding disposal sites within direct discharge or outside of wellhead protection areas should rise to the top for Cape Cod communities. Identifying disposal sites will require careful analysis and in-depth community discussions. As a starting point, a GIS analysis may be used to identify sites that meet desirable criteria, including: sites that are outside of nutrient-sensitive watersheds, avoid sensitive resources and other receptors, and/or include under-utilized lands, such as MassDOT or Eversource Energy (formerly NSTAR) rights of way. A recommendation of this plan is the development of a detailed evaluation of effluent disposal options.

> **Recommendation S4.3: The Cape Cod Commission shall provide a detailed evaluation of effluent disposal options by September 2015.**

ECONOMIES OF SCALE AND COST OF TRADITIONAL WASTEWATER TREATMENT

The Barnstable County Wastewater Cost Task Force was established to compile and analyze current local information on the costs to build and operate traditional wastewater systems on Cape Cod. Based on that information, the Task Force developed cost estimates for a wide range of wastewater system sizes and types to help Cape Cod towns fairly compare available options. The estimates are presented in the "Comparison of Costs for Wastewater Management Systems Applicable to Cape Cod," also known as the Barnstable County Cost Report (BCCR). This study was updated in 2014 to reflect additional available data and is included as Appendix 4C.

The application of the results allow communities to identify which options are best for their circumstances and thus streamline their watershed and wastewater planning.

Cost estimates are based on a uniform set of assumptions and supported by a review of actual data. They were prepared to be inclusive of all aspects of wastewater management: collection, transport, treatment, and disposal. Four measures of cost were considered:

- **CAPITAL COSTS:** The cost to design, permit and build the facilities, including land costs.
- **OPERATION AND MAINTENANCE (O&M) COSTS:** The ongoing expenses for labor, power, chemicals, monitoring, sludge disposal, etc.
- **EQUIVALENT ANNUAL COSTS (EAC):** A mathematical combination of O&M expenses and amortized capital costs.
- **COSTS PER POUND OF NITROGEN REMOVED:** The equivalent annual cost divided by the annual nitrogen load removed from the watershed of a nitrogen-sensitive embayment.

Twelve scenarios were developed to combine capital and O&M costs for wastewater collection, transport, treatment and disposal and to compare those costs with the nitrogen removal that can be expected. Costs and performance were estimated both for base cases (with a uniform set of assumptions for all scenarios) and as part of a sensitivity analysis to determine how costs might change with assumptions that are either more or less favorable for each system size.

The sensitivity analysis allows for the identification of the most important cost factors, which are:

- **ECONOMIES OF SCALE:** Large systems may be significantly less expensive per gallon treated because many of the cost components do not increase directly with the flow.
- **DENSITY OF DEVELOPMENT:** Wastewater collection costs are the largest component of a complete system and they increase in direct proportion to the lot size served (**Figure 4-29** shows density, measured by road length between parcels).
- **LOCATION OF DISPOSAL FACILITIES:** An effluent disposal site within a nitrogen-sensitive watershed returns some of the collected nitrogen to the watershed because there is residual nitrogen in the effluent. Compared to a disposal site that is outside of a sensitive watershed, the in-watershed disposal option must have a collection and treatment system which is more widespread to eliminate more septic systems and to remove enough additional nitrogen to offset that returned in the effluent.
- **LAND COSTS:** Land suitable for wastewater management functions is scarce and expensive on Cape Cod. Using town-owned parcels is cost-advantageous for any scenario, but particularly if multiple small systems are to be built, each with its own need for set-backs and buffer zones. Land has been estimated at $250,000 per acre.

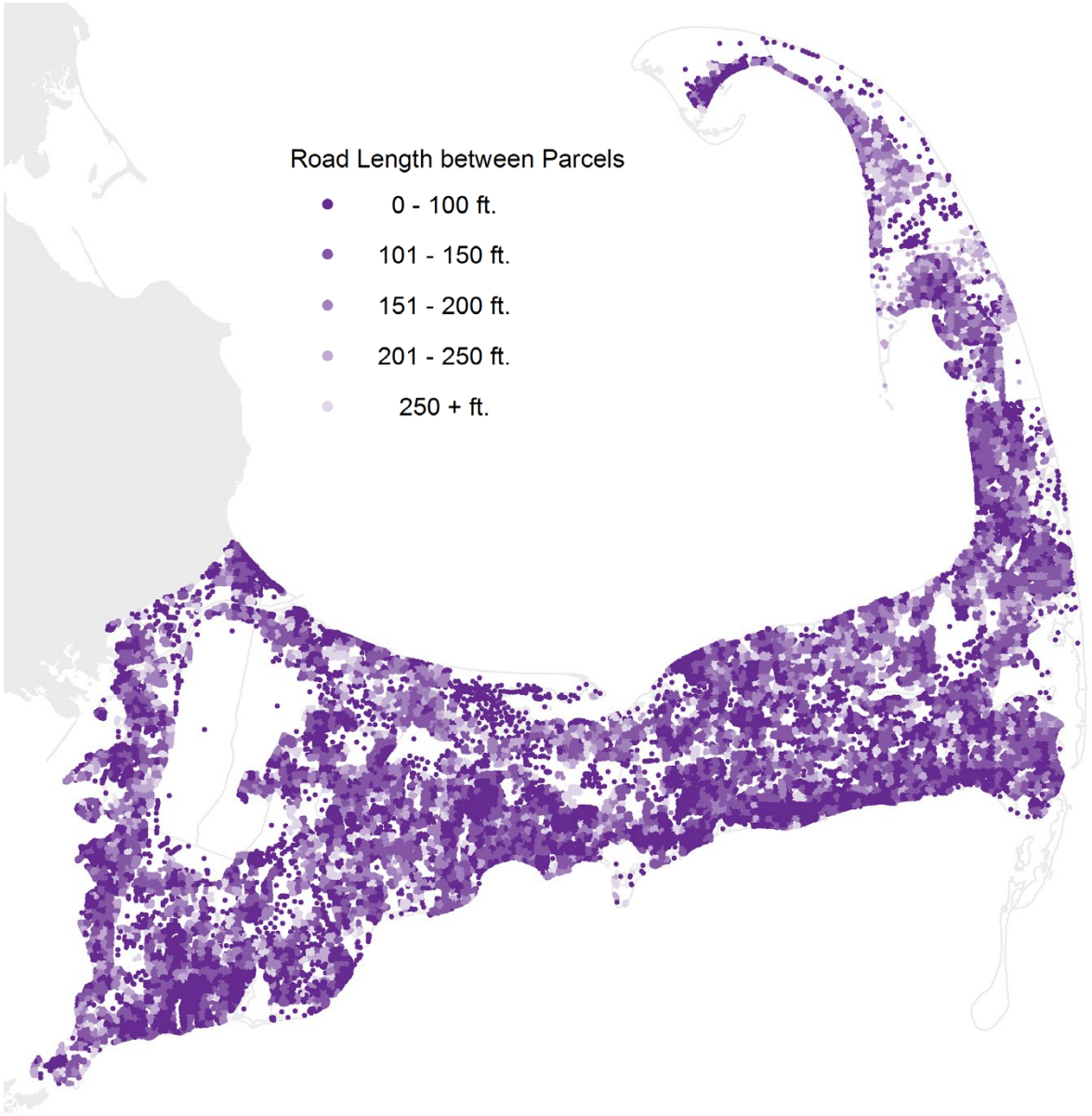
From this sensitivity analysis, conclusions can be drawn about the circumstances that favor one size of system over another.

- **INDIVIDUAL NITROGEN REMOVING SYSTEMS (I/A SYSTEMS):** Their most efficient applicability is within areas of low density and in watersheds that require less than 50% wastewater nitrogen reduction. Their location on the parcel where the wastewater is generated eliminates collection costs.
- **CLUSTER SYSTEMS:** These systems should be considered for existing neighborhoods with small lots that are remote from sewered areas and have publically-owned land nearby. They also are good options for new cluster developments where infrastructure can be installed by the developer and later turned over to the town or for shorefront areas that may not be connected to larger-scale systems until later phases of a project.
- **SATELLITE SYSTEMS:** Satellite facilities make the most economic sense in remote watersheds (more than five miles from existing sewer systems or other areas of need), with vacant publically-owned land nearby. These systems are also applicable when existing or proposed private facilities can be converted to public operations and expanded to provide wastewater services to existing nearby properties on septic systems.
- **CENTRALIZED SYSTEMS:** This option is likely to be the most viable when:

- Dense development exists in nitrogen sensitive watersheds;
- Suitable treatment and disposal sites (outside sensitive watersheds and water supply recharge areas) are available at no or low cost;
- A high degree of nitrogen remediation is required;
- Areas of dense development in sensitive watersheds are within three miles of desirable effluent treatment and disposal sites; and
- Opportunities are available for cost reductions through regionalization.

Given the lack of required collection systems for the non-traditional technologies and approaches, traditional approaches are more likely to benefit from optimizing the factors described above. However, some non-traditional technologies, such as waste reduction toilets, may benefit from regional management arrangements for O&M. For example, a regional effort for managing urine and compost removal and/or reuse, as opposed to a town-by-town or even homeowner-by-homeowner arrangement, may present a cost savings.

Taking advantage of existing inter-municipal arrangements for water and/or wastewater is another potential cost savings method. For example, the Upper Cape Regional Water Supply Cooperative is a regional agreement to supply water to the four Upper Cape towns of Bourne, Falmouth, Mashpee and Sandwich. Management of the Cooperative is by a Board that represents the four public water supply systems – the Town of Falmouth, Bourne Water District, Mashpee Water District and Sandwich Water District. The wells for the Cooperative are located toward



Density as Measured by Road Distance Between Parcels

Figure 4-29

the north end of Joint Base Cape Cod (JBCC), in the town of Sandwich. JBCC is also the site of a federally-owned wastewater treatment facility with the potential to support regional wastewater management needs of the Upper Cape. Potential benefits could be realized in this area given the existing inter-municipal arrangement for water supply and the existing infrastructure at JBCC. More information on the JBCC infrastructure can be found in Chapter 7.

Growth Management Tools

Several planning tools are available for directing growth to appropriate locations where suitable infrastructure exists to support the resource use and wastewater management needs of development and/or where the impact to the environment is not as great. Land use tools such as compact and open space development, transfer of development rights, and nutrient reducing development may be utilized to manage growth and more efficiently utilize resources. These concepts are discussed in more detail in Chapter 7.

Merits of Traditional and Non-Traditional Nutrient Management Approaches

Using traditional technologies to manage wastewater on Cape Cod can offer many benefits, in the right setting. Traditional collection systems and treatment plants can reduce nutrient loads in wastewater before they hit groundwater. They can provide predictable and reliable levels of nutrient removal; they can provide infrastructure that may be retrofitted in the future to address contaminants of emerging concern (CECs), pharmaceuticals, and salt water intrusion. However, traditional technologies may not always offer the most cost-effective solution. Much of Cape Cod sprawls at a low density over miles of roadways, and the cost of installing collection systems may be prohibitively expensive. Additionally, traditional technologies can't remediate the concentration of nitrogen already in the groundwater and estuaries and embayments. Decades of disposal of nutrient-rich wastewater from Cape Cod septic systems resulted in concentrations of nitrogen and other contaminants that will take decades to migrate via the groundwater to ultimately discharge into the Cape's coastal waters. Approaches that remediate nutrient impacts in or adjacent to affected water bodies are important components of efficiently addressing water quality problems.

Many non-traditional techniques offer the promise of remediating water quality within the affected embayment or estuary, thereby having a more immediate result. Non-traditional technologies can intercept and remediate nutrient-laden groundwater close to the water body, or can remediate water in-situ, potentially resulting in faster water quality improvement. In addition, non-traditional approaches can have collateral benefits in the form of creating or improving habitat, one of the desired outcomes of implementation of the Section 208 Plan Update. Because many of the alternative approaches are ideally sited within impacted water bodies and employ natural systems to improve water quality, there is minimal or no water transport between watersheds. Remediation of water quality within coastal resource areas will likely provide additional ecosystem benefits as the "performance" of the coastal resources is enhanced. However, stakeholders have expressed concern about the reliability and/or performance of many of these non-traditional approaches. Many technologies are untested on Cape Cod. Research suggests that some alternative technologies could have widely ranging performance. Performance can be affected by seasonal temperatures, disease, storm damage or poor siting choices. Pilot projects will be needed to identify technologies that can be successfully, and reliably, employed on Cape Cod to remediate water quality.

Water Reuse

Over 97% of water on earth is salty and nearly 2% is locked up in snow and ice. That leaves less than 1% of water for human uses such as drinking, growing crops, household uses and commercial/industrial processes. This limited resource has driven the need for wastewater reuse.

The most common form of wastewater reuse is for non-potable purposes or water which is not used for direct human consumption. Treated wastewater is reused for beneficial purposes such as agricultural and landscape irrigation, industrial processes (such as cooling), toilet flushing and replenishing a groundwater basin (known as groundwater recharge). The quality of wastewater effluent to be reused is treated to standards, criteria and regulations considering the planned reuse.

"Gray water" is the term for the reuse of wastewater that originates from bathroom sinks, bath/shower drains and clothes washing equipment drains. Gray water can be reused onsite as a source of landscape irrigation. Recycled water can satisfy most water demands, as long as it is adequately treated to ensure water quality appropriate for the use. As for any water source that is not properly treated, health problems could arise from drinking or being exposed to recycled water if it contains disease-causing organisms or other contaminants.

Given the challenge of identifying new wastewater disposal sites, the reuse of treated effluent on Cape Cod should be considered in watershed solutions. MassDEP has promulgated regulations defining the reuse of treated wastewater depending on its final disposition. See Appendix 4A; Wastewater Reuse for more information.

Septage

Some significant percentage of wastewater generation will continue to rely on septic systems, at least into the foreseeable future. Consequently, there will continue to be demand for septage treatment. In the near future Barnstable County anticipates the release of the Septage and Food Waste Market Study prepared for the Town of Orleans by Stantec. Similar studies may be appropriate in other parts of the Cape to address the demand for septage processing, identify available facilities, and assess capacity. See Appendix 4A; Solids Collection, Treatment and Disposal Technologies for more information.

Recommendation I4.4:
Barnstable County or towns should commission septage studies to evaluate the demands for septage treatment.

Resiliency to Climate Threats: Sea Level Rise and the Potential for Increased Storm Severity

Massachusetts' climate has changed and will continue to change over the course of the next century. Winter temperatures are increasing and extreme summer heat events are becoming more frequent (Massachusetts Climate Change Adaptation Report, Massachusetts Executive Office of Energy and Environmental Affairs and the Adaptation Advisory Committee, 2011). The high emission scenario of the Intergovernmental Panel on Climate Change (IPCC), predicts that Massachusetts will experience a 5-10°F increase in average ambient temperature by the end of the century. The report cites further predictions that there will be 28 days each year that reach above 100°F, compared to only two days annually today.

Climate change will also affect water resources and coastal processes in Massachusetts. Under very conservative estimates, sea level will rise approximately 10 inches per century, which will increase the height of storm surge and associated coastal flooding frequency, inundate low-lying coastal areas, and amplify shore-line erosion. Even with successful mitigation strategies, these climate trends will continue for generations and new trends, such as increased intensity of hurricanes, are expected to emerge.

Cape Cod is vulnerable to these changes in climate. With 586 miles of tidal shoreline and only 10 miles of land at its widest point, the entire peninsula is vulnerable to the forces of storm activity, sea-level rise and catastrophic forces of hurricanes and nor'easters. The National Climate Assessment has documented an increase in heavy downpours, or extreme precipitation events, since 1958 in the Northeast region of the United States. Sea level rise will increase the region's risk to coastal flooding especially when coupled with extreme precipitation events and increases in hurricane intensity. Also, as a result of sea level rise, water levels will rise and damage infrastructure and property along the Cape Cod coastline.

While the effects of climate change are projected to occur in the distant future, it will take years to develop and implement adaptation strategies for the region. The Section 208 Plan Update provides an opportunity to determine how to adapt the region's water infrastructure to changes in climate, particularly as siting and construction of new infrastructure are considered.

The Association to Preserve Cape Cod, in partnership with the US Geological Survey (USGS) and the Cape Cod Commission, is conducting an assessment of the impacts of sea level rise on groundwater conditions in the Sagamore and Monomoy Lens. This study will assist the Commission

and towns in identifying vulnerable areas for proper infrastructure management. The results are anticipated in 2016.

An assessment of the threats to, and resiliency of, each nutrient management technology to the primary climate-related risks anticipated on Cape Cod was developed as part of this plan. For example, many of the techniques that rely on biological communities may benefit from increased air and ocean temperatures, improving performance through lengthened growing seasons. At the same time, anticipating increased intensity of downpours suggests that stormwater systems should be designed to accommodate higher runoff volumes.

In assessing the technology options, the following possible climate-related risks were identified:

- Damage to, or increased degradation of, structures and materials.
- Mobilization of contaminants into the environment as a result of storage system failures.
- Backflow of saline water into wastewater systems causing overflows, increased degradation of materials and change in biological processes.
- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water.
- Destabilization of wastewater infrastructure as a result of change in groundwater levels or erosion.
- Restricted ability to access systems to collect outputs or re-use outputs due to salinity.

The following solutions were identified to help minimize the impact of the identified risks:

- Design systems to avoid hazard areas, or allow migration of vegetation as hazard areas change.
- Select materials, coatings and species that are able to cope with an increasingly saline environment.
- Install backflow valves on systems
- Anchor buried infrastructure
- Ensure frequent maintenance inspections to monitor infrastructure condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets).
- Use protective structures to reduce wave or wind impacts to systems.

See Appendix 4A; Sea Level Rise and Storm Surge Risks to Technology Options for more information and Appendix 4D for a summary of the risks and solutions that are relevant to each technology option that was assessed.

Ocean Acidification

Ocean acidification (OA) is one of the lesser-understood effects of increased carbon dioxide in the atmosphere. According to some research, one quarter of fossil fuel emissions fall on the ocean, causing it to acidify. There is evidence that acidification of the oceans may have significant impacts on ocean ecosystems. Shellfish growers in the Pacific Northwest have observed declining oyster harvests linked directly to ocean acidification. Scientists have documented poor shell development in certain classes of plankton under increased ocean acidity (WHRC Ocean Acidification and Southern New England Conference, October 2014). As ocean pH declines in ocean waters, direct impacts may be observed in some marine organisms, disrupting estuarine and marine ecosystems, affecting the fishing economy, and possibly having adverse effects on some of the technologies that have shown promise in mitigating the nutrient loading problems in coastal waters. More research is needed to understand the effects of ocean acidification on shellfish and other organisms on Cape Cod. In the meantime, OA should be recognized as one of the potential challenges in implementing restoration-based techniques over the long-term.

Contaminants of Emerging Concern

Contaminants of emerging concern (CECs), as described in Chapter 2, include chemicals found in the environment where the risk to human health and the environment is not well known. The US EPA identifies CECs, including pharmaceuticals, personal care products, polybrominated diphenyl ethers (PBDEs) and perfluorinated compounds (PFCs) as requiring further study. The US EPA has undertaken national testing for CECs in public water supplies, referred to as the Unregulated Contaminant Monitoring Rule (UCMR). Monitoring is required for

supplies serving over 10,000 connections or by voluntary action. A number of water suppliers have volunteered to have their supplies tested. As data becomes available through the UCMR the US EPA will be able to target more prevalent contaminants for review, research and action.

Several stakeholders have raised questions about how the technologies considered for water quality remediation might address CECs, and how the plan will address this growing concern. There is still a lot to understand before action can be taken: what priorities to set, what technologies can address the priority contaminants, and what other actions to take to prevent the introduction of CECs into the waste stream. The study and regulatory changes that may be needed are outside the scope of this plan update, but should be the continuing focus of federal and state research and regulatory bodies.

Identifying Suitable Locations for Non-Traditional Technologies: GIS Screening Analysis

The alternative technologies offer different opportunities and limitations for application in the development of watershed-based solutions. Many of the considerations for siting a technique are based on the physical characteristics of the land. During the section 208 planning process, identifying viable potential sites for specific nutrient management techniques became an important objective in understanding the opportunities for using alternative technologies on Cape Cod. With this goal in mind, criteria were selected that define the necessary characteristics for identifying an appropriate site for a particular alternative technology. These criteria were then applied through a Geographic Information Systems (GIS) parcel analysis to rank potential sites for their suitability to support a given technology, and illustrate these opportunities in a map. These GIS site screening analyses have been performed for several alternative technologies, including:

- Constructed wetlands
  - For wastewater treatment
  - For groundwater treatment
  - Saltwater wetland expansion, migration, or restoration
- Phyto-technology
- Permeable reactive barriers - injection well
- Permeable reactive barriers - trench
  - Trench type along roads
  - Trench type in areas other than along roads

The results of these analyses, as well as relevant resource information, will be made available as a resource through the Watershed Team technical assistance program, as described in Chapter 5. Additional GIS screening analyses are needed for additional technologies.

More detailed information on the criteria identified for each technology and how the screening was applied may be found in Appendix 4E.

Selection of Pilot Projects

Many of the practices identified for nutrient management need to be piloted locally in order to determine their effectiveness and identify with more certainty potential construction and operation and maintenance costs. Some of the techniques collected in the Technologies Matrix show more promise for positively contributing to nutrient management on Cape Cod than others. The most promising practices have been identified as such in the summary descriptions presented earlier in this chapter.

Many of these, however, require site-specific evaluation to determine their applicability on Cape Cod, and are recommended for piloting. To minimize risk and avoid having many communities expend funds and time to design and install technologies that may not perform as hoped, a small number of pilot projects should be implemented in settings that allow for fair evaluation of performance. Site selection and pilot project design should also ensure that the results may be transferred to other Cape Cod settings, to the extent feasible.

As part of the Section 208 Plan Update, the Cape Cod Commission suggests that criteria for identifying and evaluating potential technologies and specific sites eligible for pilot programs on Cape Cod be established.

Recommendation S4.5: The Cape Cod Commission, in conjunction with MassDEP, shall establish criteria for eligible pilot projects.

The criteria should include factors that will ensure that the pilot projects fairly evaluate performance, and also allow for transferability among Cape Cod communities .

Recommendation S4.6: In coordination with US EPA and MassDEP, the Cape Cod Commission shall work with communities, state and federal agencies to identify opportunities to implement pilot projects in suitable locations across Cape Cod.

Several locally supported pilot projects are in progress or anticipated by the towns and are discussed in more detail in Chapter 2. These include aquaculture in Wellfleet, Falmouth and Mashpee, eco-toilets in Falmouth and testing of I/A systems by the BCDHE at the septic system test center.

The United States Environmental Protection Agency (US EPA) received $2 million in funding in FY14 to begin implementing the Southeast New England Coastal Watershed Restoration Program (SNECWRP). SNECWRP is a partnership among public and private stakeholders collaborating to create a broad ecological and institutional framework for protecting and restoring the coastal and watershed area in Connecticut, Rhode Island and Massachusetts.

In FY14, the two National Estuary Programs (NEPs) – Narragansett Bay and Buzzards Bay – awarded $723,869 and $728,559, respectively, on behalf of SNECWRP for projects in their study areas. The Buzzards Bay NEP awards included a $50,000 award to the Buzzards Bay Coalition to fund restoration efforts in Red Brook Harbor in Bourne through the development of a public-private partnership that will supply wastewater treatment to an existing development and a $250,000 award to the Town of Falmouth to upgrade septic systems adjacent to West Falmouth Harbor. An additional $500,000 in technical assistance through a US EPA contract was awarded to the towns of Barnstable and Chatham to develop preliminary stormwater best management practices (BMPs). Project selection required an emphasis on demonstrating early environmental success and/or laying the groundwork for more expansive efforts in the near future. It is anticipated that similar future federal funding will be available to support pilot projects in the region.

Monitoring

Monitoring for water quality improvements and performance of technologies will be necessary elements of implementing the Section 208 Plan Update. Monitoring is important to measure progress toward meeting water quality goals; it will provide baselines and metrics for adjusting a watershed approach through an adaptive management plan. This section summarizes some of the necessary components of monitoring for water quality improvement on Cape Cod.

EXISTING MONITORING

All of the embayments studied by the Massachusetts Estuaries Project (MEP) have established stations that were monitored for a period of three years or more for development of the technical reports. Monitoring of embayment water quality is continuing on a year to year contract basis with some towns, but a number of programs have been reduced or discontinued. The Cape is fortunate that many ponds continued to be monitored through the Pond and Lake Stewardship (PALS) program and that specific pond assessments and restoration projects are proceeding. Drinking water supplies and wastewater treatment facilities continue to be monitored through state permitting programs. Some stormwater outfalls are monitored as part of NPDES compliance and more monitoring will likely be required under the proposed draft Municipal Separate Storm Sewer Systems (MS4) permit. In many cases, active monitoring programs rely heavily on citizen volunteers. The development of watershed scenarios will require baseline monitoring of affected water bodies to establish water quality metrics and goals. Ongoing monitoring specific to informing whether progress is made toward meeting watershed goals or an individual pilot project's performance will need to be customized to the setting.

NON-TRADITIONAL TECHNOLOGY MONITORING

The need to better understand the effectiveness of non-traditional technologies will require rigorous technology-specific performance monitoring. At a minimum, a

monitoring protocol should include an assessment of downgradient resources or sensitive receptors, placement of monitoring stations, parameters of evaluation, methods for collecting and analyzing data, and frequency of data collection. Reasonable time frames for piloting a project must be established, and should take into account:

- acceptable timeframes for achieving water quality goals,
- extent of water quality degradation,
- anticipated time for performance, and
- occurrence of anomalous events, such as hurricanes or other weather.

Monitoring protocols for non-traditional technologies are in development. These draft protocols will be made available in a technical guidance document by September 2015. Specific protocols will need to be developed as pilot projects move forward.

Monitoring to understand the impacts of stormwater infrastructure upgrades and the effectiveness of fertilizer reduction programs will also require site-specific monitoring and extrapolation of performance and compliance monitoring results to determine effectiveness.

Recommendation I4.7:
Performance monitoring shall be required for all technologies.

MONITORING COMMITTEE

With the extensive monitoring required to implement the Section 208 Plan Update, an ad hoc Monitoring Committee was established in April 2014 to review monitoring needs and make recommendations. The Monitoring Committee has discussed non-traditional technologies and characterized general monitoring approaches for piloting. The Committee is developing eight conceptual protocols for aquaculture, shellfish bed restoration, inlet widening, permeable reactive barriers, innovative/alternative septic systems, eco-toilets and constructed and floating wetlands. The Committee has been working to identify criteria for selecting and prioritizing pilot projects of nutrient remediation technologies, as well as developing a strategy and framework for evaluating the performance of these technologies. It is anticipated that monitoring data collected from the pilot projects will support updates to the Technologies Matrix. The Committee is also charged with developing specific recommendations for improving baseline and compliance monitoring in the region and identifying needs and services that will be necessary to support implementation of the Section 208 Plan Update. Committee recommendations will be detailed in a technical guidance document and implemented through permit conditions at the state and regional levels.

Recommendation I4.8: Draft monitoring protocols for non-traditional technologies shall be provided by the Cape Cod Commission based on input from the Monitoring Committee in a Technical Guidance document by September 2015.

It is recommended that the ad hoc Monitoring Committee become a standing committee and continue to support implementation of the Section 208 Plan Update. In addition, the Committee should identify and track developing issues (such as contaminants of emerging concern, or climate change) that may affect performance of technologies, or progress toward improving water quality in coastal embayments.

Recommendation I4.9: The Cape Cod Commission shall create a standing Monitoring Committee to support implementation of the plan and identify and track developing issues, such as CECs and climate change impacts to technology performance, subject to available resources.

DATA WAREHOUSE

Data collection to demonstrate progress toward water quality goals presents both an opportunity and a challenge. As conceived in this plan, the extensive monitoring recommended will result in large quantities of data that will need to be stored, managed, and made accessible to the public. A data warehouse and "custodians" are needed: significant storage capacity will be needed, as well as the structure to support the data, and a web-based interface. Technical studies, reports, and maps that may be generated as a result of data analysis will need to be housed and made available to the public. To date, monitoring data has not been readily available on Cape Cod.

The Commission's Strategic Information Office (SIO) currently maintains an expansive data warehouse, and the Commission's Watershed Management Program maintains a regional historic warehouse of water resources information on behalf of Barnstable County and the 15 towns. Data hosting and maintenance would be available for a robust monitoring program providing consistent and accurate data feedback loops among the towns and appropriate agencies. This Plan Update recommends that the Cape Cod Commission assume responsibility for monitoring and maintaining regionally consistent data sets that are freely accessible to the public. Maintaining data in a centralized, accessible location will allow information to transfer from one project to another, and assist the region in prioritizing projects based on water quality improvements and/or further degradation.

Recommendation I4.10: A regional water quality monitoring program and data warehouse shall be established and the Cape Cod Commission shall assume responsibility for monitoring and maintaining regionally-consistent data sets that are freely accessible to the public, subject to available resources.

05 EVALUATION

The Cape Cod Model - Regional Watershed Analysis

A watershed approach looks at the jurisdiction of the problem – watersheds. Of the 53 watersheds to coastal embayments on Cape Cod, 32 are shared by more than one town. The current regulatory process often requires town wide planning which, in many areas, represents only a partial solution to the problem. This document outlines a technical review process designed to provide insight into new and innovative ways of implementing solutions at the watershed level. Conversations to date have resulted in polarizing local debates, sometimes discussed in terms of centralized versus de-centralized approaches or traditional solutions versus alternative solutions. One of the key distinctions depends on a considered option's reliance on a permanent physical connection among multiple sources, a collection system. The process outlined in this report grouped points of view associated with these categorizations into two approaches to solving Cape Cod's nitrogen problem: a traditional approach and a non-traditional approach.

TEAM 1

Collection Systems

cost and effectiveness
septic nitrogen load
economies of scale
potential limitations
permittable

Traditional Approaches

TEAM 2

Non-Collection Systems

total controllable nitrogen load
watershed/embayment options
innovation
nitrogen reduction credits
no collection

Non-traditional Approaches

Scenarios define the outer bounds of an adaptive management plan

EVALUATION

Chapter 5: The Cape Cod Model - Regional Watershed Analysis

The regional analysis of watersheds began with a review of local nutrient management planning, consideration of the best available scientific assessments and the collection of all relevant geographic data. Most Cape Cod communities have been engaged with nitrogen planning but few have moved forward to construct watershed scale projects capable of protecting and restoring water quality.

It's not a lack of awareness on the issue. Many local decision-makers have an understanding of the nitrogen problem and the accompanying environmental and economic threats. Wastewater always ranks high in surveys inquiring about the biggest challenges for the region. Education is important, but it's not the reason communities have struggled to address the problem.

Image on facing page: The Section 208 Plan Update utilized two different technical teams to develop two different approaches in each watershed. The outcome is a hybrid process that considers both traditional and non-traditional technologies together in a watershed. Together, this process reflects the outer bounds of an adaptive management plan with a locally preferred combination of technologies for implementation.

It's not an engineering problem either. There are many engineering solutions that will remove enough nitrogen to meet standards. Many towns have offered such plans only to have them rejected by voters.

Existing regulation drives a traditional wastewater planning process, producing a predictable and narrow set of point source solutions to a non-point source problem without point source enforcement action. This creates an equally predictable implementation problem. The local communities sense the mismatch and resist the proposals. The existing regulatory framework is part of the problem.

It's a design problem. Proposed solutions have to be designed with more emphasis on the cultural identity of the community involved. The process should examine an expanded number of options and develop a range of simulated outcomes communicated in a geographic context with greater public participation and community engagement. The Cape Cod Commission, in the technical review and regional watershed analysis, piloted this approach. Lessons learned inform a recommended process for local communities in developing achievable water quality solutions by promoting efficient and effective watershed planning, expanding technologies and policies available to communities, and using new decision support tools to empower citizens and stakeholders.

A New Approach

Cape Cod's geology, density patterns and lack of existing infrastructure support a new approach to addressing water quality goals in the region. The Section 208 Plan Update suggests a new approach to gain consensus earlier in the process, to ensure that shared watersheds are addressed, and to better coordinate needed infrastructure expenditures with municipal budgets. Striving for stakeholder consensus early in the planning process, including consensus on the range and locations of technologies to be employed, will lead to more community support during implementation than Cape Cod communities have seen to date. Watershed scenarios should include more detailed discussions about the development of adaptive management plans to

identify phasing strategies for implementation, the risks and benefits associated with each technology, piloting and monitoring necessary to support the approach, and the ability of a community to pay for the solution.

The regional watershed analysis creates a framework for local decision-making. It does not attempt to produce a preferred solution, but instead provides decision-support tools to help define a range of possible options to meet water quality standards, leaving the selection of specific strategies to the local communities closest to the problem.

This approach integrates science, design and information. Evaluating environmental problems in a geographic context with active stakeholder participation and collaboration, the process interactively considers issues of representation, process, change, impact, evaluation and decision-making.

DECISION SUPPORT TOOLS

The Commission developed a number of decision support tools, using data described in Chapter 4, to facilitate the creation of watershed scenarios and adaptive management plans. These new decision support tools and the supporting databases and methodologies will be available through the Cape Cod Commission's Watershed Team technical assistance program discussed later in this chapter. Some are still in development and/or undergoing beta testing. These tools make complex data sets easier to understand and provide an avenue for increased informed deliberation at the local and hyper-local planning levels, expediting the selection and implementation of watershed solutions.

Tools related to scenario development include the following:

- **WATERSHEDMVP (MULTI-VARIANT PLANNER):** A dynamic web-based, geospatial scenario planning tool developed by the Cape Cod Commission that allows technical experts and the general public to compare various water quality management options at scales ranging from the neighborhood, watershed and subregional level (www.watershedmvp.org).
- **WATERSHED TRACKER:** A companion tool to WatershedMVP that tracks nitrogen loads and interventions chosen by the user.
- **SITE SCREENING VIEWER FOR NON-TRADITIONAL TECHNOLOGIES:** A geographic information systems (GIS)-based data analysis of non-traditional technologies and approaches to weigh potential nitrogen attenuation enhancements, improvements to existing green infrastructure networks and conditions necessary to maximize effectiveness.
- **WATERSHED CALCULATOR:** A tool used to track cumulative nitrogen reductions and cost through the layered application of technologies in a watersheds to meet reduction targets.
- **TECHNOLOGIES MATRIX:** A flexible, dynamic and continually updated source of performance and cost information on currently available technologies and approaches for reducing nitrogen from wastewater, groundwater and saltwater and their applicability for use on Cape Cod.
- **SCENARIO ASSESSMENT MODEL (SAM):** A web-based assessment and decision model that allows communities to identify priorities and evaluate scenarios in terms of social impacts, reliability of solutions, and cost considerations.
- **BARNSTABLE COUNTY COST REPORT UPDATE:** The 2014 update by AECOM to the 2010 report "Comparison of Costs for Wastewater Management Systems Applicable to Cape Cod" by the Barnstable County Wastewater Cost Task Force (2010 report prepared by the Barnstable County Wastewater Cost Task Force) on Cape-wide collection, treatment, disposal, and non-traditional approaches prepared to provide an updated basis for financial decisions in the Section 208 Plan Update.

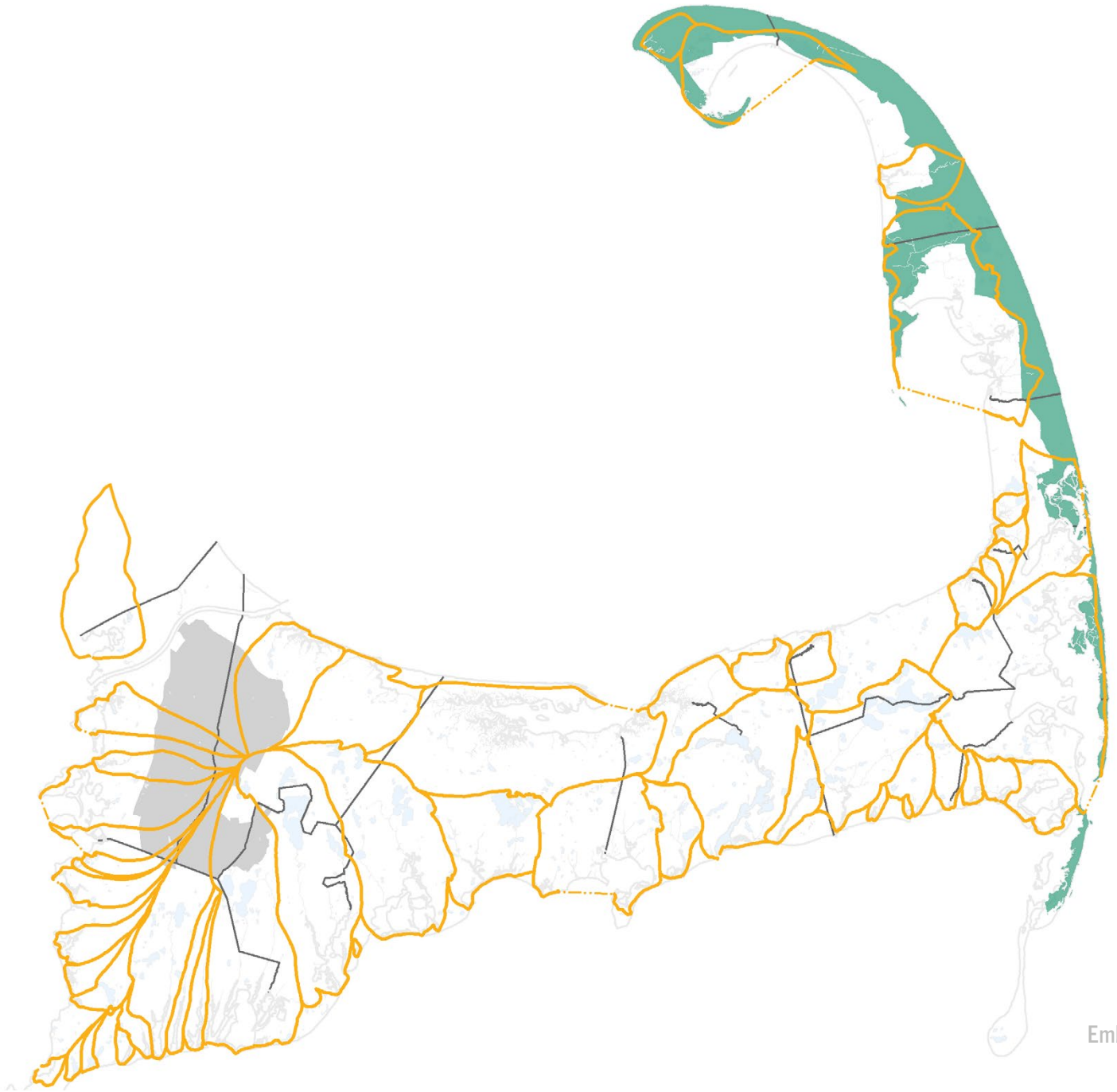
Watershed Based

Watersheds define the jurisdiction of the nitrogen problem.

A watershed is a geographic area separated from other regions by drainage divides within which all water flows to

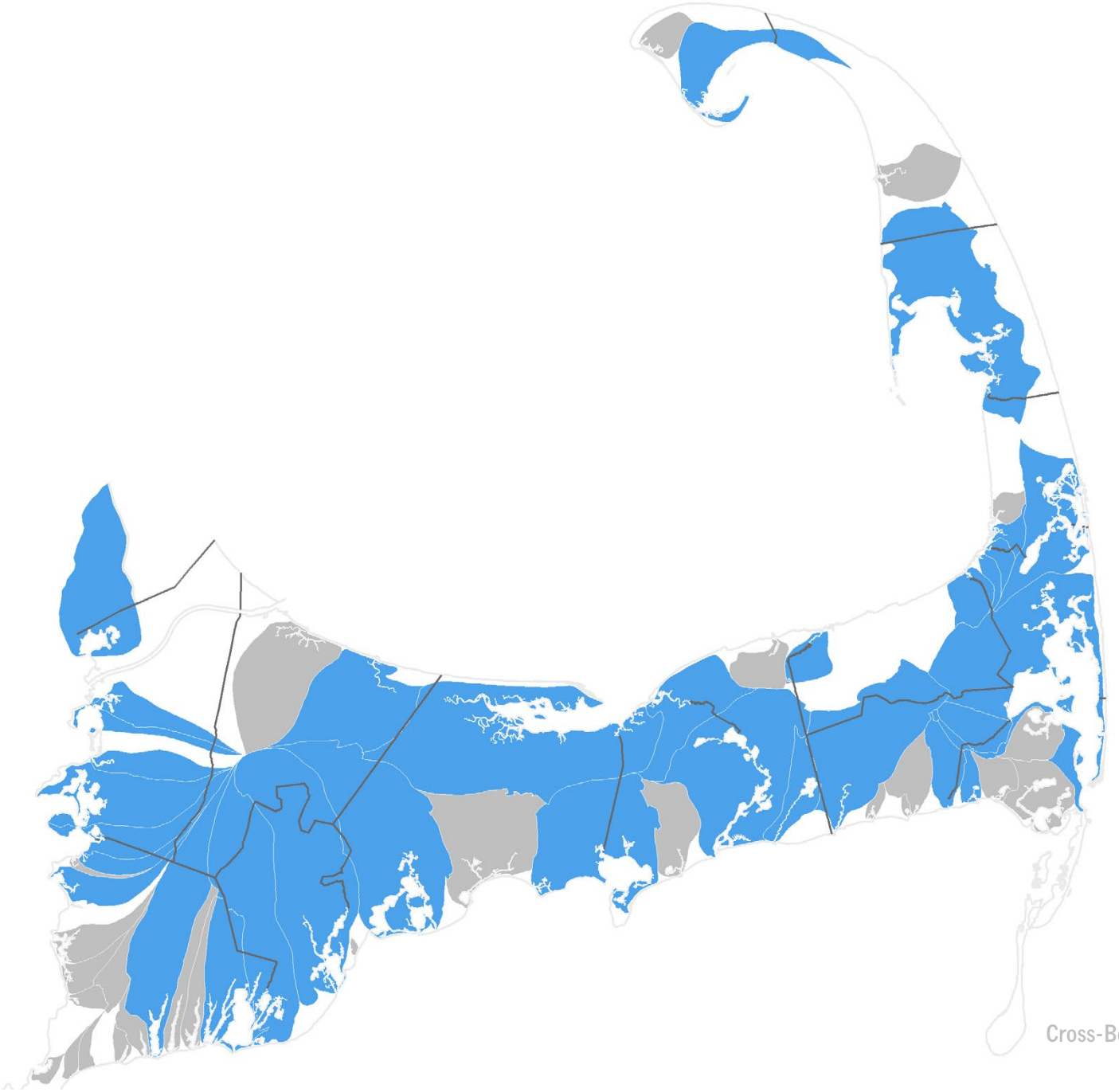
Decision Support Tool Data

WatershedMVP utilizes updated land use and water use data to inform wastewater load calculations, nitrogen load calculations and scenario planning. See **Appendix 5A** for more information on decision support tool data.



Embayment Watersheds

Figure 5-1



Cross-Boundary Watersheds

Figure 5-2

a common outlet, such as an embayment. There are 101 watersheds that flow to the surrounding marine waters of Cape Cod. Due to the highly-permeable nature of the Cape's geology, its watersheds are delineated based upon groundwater flow and water table maps. Fifty-three are watersheds to semi-enclosed coastal embayments (see **Figure 5-1**).

The remainder flow directly to Cape Cod Bay, Nantucket Sound, Buzzards Bay or the Atlantic Ocean. The coastal embayments are located at the margin of the aquifer and are the ultimate receiver of the aquifer's groundwater discharge. The south side embayments are more heavily impacted by nutrients and pollutants within the watershed, as they are shallower and receive less tidal flushing than water bodies on the north side.

Watersheds do not follow the municipal boundaries separating one town from another. Of the 53 watersheds to coastal embayments, 32 are shared by more than one town (see **Figure 5-2**).

Many of these watersheds have established total maximum daily loads (TMDLs). See Appendix 5B for details on each watershed, including characteristics, such as size and development, contributing towns, and TMDL status.

Comprehensive wastewater management plans (CWMPs) are a key step in addressing current and future wastewater needs in order to meet TMDLs; however, CWMPs are typically completed on a town-wide basis.

A watershed approach looks at the jurisdiction of the nitrogen problem – all of the contributing sources within a watershed and the receiving water, without regard to political boundaries. As discussed in Chapter 2, estuary water quality problems on Cape Cod have been negatively impacted by increased nitrogen generated by wastewater, fertilizer and stormwater runoff as a result of development that has outpaced infrastructure.

While watersheds define the jurisdiction of the problem, wastewater planning on Cape Cod has rarely been completed on a watershed basis. Communities have had difficulty implementing town-wide CWMPs that are perceived as too expensive and inflexible. The result often orphans necessary plans to address degraded water quality in individual watersheds . Communities shouldn't have to plan to the municipal jurisdiction. This regional water quality plan provides the background to support the design of local targeted watershed plans to result in faster, better and less expensive plans that yield higher rates of implementation.

Planning jurisdictions defined only by municipal boundaries will not necessarily meet TMDLs established for shared watersheds and often results in a plan so large and so expensive that it becomes difficult for a community to commit funding. A targeted watershed approach that does not require planning within the entire municipality, but instead, focuses on addressing the entirety of a watershed becomes more manageable and directly focused on the problem.

TARGETED WATERSHEDS

Designated Waste Treatment Management Agencies (WMAs) for those watersheds designated by this plan as nitrogen-sensitive are eligible for Targeted Watershed Management Plans (TWMPs).

Targeted watershed plans will qualify for expedited review and comprehensive permits with component reduction, remediation and restoration projects eligible for funding through existing and proposed resources identified in this Section 208 Plan Update, including the State Revolving Loan Fund.

TWMPs will include baseline water quality information and a nutrient management program (NMP) identifying watershed-based solutions to nitrogen over-loading of coastal waters.

TWMPs and CWMPs will be reviewed as Capital Developments of Regional Impact reviewed for consistency with this Section 208 Plan Update and the Cape Cod Commission Act.

A new approach supporting Targeted Watershed Management Plans (TWMPs), based on watershed boundaries, is recommended.

Recommendation R5.1:
Targeted Watershed Management Plan (TWMP) guidance including minimum performance standards for nitrogen in degraded water bodies shall be drafted and issued by the Cape Cod Commission, in concert with MassDEP, pursuant to this update within 90 days of its approval.

REGIONAL OPPORTUNITIES AND ECONOMIES OF SCALE

Working at the watershed level to develop local solutions makes the most sense from an environmental perspective; solutions should be identified within the jurisdiction of the problem. However, realizing potential savings from regional approaches may assist communities in implementing solutions. The following factors influence the cost of traditional infrastructure (Cape Cod Commission 2013):

- **EXTENT OF SEWERS:** Wastewater collection costs represent about 70% of the cost of constructing a system of sewers, treatment plants, and effluent disposal facilities. Costs can be reduced by focusing on the most densely developed areas, where the least amount of sewer pipe is needed to collect wastewater flows requiring nitrogen control. A cost advantage of the watershed-based approach is the assumed greater ability to find and serve these densely developed areas regardless of town boundaries. Watershed scenarios may be combined on a subregional level where densely developed areas cross watershed boundaries
- **GROWTH:** Growth in nitrogen-sensitive watersheds carries a heavy price. While only a portion of the existing nitrogen must be removed in these areas, all of the future nitrogen load must be mitigated. A 15% growth in wastewater flow translates to a potential 20% increase in capital cost. A 30% growth potentially increases the capital cost by 40%.
- **LOCATION OF EFFLUENT DISPOSAL SITES:** Even highly-treated effluent contains some nitrogen. If effluent is disposed of within nitrogen-sensitive watersheds as opposed to non-sensitive locations, more septic systems in that watershed must be eliminated or fitted with denitrification systems to meet the TMDL. If land availability within a town dictates that effluent must be disposed of in water supply recharge areas, then a higher level of treatment is needed at sharply increased costs for both capital facilities and for operations and maintenance (O&M). Looking regionally may increase the number of potential disposal sites in non-sensitive locations.
- **ECONOMIES OF SCALE:** Cost efficiency of wastewater treatment generally increases with flows treated. Significant cost savings can accrue if Cape Cod wastewater is treated at expanded existing public facilities, with selected new facilities, as needed, compared with a larger number of smaller facilities. Cost savings attributed to economies of treatment must be balanced with costs of conveying wastewater from collection areas and to disposal facilities.

With funding from Barnstable County, the Town of Orleans supplemented its CWMP with a focused study of the options available to share wastewater facilities with the towns of Eastham and Brewster. The details of this evaluation are presented in the December 2009 Wastewater Regionalization Study (Orleans-Brewster-Eastham) (Wright-Pierce 2009). Compared with each town building its own separate wastewater facilities, two-town and three-town regional solutions identified potential cost savings of 6% to 9% for capital costs and 18% to 25% for O&M costs.

Consideration of shared traditional infrastructure, as well as cooperative agreements to implement non-traditional technologies, should be given full consideration in order to limit the financial burden of water quality improvements to the community.

EXPANDED OPTIONS

SCENARIO PLANNING

Disagreement about technology solutions has resulted in polarizing local debates, sometimes discussed in terms of centralized versus de-centralized approaches or traditional solutions versus alternative solutions. One of the key distinctions depends on a considered option's reliance on a permanent physical connection of multiple sources to a collection system. The scenario-building approach

presented in this report used two contrasting approaches to solving Cape Cod's nitrogen problem, a traditional approach and a non-traditional approach, as an initial means to compare technologies and their effectiveness.

Watershed scenarios are a set of possible actions and interventions to meet nitrogen TMDLs and test the effectiveness of one or more combinations of potential solutions within a watershed. "Traditional" and "non-traditional" scenarios represent the limits of these two different approaches and define the parameters within which future scenarios can be developed. Two scenarios were developed for each watershed on Cape Cod and will be available through the Cape Cod Commission's Watershed Team technical assistance program discussed later in this chapter. The scenarios developed are NOT recommended, or preferred alternatives. Rather, the scenarios:

- Demonstrate the deployment of a wide spectrum of nutrient reduction technologies available to stakeholders when considering local options;
- Serve as an example of the Section 208 Plan Update recommended methodology to analyze both traditional and non-traditional technologies before making water quality management decisions;
- Provide a valid starting point for discussions about building local consensus for water quality management planning;
- Demonstrate the range and effectiveness of tools and methods developed by the Commission to assist stakeholders in creating conceptual level plans to support consensus building; and
- Define the possible scope of an Adaptive Management Plan.

Watershed scenarios were developed by two independent teams applying the following agreed upon conditions.

- Both teams used the same identified nitrogen targets (or the amount of nitrogen, in kilograms, that a water body can receive without exceeding the TMDL), as identified in the Massachusetts Estuaries Project (MEP) technical reports and TMDL reports for individual sub-embayments.
- Both teams attempted to solve the problem within the boundaries of the watershed.
- Both the traditional and non-traditional approaches utilized siting, performance, and cost information and data from the Technologies Matrix and the Barnstable County Cost Report and used WatershedMVP and the Watershed Tracker to make decisions about collection, treatment and technology siting.
- As a mutual point of reference, the traditional team evaluated a hypothetical analysis of an "all sewer" scenario and compared it to an "all innovative/alternative (I/A) septic system" scenario. Neither was necessarily a best choice for taxpayers or the environment, suggesting scenario approaches be targeted and mixed.

Traditional Scenarios

Traditional scenarios include centralized, satellite and cluster collection and treatment technologies and maintain as many homes and businesses on Title 5 septic systems as possible. This approach provides a reliable and predictable level of nitrogen source reduction with a known cost structure. Less advantageous considerations of traditional scenarios are the high cost of constructing collection systems in low-density residential areas inability to address nutrients already in the ground water.

Non-Traditional Scenarios

Non-traditional scenarios include use of other technologies and approaches as outlined in the Technologies Matrix. Many non-traditional technologies will intercept and remediate nutrient laden groundwater, resulting in the potential for faster water quality improvement. Non-traditional technologies that intercept groundwater remediate nutrients from stormwater and fertilizers,in addition to wastewater. However, many non-traditional technologies vary widely in performance and cost. They also don't reduce the source load and can be more difficult to permit. See Chapter 4 for a more detailed discussion of benefits and drawbacks of each technology identified in the Technologies Matrix.

TRADITIONAL AND NON-TRADITIONAL SCENARIO DEVELOPMENT

TRADITIONAL APPROACH

The traditional approach considered the greatest controllable source of nitrogen (wastewater) as a percentage of the whole, identified the most efficient groupings of wastewater sources in each watershed, and suggested collection and treatment options. In developing the traditional scenarios, the present watershed nitrogen loads and the amount of necessary reductions to meet the TMDL were determined.

NON-TRADITIONAL APPROACH

The non-traditional approach started with the premise that collection systems should be avoided or minimized to the greatest extent possible. Although conventional wisdom and practice suggests that economies of scale in the construction of wastewater treatment facilities result in the least expensive and most effective treatment, there is valid concern that the case studies supporting this view are from more urban communities with existing but degraded infrastructure. Cape Cod is missing both of these qualifications, having neither the urban density characteristics nor the existing infrastructure. Cape Cod has less than 4% of the population of the state and approximately 20% of the septic systems. Only 3% of the parcels and 15% of the wastewater flows on Cape Cod are centralized.

The Cape also has an attribute not shared by other communities - its seasonal second homeowner economy. The population of Cape Cod increases from 216,000 year-round residents to nearly 650,000 or more on any given day between Memorial Day and Labor Day, hosting an average of 7.2 million people in that four-month period. Wastewater treatment facilities designed for the four weeks of potential peak flow would have a much larger capacity than needed 48 of 52 weeks a year.

Additionally, there are people in every community advocating for wastewater solutions that rely less on structural interventions, which may be less sustainable over time, than strategies that favor the modification of natural systems. The technologies and strategies prioritized in the non-traditional approach also tend to result in less movement of water between watersheds and put a greater emphasis on comprehensive system restoration or improvement.

The non-traditional team began with the same nitrogen removal target as the traditional team and began by assigning nitrogen reduction credits to the watershed for fertilizer reductions and stormwater management. The team then considered an array of watershed and in-embayment options, as detailed in the Technologies Matrix, consisting of a broad range of innovative nitrogen management strategies to intercept and treat nitrogen in the groundwater or to assimilate and treat it in the receiving waters. Watershed practices include permeable reactive barriers (PRBs), constructed wetlands, phytoremediation and fertigation wells, among others. Sites were located using the Cape-wide site screening analysis for non-traditional technologies described in Chapter 4. Embayment practices include, but are not limited to, shellfish bed restoration, aquaculture, floating wetlands, dredging and inlet modifications.

Stormwater and fertilizer constitute approximately 20% of the nitrogen load across Cape Cod and in some areas a higher percentage. The non-traditional team estimated watershed stormwater and fertilizer loads and applied a 25% reduction credit to those loads based on the adoption of management programs. Adoption of policies and development of capital projects are both recommended to achieve these levels of reduction.

For stormwater projects, certain reductions can be assumed based on site specific conditions and methods employed. Direct and untreated stormwater discharges are no longer allowed under the Massachusetts Department of Environmental Protection (MassDEP) Massachusetts Stormwater Standards and are being mitigated using a range of stormwater retrofit projects including infiltration, bioretention, vegetated swales and other low impact development (LID) practices. These retrofits will also contribute toward compliance with the emerging United States Environmental Protection Agency (US EPA) Municipal Stormwater Separate Storm Sewers (MS4) Program (discussed in Chapter 3) which will require regulated communities to address water quality impairments.

Significant efforts and accomplishments to reduce fertilizer impacts are also being instituted on Cape Cod. These include a successful program developed and instituted by the Cape Cod Golf Course Association to

reduce fertilized areas and rates that havs resulted in a reduction of approximately 50% of the applications. Similarly, a District of Critical Planning Concern (DCPC), adopted by the Cape Cod Commission in 2014, enables towns to develop regulatory programs to more carefully manage fertilizer applications, thereby reducing the rate of fertilizers leaching into the groundwater. Monitoring to prove that anticipated nutrient reductions are achieved will be required and reductions should be considered as part of the watershed adaptive management plan.

The next step in the non-traditional approach considered alternative on-site options that have been screened for geographic suitability. A number of alternative wastewater source controls were evaluated in this step. Ecotoilets are alternative toilets that target the source within the building. These include urine diversion (UD), composting, incinerating and packaging toilets where the waste materials are collected and temporarily stored before processing. These technologies allow little or no human waste to enter the septic system (only gray water from the shower, laundry and sinks). Social acceptability and significant, but improving, regulatory impediments had the team using these strategies in a targeted way (schools, for example).

The non-traditional approach produced a targeted starting point for consideration as part of an adaptive management program in most watersheds.

Together, the traditional and non-traditional approaches provide the tools and parameters around which towns within a watershed can develop locally-preferred options to meet TMDLs.

Development of these two approaches led to another distinction between technology options. Technologies and approaches can be grouped in to three categories: policy, collection, and non-collection. The primary difference between the categories lies in the need for a collection system, which is largely defined as a system for removing waste from the property, and in many cases is the most expensive component of a strategy. Locally developed plans should design watershed scenarios with an appropriate mix of technologies using a hybrid planning approach, which should be used as the basis for a NMP as part of a TWMP.

In order for expanded options to be permitted there has to be a sustainable and robust monitoring program.

TARGETED WATERSHED MANAGEMENT PLANNING - HYBRID WATERSHED APPROACH

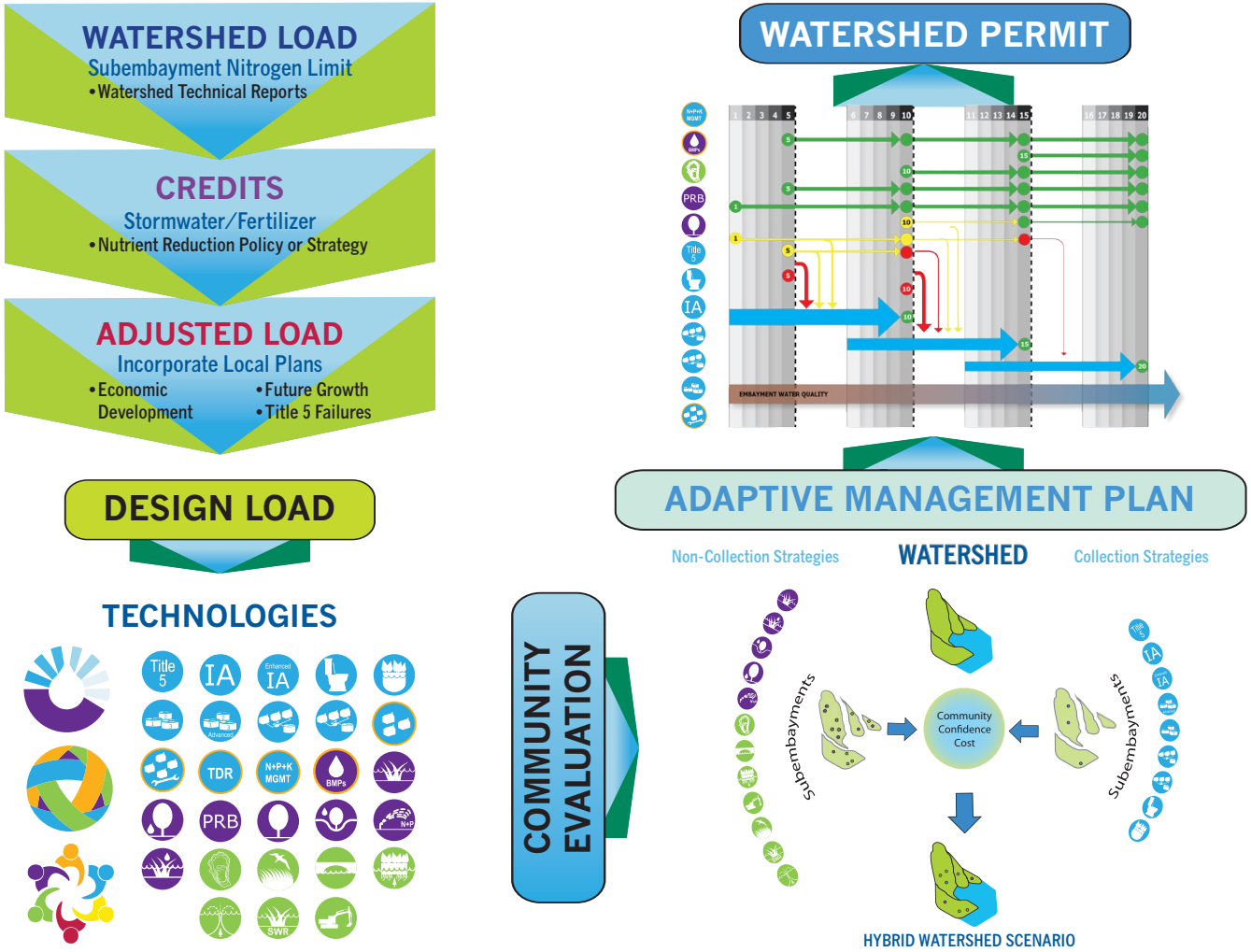
The technical review detailed above grouped technologies as “traditional” or “non-traditional.” That nomenclature was specifically defined for that purpose but its continued use may unnecessarily bias future planning and regulatory efforts. In the recommended adaptive planning format the contrasting approaches are referred to as collection management and non-collection management of nitrogen.

The recommended process encourages the establishment of an agreed watershed target for nitrogen reduction and then adjusts those targets by incorporating credits for nitrogen-reducing policies and any other nitrogen impacts of local plans. Structuring contrasting approaches to meet water quality standards sets the parameters for the public discussion. A subembayment consideration of a collection scenario and a non-collection scenario with the assistance of Cape Cod Commission decision support tools will allow local decision makers to move beyond “engineering” discussions and instead focus on issue of community, cost and confidence in identifying the most efficient and effective nitrogen management plan.

This planning process begins with identified nitrogen reduction targets and then sequentially and cumulatively reduces the load to achieve those targets. Depending on the embayment impacted, this process may be most effectively done on a subembayment scale (see **Figure 5-3**).

- **IDENTIFY TARGET REDUCTIONS AND GOALS:** To determine the level of intervention necessary to restore water quality in each embayment, nitrogen reduction goals are established for each watershed. Where MEP reports have been prepared or TMDLs established the values identified are utilized. For those watersheds where these studies have not yet been completed interim targets could be utilized. A 25% reduction of existing nitrogen is assumed as a placeholder for those watersheds without MEP reports and established targets. The reduction goals

Targeted Watershed Planning



Targeted Watershed Planning

Figure 5-3

are calculated as the difference between the existing load and the target load (**reduction required (kg)= existing load – target load**).

- **ESTABLISH DESIGN LOAD:** Cape Cod towns are actively targeting stormwater and fertilizer nitrogen, among other preventative measures, and developing mitigation projects/programs to reduce their loads. These efforts should be taken as a credit towards achieving the required nitrogen reductions. Aside from water quality restoration in coastal embayments there are a number of reasons a community may want or need to provide infrastructure within a watershed. Areas that cannot comply with Title 5, due to depth to groundwater, poor soils, inadequate setbacks or lot areas, among other reasons, need new infrastructure solutions. Communities may have identified growth areas, such as village centers and growth incentive zones, where high density is anticipated. Or pond recharge areas may be significant in the watershed. A design load is the total nitrogen load to be removed after accounting for other needs of the community and is calculated as the difference between the reduction required and the credits, with the addition of the non-nitrogen community needs (**design load (kg) = reduction required (kg) – credits + non-nitrogen community needs**).
- **NON-COLLECTION MANAGEMENT OPTIONS:** A broad range of innovative and non-traditional nutrient management options evaluated as part of the non-traditional scenario to intercept and treat nutrients along their flow paths through the watershed or to assimilate and treat them in the receiving waters (embayments) should be considered.
- **COLLECTION MANAGEMENT OPTIONS:** Alternative on-site wastewater source controls, such as ecotoilets and I/A systems, should be considered first in areas where a lack of housing density coupled with a need for nitrogen reduction are present. If the cumulative nitrogen reductions following the use of these source controls and the non-collection options have not achieved the required reduction then collection and treatment in these areas may be necessary.

This iterative process of comparing technologies based on available sites, cost efficiency and performance in a phased manner with community input allows consideration of "right-sized" infrastructure. It is recommended that targeted watershed planning efforts adopt this hybrid approach.

> **Recommendation S5.2:**
> **Targeted watershed planning efforts shall adopt a hybrid watershed scenario planning process.**

MONITORING

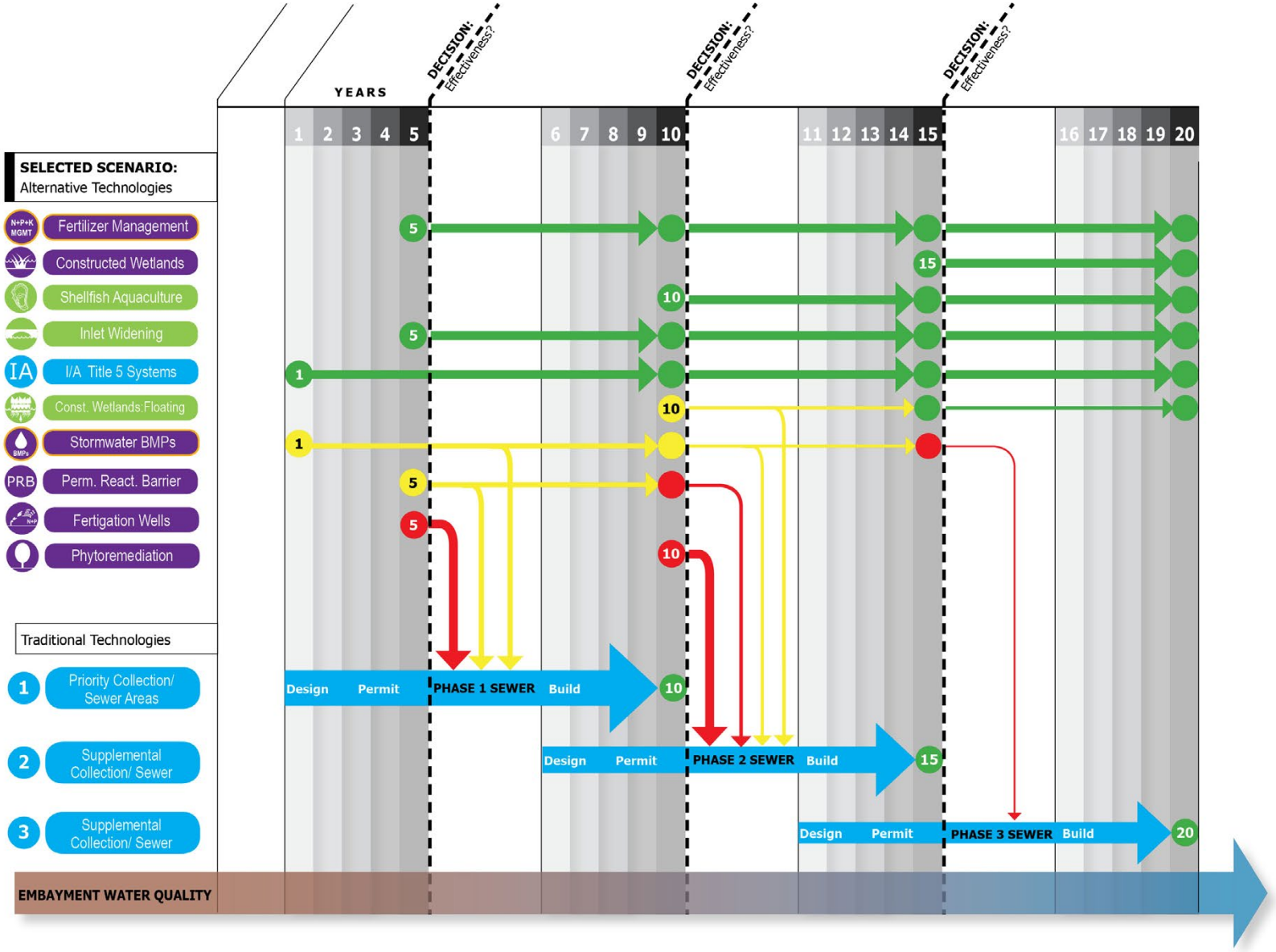
Monitoring is crucial to measure progress toward meeting water quality goals; it will provide baseline metrics for evaluating technology performance (pilot testing), TMDL compliance of the implemented solution, and adaptation of the hybrid plan to optimize TMDL compliance. Both performance monitoring and water quality monitoring will be necessary to determine success of individual technologies and changes in water quality. See Chapter 4 for more detailed information on monitoring.

ADAPTIVE MANAGEMENT

Adaptive management provides a framework to move forward efficiently with practices that can generate short-term results, and allow for adjustments to optimize the plan over the implementation period (see **Figure 5-4**). The proposed adaptive management framework enables a thorough vetting of new technologies while maintaining a secure foundation of proven traditional technologies. The plan provides a thoughtful process for integrating emerging and non-traditional technologies with traditional practices concurrently in watershed plans.

Applying this approach, each TWMP that is developed will have an adaptive management plan to condition its approval, with specific milestones and reporting.

Each TWMP will include a set of traditional and non-traditional practices assembled to meet identified nutrient reduction targets and desired water quality goals. Traditional technologies may best serve densely developed town centers, while non-traditional technologies may be applied in water bodies for short term water quality improvements. The adaptive management process provides a means to optimize this combination of technologies.



Adaptive Management Framework

Figure 5-4

In some watersheds a traditional sewering plan may be identified for construction during the first phase of implementation. Future expansion, or phases, of this core collection system will be part of the initial wastewater management planning, and will serve as the backup plan for future phases of the watershed plan in the event that the non-traditional practices do not perform adequately.

As discussed in Chapter 4, piloting some of the alternative technologies that show particular promise for remediating Cape Cod water quality problems is needed to establish performance of these technologies. In cases where pilots suggest that a technology will not perform as hoped, the adaptive management plan will identify a back-up strategy using more certain approaches that will lead to water quality improvement.

This adaptive management framework is structured in five year increments. This timeframe enables two years for the design, permitting and construction of technologies along with a minimum three year testing period. At the completion of each five year period, an evaluation of the performance of deployed technologies takes place. These assessments will include the achieved nutrient removal performance, cost effectiveness, and any associated co-benefits.

Technologies that meet the identified objectives can continue to be used and additional installations may be implemented in the watershed. In instances where partial success is realized, an evaluation of possible adjustments and improvements takes place and, if deemed appropriate, continued application of that technology may occur. Where poor performance is realized, further application of that technology will be discontinued or modified within that watershed.

Essential to the successful implementation of a TWMP is comprehensive monitoring of water quality within sensitive water bodies. Overall water quality improvements at the established MEP sentinel stations will need to be evaluated. This information will be integrated with the technology performance to determine next steps in the implementation of the watershed plan.

In recognition of the complexity associated with implementing a monitoring and adaptive management plan, the following components are recommended for inclusion and should be incorporated into Commission and MassDEP approvals and permits. These components include but are not limited to:

- Establishment of a technical review panel to meet regularly and comprised of local, regional and state representatives
- Pilot project design, development and monitoring
- Targeted watershed project funding, design, construction, and permit compliance
- Compliance monitoring including baseline water quality and habitat monitoring for estuaries

EMPOWER COMMUNITIES

Community Engagement is more than a box to check when developing a plan. Taking it seriously means making complex data sets easier for citizens to understand and use in local decision-making.

WATERSHED TEAMS

Municipalities are encouraged to consult with the Commission to ensure coordination between active watershed planning efforts and the Section 208 Plan Update and to establish consistency between proposed municipal plans and the Section 208 Plan Update with respect to the evaluation of wastewater needs, watershed management alternatives and alternatives analyses. The Commission will assign a Watershed Team to the specific planning efforts to assist with the decision support tools, permitting of technologies and financing.

Recommendation S5.3: The Cape Cod Commission shall assign Watershed Teams to provide technical assistance to Waste Treatment Management Agencies (WMAs) and municipalities.

COMPOSITION

Watershed teams may include experts in water resources, GIS, land use and economic development planning, finance modeling, legal/regulatory, technologies, and facilitation.

Water resources experts include hydrologists and engineers with extensive experience in Cape Cod's unique hydrogeology and water quality challenges. They can assist in developing targeted watershed plans by applying Watershed MVP and the Watershed Tracker, and can evaluate site-specific nutrient mitigation projects using groundwater modeling, and nutrient loading and mitigation assessments.

GIS analysts have direct access to the most current databases and are directly involved in the continual development and updating of GIS-based analytical programs such as Watershed MVP. They can provide screening for potential nutrient management sites, apply a GIS technology viewer that is designed to track and illustrate watershed management scenarios, and can optimize collection areas based upon an integrated density-frontage-proximity algorithm.

Land use planners are involved in updates to the Regional Policy Plan (RPP), local comprehensive plans, establishment of Critical Planning Areas of Concern, and conduct Regional Economic Strategy Executive Team (RESET) projects. They can advise on consistency of watershed plans with the RPP, buildout scenarios and related land use issues.

Legal and regulatory experts work closely with MassDEP and US EPA regulatory staff and are very familiar with the Section 208 consistency requirements. They can provide assistance with permitting, Massachusetts Environmental Policy Act (MEPA) compliance, regional arrangements, and the development and implementation of an adaptive management plan.

Non-traditional technology experts are directly involved in the state-of-the-art research (including performance and costs) on a broad range of green infrastructure and non-traditional technologies. They can provide assistance in selecting, siting, evaluating non-traditional/green infrastructure technologies, and in the application of Technologies Matrix and Watershed Calculator.

Facilitators have served a critical role in the successful development of the Section 208 Plan Update. They can assist the WMA with consensus building, public engagement and outreach and overall project management.

ROLE

The role of the Watershed Team is to provide assistance to communities in developing an effective local watershed restoration and management plan in compliance with the Section 208 Plan Update. The Watershed Team will work with towns, identified stakeholders and third-party consultants to develop an integrated hybrid plan that addresses identified water quality restoration goals and incorporates local preferences. Specifically, the Watershed Team can assist in developing a step-by-step approach to building a locally-supported watershed strategy. Specific tasks that the Watershed Team can assist with include:

- Developing a watershed plan outline, tasks and schedule including a consensus-building process and a public engagement strategy
- Developing a scope of services for a third-party contractor to provide specific engineering tasks necessary to compliment the Watershed Team
- Presenting Section 208 watershed plans to identify a range of options potentially-available to address the nutrient reduction goals
- Explaining and applying analytical tools including Watershed MVP, the Watershed Tracker, the Technologies Matrix and the Watershed Calculator
- Assisting in the development of a hybrid plan by providing recommendations for green infrastructure/non-traditional practices and traditional sewer collection systems
- Working with the WMA, stakeholders and third-party contractor to evaluate the feasibility of individual Hybrid Plan components using site-specific data and local knowledge
- Identifying and evaluating potential public/private options such as satellite wastewater treatment systems
- Working with the third-party contractor in developing comparative cost information

- Assisting in the development of permitting strategies
- Developing targeted monitoring plan and associated adaptive management

BENEFITS

Utilizing a Watershed Team positions a community to align their watershed planning efforts with the Section 208 Plan Update early in the process. There should be benefits to this approach. Benefits to a community utilizing this resource fall in to three categories:

- Technical Assistance
- Regulatory Flexibility
- Financial Resources

The Watershed Team provides interdisciplinary, watershed specific technical assistance, creating a clear path toward consistency with the Section 208 Plan Update. With consistent communication with a Watershed Team from the outset, communities should be able to bypass some of the regulatory review that would otherwise be required. As described in Chapter 3, it is recommended that the 2015 Update to the Regional Policy Plan (RPP) include a consideration for Capital Developments of Regional Impact (CDRIs), which would exempt capital planning projects, such as TWMPs, that have been deemed consistent with another regional plan from DRI review. Consistency with the Section 208 Plan Update and a CDRI certificate should allow communities access to new sources of revenue that are made available to the region (see Chapter 6 for a more detailed discussion on revenue).

Recommendation C5.4: Local targeted watershed management plans consistent with the Section 208 Plan Update should qualify for existing and potential revenue sources.

WATER RESOURCE CENTER

With decision making, project sponsorship and operations based at the local level, there remain certain activities and functions that, managed regionally, would benefit municipal operations, attract resources and lower costs to residents. Four specific functions: financing, monitoring, scenario analysis and septic management would all become cheaper and more beneficial in a regional service center than if left to the individual communities.

Enhanced or new authority would be needed to establish the capability to operationalize these services, but the descriptions below provide a brief synopsis of their potential:

1. Financing: A regionally-based financing capability would offer towns the option to seek financing from a regional entity rather than extend the town's full faith a credit as is currently required. A regional financing entity could be eligible for State Revolving Fund (SRF) loans and also attract additional funds to increase community access to additional subsidy. Financing through such an entity would preserve the town's full faith and credit for use in other municipal projects and would enable towns to proceed with projects based upon majority action by the voters of each respective community.
2. Monitoring: Adaptive management, as envisioned in this plan, relies on a robust program of water quality monitoring both pre and post implementation. The procurement of sentinel station monitoring of all embayments and near shore stations will lower the overall cost of monitoring while also relieving towns of a major and ongoing expense. An additional benefit of a unified approach to monitoring is the ability to ensure easy and consistent availability of monitoring results to the communities and the general public.
3. Scenario Analysis: As a part of the Section 208 Plan Update process the Commission has developed leading edge capabilities to analyze the outcomes and water quality implications of differing nitrogen management scenarios. The ability of communities to assess the costs and benefits of different alternatives will enhance local decision making and provide a low/no cost capability that would otherwise have to be procured by towns at great local expense.
4. Septic Management: Integral to the cost control strategy of this plan is the retention of as many existing septic systems as possible. Extending the useful life of septic systems to be retained will both lower and spread out the costs associated with system replacement. The scheduled pumping and maintenance of systems will also allow for the

optimization of the use of septage treatment. The current system relies exclusively on homeowners to properly maintain systems and also leaves them at risk of the high cost of replacement should a system abruptly fail.

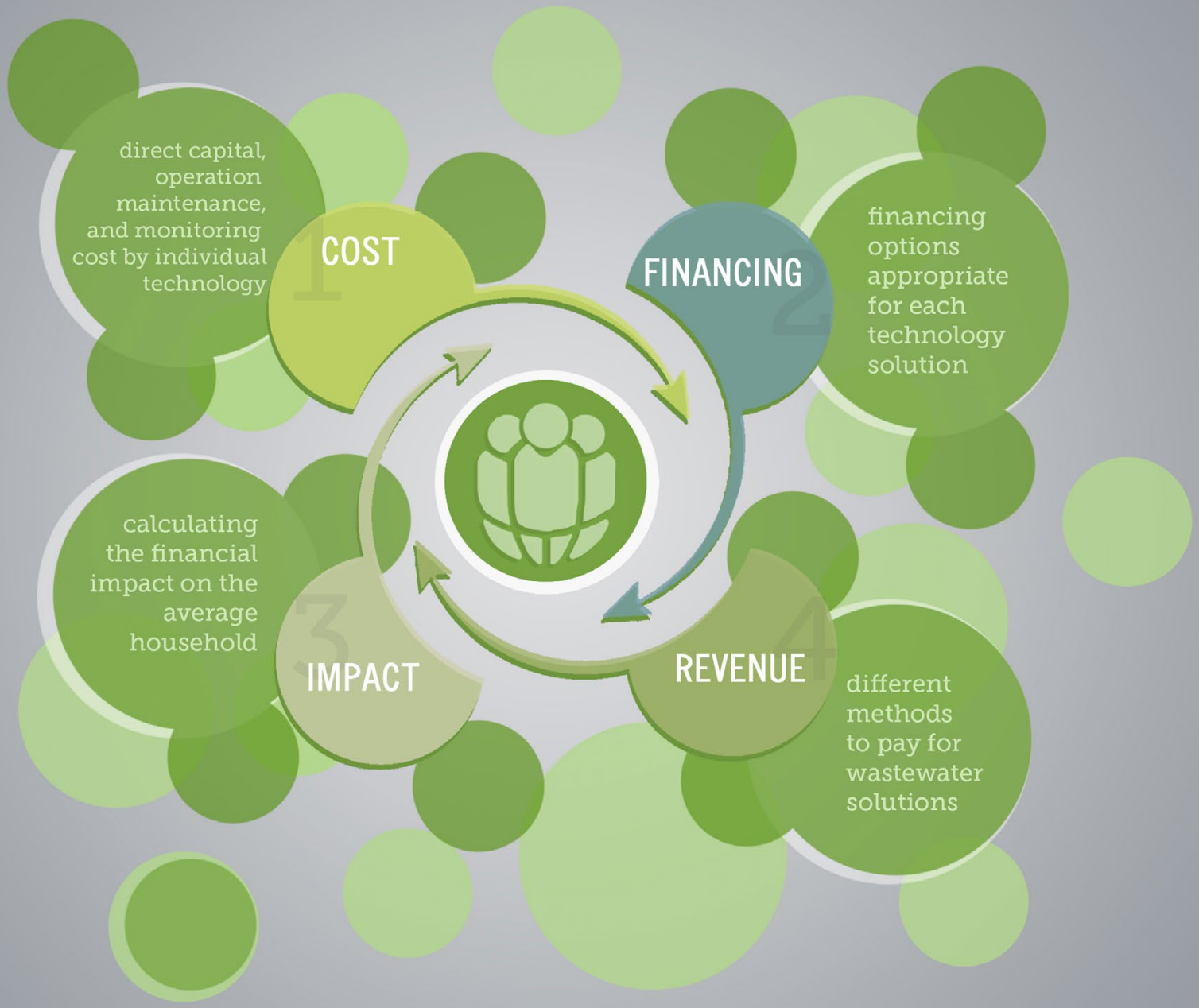
The institution of a regionally-based program that would ensure proper pump out and maintenance as well as providing replacement services would have the multiple benefits of extending the life of existing systems, controlling the flow of septage to treatment plants and protect homeowners from exposure to financial hardship associated with system failure. Such a system could be established based upon an annual septic fee that would cover the cost of pump out as well as replacement.

06 MONEY

Cost & Financial Affordability

A primary goal of this plan is to lower the cost of meeting water quality standards and spread the remaining costs equitably among all who enjoy and benefit from Cape Cod. In a region that has largely deferred and avoided the cost of necessary wastewater management, residents are appropriately sensitive to costs. The high cost of traditional approaches has been a major impediment to wastewater planning and implementation on Cape Cod.

Of particular concern to the region is its large seasonal fluctuation in population and wastewater flows. The need to accommodate the large flows experienced over a brief four week period – the last two weeks of July and first two weeks of August – creates an additional burden on the smaller year-round population.


direct capital, operation maintenance, and monitoring cost by individual technology
COST
FINANCING
financing options appropriate for each technology solution
calculating the financial impact on the average household
IMPACT
REVENUE
different methods to pay for wastewater solutions

MONEY

Chapter 6: Cost & Financial Affordability

The Cape Cod Economy

The Cape Cod economy is heavily seasonal with more than one third of its gross regional product (GRP) coming from tourism-related industries. With the arrival of second home owners and summer tourists, the population more than doubles at any given time in July and August. The region's infrastructure, including wastewater infrastructure, must be scaled to handle this population peak of approximately 650,000 people.

The GRP for Cape Cod hovers between $7 and $7.5 billion a year (between 1.5% and 2% of the gross state product). Significant portions of the GRP come from retail trade, real estate and rental activities, and accommodation and food service. Wages in these industries are generally low, and wages in Barnstable County lag behind the state and the nation. Moreover, Barnstable County is below the state median income, at $60,685, and wages have not grown in real terms since 1990.

The current (2014) equalized evaluation of property values for property tax purposes on Cape Cod is $77.8 billion for all 15 towns combined. The total property taxes collected (the levy) in 2014 was $615 million with an average single family tax bill of about $4,000 a year. In comparison, the average annual single family tax bill in Massachusetts is nearly $5,000.

A recent study by the Cape Cod Commission on the Three Bays watershed in Barnstable showed that a decline in water quality results in lower property values (http://www.capecodcommission.org/3bays/). Given the way property tax works, a reduction in coastal property values due to poor water quality will shift the tax burden to those with property away from the water and less able to absorb increased taxes not associated with any water quality improvement.

Image on Facing Page: Topics addressed in this chapter can be grouped in to four categories – the total cost of the solution, how to finance solution, how to pay for the solution, and how to address the financial impact on individual households.

Estimated Cost and Affordability

Just as Cape Cod's watersheds have a finite capacity to absorb nitrogen, the Cape's property owners have finite financial resources to implement solutions to address water quality impairments. The estimates for solving the Cape-wide problem through traditional centralized treatment, whether working town-by-town or watershed-by-watershed, range from $4.2 to $6.2 billion (Cape Cod Commission 2013). If paid through property tax betterments and user fees, the cost of such a traditional approach exceeds the United States Environmental Protection Agency (US EPA) affordability standard of 2% of median income being allocated to wastewater solutions. It's also important to note that the 2013 median income for Massachusetts is $62,963, leaving Cape Cod residents (median household income is $60,685), on average, less able to afford necessary wastewater infrastructure than other state residents.

Property owners on Cape Cod will not bear the burden equally, although most contribute to the problem and all

will benefit from its resolution. Much will depend on how the solutions are financed and what sources of funding can be employed. The challenge is to equitably and fairly spread costs among all who enjoy Cape Cod, from the year-round resident to the second homeowner to the tourist visiting for a week or a day. Just as this plan has advocated considering a variety of water quality solutions, it encourages consideration of many different revenue sources available at the federal, state, regional and local levels. A goal of the Section 208 Plan Update is to reach a common understanding that the burden of funding needs to be shared by everyone who benefits from a healthy Cape Cod environment.

This plan strongly encourages collaboration among towns to address the nutrient problem in the shared watersheds across the Cape. Conservative estimates from the Regional Wastewater Management Plan suggest that shared infrastructure and economies of scale could result in a savings of up to 9% on capital/construction costs and up to 25% on annual operations and maintenance costs (Cape Cod Commission 2013). This plan also encourages collaboration at the local, regional and state level to implement land use policies that focus future growth in those areas where wastewater treatment exists or can be constructed for the lowest cost and serve the greatest number.

Watershed Plan Cost Categories

PLANNING & DESIGN COSTS

Planning and design costs are incurred prior to any construction. Towns may access funds from the State Revolving Loan Fund (SRF) to support wastewater or watershed planning but much of the design must be covered using local funding sources.

CAPITAL COSTS

Capital costs are those incurred in the construction of any type of treatment system, including traditional collection and treatment technologies and non-traditional technologies, such as permeable reactive barriers or constructed wetlands. Capital costs are generally financed through borrowing, although some limited grant opportunities exist to lower the amount to be financed.

OPERATION AND MAINTENANCE COSTS

Operation and Maintenance (O&M) costs are the annual recurring costs of nutrient interventions, including nontraditional technologies, and keeping them in working order. O&M is generally paid for through fees or tax revenues as costs accrue. These costs are generally not financed using loan or bonding programs. O&M costs will vary greatly by technology solution and are estimated on a technology-by-technology basis in the Section 208 Plan Update Water Quality Technologies Matrix (Technologies Matrix), discussed in Chapter 4.

MONITORING COSTS

Monitoring is an essential component of adaptive management. Monitoring will assess the effectiveness of the different technologies at removing nutrients from the watershed. The results of monitoring will indicate which technologies are working and which are less successful. Permitted discharges are always required to undertake discharge monitoring and new technologies being piloted will also be required to monitor to determine actual performance.

In addition to monitoring of individual systems or management measures, baseline water quality will also be monitored to understand how marine systems are responding to the suite of management measures being implemented. The cost of this monitoring is significant, but small when compared to the potential savings in investment in unnecessary management measures should monitoring not have undertaken. Monitoring costs are typically considered an operating expense and paid for as they are incurred.

One way to manage costs is to consolidate the monitoring of sentinel stations around Cape Cod. Both the Section 208 Plan Update Technologies Panel and Monitoring Committee identified the need to establish a process and structure

for reporting and maintaining data in a consistent and centralized location as two major issues associated with monitoring and compliance.

Mandating monitoring at the town level puts a financial burden on towns that, in some cases, may make implementation infeasible. In addition, monitoring at the local level allows for inconsistencies in sample collection, analysis and distribution.

The appropriate scale for monitoring and maintaining monitoring data is at the regional scale. The Commission's Strategic Information Office (SIO) currently maintains an expansive data warehouse, and the Commission's Watershed Management Program maintains a regional historic warehouse of water resources information on behalf of Barnstable County and the 15 towns. Data hosting and maintenance would be available for a robust monitoring program providing consistent and accurate data feedback loops among the towns and appropriate agencies. Chapter 4 recommends that Barnstable County assume responsibility for monitoring and maintaining regionally consistent data sets that are freely accessible to the public. Maintaining data in a centralized, accessible location will allow information to transfer from one project to another, and assist the region in prioritizing projects based on water quality improvements and/or further degradation. In addition, designating a single responsible party for monitoring will allow for efficiencies and economies of scale in purchasing equipment and managing data. The program should be developed in conjunction with the Massachusetts Department of Environmental Protection (MassDEP) to ensure consistency in water quality assessments.

There is currently an effort underway by the Cape Cod Water Protection Collaborative to coordinate local sampling with an appropriate regionally procured laboratory(ies) for analysis. The Collaborative is seeking state matching funds to allow for a single procurement to provide ambient water quality sampling at the base stations all around Cape Cod. Data hosting and data accessibility should be through the SIO at the Cape Cod Commission. Regional technical assistance to provide data interpretation, assistance and outreach on watershed assessments and monitoring programs for Total Maximum Daily Load (TMDL) compliance and performance monitoring would provide communities with necessary information to move forward with their adaptive management plans.

Financing a Watershed Plan

Municipal finance limits the options available to communities looking to finance wastewater implementation. The vast majority of municipal revenue comes from two sources – local property tax assessments and state aid. Property tax collection operates under the constraints of Proposition 2 ½ – a voter-adopted law that limits the ability of a town to increase taxes beyond 2.5% annually without specific voter approval. This represents a barrier that has acted as a brake on municipal spending, especially on large capital projects. State aid is a critical piece of the municipal revenue picture but is subject to the vagaries of the state budget process and is based on a formula heavily weighted on property valuation, a disadvantageous approach for Cape Cod and other coastal communities.

Levy collections can increase above the legal limit specified by Proposition 2 ½ one of two ways. Voters may elect to override the limit by an amount in excess of 2.5% through a ballot question. An override provides a permanent and lasting increase in the amount of money a town may raise in property taxes and is a non-specific increase that can be expended on any municipal function. Debt exclusion allows for a temporary increase in tax collections that is earmarked to pay off the debt associated with the bonding of a specific capital expenditure. The tax increase expires once the bond payments associated with the project are paid off. The use of debt exclusions is most commonly associated with large capital projects, such as those associated with wastewater. Debt exclusion typically requires two steps, a local town meeting or town council vote, by a 2/3 majority, to authorize a borrowing and then a town-wide simple majority ballot question on the debt exclusion question. Some towns have room within their municipal levy limit to borrow inside the constraints of Proposition 2 ½ and do not need to obtain voter authorization beyond the vote to incur debt. Most wastewater infrastructure is too expensive to pay for in cash without borrowing; it must be financed over a long period of time during which revenues may be collected to pay for it. This section outlines several borrowing mechanisms available to municipalities:

- State Revolving Loan Fund,

- Rural Development loans from the US Department of Agriculture (USDA) and
- Conventional municipal financing.

Massachusetts also provides District Improvement Financing and the Local Infrastructure Development Program to help municipalities finance infrastructure development. All of these tools are described in more detail below. Each has its own cost, loan duration, use limitations and interest rate.

STATE REVOLVING LOAN FUND

The Massachusetts State Revolving Loan Fund (SRF) is a self-perpetuating loan fund administered by the State under the direction of the US EPA. The SRF program provides a low-cost funding mechanism to assist municipalities in complying with federal and state water quality requirements. The SRF program was originally funded by an act of Congress in 1987 as part of the implementation of the Clean Water Act and coincided with the decision stop providing federal capital grants to communities to build infrastructure. It is jointly administered by the Division of Municipal Services of the MassDEP and the Massachusetts Clean Water Trust (Trust). The state has two SRF programs, one for clean water and another for drinking water, which are administered by MassDEP. The clean water SRF may be used for planning or construction of wastewater and stormwater management systems. Eligible uses are outlined in the MassDEP regulations at http://www.mass.gov/eea/agencies/massdep/water/grants/state-revolving-fund.html. SRF loans vary by interest rate depending on the duration of the loan and locally-adopted regulations to manage growth after construction of the wastewater system.

Each year MassDEP solicits projects from Massachusetts municipalities and wastewater districts to be considered for subsidized loans. The current subsidy is provided via a 2% interest loan or, under certain growth-neutral criteria, 0% financing. Loans may be forgiven or partially forgiven. In recent years the program has operated with $300 to $350 million per year, representing the financing of 50 to 70 projects annually. The SRF Program continues to emphasize watershed management priorities. A major goal of the program is to provide incentives to communities to undertake projects with meaningful water quality and public health benefits and that address the needs of the communities and the watersheds.

Comprehensive Wastewater Management Plans (CWMPs) do currently have an advantage in receiving SRF funds.

ELIGIBLE PROJECTS

Financial assistance from the SRF is available for planning and construction of projects, including:

- combined sewer overflow (CSO) mitigation;
- new wastewater treatment facilities and upgrades of existing facilities;
- infiltration/inflow correction;
- wastewater collection systems;
- nonpoint source pollution abatement projects (e.g. landfill capping);
- community programs for upgrading septic systems (Title 5);
- brownfield remediation;
- pollution prevention;
- stormwater remediation;
- and climate change adaptation (e.g. stream bank stabilization and berms).

In addition, non-structural projects are eligible for SRF funding, such as planning projects for nonpoint source problems which are consistent with the MassDEP's Nonpoint Source Management Plan and that identify pollution sources and suggest potential remediation strategies.

For details on the application process see Appendix 6A.

On August 6, 2014, a bill aimed at "improving drinking water and wastewater infrastructure" was signed by the Governor as Chapter 259 of the Acts of 2014. The new law creates another form of financial assistance for communities with SRF loans - principal forgiveness. The Clean Water Trust, the entity that awards SRF loans, is now able to offer principal forgiveness so long as that subsidy does not exceed 25% of the total cost of all projects for the year, and does not exceed the equivalent of a 75% subsidy compared to a market rate loan.

The law also details how MassDEP may establish who is eligible for principal forgiveness. The project must satisfy one of the following criteria:

1. pursuant to an adopted regional wastewater management plan;
2. connects a local or regional government unit to a Massachusetts Water Resources Authority facility;
3. is a green infrastructure project, as defined in the bill;
4. uses regional water resources to offset local impacts of water withdrawals in the watershed basin of the receiving community;
5. is a direct result of a disaster subject to a declaration of emergency;
6. provides public water supply to consumers with contaminated groundwater or wells; or
7. uses innovative technology to improve drinking water infrastructure.

This plan recommends MassDEP exercise its discretion in providing principal forgiveness up to 25%.

Recommendation C6.1:
MassDEP should exercise its discretion in providing principal forgiveness up to 25%.

USDA RURAL DEVELOPMENT LOAN PROGRAMS

The United States Department of Agriculture (USDA) offers loans for water and wastewater disposal systems in rural areas and towns with populations below 10,000 and a median household income that meets certain guidelines. Funds may be used for "land acquisition, legal fees, engineering fees, capitalized interest, equipment, initial operation and maintenance costs, project contingencies, and any other cost that is determined by the Rural Development to be necessary for the completion of the project" (for more information visit: http://www.rurdev.usda.gov/UWP-dispdirectloansgrants.htm). The maximum loan term is 40 years and the interest rate is determined when the loan is negotiated.

CONVENTIONAL MUNICIPAL FINANCING

Conventional municipal financing occurs when a community uses its own full faith and credit to borrow money. A stand-alone bond sale relies on the bond rating of the community, which can create great variability in the interest rate paid. Many communities have limited bonding capacity and may have difficulty self-financing major capital wastewater infrastructure.

In addition to the local borrowing options described earlier in this chapter, Massachusetts offers two other programs that work with conventional financing – District Improvement Financing and Chapter 23L.

District Improvement Financing (DIF) allows the town to designate an area within which new property tax revenues generated from development may be used to pay off bonds issued to build public infrastructure, including sewer, which enables new development to occur.

Chapter 23L is a tax-exempt bonding program enabled through a public-private partnership to build public infrastructure improvements associated with a large development. In this case, the debt service is paid by a special property tax assessment, much like a betterment, that remains with the property if the property changes hands.

Paying for a Watershed Plan

While constructing wastewater treatment facilities is financed through loans and bonds, the incurred debt must be paid for with taxes, fees, unrestricted local aid from the state and grants. Such sources of funds are available at the local, state and federal level. The Section 208 Plan Update also recommends some additional methods for paying the cost of addressing the Cape's nutrient problem. The section below reviews a range of possible payment options that could be considered, but is not intended to be inclusive of all potential funding options.

LOCAL REVENUE

Local options to pay for the management of wastewater and stormwater fall into two categories: taxes and fees. Tax revenues may come from property taxes or local option

taxes, such as meals or room occupancy taxes. Betterments are a hybrid of taxes and fees and are assessed on properties that will be improved through the provision of public infrastructure. This method can be applied to traditional sewer or, potentially, other traditional and non-traditional water quality remediation methods that provide a direct benefit to an abutting property. Fees are payments for specific services such as the provision of water, electricity, or in this case, wastewater treatment. Fees are generally used to pay for the operation and maintenance of services being provided.

TAX OPTIONS

In Massachusetts and as described above, the main source of local revenue is property taxes. However, there are betterments as well as two local option taxes: meals tax and room occupancy tax. Other states have local option income taxes and local sales taxes, among others.

Property Tax

Taxes are broadly collected, based on property valuation and used to fund general services that benefit all taxpayers, whether they are direct users of a service or benefit indirectly through a stronger community and economy.

Property Tax Betterment

Property tax betterments are traditionally used to help pay for public water and sewer and road construction. Betterments are paid by property owners whose properties are bettered by public investment in infrastructure such as water or sewer service. The justification for such an assessment is that the market value of the property has increased for the owner as the result of a publicly-funded improvement. The betterment assessment transfers this market benefit back to the public from the property owner and is collected on tax bills. Betterments are used to pay for construction, but cannot be used to pay for the operation or regular maintenance of water or sewer systems.

Local Option Taxes

Massachusetts offers a local option tax on meals and a local option tax on room occupancy. Every town on Cape Cod has adopted the local option rooms tax and all but two towns have adopted the local meals tax (see **Table 6-1**). The Commonwealth does not restrict how these funds may be used. The town of Barnstable sought and received Special Legislation to have its 0.75% meals tax and 2% additional rooms tax (both made available in 2010) automatically flow to a dedicated Wastewater Infrastructure Fund to defray future costs.

	MEALS LOCAL OPTION		ROOMS LOCAL OPTION	
Municipality	**Local Tax Rate**	**Effective Date**	**Local Tax Rate**	**Effective Date**
Barnstable	0.75%	10/1/2010	6.00%	10/1/2010
Bourne	0.75%	7/1/2014	4.00%	7/1/1986
Brewster	0.75%	7/1/2010	6.00%	7/1/2010
Chatham	0.75%	7/1/2011	4.00%	7/1/1988
Dennis	0.75%	7/1/2010	4.00%	4/1/1987
Eastham			4.00%	1/1/1987
Falmouth	0.75%	1/1/2011	4.00%	1/1/1987
Harwich	0.75%	7/1/2010	4.00%	1/1/1987
Mashpee			4.00%	10/1/1986
Orleans	0.75%	7/1/2010	4.00%	4/1/1988
Provincetown	0.75%	7/1/2010	6.00%	7/1/2010
Sandwich	0.75%	7/1/2013	4.00%	7/1/1986
Truro	0.75%	7/1/2011	4.00%	12/1/1985
Wellfleet	0.75%	1/1/2010	4.00%	7/1/1986
Yarmouth	0.75%	7/1/2010	6.00%	7/1/2010

Local Option Meals Tax and Room Occupancy Tax Acceptance

Table 6-1

FEES

Fees are for direct services received such as the provision of water or other utility services and for licenses. In the context of wastewater, they may be used to fund the cost of operating, maintaining or constructing a wastewater management system.

STATE REVENUE

State revenue will likely come in the form of grants and lower interest rates on loans. Grants are outright support while lower interest rates save in the overall cost of servicing the debt incurred in building a system.

MASSWORKS GRANTS

The MassWorks Infrastructure Program provides grants for publicly owned infrastructure including but not limited to: sewers, utility extensions, streets, roads, curb-cuts, parking facilities, site preparation and improvements on publicly owned land, demolition, pedestrian walkways and water treatment systems to support three project types:

- Housing development at a density of at least four units to the acre (both market and affordable units);
- Transportation improvements to enhance safety in small, rural communities;
- Economic development and job creation and retention.

Applications are accepted once a year from municipalities and other eligible public entities.

FEDERAL CLEAN WATER ACT 604(B) WATER QUALITY PLANNING GRANTS

The Federal 604(b) Water Quality Planning Grants are administered by MassDEP. The grants may be used for watershed- or sub-watershed-based nonpoint source assessment and planning projects leading to the: 1) determination of the nature, extent and causes of water quality problems; 2) assessment of impacts and determination of pollutant loads reductions necessary to meet water quality standards; 3) development of green infrastructure projects that manage wet weather to maintain or restore natural hydrology; and 4) development of assessments, preliminary designs and implementation plans that will address water quality impairments in impaired watersheds.

During the course of the Section 208 Plan Update, several new funding sources became available to towns taking action to address nitrogen impacts in their watersheds.

STATE CAPITAL SPENDING PLAN

On August 13, 2014, the governor signed a $2.2 billion environmental bond bill into law, the largest in Massachusetts's history. The bond bill authorizes the State to fund projects that evaluate, protect and improve its environmental resources. Funding is now authorized for maintaining water quality, enhancing coastal infrastructure, managing waste, and supporting local fisheries and agriculture, among other programs. However, these types of projects must be included in the governor's annual Capital Spending Plan to be made available to Cape communities.

As part of an investment in Massachusetts' water quality, $4 million is authorized for monitoring programs, specifically to implement and evaluate adaptive management as it relates to the reduction of nitrogen pollution in coastal waters. The County is developing a strategy to partner with the Commonwealth to make this $4 million available to monitor water quality in locations where adaptive management is implemented.

An additional $4.5 million is authorized to be invested in pilot projects that aim to restore water quality of degraded estuaries in pursuit of TMDL compliance. The funding is designated for "innovative and green wastewater management technologies and approaches," including constructed wetlands, aquaculture, permeable reactive barriers, ecotoilets, and other technologies listed in the Technologies Matrix. The $4.5 million could also be spent on the installation of sustainable technologies at wastewater treatment facilities, such as co-digestion and resource recovery, that will target regional needs.

Both investments require monitoring programs and pilot projects to be "consistent with a current area-wide water resource management plan adopted under Section 208 of the Federal Clean Water Act."

The Commonwealth of Massachusetts should make funds designated for monitoring programs and pilot projects available to Cape Cod for efforts that are consistent with the Section 208 Plan Update.

Recommendation C6.2: The Commonwealth of Massachusetts should make funds designated for monitoring programs and pilot projects available to Cape Cod for efforts that are consistent with the Section 208 Plan Update.

FEDERAL FUNDING

Similar to state funding, federal support will likely be found through grant programs or loan forgiveness programs for construction.

USDA GRANTS

The purpose of USDA grants is to develop water and waste disposal systems in rural areas and towns with populations not in excess of 10,000. The funds are available to public bodies, non-profit corporations and Indian tribes. To qualify, applicants must be unable to obtain the financing from other sources at rates and terms they can afford and/or their own resources. There are some systems that qualify for grant funding; however, grant funding availability is limited. Program details are available on the USDA website: http://www.rurdev.usda.gov/UWP-dispdirectloansgrants.htm.

US ECONOMIC DEVELOPMENT ADMINISTRATION (EDA) GRANTS

EDA grants are meant to support the development and implementation of economic development strategies for economically distressed communities. Funding priorities are given to investment applications that support long-term, coordinated and collaborative regional economic development approaches; innovation and competitiveness; entrepreneurship; and strategies and investments that connect regional economies with the worldwide marketplace. Additional consideration will be given to investment applications that respond to sudden and severe economic dislocations, including natural disasters; enable the transition of Base Realignment and Closure (BRAC) impacted communities; support EO 13287, Preserve America; and promote the revitalization of brownfields. EDA grants may be used to pay for the design phase of capital construction projects. Awards are between $500,000 and $5 million, the larger size being very rare. Applications are accepted on a rolling basis.

HUD COMMUNITY DEVELOPMENT BLOCK GRANTS

Community Development Block Grants (CDBG) may be used to finance wastewater infrastructure. The CDBG Program is administered by the United States Department of Housing and Urban Development (HUD) in partnership with municipalities above a certain size and for other communities through the states. No less than 70% of CDBG funds must be used for projects that directly benefit low- and moderate-income persons. To be eligible, projects must also meet one of three national objectives: benefit low- and moderate-income persons, prevent or eliminate slums or blight, or address community development needs having a particular urgency because existing conditions pose a serious and immediate threat to the health or welfare of the community for which other funding is not available. CDBG funds may be used to build or expand wastewater infrastructure. They may not be used to defray repair, maintenance, or operating costs. The towns of Barnstable and Yarmouth are entitlement communities, meaning they get CDBG funds directly from HUD. The remaining towns may apply to the state to compete for CDBG funds. The CDBG Program, in addition to providing grants, also includes a loan program, "Section 108," which enables CDBG entitlement communities to borrow up to five times their annual entitlement grant. The entitlement community pledges current and future CDBG funds as security for the loan. Non-entitlement communities may also use this program but must do so through an agreement with the state. The maximum loan duration is 20 years.

US EPA NONPOINT SOURCE SECTION 319 GRANT PROGRAM

Under section 319 of the Federal Clean Water Act, US EPA annually provides grants to states for controlling nonpoint sources of pollution, such as agricultural runoff, mining activities and malfunctioning onsite septic systems. In Massachusetts these grants are administered by MassDEP. In states where onsite systems have been identified as a significant source of such pollution, the section 319 funds may be used to construct, upgrade or repair onsite systems.

US EPA STAR GRANTS

The Science to Achieve Results (STAR) grant program funds targeted research on environmental science and

engineering issues through a competitive process. The National Center for Environmental Research names areas of natural concern. At present, these centers focus on children's health, hazardous substances, particulate matter and estuarine and coastal monitoring. Those eligible for STAR grants include academic and non-profit institutions in the United States, as well as state, local and tribal governments.

POTENTIAL NEW REVENUE SOURCES

Much of this plan focuses on ways to lower the overall cost of reducing the impacts of nitrogen from wastewater, stormwater and fertilizer on coastal water quality. Still, the remaining costs are burdensome to the year-round population of Cape Cod. Having done its share to lower costs, the Cape now looks to alternatives to property taxes and fees to help finance the cost of preserving the economic benefits that a healthy Cape Cod provides to the rest of the Commonwealth. The Commission encourages implementation of additional funding sources to more fairly

LOCAL/REGIONAL: NITROGEN IMPACT FEES

New development located where it must rely on septic systems should participate in managing the nutrient loading problem on Cape Cod. This can be achieved by applying a nitrogen impact fee to new development dependent on traditional septic systems. The fee could be based on the amount of nitrogen generated by the development, and would internalize the cost of nutrient mitigation of the additional loads attributable to the property. The fee will encourage new development to locate in areas already served by wastewater treatment systems that remove nitrogen, an objective of the Regional Policy Plan. See the discussion on impact fees in Chapter 7 for more information.

Recommendation S6.3: The Cape Cod Commission shall evaluate the steps required for a regional or locally based nitrogen impact fee.

REGIONAL: SEPTIC TRUST FUND

A Septic Trust Fund should be established to optimally manage the maintenance, repair, and replacement of septic systems. In exchange for an annual fee, property owners served by traditional septic systems would have their systems regularly pumped out, repaired as needed, and replaced with a standard Title 5 system when necessary. The benefits of the program would be to extend the life of existing septic systems, lower overall replacement costs, optimize the treatment of septage by managing the timing of treatment at septage treatment facilities and relieve the homeowner from the high cost of replacement upon failure of their septic system.

Recommendation C6.4: The Cape Cod Commission shall develop a proposal for a Septic Trust Fund and pursue authorizing legislation.

REGIONAL: CAPE COD CAPITAL TRUST FUND

The Cape Cod Commission should identify and allocate resources to develop a revolving loan fund to finance infrastructure development on Cape Cod, particularly as it relates to water quality. A Cape Cod Capital Trust Fund for infrastructure financing should be established. The Trust Fund would be a regional entity with a professional staff experienced in public finance and would focus on providing funding for design and other aspects of infrastructure development not supported by other funding agencies at the state and federal levels. The Trust Fund would provide towns with additional funding at low interest rates to complete the design and construction of infrastructure needed to establish a sustainable economy on Cape Cod that does not negatively impact the environment and rectifies past negative impacts on the region's natural resources.

Recommendation C6.5: The Cape Cod Commission shall develop a proposal for a Cape Cod Capital Trust Fund for the financing of infrastructure design and construction.

STATE: WATER MIL CHARGE

One potential source of funding for wastewater infrastructure projects is an excise tax on water consumption, as recommended by the Massachusetts Legislature's Special Blue Ribbon Commission on Water

and Wastewater Infrastructure. An excise tax millage of one to three mils per gallon could be paid into a specific fund that could be used for necessary capital repairs and the replacement of aging infrastructure related to drinking water and wastewater (e.g. Title 5 Systems).

In the Boston Globe on April 13th, 2011, it was stated:

"Massachusetts has more than 20,000 miles of sewer and 21,000 miles of water pipes, and most of those pipes were installed more than 50 years ago… A draft… recommendation presented at yesterday's meeting [of the Special Blue Ribbon Commission] describes as a "good first step" a statewide surcharge of 1 mil per gallon — a mil equals one-tenth of one cent — on residential and commercial wastewater and drinking water.

Under the 1-mil scenario, the added cost per individual would be $23 per year, based on the state's goal for individual water consumption of 65 gallons per day."

If adopted by the state Legislature, a one mil charge would result in annual revenue of $81,993,600, based upon annual household water usage of 65 gallons per person per day and the total population on Cape Cod. Over 20 years, the excise would generate $1.64 billion, and $4.10 billion would be generated over 50 years.

This funding source is attractive as it is directly related to wastewater, and it discourages the excessive household use of water and should be pursued.

OTHER CONSIDERATIONS:

ALLOCATING COSTS IN SHARED WATERSHEDS

In shared watersheds, towns working together must agree upon a methodology to allocate costs. One approach may be to allocate costs proportionally to the share of nitrogen contributed to the watershed by each town. See Chapter 8 for a discussion on allocating responsibility, the requirement of Section 208 of the Federal Clean Water Act to designate Waste Management Agencies to take responsibility for nitrogen, and ways in which to collaborate.

ENVIRONMENTAL JUSTICE

Title VI of the Civil Rights Act of 1964 prohibits discrimination by recipients of federal financial assistance on the basis of race, color and national origin, including matters related to language access for limited English proficient (LEP) persons.

As federal financial assistance will be sought in support of this Section 208 Plan Update, it is incumbent upon the local and regional governments that may receive such assistance to have appropriate Title VI programs, including an effective Public Participation Plan. Outreach to all populations on planning decisions related to cost, affordability and the siting of potential technologies and infrastructure resulting from this plan, among other considerations, not only ensures compliance but can stimulate wider community discussion and acceptance of selected options.

The year 2014 marked the 20th anniversary of the signing of Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations. Because of this legislation federal agencies are required to, "identify and address the disproportionately high and adverse human health or environmental effects of their actions on minority and low-income populations, to the greatest extent practicable and permitted by law." The order also directs each agency to develop a strategy for implementing environmental justice (EJ).

Key principles of environmental justice include:

- Avoiding, minimizing or mitigating disproportionately high and adverse human health and environmental effects, including social and economic effects, on minority and low income populations; and
- Ensuring the full and fair participation by all potentially affected communities in the decision making process.

There are a number of designated environmental justice communities on Cape Cod. An area is described as an EJ area when the median household income of the census block group is equal to or less than 60% of the Barnstable County median household income, while also accounting for areas where 15% or more residents of Census block group identify as a race other than white.

In 2011, US EPA published Plan EJ 2014, the Agency's overarching strategy for advancing environmental justice. The Plan has three goals:

- Protect health and the environment in overburdened communities;
- Empower communities to take action to improve their health and environment; and
- Establish partnerships with local, state, tribal, and federal governments and organizations to achieve healthy and sustainable communities.

In overburdened communities, barriers can include lack of trust, lack of awareness or information, lack of ability to participate in traditional public outreach opportunities, language barriers and limited access to technical and legal resources. More transparency and dialogue can to lead to more meaningful engagement and participation of overburdened communities in the permitting process. More meaningful engagement, in turn, can lead to better permit outcomes for communities as well as permit applicants.

The planning and implementation of the Section 208 Plan Update will continue to facilitate outreach and participation in all aspects of the plan and permitting, and particularly as it relates to paying for the infrastructure necessary to meet water quality goals. While not every action may be legally required of regional and local governments as they pursue plan implementation, a robust outreach process is recommended as it leads to a more successful conclusion, as more participation leads to community acceptance of solutions chosen and implemented.

Recommendation S6.6:
Implementation of the Section 208 Plan Update shall include a local public participation process that includes efforts specifically designed to reach environmental justice communities.

Section 208 Plan Update Finance Model - A Tool for Towns to Utilize

As part of the Section 208 Plan Update, the Cape Cod Commission is providing communities with a model that will help them plan and manage the costs of building infrastructure to meet TMDLs for nitrogen in impacted watersheds. The Finance Model will be available to communities through the Commission's Watershed Team technical assistance program, described in Chapter 5.

PURPOSE

The model, developed by the Cape Cod Commission, AECOM Technical Services, Inc., and the Abrahams Group, estimates the total cost to build, finance and operate a proposed set of solutions and helps determine if the plan is affordable to the average household. The model is also designed to indicate if municipalities included in a proposed nutrient reduction scenario have the capacity to cover the total costs given current tax and borrowing restrictions. The model then allows users to select from a variety of potential revenue sources to determine how to best pay for the scenario proposed. This tool can assist in general policy discussions but is not a substitution for detailed financial planning.

MODEL STRUCTURE

The model includes three modules:

- Cost Module
- Financing Module
- Revenue Module

The Cost Module determines direct capital, operation and maintenance, and monitoring costs by individual technology. Financing costs are determined in the Financing Module, which allows users to select between various financing options appropriate for each technology solution included in the proposed scenario. The module then calculates the annual cost of a proposed scenario, including loan fees and interest payments. The final step is the Revenue Module, which allows users to select different methods to pay for the solution, including the financing costs. These modules are discussed in detail in the rest of this section.

COST MODULE

The Cost Module is based on cost estimates included in the Section 208 Plan Update Technologies Matrix (described in

Chapter 4), which is also the basis for the scenario building and decision support tools developed during the Section 208 Plan Update process.

This model will show capital costs by technology solution for any given scenario, which can be expected to include a variety of technologies selected by the user. Defining costs by individual technology is essential given the eligibility requirements of different financing programs and revenue sources. Land costs are not included in the total capital cost; however, the availability of municipally-owned land was a determinant in identifying potential sites for implementing technologies.

The model also includes the total operation and maintenance costs for the full scenario over time, as well as annual monitoring costs for each technology.

FINANCING MODULE

The Financing Module focuses on how money needed to build capital infrastructure will be obtained up front and paid for over time, which requires borrowing from state, federal and regional sources as detailed above. The model will allow users to select different borrowing options for different technologies included in proposed scenarios to allow for variability in financing eligibility and borrowing costs.

The model includes amortization tables for each type of SRF loan in order to calculate annual costs of the loan repayment process, including:

- SRF programs for clean water and drinking water; and
- USDA Rural Loan program.

The Financing Module also provides the ability to calculate debt service schedules and maturing principal and interest payments for conventional financing with general obligation bonds, including short-term bonds in anticipation of borrowing (BANs), long-term general obligation bonds and debt issuance costs.

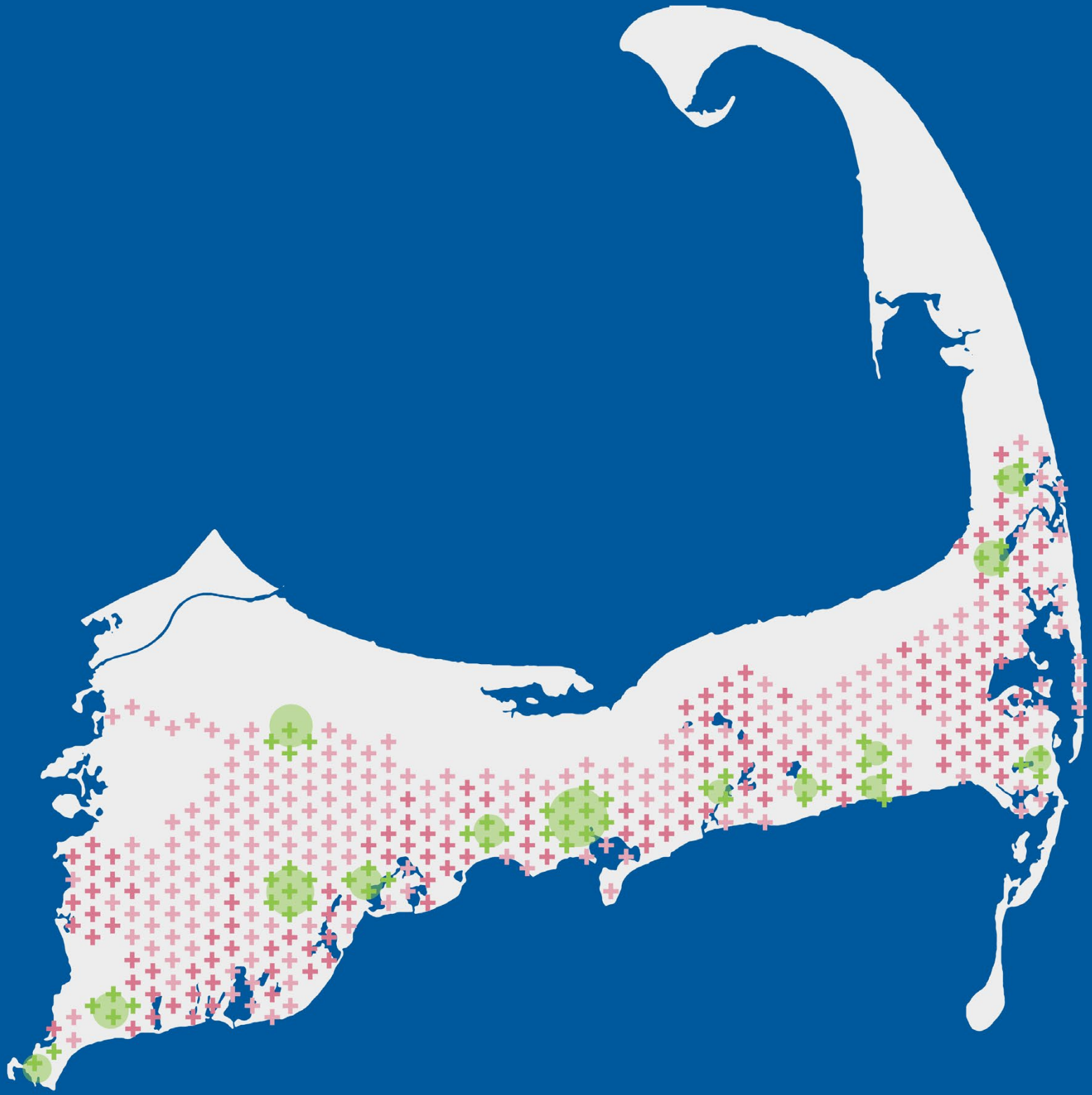
REVENUE MODULE

The Revenue Module will help policymakers assess the different options available for payment of the costs associated with the proposed set of technology solutions. The module allows the user to pick from the variety of funding sources described previously in this section. These range from general property taxes, to property tax betterments, to state or federal grants. The module is flexible to allow for the addition of new revenue sources as they become available.

07 BALANCE

Planning & Growth Management

Open space is one of the region's most valuable assets. Naturally forested open space also provides a valuable nitrogen "sink" as natural systems attenuate nitrogen contributions from atmospheric deposition. The rapid development pressure of the 1980s led to decreased open space and focused attention on the need to manage growth, guide land use, promote balanced economic growth, provide for adequate capital facilities and infrastructure, and protect environmental resources. Towns need to stimulate their tax base in order to afford the wastewater costs necessary to meet water quality standards and, at the same time, the economic development necessary to achieve that result is limited by the problem that needs to be solved. Without additional ability to treat wastewater, towns don't have the capacity for appropriate patterns of growth that don't add to the cost of remediating marine ecosystems.

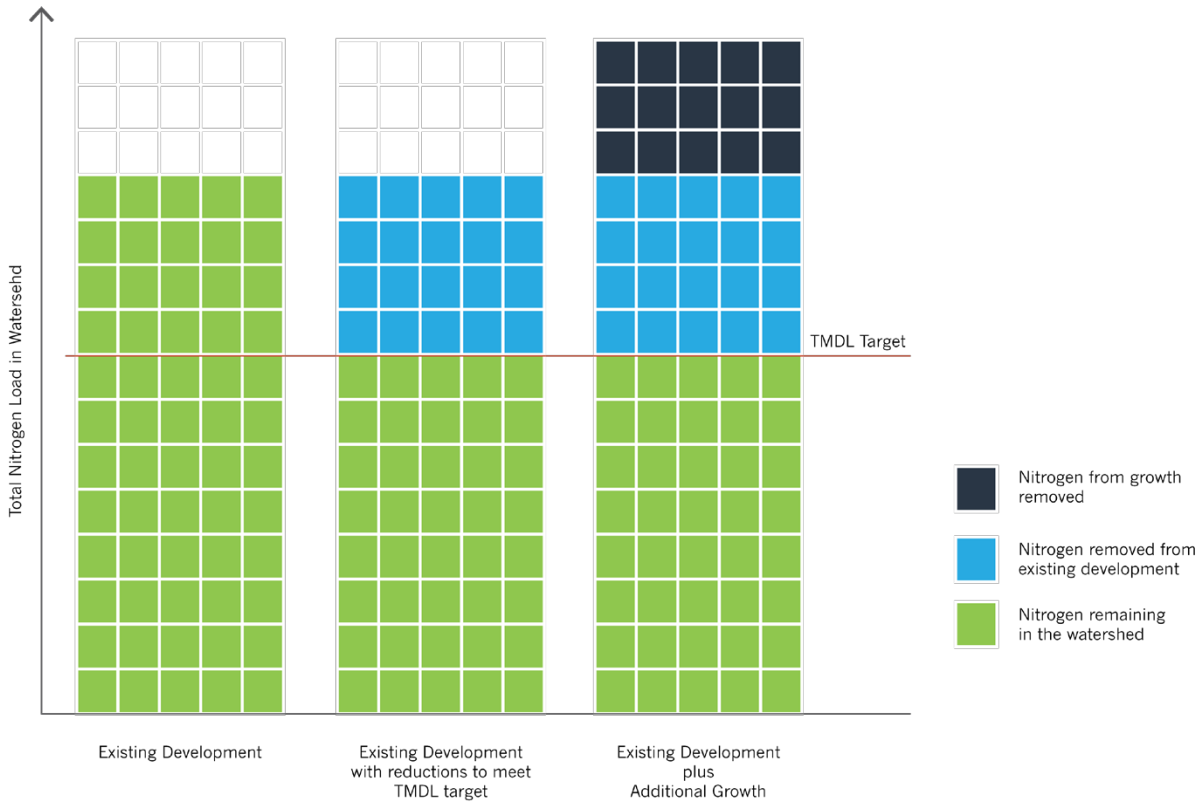


Managing Growth

Once nitrogen loads are sufficiently mitigated for existing development, 100% of the load from new development must also be mitigated in order to continue to achieve water quality goals (**Figure 7-1**).

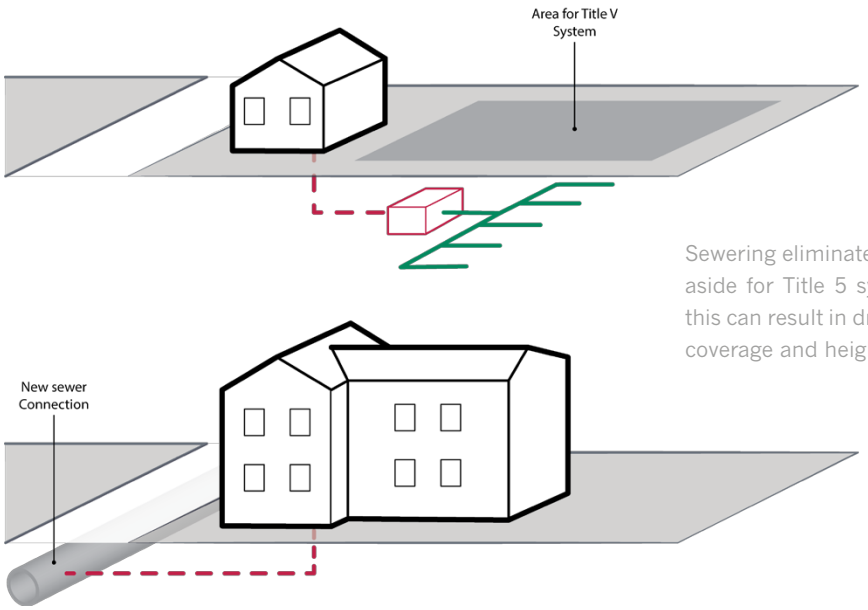
Projected growth can be significant in some towns and watersheds. The Cape-Wide Buildout Analysis to Support Regional Wastewater Planning was conducted by the Commission in 2012 with a grant from the Massachusetts Department of Environmental Protection (MassDEP).

Image on facing page: Cape Cod's water resources drive the regional economy. Development, or redevelopment, in watersheds to nitrogen impaired water bodies has the potential to further degrade water quality. Towns must continue to grow to promote a vibrant community. New growth has the potential to provide for a net nitrogen reduction if it occurs in places suitable for cost effective connection of existing properties to wastewater infrastructure.



100 Percent Future Nitrogen Removal

Figure 7-1



Sewer Induced Growth

Figure 7-2

The analysis identified the following potential municipal growth projections.

- Municipal residential growth for individual towns is estimated between 8% and 58% of new residential units. A Cape-wide average of 18% growth in additional residential units is projected.
- Municipal non-residential growth for individual towns is estimated between 8% and 163% of new square footage. A Cape-wide average of 53% of new square footage is projected.

The cost of addressing 100% of nitrogen from new growth can be substantial. "Estimating Cape-Wide Costs of Wastewater Infrastructure," a report dated March, 2013, identified additional costs of growth, assuming a 15% and 30% increase over current wastewater flows and assuming the construction of traditional wastewater infrastructure. That analysis showed that a 15% growth in wastewater flow translates to a 20% increase in capital cost. A 30% growth increases the capital cost by 40%. Because wastewater collection costs represent about 70% of the cost of constructing a system of sewers, treatment plants, and effluent disposal facilities, costs to mitigate nitrogen from new growth can be reduced by promoting density and discouraging sprawl (Cape Cod Commission 2013).

SEWER INDUCED GROWTH AND SMART GROWTH

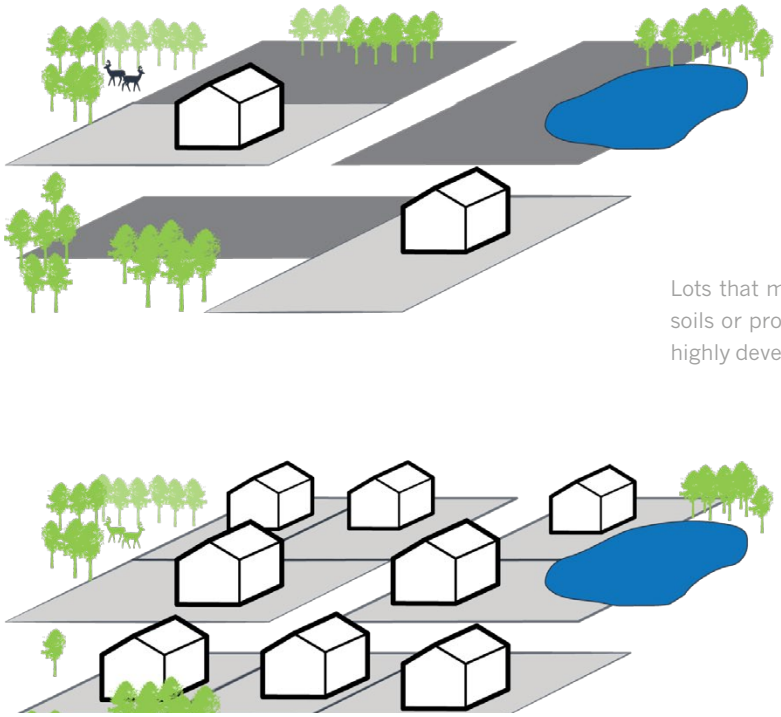
The Commonwealth of Massachusetts' Title 5 regulations for on-site systems can limit the amount of development on parcels where sewer or other wastewater treatment technology is not available. In some cases, property owners may not be able to add additional bedrooms or dwelling units allowed under zoning because the parcel relies on a septic system for wastewater management. Removing a parcel's septic system and connecting it to wastewater treatment lifts such as Title 5 restrictions and can result in additional development (**Figure 7-2**).

Both the Commonwealth and the Commission support well-planned growth to enhance community character, preserve high-quality open space, improve and support municipal budgets and improve impaired areas. To help reshape the development pattern on Cape Cod, measures must be taken to encourage mixed-use and compact forms of development (encouraging density) in existing centers and discourage sprawling development in sensitive areas. There are several ways in which this can be accomplished. First, the 2009 Regional Policy Plan (RPP) encourages mixed-use development in Economic Centers and infill in Villages as appropriate. To accomplish this, a Regional Land Use Vision Map (RLUVM) was created as the basis for such planning, helping to identify areas appropriate for

additional development and focusing on specific types of development, as well as those areas where such activity should be discouraged. As the Commission undertakes the five-year revision to the RPP in 2015, there is an opportunity to revisit the RLUVM to align desired future growth patterns with wastewater infrastructure planning. In addition, Cape Cod towns could change local zoning bylaws to support mixed-use and compact development. Finally, the state offers incentives to local governments that put policies in place to encourage such growth patterns. Areas that are eligible for the state incentives include:

- Areas near transit stations, including rapid transit, commuter rail, and bus and ferry terminals;
- Areas of concentrated development, including town centers, other existing commercial districts, and existing rural village districts; or,
- Areas that by virtue of their infrastructure, transportation access, existing underutilized facilities, and/or location make highly suitable places for residential or mixed-use smart growth zoning districts.

In the absence of Title 5 regulated septic systems, there is potential for uncoordinated and unplanned growth (**Figure 7-3**). A variety of regulatory and land use planning tools can be put in place at regional and local levels to manage growth in the absence of Title 5 and growth induced by sewers outside of defined growth areas. As towns move forward with local implementation of watershed-based plans and/or municipal wastewater management plans,



Increased Density as a Result of Proximity to Sewer

Figure 7-3

a combination of approaches will be needed to manage growth, meet community goals and protect natural resources and community character.

A review of Comprehensive Wastewater Management Plans (CWMPs) across the region shows that many of the areas targeted for collection systems do not always conform to growth center boundaries, and often extend well beyond what communities consider the boundary of a village or economic center. This overlap of nitrogen management areas with existing and desired growth patterns in Cape communities requires consideration of a combination of growth management tools to achieve water quality goals, while maintaining community character and preventing further sprawl and over-development. Such tools include: open space protection, transfer of development rights (TDR) sending and receiving districts, tax increment financing, checkerboarding, and zoning and regulatory changes. These and other planning and growth management tools are discussed further below.

The Section 208 Plan Update recommends that a range of technologies be considered at the watershed level. Those

that utilize a collection system and those that enhance natural systems or are located on-site all may play a role in remediation efforts. Communities may choose to construct sewer systems for a variety of reasons. The major objectives of collecting wastewater flows for treatment is to restore or protect the health of coastal embayments. In designing systems to achieve this important goal, communities need strategies to ensure that the location of collection systems does not facilitate growth patterns that threaten community character or encroach on habitat and natural resources. Additional considerations that should be addressed in designing systems include environmental issues such as failing Title 5 systems, drinking water issues, freshwater pond degradation due to phosphorus and the provision of infrastructure to support economic growth. There are several broad principles that communities should consider when coordinating community character goals with planning for sewer infrastructure:

- Coordinate watershed infrastructure planning to ensure that total maximum daily loads (TMDLs) are met and are met for current and future conditions. Sewer system capacity designed to meet TMDLs will take into account build-out within the entire watershed, even if the entire watershed is not sewered. This is because unanticipated growth outside the sewered area of a watershed with a TMDL could also result in increased nitrogen loading to the watershed. This additional growth could cause the watershed to exceed the level of total nitrogen from effluent consistent with TMDLs and require sewering of additional areas.
- Allocate limited collection system capacity to areas and uses that support broader community planning goals.
- Provide treatment capacity needed to achieve TMDLs through collection system design. In many towns there may be multiple system design alternatives that could meet that objective. One of the criteria used to select among alternatives should be how the collection system configuration would facilitate desired land use patterns in terms of the type, location or intensity of growth. Similarly, the selected alternative should not facilitate intensification of undesired growth. See also the discussion of "checkerboarding" sewer collection systems below.
- Ensure that community character and natural resources are protected or enhanced.

The 2009 RPP is currently being updated. Part of the RPP update includes the development of a decision support tool (Envision Tomorrow) that allows communities to test alternate land use scenarios, and instantly see the effects of their land use choices across a variety of criteria such as jobs, housing, transportation systems and the municipal tax base. Envision Tomorrow and other tools made available through the section 208 process will provide communities with valuable information to aid decisions about whether, and where, collection systems for sewers may be most appropriate.

OPEN SPACE PROTECTION

Open space is one of the region's most valuable assets. Naturally forested open space also provides a valuable nitrogen "sink" as natural systems attenuate nitrogen contributions from atmospheric deposition. Nearly 30% of the Cape's upland is currently protected as open space. This significant accomplishment can be attributed to foresight and investment by all levels of government: designation of the Cape Cod National Seashore in 1961 by the federal government; establishment of the 1,900-acre Nickerson State Park in Brewster and 700-acre Shawme Crowell State Forest in Sandwich; the approximately 15,000 acres within Joint Base Cape Cod protected as public conservation land since 2002; and protection of large town-owned conservation areas such as the 4,700-acre Sandy Neck Park in Barnstable, the 383-acre Beebe Woods in Falmouth, and the 800-acre Punkhorn Parklands in Brewster. In recent years, Cape communities significantly increased local land in conservation through smaller purchases, ranging in size from one or two acres to over 200 acres. Due in large part to the adoption of the Cape Cod Land Bank in 1999 and the Community Preservation Act in 2005 as local revenue sources for open space acquisition, Cape towns protected more than 4,000 acres of open space through strategic acquisitions of lands of conservation interest. Many Cape communities sought to protect significant natural and fragile areas and outstanding water resources, including lakes, rivers, aquifers, shore lands and wetlands.

Private land trusts play a vital role in land protection as well. Land trusts can serve as valuable intermediaries in preserving lands through less expensive means than

outright acquisition, such as accepting charitable donations or purchasing conservation restrictions. Private trusts are also valuable partners with towns in conserving key properties. Trusts are able to reach out to their membership and raise funds for acquisitions, a role that towns cannot perform.

Grants are also an important source of funds for acquiring land. The Cape has been fortunate in attracting significant outside funding in recent years through state, federal and private grants. This may be attributed to off-Cape recognition of the sensitivity of the natural resources on the Cape, and support for protecting cohesive habitats, recreation areas and water supply protection areas.

While growth management has not typically been the driving force behind open space acquisitions, it has become a significant side effect of conserving land. Future growth potential on the Cape has been managed or reduced through the dedicated efforts of governments and private organizations to permanently protect open space on Cape Cod. This Section 208 Plan Update recommends continued acquisition of protected open space to protect sensitive environmental areas, decrease potential for sprawl development, and maintain natural, forested areas that attenuate nitrogen contributions from atmospheric deposition.

CHECKERBOARD SEWER INFRASTRUCTURE

Prior to the passage of Section 10 of the Environmental Bond Bill in 2008, in the absence of special legislation, towns were required to connect all properties that had frontage along a sewer line. This law deprived towns the ability to identify areas that were and were not appropriate for future growth and redevelopment. In some cases, large vacant tracts of land with frontage, or parcels with redevelopment potential at significant densities, forced communities to design for more treatment and disposal capacity than they wanted, and subjected portions of the community to inappropriate growth. Since the passage of the Environmental Bond legislation in 2008, towns may adopt the provisions of the recently amended Massachusetts General Law (MGL) Chapter 83 to accomplish "checkerboarding." This authority allows communities to coordinate land use planning with planning for wastewater infrastructure in a way that supports smart growth development patterns. In order for a town to utilize the checkerboarding provision, it must have a MassDEP-approved wastewater management plan that clearly differentiates properties requiring sewering and those that do not.

FLOW NEUTRAL PLANNING

The passage of Section 5 of the 2008 Environmental Bond Bill provides towns access to State Revolving Fund (SRF) loans without interest for construction of wastewater infrastructure projects intended for nutrient management that meet certain criteria (Chapter 312 of the Acts of 2008).

The availability of zero rate of interest SRF loans is contingent upon a town's ability to demonstrate that sewers will not enable more growth than otherwise would be allowed under zoning and current wastewater regulations. For example, among the criteria required to access the zero percent SRF funds, a town must have adopted land use controls intended to limit wastewater flows to a level that would have been allowed under regulations in effect when the wastewater management plan was approved. These flows are calculated in the aggregate with flexibility to allocate flows for new growth and expansions of existing development. Flows associated with undeveloped and underdeveloped parcels can be allocated to areas identified for mixed use and compact development. Mandates for water saving devices can also accommodate new growth.

Consistent with the goals of the Environmental Bond Bill, towns should correlate land use planning with wastewater infrastructure planning examine zoning and land use regulations to ensure that sewers meet the resource protection and growth management goals of the community, and support growth where it is desired. Towns should also consider adopting sewer system checkerboard authority to implement growth management goals.

MassDEP has promulgated regulations (310 CMR 44.00) prescribing how towns should conduct a buildout analysis to demonstrate baseline flows, and requiring towns to provide proof of adoption of flow neutral land use controls. To date, Cape Cod towns seeking zero interest loans have adopted sewer and board of health regulations and bylaws limiting flows from new development and redevelopment. One example of such regulation is from Chatham, which adopted a sewer department regulation. The Chatham regulation limits existing structures to flows that existed prior to the development of sewer infrastructure. Flows from undeveloped parcels are limited to flows allowed by

Title 5 or Chatham Board of Health regulations. Variances for additional flows may be granted if allocated from the Chatham Sewer Bank by the Chatham Board of Water and Sewer Commissioners. Other Cape communities have adopted regulations allowing existing residential structures to add a bedroom or to add up to a maximum amount of flow upon connection to sewer.

LONG-TERM PLANNING

LOCAL COMPREHENSIVE PLANS

The Cape Cod Commission Act promotes the establishment of local planning committees in Cape towns to prepare, update and implement Local Comprehensive Plans (LCPs). Through the LCP and in consultation with the Commission, each town defines its vision for how to achieve the goals of the Act and articulates the town's growth policy. In addition, the LCP is an information source about existing and expected conditions. Implementation of an LCP through changes in local zoning or other actions can help a town manage growth and its impacts on local and regional resources, and to plan for and fund adequate infrastructure and capital facilities. Eleven of the 15 Cape towns have adopted LCPs that have been certified by the Commission as consistent with the RPP. Several towns are currently undertaking LCP updates or, in the case of Brewster, its first LCP effort. The LCP process provides an excellent opportunity for towns to create the vision and goals for managing growth on the local level.

LAND USE VISION MAPPING

The Commission has worked collaboratively with Cape Cod towns to develop a vision for the future of Cape Cod through adoption of local Land Use Vision Maps (LUVMs) that categorize Economic Centers, Villages, Industrial and Service Trade Areas, and Resource Protection Areas. The maps provide a framework for regional land use planning and identify discrete areas to focus future development activities as well as areas for additional protection. Towns with an endorsed LUVM may apply for flexible thresholds that trigger the Commission's regulatory review of Developments of Regional Impact (DRIs). The Land Use Vision Map is also a tool to encourage towns to consider zoning and other changes to guide growth toward desired areas that have infrastructure to support it and away from areas that have significant ecological or cultural resources that could be degraded by inappropriate development. To date, eight of the 15 towns on Cape Cod have adopted a LUVM with the town of Bourne partially designated. The 2015 update to the 2009 RPP will likely result in a further refinement of these growth and protection areas across the region.

GROWTH INCENTIVE ZONES

The Commission adopted Growth Incentive Zone (GIZ) regulations in 2005, establishing a process for directing development and redevelopment into areas with adequate infrastructure and away from sensitive resources areas. GIZs facilitate mixed-use compact development and redevelopment. By creating a master plan and providing infrastructure and mitigation strategies to accommodate development, a town can pursue reduced regulatory involvement by the Commission for projects proposed within the zone. To establish a GIZ, a town must first ensure that all growth is properly served by infrastructure. Towns may request modifications to existing DRI thresholds as part of the GIZ designation. To date, three GIZs have been designated by the Commission, including:

- Main Street Buzzards Bay - Bourne (2012)
- Route 28 Corridor - Yarmouth (2007)
- Downtown Hyannis - Barnstable (2006)

Downtown Hyannis is served by the Hyannis Water Pollution Control facility. Main Street Buzzards Bay is partially sewered and the town of Bourne has contracted to treat and dispose of a limited amount of wastewater in Wareham. Bourne is currently in the process of examining options for collection, treatment and disposal to bring additional wastewater capacity to Buzzards Bay to support new development and redevelopment.

ZONING

Zoning represents the primary tool for regulating land use. MGL Chapter 40A, the state's zoning act, enables cities and towns to establish zoning regulations designed to achieve broad purposes including protection of public safety and welfare, lessening congestion and encouraging the most appropriate use of land in a community. Municipal planning boards are responsible for land use planning and administration and are authorized by the zoning act to prepare zoning amendments for town meeting vote.

Through zoning bylaws, communities set forth development standards such as minimum lot size, maximum density, site coverage, setbacks, building height and other dimensional requirements. Zoning also controls what types of uses are permitted and where in order to minimize conflicts between uses and allow for the types of development desired by a community. Zoning is a powerful tool and has a significant impact on development patterns and character of a community. The adage "you get what you zone for" aptly characterizes the power of zoning regulations.

Municipal planning boards may draft revisions to the zoning bylaws to address development and land use issues. Adoption of proposed changes requires a two-thirds majority vote by a town's legislative body. While zoning changes are applicable to new development, the state zoning act provides extensive protections to legally established pre-existing uses or structures, including undeveloped subdivisions, allowing them to continue without meeting new zoning requirements. This tends to limit the extent and effectiveness of a zoning change. Pre-existing uses and structures may be required to meet new zoning when altered or expanded, depending on the requirements of the local zoning. Districts of Critical Planning Concern (DCPCs), authorized by the Cape Cod Commission Act, can eliminate the legal protections for pre-existing uses, structures and subdivision plans conferred under Chapter 40A.

OVERLAY DISTRICTS

The overlay district is a zoning tool that can be used for growth management. An overlay district lies "on top" of one or more zoning districts and establishes an area where certain growth opportunities or limitations are in effect. In addition to the dimensional and use limitations established by zoning, the overlay district can apply water quality standards for the purposes of drinking water protection or coastal water quality protection, or can identify economic development zones or growth incentive zones based on the presence of infrastructure or other features designed to support dense economic activity. Overlay districts also can be established for other specialized uses such as wireless towers, adult entertainment or medical marijuana.

On the Cape, most towns have adopted overlay districts to support resource protection. Examples include groundwater protection districts, floodplain districts, wildlife corridors, and coastal pond protection districts. Overlay districts can include additional permitting or review requirements, stricter performance standards, or outright prohibition of certain activities (i.e. use of hazardous materials). Several towns have also adopted overlay districts to support growth, including village center districts, revitalization districts, and growth incentive zones. Standards in these kinds of districts may require specific design features or amenities in exchange for allowing for increased density and flexibility in the dimensional requirements and mix of uses allowed.

DISTRICTS OF CRITICAL PLANNING CONCERN (DCPC)

As noted above, the DCPC is a powerful planning and regulatory tool that has been used by Cape communities to manage growth and protect sensitive resources. To date, a total of nine local DCPCs and two Cape-wide DCPCs have been designated with either implementing regulations or other regulations adopted by the towns or the Commission. A complete list of designated DCPCs is available in Appendix 7A.

The following are a few examples of DCPCs that have been adopted for growth management purposes.

- Brewster Water Protection DCPC: designated in July 2008 to protect "zones of contribution" (or watersheds) to public drinking water wells. The DCPC encompasses 6,538 acres in several areas: one in the southeastern part of Brewster, another in the southwestern part of town, and all land in Brewster that is within the Pleasant Bay Water Recharge Area. The DCPC has two purposes: a water resources district and a major public investment district. Watersheds within the DCPC include wellhead-protection lands for public wells in Brewster and for wells in Orleans, Harwich and Dennis. The four Brewster wells in the DCPC provide about 95% of the town's public water supply, and the remaining need is met mostly from private wells. Brewster has invested millions of dollars in the development and protection of the public drinking water supply wells within the DCPC. The Cape Cod Commission approved the town's proposed implementing regulations on October 1, 2009.

- Six Ponds DCPC (Harwich): designated in May 2000 to protect the water and natural resources and to manage growth over more than 1,200 acres of land and 110 acres of water in northeastern Harwich.
- Three Ponds DCPC (Sandwich): designated in February 2000 to protect water quality, preserve open space, and maintain the character of nearly 700 acres of land and more than 300 acres of water in southeastern Sandwich, this DCPC resulted in a reduction of residential development potential.

While prior district nominations have focused on natural resource protection, there are a variety of ways in which DCPCs may be instrumental in coordinating land use goals with infrastructure development to carry out local and regional goals. Reasons for potential DCPC designations might include:

- Coordination of major capital public facilities or areas of public investment,
- Economic development,
- Protection of cultural, scientific and recreational resources or,
- Natural resource protection.

A DCPC nomination may invoke a one year (18 months with extension) moratorium on the issuance of specified local permits within the nominated areas, thus providing a planning window to develop plans and regulations to meet community goals. Materials related to the process for establishing a DCPC are available in Appendix 7B.

There have been two Cape-wide Districts of Critical Planning Concern (DCPCs) designated to enhance the jurisdiction of Cape Cod communities. In response to the enactment of Chapter 262 of the Acts of 2012, Barnstable County established the Fertilizer Management DCPC by ordinance in September 2013. Chapter 262 of the Acts of 2012 vested exclusive authority over nutrient regulation in the Commonwealth (including regulation over fertilizer use and application) to the Massachusetts Department of Agricultural Resources (MDAR). The law contained certain exceptions to MDAR's exclusive jurisdiction, such as regulation adopted pursuant to the Cape Cod Commission Act. Development of the Cape Cod Pesticide and Fertilizer Use Inventory (see Appendix 7C) supported the need for special regulation in Barnstable County to protect Cape Cod's unique water resources. The Fertilizer DCPC designation allows towns to adopt and administer local turf fertilizer regulations.

The enactment of the Oceans Act of 2008, where the state legislature established the need for a state-wide ocean management plan, also inspired Barnstable County government to employ the DCPC tool to preserve jurisdiction and local control of our ocean resources. Barnstable County established the Ocean Management Planning DCPC in April of 2010, and the Cape Cod Commission adopted the Cape Cod Ocean Management Plan (CCOMP) in October 2011 (available at http://www.capecodcommission.org/ccomp). The CCOMP establishes goals, policies and actions to ensure protection of important natural, cultural and scenic resources in balance with certain limited development activities in the ocean.

Later, Barnstable County government adopted regulations in the RPP, consistent with the DCPC purpose, to address off-shore sand mining and cable installations.

NATURAL RESOURCE PROTECTION ZONING

Natural Resource Protection Zoning (NRPZ) is a relatively new form of zoning that has been adopted in several towns in Massachusetts since 2009. It is a variation of a clustered subdivision, but with several enhancements. NRPZ preserves large areas of open space, concentrating all development in a small area. The number of allowed dwelling units is determined by a calculation that first eliminates the amount of important natural resource lands from the determination of the number of allowed units. The net acreage is then divided by the base density to determine the number of units. The base density is generally the same as allowed by the underlying zoning, but the number of units can be increased if the development includes public benefits such as affordable housing, wastewater treatment for the development itself as well as for other units, preservation of farmland, and other benefits to the larger community.

BULK AND BUILDING FORM REGULATIONS

Bulk and building-form regulations, also known as dimensional requirements, include lot size and coverage, building height and setbacks (or build-to lines). Towns can alter these regulations to encourage additional growth in a town center by relaxing height, lot coverage and/or

setback requirements. Conversely, towns can discourage future growth or redevelopment in other areas by tightening dimensional regulations.

Community character can be negatively impacted when small lots (6,000 square feet or less) are connected to wastewater treatment. Due to the size of these lots, removal of Title 5 setback requirements can create development options that are substantially different from limitations imposed by Title 5 (as shown in **Figure 7-2**). Towns should examine lot line setback requirements for small lots if they wish to limit the significant expansion of existing development on small lots. A more detailed discussion of these impacts is provided in the report entitled Sewers and Smart Growth: Challenges, Opportunities and Strategies (Ridley & Associates, Inc. 2009).

USE-RELATED REGULATIONS

Use regulations specify both the kind and intensity of activities that can take place on a given parcel. In communities seeking to promote a vibrant town center, a mix of residential and commercial uses can be allowed through modifications to use-related zoning provisions. This kind of regulation can also be used to encourage or restrict intensity of uses, depending upon the desired outcome.

TOWN CENTER ZONING

It has been difficult to invigorate traditional town centers on Cape Cod due to the lack of adequate wastewater infrastructure to support dense development, and zoning bylaws that were set in place decades ago did not support dense, compact development patterns. With the advent of sewers and other technologies, communities have an opportunity to rezone villages and town centers where additional growth is desired. Such rezoning can include dimensional standards that increase height and lot coverage and decrease setbacks, requirements to include mixed-use development, and support for public places and other pedestrian amenities, such as parking on the sides and rear of buildings. Rezoning to allow for denser, more compact development patterns may be balanced with other growth management measures outside of these areas to achieve local goals such as limiting sprawl to reduce wastewater infrastructure costs, preserving community character, and in some instances, for demonstrating "flow neutral" land development controls.

PROVINCETOWN GROWTH MANAGEMENT BYLAW

Provincetown adopted a Growth Management Bylaw in 1989. Its purpose is "both to maintain a level of development that will meet the needs of its current and future population without overburdening its natural resources or the capacities of public facilities, particularly the provision of potable water, wastewater disposal, and solid waste disposal, and at the same time encourage affordable housing and year-round economic development." The bylaw was adopted more than a decade before the town installed sewers, primarily due to the town's limited potable water supply. The metric for the Growth Management Bylaw is water usage (based on gallons per day Title 5 design flow), but it provides a model zoning (or other regulatory) framework for prioritizing future growth based on resource carrying capacity and for structuring permit allocation to encourage priority uses.

The bylaw limits new growth and expansion based on Title 5 flow. Applicants proposing development (new construction, expansion, change of use) that would result in an increase in Title 5 flow over the existing use must obtain a growth management "allocation permit." The permits are issued in accordance with Table of Use Categories and Priorities that establishes the order for how the pool of available gallons shall be allocated among different uses. The bylaw assigns a gallonage available to each category and the annual process for re-allocation of unused gallons within the use table. Applicants must "get in the queue" for an allocation permit if all available gallons for a particular use have been allocated for the year. The bylaw requires the town manager to provide an annual growth management report that reviews the year's gallonage allocations (as well as overall water usage and solid waste disposal data). Based on the findings of the report, the Board of Selectmen may revise the gallonage allocations for the upcoming year. Since the bylaw's adoption in 1989, voters at town meeting have approved several amendments and revisions to the mechanics of the bylaw and the priority of uses brought forth by the Planning Board, generally in response to fluctuations in the economy.

SLIDING SCALE LOT COVERAGE

In response to concerns about tear-downs of older homes and subsequent "mansionization," out-of-scale

development within the Cape Cod National Seashore, the town of Wellfleet adopted a zoning bylaw that limits lot coverage allowances based on a sliding scale. It provides a higher percentage coverage allowance for smaller lots, which decreases gradually as lot size increases. The bylaw also provides site plan review criteria and special permit review requirements for higher lot coverage.

The town of Barnstable adopted a similar type of sliding scale lot coverage limitation in the Craigville Beach district as part of the Craigville Beach DCPC implementing regulations. See previous discussion on DCPCs for more information.

The town of Provincetown also has a "scale bylaw" that is intended to preserve the existing scale of buildings in a neighborhood. It is an unusual example of a zoning bylaw that addresses and limits building volume. The intent of the bylaw is to preserve existing building scale by requiring all new structures and additions to comply with "appropriate" neighborhood scale. The Zoning Enforcement Officer directs the determination of each building's scale/volume based on a methodology set forth in the bylaw and calculates an average neighborhood scale. New structures and additions are limited to an increase/deviation from average scale of 25% or 15% within the historic district unless granted a special permit to exceed the allowance.

PAYING FOR NEW GROWTH

IMPACT FEES

An impact fee is a growth management tool used to help pay for the expansion of public infrastructure by requiring developers to pay their proportionate share of the costs. They are intended to help ensure that there is an adequate availability of public facilities and facilitate fiscally responsible growth. Usually charged when the occupancy permit is issued, impact fees can only be used to help offset the costs associated with that particular development. The funds cannot be charged to correct existing deficiencies in public facilities in the community at large.

The Section 208 Plan Update suggests that nitrogen budgets could be developed to better explain nitrogen cycling on Cape Cod. The following are suggested for inclusion:

- Nitrogen content in precipitation
- Watershed attenuation/denitrification
- Nitrogen loads to estuaries
- Food imports
- Fertilizer imports
- Atmospheric deposition

A comparison could be made between the existing nitrogen budget and a pre-development nitrogen budget to identify how nitrogen imports and natural attenuation capacity have changed over time. This effort would provide an overall picture of nutrient impacts on the region, including, in part, an assessment of nitrogen deposition from environmental and other non-controllable sources and could be used to form the basis for creating an impact fee system.

NITROGEN IMPACT FEES

One way to pay for new growth is through adoption of a nitrogen impact fee program. A nitrogen impact fee is a monetary charge imposed by a local government on new developments to recoup or offset a proportionate share of public costs associated with mitigating nitrogen pollution caused by that new development. In other words, a nitrogen impact fee shifts some portion of the financial burden to mitigate new nitrogen contributions from the public to the private sector. Impact fees take into account the direct capital costs required to accommodate new developments with wastewater infrastructure and, to the extent measurable, the costs of other negative consequences borne by the public. The result is to incorporate the full social and environmental costs of new development into the impact fee.

To withstand judicial scrutiny, impact fee systems must establish a rational nexus between the impact caused by the new development and the fee imposed to mitigate that impact. The Section 208 Plan Update sets forth the following guiding principles for establishing a nitrogen impact fee system:

- Any nitrogen impact fee must be based on the amount of nitrogen discharged from a property and any costs associated with mitigating its effects. Based on available data, it is possible to formulate

an equation that calculates nitrogen output by parcel by combining wastewater flow and lawn fertilizer run-off. Given existing state and federal statutes and recent legal challenges, the envisioned system would be best served by imposing a fee as a direct function of a parcel's nitrogen discharge, satisfying both "nexus" and "rough proportionality" standards of the courts (Koontz v. St. John's River Water Management District, 133 S. Ct. 2586 (2013)).

- Nitrogen pollution damages the environment and social welfare as a whole and its remediation increases infrastructure costs. To be fully effective, a nitrogen impact fee system should cover both direct and indirect costs, quantified in a manner that establishes a rational "nexus" for nitrogen output from development. An incentive system that does not account for the full cost of development could unintentionally incentivize over-development and consequently irreparably damage the environment and society (Rosenberg 2003).
- A nitrogen impact fee system should incentivize commercial and residential development and redevelopment in designated areas for growth based on community vision mapping process, and only in nitrogen sensitive areas with adequate wastewater infrastructure.
- The fee system needs to contain waivers based on affordability and monetary incentives for adoption of nitrogen-reducing technologies in new developments.

Nitrogen impact fees can be adopted by towns or on a regional level.

Cape Cod's current development incentive structure will continue to lead to over-development and degraded water quality from nitrogen pollution. Realigning development incentives, particularly through the use of nitrogen impact fees, can begin to remedy this situation.

Cape Cod towns make their own decisions about how much development to allow by adopting zoning and other land use regulations. To the extent that development has occurred or continues to occur without the benefit of wastewater treatment, there is a development threshold above which nitrogen harms the region's beaches and other tourist attractions. The region as a whole is dependent on tourism and recreational ecosystem services. Each town's individual development decision impacts not only its neighbors, but the long-term viability of the region. If a town allows unmitigated development, it receives a private benefit in the short-term by externalizing costs, such as nitrogen pollution, onto other towns in the region. In this situation, the long-term viability of the town and the region will be threatened by the degradation of the Cape's environment. In the long-term, limited development and the provision of wastewater infrastructure will maximize economic benefits for all towns.

A nitrogen impact fee system aims to include the complete social and environmental cost of a development into the developer's project cost, neutralizing private short-term benefits at the expense of long-term public costs. Several states are testing elements of a region-wide impact fee system. Eighteen states have implemented or intend to adopt variations of an impact fee for harmful externalities as part their growth management strategy. In addition, a form of "nutrient trading" is being considered for the Chesapeake Bay watershed, which includes portions of New York, Pennsylvania, Maryland, Virginia, West Virginia, Delaware, and Washington D.C. Lessons from these prior approaches have varying degrees of relevance and can be informative in future discussions across the Cape about nitrogen impact fee systems.

The next step in exploring the viability of implementing nitrogen impact fees is a discussion with Cape officials and stakeholders about the benefits and drawbacks of instituting local and/or Cape-wide nitrogen impact fees.

TAX INCREMENT FINANCING

Tax increment financing (TIF) creates a redevelopment district in which infrastructure improvements and/or project developments are financed based upon an anticipated future increase in property values. The idea is that the development improvements will eventually result in higher property taxes and therefore the financing "increment" is justified. TIF can be initiated either by a private developer or the municipality itself. Once the redevelopment district is determined, a base property value assessment is performed, and the revenue to agencies other than the redevelopment authority is "fixed" at a present-day amount. Any increase in tax revenue through increase in property value will accrue to the redevelopment authority. The TIF district is created for a set time period, usually between five and 30 years, and once the time period

ends, the increase in revenue from the property value increase reverts to the baseline taxing structure. For more information visit: https://www.planning.org/divisions/planningandlaw/propertytopics.htm.

TRANSFER OF DEVELOPMENT RIGHTS

Transfer of Development Rights (TDR) is a market tool communities can use to achieve land preservation. The preservation is accomplished by allowing one landowner to sever his/her development rights in exchange for compensation from another landowner who wants his/her development rights to increase. TDR programs transfer the development rights of a predetermined lot , known as a sending area, to another lot , known as the receiving area. Thus, while the development rights are reduced or severed on the sending area, increased density and development is allowed on the receiving area. The sending sites are typically deed-restricted so that only appropriate uses are allowed from the rights sale onward. TDR programs can be mandatory or voluntary. With mandatory TDR programs, the sending and receiving areas are pre-designated by downzoning the sending areas and decreasing the base density of the receiving areas so more development rights must be purchased in order to build at higher densities. With voluntary TDR programs, the sending areas are not downzoned. Instead, owners retain the option to receive payment for development on their property; these transferred rights are known as development credits. For more information visit: https://www.planning.org/divisions/planningandlaw/propertytopics.htm.

NUTRIENT REDUCING DEVELOPMENT

The development or redevelopment of property provides an opportunity to address wastewater treatment for the particular parcel under development, as well as the wastewater treatment needs of surrounding development. This solution removes both the new nitrogen generated by the new development and the existing nitrogen generated by existing proximate development, so that a net nitrogen reduction is realized in the area. This model can also be applied to existing developments, where one existing development has excess treatment and disposal capacity and allows another existing development to connect to their underutilized wastewater treatment infrastructure.

Two example projects that have been permitted on Cape Cod are Willowbend (Mashpee) and Red Brook Harborview (Bourne). The Willowbend project entailed construction of a nine-hole golf course expansion on Shoestring Bay. In addition to using an Integrated Pest Management Plan to minimize the use of fertilizers and chemicals, the project provided a nitrogen loading offset by connecting the neighboring Cotuit Bay Condominiums to the Willowbend Wastewater Treatment Plant. Willowbend paid for and constructed the sewer connection at no cost to the Cotuit Bay Condominiums resulting in a net reduction of 1,274 pounds of nitrogen per year to Shoestring Bay.

The Red Brook Harborview project is a mixed-use (residential and commercial) project that provides a village-scale wastewater treatment plant located on Red Brook Harbor in Bourne and was enabled by the Marine Commercial Overlay District zoning amendment. The bylaw allowed an increase in density (from four to 15 residential units) in exchange for an advanced wastewater treatment plant. The plant was oversized to treat wastewater from the adjacent Kingman Yacht Center, the 15 townhomes and up to 52 existing single family homes in the Cedar Point neighborhood. Upon buildout the project will result in a net reduction of 2,468 pounds of nitrogen per year to Red Brook Harbor. The wastewater treatment plant will be constructed and paid for by the private developer and made available to the neighborhood residents.

In general, the costs of this solution will be variable according to the technology employed. The cost to all involved parties will likely be reduced in relation to construction of separate, independent wastewater treatment works, by spreading the cost across more users in close proximity.

The performance and potential challenges of this approach will depend on the technology employed. In the past this approach has been employed by commercial development utilizing traditional infrastructure that has excess capacity to cover other new or existing development. Maintenance and monitoring responsibilities are typically established through private contractual agreements.

The benefit of this solution is the net nitrogen reduction in an area that is experiencing beneficial growth and development. The greatest challenge is that, under current regulations, this approach to addressing impacts from new development is voluntary and could be more complicated than addressing the on-site nitrogen generated by the new development. In order for this approach to be widely

used, incentives within the regulations would need to be developed. These could include density bonuses or reductions in other mitigation costs for non-nitrogen impacts. Current potential permitting agencies include: MassDEP, local departments of public works, boards of health, building departments, and the Cape Cod Commission.

The next step in exploring this approach is to initiate a discussion with Cape officials and stakeholders regarding potential regulatory amendments to promote sharing of private wastewater infrastructure to achieve net nitrogen reductions in nitrogen sensitive watersheds.

Planning Partnerships

Cape Cod is greater than the sum of its 15 towns. Because Wastewater Management Agencies will need physical domain over the lands and nutrient contributions they seek to manage, coordination with federal and state partners will be necessary to achieve water quality goals. Joint Base Cape Cod and the Cape Cod National Seashore are the largest of these state and federal land holdings, and they provide important open space and significantly reduced residential density and related nitrogen loads within their borders.

The Massachusetts Department of Transportation (MassDOT) state roadway system impacts coastal and freshwater bodies through stormwater runoff and tidal restrictions caused by state roadway bridge abutments and there is an opportunity to work cooperatively to address these issues. Federal, state and municipal governments and local land trusts play an important role through past and future open space acquisitions that prevent new development and protect water resources (see open space protection section above). Various federal and state programs are also available to assist the region as we implement water quality restoration measures.

JOINT BASE CAPE COD

RELATIONSHIP TO SURROUNDING TOWNS

At approximately 22,000 acres, Joint Base Cape Cod (JBCC), formerly known as the Massachusetts Military Reservation (MMR), is one of the largest contiguous properties in state or federal ownership on Cape Cod. There are four military commands operating on the base, including: the Massachusetts Army National Guard at Camp Edwards, the Massachusetts Air National Guard's 102 Intelligence Wing at Otis Air National Guard Base, the 6th Space Warning Squadron phased array radar site at Cape Cod Air Force Station, and the U.S. Coast Guard at Air Station Cape Cod.

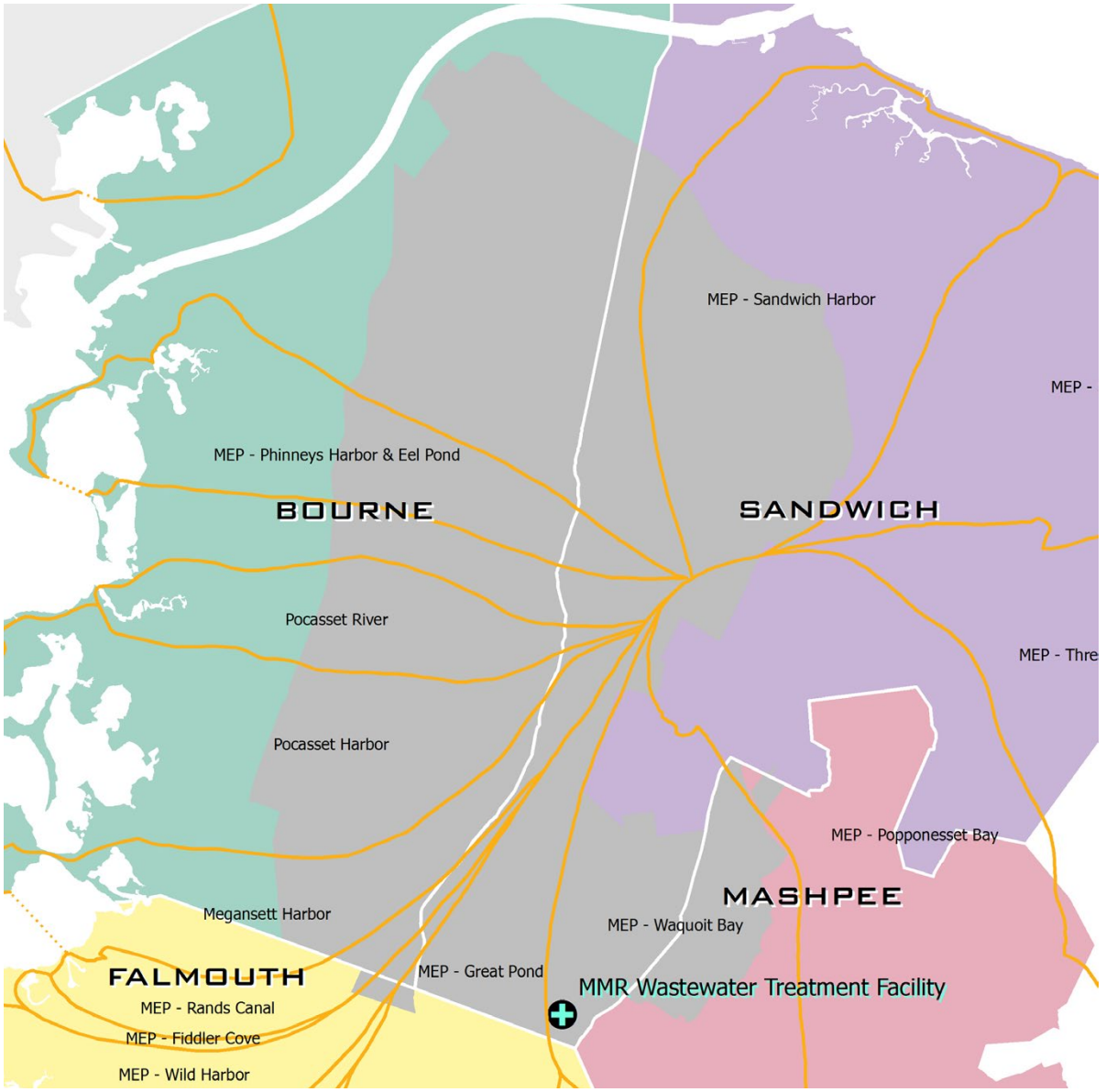
Camp Edwards, principally used for Army National Guard training, is comprised of approximately 15,000 acres in the northern portion of the base. The cantonment area, which is substantially more developed with structures, roads and other infrastructure, is comprised of approximately 7,000 acres in the southern portion of the base. JBCC includes parts of the towns of Bourne, Mashpee, and Sandwich, and abuts the town of Falmouth in Barnstable County, Massachusetts. The northern 15,000 acres of the base, also called the Upper Cape Water Supply Reserve, where the majority of the Army National Guard training occurs, was protected through a Memorandum of Agreement (MOA) and an Executive Order in 2001. The MOA was codified into law in 2002. Activities in the Reserve are subject to Environmental Performance Standards that were enacted to ensure the permanent protection of the Cape's drinking water supply and wildlife habitat in that area (Harshbarger 1998). The Environmental Management Commission ("EMC") of the JBCC consists of three members: The Commissioner of the Department of Fish and Game, the Commissioner of the Department of Conservation and Recreation, and the Commissioner of the Department of Environmental Protection. The EMC's responsibility is to ensure the permanent protection of the drinking water supply and wildlife habitat of the Reserve and to ensure all military and other activities in those 15,000 acres are consistent with the Environmental Performance Standards. The northern 15,000 acres contains four public water supply wells, three as part of the Upper Cape Regional Water Supply Cooperative and one as part of the Bourne Water District. The EMC is assisted by the Community Advisory Council ("CAC"), which consists of the following members: one each from Falmouth, Bourne, Sandwich and Mashpee; one family member resident of the JBCC; two representatives from the military; one from the Cape Cod Commission; one from the Wampanoag Tribe; one from the Upper Cape Regional Water Supply Cooperative; and five other at-large members. All members are appointed by the Governor.

STATUS OF JBCC WASTEWATER TREATMENT FACILITY

The 102nd IW is the host for utilities at JBCC, including the wastewater treatment plant (WWTP). Massachusetts DEP issued the 102nd IW a new discharge permit early in 2004 that authorizes an average 360,000-gallon per day discharge from the WWTP to enable it to accept a maximum 60,000-gallon per day sewage discharge from the new Barnstable County Jail and House of Corrections just north of Connery Avenue, in addition to wastewater from military installations. The location of the treatment facility is shown in **Figure 7-4**.

The MAARNG operates two facilities in the Reserve (Camp Edwards) with individual septic systems: Range Control and the Ammunition Supply Point (ASP). The US Air Force's Cape Cod Air Force Station also operates septic systems at their facility within the northern 15,000 acres. These discharges should be quantified and allocated to their appropriate watersheds.

The status of the 102nd's wastewater treatment plant is based in part on information contained in Appraisal Consulting Services for the Wastewater Treatment System at the MMR (Appraisal) completed in December 2012 by CH2MHill for MassDevelopment, a quasi-public state financing and development agency for the Commonwealth. Additional information was obtained from CWMPs either completed or currently in process by the four Upper Cape towns.



Joint Base Cape Cod, Surrounding Towns and Location of Wastewater Treatment Facility

Figure 7-4

The wastewater management system at JBCC was designed to provide wastewater collection, onsite treatment, and onsite disposal of treated wastewater from installation facilities. Wastewater is collected and conveyed by gravity and force mains to the WWTP located at the southern boundary of the base. Treated wastewater from the onsite WWTP is pumped through a 10.5 mile long effluent force main and disposed through rapid infiltration beds (RIBs), which are located on the northern boundary of the installation. The effluent force main and the disposal beds were constructed in 1996. The system was originally designed to allow biosolids from the WWTP to be composted and disposed of onsite as a soil amendment. Currently, wet biosolids are trucked offsite for disposal.

The general condition of the wastewater treatment plant was found by the CH2MHill report to be "fair" since it was upgraded in 1996 and underwent a number of part replacements in 2002. The report also noted the condition of the collection system was "cautious" since the collection system is over 50+ years old and no formal assessments have been completed. A 2001 inflow and infiltration study (I/I) indicated that I/I was a significant portion of the flow captured by the system.

The study reported that the replacement cost was $44 million, but that the replacement cost less depreciation was $16 million. The near-term and 20-year needs for JBCC users were reported as 140,000 and 147,000 gallons per day (gpd) respectively.

The study attempted to gauge the wastewater needs of the surrounding communities. This effort made use of the best available information from the towns to reflect existing and potential wastewater needs. The total short-term and future needs for treatment and total disposal are indicated in **Table 7-1** (excerpted from the study). Since the completion of the 2012 Appraisal, the Town of Mashpee filed a draft CWMP with the Massachusetts Environmental Policy Act (MEPA) Unit indicating a potential for treatment and disposal of 200,000 gpd of wastewater generated in the western portion of the town to be transported to and treated at the 102ndIW's WWTP.

ENTITY	NEAR-TERM NEEDS (GPD)	20-YEAR NEEDS (GPD)	REQUIREMENTS
JBCC Users	140,040	147,300	Treatment and Disposal
Town of Falmouth	200,000	200,000	Disposal only
Bourne Landfill	40,000	80,000	Disposal only
Town of Bourne	0	1,836,000	Treatment and Disposal
Town of Sandwich	156,000	630,000	Treatment and Disposal
Town of Mashpee	158,000	658,600	Treatment and Disposal
Total: Treatment and Disposal	454,040	3,271,900	
Total: Disposal Only	240,000	280,000	

Summary of Wastewater Treatment and Disposal Needs

Table 7-1

STATUS OF DISPOSAL SITE

Final treated effluent is pumped through a 10.5-mile ductile iron force main to four sand-lined RIBs located on the northern boundary of the JBCC south of Route 6 (Sandwich Road).

The effluent disposal system consists of the following components:

- Piping to distribute effluent to RIBs
- Four sand lined RIBs that cover approximately six acres
- Seven groundwater monitoring wells (three pairs downgradient, one upgradient)

The soil characteristics and design parameters for the treated wastewater disposal system are described in the Hydrogeologic Investigation and Design Effluent Infiltration Basins technical memorandum (CDM Smith 1993). Review of the hydrologic analysis indicates that the design capacity of the RIBs, according to Massachusetts Department of Environmental Protection (MassDEP) criteria, is substantially higher than the permitted flow to the WWTP. Based on the size of each infiltration basin and an assumed hydraulic conductivity that is typical of the Cape, the total

capacity of the four RIBs is approximately 907,000 gpd. With one RIB as reserve capacity, the disposal capacity is about 672,000 gpd.

JBCC JOINT LAND USE STUDY

The Cape Cod Commission completed an update to a 2005 JBCC Joint Land Use Study (JLUS) in October, 2013. Factors prompting the Army's re-nomination of JBCC for a JLUS were changes to missions on the installation due to the 2005 Base Realignment and Closure (BRAC) round, an increase in the training population using JBCC's ranges, and concern about the compatibility of future civilian land uses surrounding JBCC.

As demonstrated in the Appraisal discussed above, the WWTP and RIBs have sufficient capacity for existing and future (20-years) JBCC military wastewater needs. Those facilities also have excess capacity to treat and dispose of wastewater generated by non-military entities. Through the JLUS process, and based on the Appraisal, the JLUS identified the potential for a military/municipal partnership and shared services through municipal use of the excess capacity of the JBCC WWTP and RIBs for wastewater and landfill leachate disposal. The JLUS states:

Given the wastewater nutrient management needs of the region to achieve TMDL compliance and limited wastewater infrastructure on Cape Cod, it is a recommendation of this plan that existing capacity at the JBCC WWTP should be reserved for military and community needs.

The Office of Economic Adjustment (OEA), US Department of Defense provided funding for the JLUS update and provides funding for studies and preliminary design for potential shared infrastructure and services between military bases and surrounding communities.

JBCC MILITARY AND NON-MILITARY NITROGEN CONTRIBUTIONS

As stated above, there is sufficient wastewater treatment and disposal capacity for existing and future (20-years) military needs. The JBCC controls land within 13 watersheds that are shared with the towns of Bourne, Sandwich, Falmouth and Mashpee, as shown previously in **Figure 7-2**. The individual municipalities are responsible for planning and implementation to prevent violations of the Federal Clean Water Act. Because the JBCC controls land within watersheds that are shared with the towns, increases in the contribution of nitrogen from the JBCC within those watersheds will raise the bar for towns striving to meet TMDLs, and potentially increase the burden on municipal taxpayers.

While there is adequate treatment and disposal capacity for military uses, an unknown level of nitrogen contribution could result from non-military uses on the base. MassDevelopment has expressed an interest in promoting new development on the base with uses that do not compete with municipal economic development opportunities, and which are military-compatible. With these two caveats, this Plan supports the creation of new non-military uses that have proper wastewater treatment and disposal to ensure no net nitrogen impacts in nitrogen sensitive embayments.

To ensure equity and parity between the base and the surrounding towns, this Plan proposes further discussion and coordination between JBCC leadership, MassDevelopment and the Commission to establish a wastewater allocation policy for land uses within nitrogen sensitive watersheds that emanate from the base. Further, the military should ensure that future development within the cantonment area be connected to the JBCC wastewater treatment plant wherever feasible as recommended by the 2005 JLUS. Future agreements could also establish a protocol for allocating excess capacity at the WWTP and RIBs. The Commission is currently working to establish a new, proactive communications plan between the JBCC, MassDevelopment, the Commission, and the surrounding towns through a grant provided by OEA. The Commission has a webpage that provides comprehensive information on current and past plans and studies completed by the Commission regarding the JBCC, including the 2005 Joint Land Use Study and its 2013 update, as well as the MMR Master Plan Final Report, which includes background information on past environmental issues that led to subsequent planning processes. For more information, visit www.capecodcommission.org/jbcc.

Recommendation S7.1: The Cape Cod Commission shall continue discussion and coordination with JBCC and MassDevelopment regarding wastewater allocation policy for the base.

Recommendation S7.2: The Military should ensure that future development within the cantonment area be connected to the JBCC wastewater treatment plant wherever feasible.

STATE HIGHWAYS

STORMWATER MANAGEMENT

79% of the Cape's land mass is in a watershed to a coastal embayment. It is therefore not surprising that miles of municipal and state roadway run through nutrient impaired watersheds on Cape Cod (see **Figure 3-1** in Chapter 3). To varying degrees, stormwater runoff from these roadways contributes to the nutrient problems experienced on the Cape.

Through the MassDOT Impaired Waters Program (IWP), MassDOT has instituted a program to address roadway stormwater runoff draining to impaired water bodies. The program is part of the agency's compliance with its NPDES Phase II Small MS4 General Permit and commitments in an EPA enforcement letter dated April 22, 2010. Under the Program, "Impaired" water bodies are those listed as Category 4a or 5 in MassDEP's Integrated List of Waters (often referred to as the 303(d) list).

As currently proposed, MassDOT's IWP will include a methodology to assess water bodies covered by a nitrogen TMDL on the Cape. MassDOT is in the process of developing a methodology to assess stormwater contributions. This Section 208 Plan Update recommends future coordination of these assessment methodologies between MassDOT and the Commission.

Recommendation I7.3: MassDOT and the Cape Cod Commission should coordinate the methodologies for assessing stormwater contributions.

The Commission will review and comment on future NPDES regulatory filings and work with US EPA Region 1 regarding IWP methodologies adopted for the Cape. Due to the geology and hydrology of the Cape, it is recommended that Cape-specific Best Management Practices (BMPs) be developed for stormwater management in nutrient sensitive watersheds. Further discussion of specifically identified direct and indirect stormwater discharges to impaired water bodies is also recommended.

TIDAL RESTRICTION

Another area of cooperation is in the widening of coastal bridge abutments to improve tidal flushing in coastal areas where it is feasible and practical during roadway improvement projects. For example, MassDOT is proposing to replace an existing bridge over the Bass River between the Towns of Dennis and Yarmouth, associated with the Cape Cod Rail Trail extension. The existing bridge abutments constrict flow of the Bass River and are listed as a tidal restriction by the Cape Cod Atlas of Tidally Restricted Salt Marshes. The currently proposed bridge would increase the bridge opening to match upstream restrictions and would provide improvements to the hydraulics in the channel by increasing tidal flushing, decreasing channel velocities, and decreasing scour potential. Another example is the widening of the Muddy Creek bridge which is currently being undertaken by the towns of Harwich and Chatham.

To help address stormwater management issues within state highway layouts on Cape Cod, this Plan recommends the following:

- The Commission should work with the Cape Cod Metropolitan Planning Organization (MPO) to adopt policies that would require to the maximum extent practical design and construction of Cape-specific BMPs in Transportation Improvement Project (TIP) funded roadway improvement projects in the region. The Commission should also work with MassDOT through the IWP to identify Retrofit Projects to address specific roadway runoff issue affecting water quality in the area.
- The Commission should engage in discussions with MassDOT regarding the potential use of the state roadway right-of-way. These rights-of-way may present opportunities to permit, pilot and demonstrate non-traditional nutrient removal/remediation technologies, treated water effluent disposal, and water quality monitoring facilities that may be incorporated into state roadway design or constructed in existing roadway layout.

- The Commission and MassDOT should establish a data-sharing agreement to ensure that the best available infrastructure data is fully accessible to each agency.
- MassDOT should seek easements from public and private entities to accommodate the location, construction and maintenance of nitrogen reducing stormwater infrastructure where limited state road right-of-way would prohibit or complicate such location, construction or maintenance.

This Plan also recommends future coordination between MassDOT and the Cape Cod Commission to:

- Develop methodologies to assess stormwater contributions from state roadways,
- Identify opportunities to widen coastal bridge abutments to improve tidal flushing in coastal areas,
- Pursue improved data sharing between the two agencies.

The Cape Cod Commission will work with MassDOT through its IWP to identify Retrofit Projects to address specific roadway runoff issue affecting water quality. The Cape Cod Commission will comment on future NPDES regulatory filings by MassDOT with US EPA Region 1. Other areas of potential coordination include use of the state roadway rights-of-way for water quality improvement projects, and encouraging the use of easements from public and private entities on lands abutting state roadways to accommodate stormwater management systems.

Coordination between MassDOT and the Cape Cod Commission should be continued.

OTHER REGIONAL/STATEWIDE INITIATIVES

US EPA received $2 million in funding in FY14 to begin implementing the Southeast New England Coastal Watershed Restoration Program (SNEP). SNEP is a partnership among public and private stakeholders collaborating to create a broad ecological and institutional framework for protecting and restoring the coastal and watershed area spanning Westerly, RI to Pleasant Bay, MA. Nutrients, stormwater, and habitat restoration have emerged as key issues for this geographic area, and development of innovative or more effective approaches for managing them is a common priority. Those approaches that integrate habitat and water quality are of particular interest, as are projects that are transferable to the entire Region.

In FY14, the two National Estuary Programs (NEPs) - Narragansett Bay and Buzzards Bay - awarded $723,869 and $728,559, respectively, on behalf of SNEP to provide funding for projects in their study areas. See Chapter 4 for details on the projects that were funded.

The FY15 President's Budget includes additional funding for this Program - a total of $5 million for the region. Continued support for this program will allow Cape Cod communities to explore and pilot the non-traditional technologies and approaches identified in this plan that otherwise may not be possible through traditional local funding and financing. Cape Cod communities will have the opportunity to test the effectiveness of non-traditional technologies and approaches locally, continue refining the Technologies Matrix, and transfer that knowledge to other areas regionally and nationally.

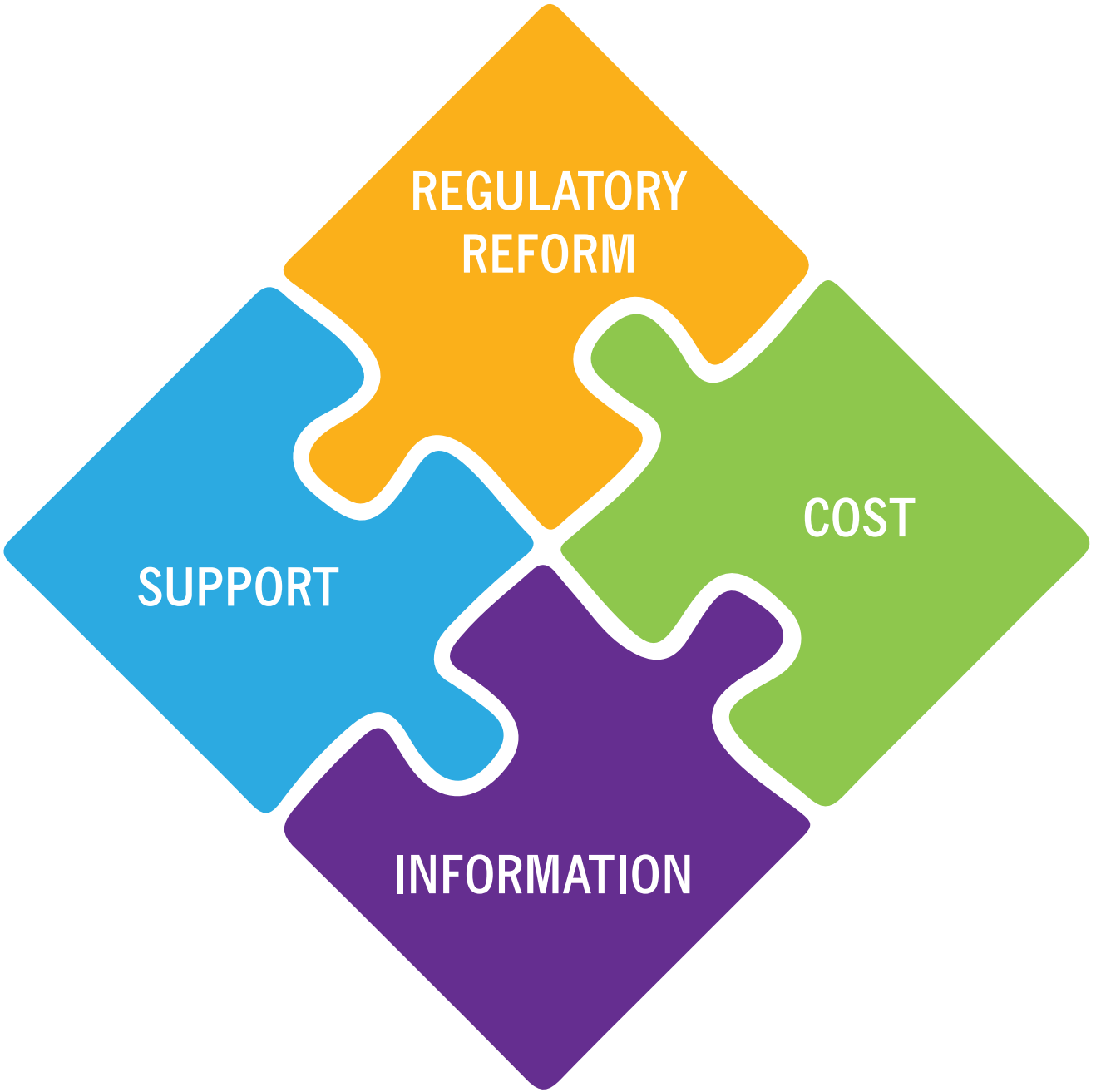
As part of the Section 208 Plan Update, the Commission suggests that US EPA continue its efforts under SNEP and encourage the continued expansion of the program moving forward.

> **Recommendation C7.4: US EPA should continue to expand the efforts of the SNEP program and encourage the continued expansion of the program moving forward.**

08 IMPLEMENTATION

Recommendations

Cape Cod is experiencing a significant decline in our near-shore water quality that threatens not only our environment but also our economy. Many towns have been engaged in this discussion for years but action has been difficult. Regulations that drive and support efforts to solve our nutrient issues are focused on the jurisdiction of political subdivisions instead of the jurisdiction of the problem – watersheds. Available enforcement measures were developed with different pollution problems in mind.


REGULATORY REFORM
COST
SUPPORT
INFORMATION

IMPLEMENTATION

Chapter 8: Recommendations

Without action the future presents Cape Cod with a limited range of possibilities, the extremes of which are equally bad. Do nothing and we threaten our seasonal economy and watch as the property tax burden in every town migrates away from the coast and toward those whom can least afford it, an economic dislocation that will permanently disfigure the region, or wait for court mandated enforcement of currently available regulations that would come at great cost to Cape Cod homeowners and alone would not solve the problem.

The recommendations that follow are the result of 12 months of active community engagement. Collectively they represent a path forward that provides an opportunity to implement a responsible plan for the restoration of the waters that define Cape Cod.

The recommendations presented throughout this Section 208 Plan Update are restated here and grouped in four categories, outlining actions necessary to implement the plan update and restore water quality:

- Information (I)
- Regulatory Reform (R)
- Support (S)
- Cost (C)

Information

The course of action proposed in this document depends on information. The collection of data, the development of tools making data easier to use, and the analysis of water quality and wastewater technologies and policies create the framework for designing responsible watershed plans. The watershed scenarios created by adaptive nutrient management planning are dependent on a regional monitoring program that provides performance monitoring of selected technologies and policies and compliance monitoring measuring the collective effectiveness of permitted watershed nutrient reduction and removal strategies (**Monitoring I4.7**). In order to effectively monitor non-traditional technologies, this plan recommends that the Cape Cod Commission provide a technical guidance document that includes draft monitoring protocols for non-traditional technologies by September 2015 (**Monitoring Protocols I4.8**).

New information and data collected and learned through monitoring and research should be reflected in the Technologies Matrix. This Section 208 Plan Update recommends that the Commission develop a process for annual updates to the Technologies matrix (**Technologies Matrix Updates I4.1**). In addition, the Commission shall seek opportunities to sponsor an annual symposium to present and review new research on nutrient management technologies and approaches that coincides with regular updates to the Technologies Matrix (**Annual Technologies Symposium I4.2**).

The information collected should be housed in a regional water quality data center and made available to the public serving as a primary source for the continued research and development of water technologies and modeling. The creation of a data center will make sure the public is afforded the highest level of transparency regarding the information used as a basis for water quality policy and

associated capital planning (**WQ Data Center I4.10**). This information loop will enhance effective modification of Targeted Watershed Management Plans (TWMPs).

In addition, the Commission shall create a standing Monitoring Committee, to support implementation of the plan and identify and track developing issues, subject to available resources (**Monitoring Committee I4.9**).

This plan update also suggests continued cooperation and coordination with MassDOT in part to develop methodologies to assess stormwater contributions from state roadways, identify opportunities to improve tidal flushing in coastal areas and use rights-of-way for water quality improvement projects (**MassDOT I7.3**).

Lastly, in order to keep costs low and still meet water quality goals, a significant percentage of wastewater generation on Cape Cod will continue to rely on septic systems creating a demand for septage treatment. More information is needed and this report recommends an evaluation of the demands for septage processing and treatment (**Septage Treatment I4.4**).

Regulatory Reform

The existing regulatory framework for wastewater is better suited for permitting traditional facilities and needs to evolve to meet the challenges of diffuse, non-point source nutrient pollution. Changes are necessary to make it easier for communities and to better respond to the problem.

The MEPA process is generally the first hurdle encountered by communities planning wastewater programs requiring SRF funds. Process improvements recommended in this update create a streamlined Special Review Procedure for the review of TWMPs jointly by the Massachusetts Environmental Policy Act (MEPA) unit and the Cape Cod Commission (**SRP R3.6**). Targeted Watershed Management Plans, based on watershed boundaries, should be required. Minimum performance standards and guidance will be drafted and issued pursuant to this update within 90 days of its approval (**Targeted Watershed Management Plan R5.1**).

The Cape Cod Commission Development of Regional Impact review that typically follows the issuance of a MEPA certificate of adequacy from the Secretary of Energy and Environmental Affairs should be reformed, and a simpler and more supportive process to review Capital Developments of Regional Impacts (CDRIs) should be developed (**CDRI R3.5**). Local water quality management plans, and material changes to existing plans will be reviewed to ensure consistency with this update (**208 Plan Update Consistency Review R3.7**). Specific guidance on the consistency review shall be issued by the Commission within 90 days of this plan update approval (**208 Consistency Review Guidance R3.8**).

Additionally the collective responsibility of localities for nutrient loading should be updated and corresponding enforcement actions clarified. This update recommends the Massachusetts Department of Environmental Protection issue guidance outlining the process for watershed permits for nutrient loads (**Watershed Permitting R3.2**). This will allow communities more flexibility in designing efforts to comply with nutrient load limitations defined in the permit.

MassDEP should consider designating Nitrogen Sensitive Areas where watersheds contributing to waterbodies impaired by nitrogen are subject to a 208 Plan, where development primarily relies on septic systems, and/or where the water body is listed on the 303(d) list due to nitrogen overloading, and should modify available remedial actions to allow appropriate time for waste treatment management agencies to plan. (**Nitrogen Sensitive Areas R3.3**). The Commission also recommends that MassDEP eliminate the regulatory language establishing the presumption that Title 5 systems meet the state water quality standards in situations where it has been established that septic systems contribute to non-attainment (**Title 5 Presumption R3.4**). Given the importance of the federal Clean Water Act and the long-term commitment necessary to implement solutions to nutrient pollution on Cape Cod, the Commonwealth should seek delegated authority under the Clean Water Act to issue and enforce NPDES permits (**NPDES Delegated Authority to the State R3.1**).

Support

More direct support of local wastewater planning is warranted. This update recommends that local planning efforts consult with the Commission early in the process to ensure coordination between active watershed planning efforts and the Section 208 Plan Update. The Commission

shall provide technical assistance by assigning Watershed Teams to Waste Management Agencies (WMAs) and municipalities to support community planning efforts and to assist with decision support tools, permitting of technologies and financing (**Watershed Teams S5.3**).

These teams will assist in targeted watershed planning efforts and will advise on the development of watershed scenarios with nutrient management plans consistent with this Section 208 Plan Update (**Hybrid Watershed Planning Approach S5.2**). In conjunction with the watershed team approach, the Cape Cod Commission shall provide a detailed evaluation of effluent disposal options by September 2015 (**Effluent Disposal S4.3**). The watershed plans developed as part of the Section 208 Plan Update will also identify pilot projects and assist in identifying financial resources and direct support through a regional monitoring program. The Cape Cod Commission should establish criteria for eligible pilot projects (**Criteria for Pilot Projects S4.5**). In coordination with The United States Environmental Protection Agency (US EPA) and MassDEP, the Cape Cod Commission shall also work with communities, state and federal agencies to identify opportunities to implement pilot projects in suitable locations across Cape Cod (**Implementing Pilot Projects S4.6**). New development located where it must rely on septic systems should participate in managing nutrient loading. The Cape Cod Commission shall evaluate the steps required for a regional or locally based nitrogen impact fee (**Nitrogen Impact Fee S6.3**).

Additionally, this report recognizes the importance of third-party facilitation of intra and intermunicipal disagreements and recommends a process or guidance to manage disagreement among parties be developed in addition to the allocation of federal, state and regional resources for this purpose (**Managing Disagreement S1.1**). Implementation of the Section 208 Plan Update shall also include a local public participation process that includes efforts specifically designed to reach environmental justice communities (**Environmental Justice S6.6**).

This Plan also proposes further discussion and coordination with JBCC and MassDevelopment (**JBCC S7.1**) regarding wastewater allocation policy for the base, and also suggests that the military ensure that future development within the cantonment area be connected to the JBCC wastewater treatment facility wherever feasible (**Development in Cantonment Area S7.2**).

Cost

This issue of cost is paramount in considering the feasibility of proposed actions to restore Cape Cod's marine water quality. In addition to the existing efforts of the Cape Cod Wastewater Protection Collaborative in working with our legislative delegation to highlight the need for a broader base of financial support for wastewater treatment on Cape Cod, this report recommends that the Cape Cod Commission develop a proposal for a Cape Cod Capital Trust Fund for the financing of infrastructure design and construction (**Cape Cod Capital Trust Fund C6.5**). In addition, this plan recommends that the Cape Cod Commission develop a proposal for a Septic Trust Fund and pursue authorizing legislation (**Septic Trust Fund C6.4**).

Pursuant to the recently signed Water Infrastructure Bill, MassDEP should exercise its discretion in providing principal forgiveness up to 25% (**Principal Forgiveness C6.1**). The Environmental Bond Bill signed by the Governor in August 2014 makes available $4 million for monitoring programs and $4.5 million for pilot projects that are consistent with a current area wide water resource management plan adopted under section 208 of the federal Clean Water Act. This report recommends that the Commonwealth of Massachusetts make these and other funds designated for monitoring programs and pilot projects available to Cape Cod for efforts that are consistent with this Section 208 Plan Update (**Monitoring and Pilot Projects C6.2**). US EPA should also continue to expand the funding and piloting efforts of the Southeast New England Program (SNEP) and encourage the continued expansion of the program (**SNEP C7.4**).

Lastly, local targeted watershed management plans consistent with the Section 208 Plan Update should qualify for existing and potential revenue sources (**Access to Funds C5.4**).

Tools for Collaboration

The subregional stakeholder process associated with the Section 208 Plan Update identified three key categories of challenges to collaboration across town boundaries: who decides, who pays and who manages.

More specifically, "who decides" includes the following questions:

- Who decides which solutions to implement and when and how to reassess?
- How do two or more towns reconcile different levels of planning across town boundaries (including approved CWMPs)?
- How do two or more towns reconcile different town decision-making processes?
- Who decides the timeline required for building agreement?

"Who pays" includes the following questions:

- How do two or more towns coordinate different funding approval processes?
- How do two or more towns apply for and allocate off-Cape funding opportunities?
- How do two or more towns reconcile differences in willingness and abilities to pay?
- Who is financially responsibility for capital funding, operation and maintenance, monitoring, data management, and reporting?

And, "who manages" includes the following questions:

- Who is responsible for preparation of the watershed plan for permitting?
- Who builds, operates, maintains, monitors, and reports?
- Who is ultimately responsible for water quality outcomes?

Included in Appendix 8A is information on existing models that could be used by Cape Cod communities to address the challenges associated with who decides, who pays, and who manages. Existing models include intermunicipal agreements, federal/municipal public/public partnerships, independent water and sewer districts, water pollution abatement districts, districts of critical planning concern, regional health districts, and other potential models. Included is a discussion of the watershed conditions on Cape Cod where each may be most appropriate as a management structure.

Waste Treatment Management Agencies

Section 208 of the Clean Water Act requires the Commonwealth of Massachusetts to designate one or more waste treatment management agencies. As discussed below, these WMAs have specific responsibilities set forth by Section 208(c)(2)(A-I) of the Act, and include.

- to carry out the area wide waste treatment management plan;
- to manage waste treatment works and related facilities;
- directly or by contract, to design and construct new works, and to operate and maintain new and existing works as required by any plan developed pursuant to subsection (b) of this section;
- to accept and utilize grants, or other funds from any source, for waste treatment management purposes;
- to raise revenues, including the assessment of waste treatment charges;
- to incur short- and long-term indebtedness;
- to assure in implementation of an area wide waste treatment management plan that each participating community pays its proportionate share of treatment costs;
- to refuse to receive any wastes from any municipality or subdivision thereof, which does not comply with any provisions of an approved plan under this section applicable to such area; and
- to accept for treatment industrial wastes.

WMAs will need to not only build and operate technologies outlined in their watershed plans to achieve TMDL compliance, but also must have the capacity to issue bonds and notes to raise revenues to carry out their plans.

Given the shared nature of the water resources on Cape Cod, collaboration across town boundaries will be necessary to fulfill the requirements of Section 208.

The March 2015 submission to MassDEP of the Section 208 Plan Update set forth a process designed by the Cape Cod Commission for designating WMAs that included opportunities for local input on establishing responsibility and collaborating on shared watershed scenarios (see box below). See Appendix 8B for documentation of the process. The following amendment to this chapter provides details on the recommended designation and next steps.

DESIGNATING WASTE TREATMENT MANAGEMENT AGENCIES

Each of the 15 Cape Cod towns has been engaged, to varying degrees, in wastewater or watershed planning to date (see Chapter 2). Towns have traditionally been the responsible party for planning, design, construction and management of wastewater infrastructure and these efforts should continue. Each town has the ability to meet the requirements set forth in Section 208(c)(2)(A-I) of the Clean Water Act and are the appropriate entities to develop and implement local decisions regarding technology selection and placement.

WMA Designation Process

The Cape Cod Commission worked with town teams in a working group approach in a series of meetings, between March and June 2015, to get feedback on the designation of waste treatment management agencies (WMAs). Town teams consisted of town managers/administrators, staff, elected officials, and interested citizens. Five watersheds across Cape Cod were used for illustration and discussion around the following topics:

- Principles for establishing allocation of nitrogen responsibility
- Developing watershed scenarios
- Organizational and institutional structures

In June 2015, the Cape Cod Commission amended the 208 Plan Update to include the recommended WMA designations and implementation guidance.

Recommendation R8.1: The Cape Cod Commission recommends the Commonwealth of Massachusetts designate each of the 15 towns in Barnstable County as the WMAs responsible for implementation of the Section 208 Plan Update in the watersheds for which they are responsible.

WMAs are responsible for all of the nitrogen that enters the groundwater from land within their jurisdiction. A process for assigning nitrogen responsibility is described below. Parcels within the jurisdiction of Joint Base Cape Cod or the Cape Cod National Seashore are excluded from the town allocations, unless the parcel is assessed as residential, commercial or industrial.

ALLOCATING NITROGEN RESPONSIBILITY

Assigning Responsibility at the Subembayment Level

The Massachusetts Estuaries Project (MEP) establishes nitrogen thresholds, or the amount of nitrogen a water body can handle and still meet water quality goals, for each subembayment within the larger embayment systems they study. This is the best available information to identify nitrogen reduction targets for specific areas across Cape Cod. Therefore, it is recommended that responsibility for nitrogen reduction be assigned at the subembayment

watershed level. For watersheds that do not have a completed MEP technical report, the entire watershed area should be used.

Stormwater Coefficients

The stormwater coefficients account for driveways, structures, parking lots, and road frontage and the assumptions are as follows:

Residential:

- 2,000 sq. ft. home
- 500 sq. ft. driveway
- 40 ft. (width) road frontage

Non-Residential:

- 15,000 sq. ft. roof
- 30,000 sq. ft. parking lot
- 40 ft. (width) road frontage

Fertilizer Coefficients

The fertilizer coefficients account for lawn area and the assumptions are as follows:

Residential:

- 5,000 sq. ft. lawn

Non-Residential:

- 10,000 sq. ft. lawn

Start with the Unattenuated Controllable Nitrogen Load and Apply Attenuation Factors where Available

The controllable watershed nitrogen load is calculated on a parcel by parcel basis in three parts: wastewater, stormwater, and fertilizer. The wastewater load is calculated based on 90% consumptive use of the water used on each parcel. Nitrogen load from wastewater is calculated by applying the level of treatment associated with each parcel to the wastewater load (for example, septic systems treat to a level of 26.25 parts per million). To calculate both the stormwater and fertilizer loads constant coefficients for each are assigned to every parcel. These assumptions are derived from the MEP process and vary depending on whether the parcel is residential or non-residential. The stormwater and fertilizer coeffficients can be found in the box that follows.

These calculated nitrogen loads are source loads, prior to attenuation in the watershed (unattenuated loads). These unattenuated loads comprise a consistent Cape-wide data set that should be used as the starting point when considering nitrogen responsibility. The MEP technical reports document the ability of ponds and streams to attenuate nitrogen at a subwatershed level, but not all watersheds have the benefit of an MEP report at this time. Wherever a report is available, the attenuation factor should be applied to calculate the controllable load that reaches the water body.

Calculate Responsibility for the Existing Nitrogen Load based on Existing Attenuated Load

Existing attenuated nitrogen load takes into account the best available information without speculating about future development and addresses the problem existing development places on nitrogen overloaded estuaries. Each town's responsibility should be calculated based on its percentage contribution to the subembayment watershed's total controllable nitrogen load. The percentage contribution should be applied to the nitrogen reduction target to calculate the amount of nitrogen, in kilograms per year, for which a town is responsible.

Appendix 8C provides a complete breakdown of subembayment watersheds and nitrogen responsibility by town.

How to Address Growth

As the impact of future growth on attenuation in ponds, streams and other natural surfaces is unknown, projections of future nitrogen load responsibility should be based on unattenuated nitrogen loads.

Future nitrogen load projections are based on a Cape-wide buildout analysis. Future nitrogen responsibility, based on the potential for growth, should be calculated based on each town's potential contribution of nitrogen after buildout.

Data Updates and Local Modifications

The Commission is committed to utilizing the best available data and will update water use data, which is used to calculate wastewater flow and nitrogen load, at the parcel level at regular intervals, likely not to exceed five years. In addition, land use parcel data will also be regularly updated to reflect changes in development. All regular requests and data updates will be completed through the Commission's Strategic Information Office.

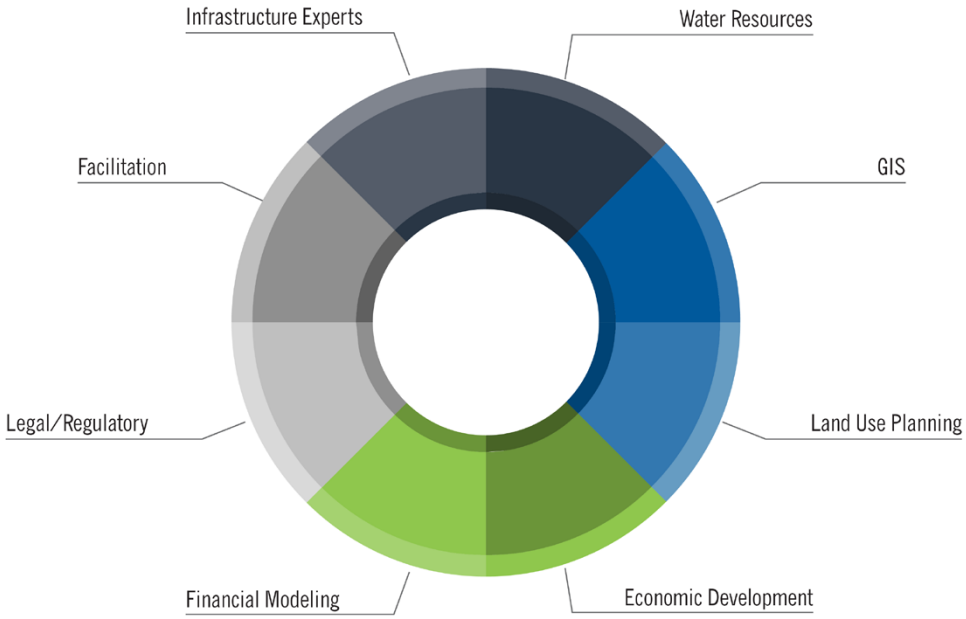
WMAs are encouraged to review the data presented in Appendix 8C and in WatershedMVP. If a WMA has better or more up to date data they will have the opportunity to provide updates to the database. Upon request of a Watershed Team, WMAs can request a data review and update. In addition, data reviews and updates will coincide with the five year incremental reviews associated with the adaptive management plan and the database will be updated as new monitoring data becomes available.

TIMEFRAME FOR IMPLEMENTATION OF THE 208 PLAN UPDATE

Upon certification of the Section 208 Plan Update by the Governor of the Commonwealth of Massachusetts, WMAs will have 12 months to develop "watershed reports" that outline potential scenarios for each of the watersheds for which they are responsible. At a minimum, these reports should include two scenarios that meet water quality goals in the watershed – a collection scenario, which relies completely on traditional collection and treatment, and a non-collection scenario which uses remediation, restoration, and on-site reduction approaches, with little to no collection and treatment.

The collection and non-collection scenarios form the outer bounds of an adaptive management plan. As time and resources allow, WMAs should also work toward establishing a design load that accounts for local non-nitrogen needs and fertilizer and stormwater reduction credits, as appropriate. Once collection and non-collection scenarios and the design load are established, WMAs should begin the development of a hybrid scenario that achieves the design load reduction and incorporates a range of both collection and non-collection technologies. Development of these high level scenarios will assist WMAs in discussions about how they can cooperate with neighboring communities in shared watersheds. A watershed report template is available in Appendix 8D.

In the event that a WMA does not develop a watershed report for a given area the Cape Cod Commission will issue a report based on feedback received in the watershed and



Technical Assistance Available Through Watershed Teams

Figure 8-1

subregional working groups described in Chapter 1 and pursuant to the watershed planning approach identified in Chapter 5. This report will stand as the WMA's plan for that watershed unless and until study is completed by the WMA and an alternate watershed report consistent with this 208 Plan Update is developed by the WMA.

Following this 12 month planning period the Cape Cod Commission will issue an implementation report describing the actions of WMAs to date.

Watershed Teams

The Commission is available to provide assistance to WMAs in developing watershed plans. As part of the process to update the 208 Plan the Commission developed watershed scenarios which will be shared with WMAs. As described in Chapter 5 and in **Figure 8-1**, Watershed Teams are available upon request and can assist WMAs in the areas of water resources, GIS, land use and economic development planning, finance modeling, legal/regulatory issues and consistency, infrastructure and technologies, facilitation, and consensus building. Upon review of the watershed scenarios developed by the Commission, a WMA may request a Watershed Team to assist with modifying the scenarios, as necessary. Specific teams will be provided based on the unique nature of the local planning and the type of assistance required and requested by the WMA.

Watershed Teams can provide training on decision support tools, coordinate local planning efforts with broader regional goals and assist in establishing consistency with local plans and the Section 208 Plan Update. This will be coordinated with the Capital Development of Regional Impact (CDRI) review, as described in Chapter 3, and WMAs that utilize a Watershed Team will receive the benefit of an expedited review based on consistency with the 208 Plan Update.

In watersheds where a Watershed Team is not requested, a 208 Plan Update consistency review in addition to typical regulatory review will be required. Guidance on this process, as described in Chapter 3, will be issued within 90 days of approval of the 208 Plan Update.

Establishing Watershed Associations

Community engagement will help move watershed scenarios, developed as part of the initial 12 month planning period, toward implementation. The process to update the 208 Plan focused on engaging the broader community from the outset, using new decision support tools that make complex data sets easier to understand. This approach involves more people and allows for better discussions and more informed local decisions.

WMAs are encouraged to coordinate with existing watershed associations and/or promote the formation of new associations early in the scenario planning process to ensure public support of the plans during implementation. As described in the proposed Special Review Process outline (Chapter 3) watershed associations might include:

- Elected and appointed municipal officials,
- Members of existing local committees,
- Representatives from the business, real estate, and environmental communities,
- A Cape Cod Commission representative,
- A traditional technology expert,
- A non-traditional technology expert,
- Interested citizens, and
- Representatives from Joint Base Cape Cod and the Cape Cod National Seashore, as appropriate.

These associations can serve as both advisors and ambassadors of local plans. The range of viewpoints represented will ensure closer coordination between plan development, local need and community values. Association members are representatives of the planning process and can share information with their constituents and broader social and professional networks, creating the potential for expanded public support for implementation of a preferred plan when one is established.

Principles for Resource Allocation

Chapter 2 outlines a process for prioritizing watersheds for study. Prioritizing watersheds for resource allocation and implementation requires additional considerations.

Once watershed reports have been developed and adopted by WMAs they should be assessed based on level of community support, including the level of collaboration and cooperation in shared watersheds, the potential for the plan

to facilitate information transfer around new technologies and approaches, estimated time to realize water quality improvements, and ongoing implementation of other capital projects. These considerations should be reviewed in addition to the nitrogen load and degree of impairment in the watershed.

Cost Savings of the 208 Approach

For over a decade Cape Cod towns have been struggling to solve the nitrogen problem and restore the health of our estuaries. Many towns have developed plans to provide wastewater infrastructure to homes and businesses and restore water quality in their embayments but few plans have been implemented. The capital costs of plans for just six of these towns range from $100-$700 million each totaling over $2 billion utilizing infrastructure better suited for urban areas with appropriate density and rate payers. Collectively these plans would remove less than half of the nitrogen necessary to meet water quality standards and do not address many less densely populated and more costly areas of the region.

The Regional Wastewater Management Plan (Cape Cod Commission 2013) estimates that it would cost between $4.2 and $6.2 billion to provide the source reduction necessary to remediate water quality problems in our embayments Cape-wide.

The 208 Plan Update process established an approach more suitable to the largely non-urban and seasonal nature of the communities on Cape Cod. The approach considered remediation and restoration approaches in addition to source reduction. It identified areas with suitable density for collection systems and identified land use characteristics associated with the appropriate use of watershed and embayment technologies, which may be implemented at a lower cost.

With this new approach comes a new challenge in financing. Remediation and restoration technologies must be supported in new ways, as those solutions may not have a defined rate base. Increasing environmental stewardship through information, education, and the development of local watershed associations should help address this challenge. Promoting community support of less expensive technologies, with the understanding that everyone benefits from healthy embayments, should increase support for cost sharing.

The development of this 208 Plan Update has resulted in ways to share the cost with State and Federal partners, who also benefit from healthy Cape Cod embayments. The region has seen an expanded time frame for zero interest State Revolving Fund (SRF) loans, the potential for principal forgiveness on SRF loans through the Environmental Bond Bill, and Federal funding for innovative nitrogen reduction projects through the Southeast New England Program (SNEP).

Based on the balanced approach set forth in this Plan Update, Cape Cod can implement appropriate source reduction, remediation, and restoration strategies for between $2 and $3.8 billion to meet water quality goals. This savings has been demonstrated locally through the development of a 208 consistent process in the town of Orleans, which is estimating a 40% savings over their original comprehensive wastewater management plan by adopting the approach set forth in this plan.

Lowering the cost of projects by considering collection and treatment in areas where it's most appropriate, broadening the use of remediation and restoration technologies, and sharing the cost with our partners results in a lower cost for Cape Cod residents and affordable scenarios for improving water quality.

Listing of Commonly Used Abbreviations:

3VS Triple Value Simulation

Act Cape Cod Commission Act

ANG Air National Guard

AOC Areas of Concern

ASP Ammunition Supply Point

BANs Bonds in anticipation of borrowing

BCDHE Barnstable County Department of Health and the Environment

BMP Best Management Practice

BRAC Base Realignment and Closure

CAC Citizen's Advisory Committee

CAC Community Advisory Council

CBI Consensus Building Institute

CCPEDC Cape Cod Planning and Economic Development Commission

CDBG Community Development Block Grants

CDRI Capital Developments of Regional Impact

CEC Contaminants of Emerging Concern

Collaborative Cape Cod Water Protection Collaborative

Commission Cape Cod Commission

CSO Combined Sewer Overflow

CWA Clean Water Act

CWMP Comprehensive Wastewater Management Plans

CWPC Comprehensive Wastewater Planning Committee

DBO Design-Build-Operate

DCPC District of Critical Planning Concern

DEIR Draft Environmental Impact Report

DIF District Improvement Financing

DRI Development of Regional Impact

EAC Equivalent Annual Cost

Abbreviations

EDA Economic Development Administration

EJ Environmental Justice

EMC Environmental Management Commission

ENF Environmental Notification Form

FEIR Final Environmental Impact Report

GIS Geographic Information Systems

GIZ Growth Incentive Zone

GPD Gallons Per Day

GRP Gross Regional Product

HUD Housing and Urban Development

I/A Innovative/Alternative

I/I Inflow and Infiltration

IMA Intermunicipal Agreement

IPCC Intergovernmental Panel on Climate Change

IUP Intended Use Plan Project Listing

IW Intelligence Wing

IWP Impaired Waters Program

IWRMP Integrated Water Resources Management Plan

JBCC Joint Base Cape Cod

JLUS Joint Land Use Study

LCP Local Comprehensive Plan

LEP Limited English Proficient

LID Low Impact Development

LUVM Land Use Vision Maps

MAANG Massachusetts Air National Guard

MAARNG Massachusetts Army National Guard

MassDEP Massachusetts Department of Environmental Protection

MassDOT Massachusetts Department of Transportation

MCL Maximum Contaminant Limit

MDF Maximum Daily Flow

MEP Massachusetts Estuaries Project

MEPA Massachusetts Environmental Policy Act

Abbreviations

Mg/L Milligrams Per Liter

MGD Million Gallons Per Day

MGL Massachusetts General Law

MMR Massachusetts Military Reservation

MOA Memorandum of Agreement

MOU Memorandum of Understanding

MPS Minimum Performance Standards

MS4 Municipal Stormwater Separate Storm Sewers

MVP Watershed Multi Variant Planner (Watershed MVP)

NEP National Estuaries Program

NPDES National Pollution Discharge Elimination System

NPS Nonpoint Source

NRPZ Natural Resource Protection Zoning

NSA Nitrogen Sensitive Area

O&M Operation and Maintenance

OA Ocean Acidification

OEA Office of Economic Adjustment

OWC Organic Wastewater Compounds

PAC Project Approval Certificate

PALS Ponds and Lakes Stewardship

PBDE Polybrominated Diphenyl Ether

PEF Project Evaluation Form

PFC Perfluorinated Compound

POTWs Publicly Owned Treatment Works

PPCP Pharmaceuticals and Personal Care Products

PPM Parts Per Million

PRA Project Regulatory Agreement

PRB Permeable Reactive Barrier

RIBs Rapid Infiltration Beds

RLI Regulatory, Legal, and Institutional Work Group

RLUVM Regional Land Use Vision Map

RPP Regional Policy Plan

Abbreviations

SAS Soil Absorption System

SBR Sequencing Batch Reactors

SIO Strategic Information Office

SMAST School of Marine Science and Technology

SNEP Southeast New England Program

SRF State Revolving Fund

STAR Science to Achieve Results

TAC Technical Advisory Committee

TDR Transfer of Development Rights

Technologies Matrix Water Quality Technologies Matrix

TIF Tax Increment Financing

TIP Transportation Improvement Project

TMDL Total Maximum Daily Load

TNMP Targeted Nutrient Management Plan

TOC Total Organic Carbon

Trust Massachusetts Clean Water Trust

UAA Use Attainability Analysis

UD Urine Diversion

US EPA United States Environmental Protection Agency

USCG United States Coast Guard

USDA United States Department of Agriculture

USGS United States Geological Survey

WMA Waste Treatment Management Agency

wMVP Watershed Multi Variant Planner (Watershed MVP)

WPCF Water Pollution Control Facility

WQM Water Quality Management Plan

WWFP Wastewater Facility Plan

WWTF Wastewater Treatment Facility

Glossary

Advanced Wastewater Treatment
Wastewater treatment process that includes combinations of physical (AWT) and chemical operation units designed to remove nutrients, toxic substances, or other pollutants. Advanced, or tertiary, treatment processes treat effluent from secondary treatment facilities using processes such as nutrient removal (nitrification, denitrification), filtration, or carbon adsorption. Tertiary treatment plants typically achieve about 95% removal of solids and BOD in addition to removal of nutrients or other materials.

Aerobic
A condition where free oxygen is present.

Algae
Any organisms of a group of chiefly aquatic microscopic nonvascular plants; most algae have chlorophyll as the primary pigment for carbon fixation. As primary producers, algae serve as the base of the aquatic food web, providing food for zooplankton and fish resources. An overabundance of algae in natural waters is known as eutrophication.

Algal bloom
Rapidly occurring growth and accumulation of algae within a body of water. It usually results from excessive nutrient loading and/or sluggish circulation regime with a long residence time. Persistent and frequent bloom can result in low oxygen conditions.

Anaerobic
A condition where free oxygen is not present or is unavailable.

Aquifer
Geologic formations (rock, sand, or gravel) that are saturated and sufficiently permeable to yield significant quantities of water.

Area of Critical Environmental Concern (ACEC)
An area that receives special recognition by the state of Massachusetts because of the quality, uniqueness, and significance of the area's natural and cultural resources. Designation creates a framework for local and regional stewardship of critical resources and ecosystems.

Attenuate
To reduce the force, amount, or magnitude.

Benthic Regeneration
The regrowth of organisms on lake or sea floors.

Best Management Practices (BMPs)
Conservation practices to reduce non-point and point pollution from sources such as construction, agriculture, timber harvesting, marinas, and stormwater.

Biochemical Oxygen Demand (BOD)
The amount of oxygen per unit volume of water required to bacterially or chemically oxidize (stabilize) the oxidizable matter in water. Biochemical oxygen demand measurements are usually conducted over specific time intervals (5,10,20,30 days). The term BOD5 generally refers to standard 5-day BOD test.

Build-Out
The total of new development and redevelopment that is projected to occur over a planning horizon, typically 20 years.

Checkerboard Sewer System
A wastewater collection system configured to serve only selected properties in a neighborhood. Such a system allows a town to restrict sewer service to only those lots in greatest need, and/or to preserve limited capacity for wastewater treatment or disposal.

Glossary

Chlorophyll
A group of green photosynthetic pigments that occur primarily in the chloroplast of plant cells. The amount of chlorophyll-a, a specific pigment, is frequently used as a measure of algal biomass in natural waters.

Cluster Wastewater Treatment System
As used in this document, a wastewater collection and treatment system that serves more than one property and has a wastewater flow less than 10,000 gallons per day.

Coliform Bacteria
A group of bacteria that normally live within the intestines of mammals, including humans. Coliform bacteria are used as an indicator of the presence of sewage in natural waters.

Combined Sewer Overflows (CSOs)
A combined sewer carries both wastewater and stormwater runoff. CSOs discharged to receiving water can result in contamination problems that may prevent the attainment of water quality standards.

Commercial Water Use
Water used for motels, hotels, restaurants, office buildings, and other commercial operations.

Concentration
Mass amount of a substance or material in a given unit volume of solution. Usually measured in milligrams per liter (mg/l) or parts per million (ppm).

Comprehensive Wastewater Management Plan (CWMP)
A plan that identifies all the community's wastewater needs and problems, evaluates alternative means of meeting those needs, selects the most cost-effective and environmentally appropriate remedy, and proposes an implementation plan and schedule.

Constructed Wetlands
A type of wastewater treatment that mimics a natural wetland ecosystem in which water-loving plants filter wastewater and debris through their roots.

Consumptive Use
That part of water withdrawn that is evaporated, transpired, or incorporated into a manufactured product, or consumed by humans or animals, or otherwise removed from the immediate waterbody environment.

Contamination
Act of polluting or making impure; any indication of chemical, sediment, or biological impurities.

Denitrification
A process of transforming nitrate to nitrite to nitrogen gas, often mediated by microbial processes.

Design Flow
The amount of sanitary sewage, in gallons per day, for which a system must be designed in accordance with CMR 15.203. Design-flow criteria are the amounts of sanitary sewage that are assumed to be generated by a specific land use. For example, under Title 5, one bedroom is assigned a design flow of 110 gallons per day.

Direct Discharge
An area where groundwater discharges directly to open coastal water.

Dissolved Oxygen (DO)
The amount of oxygen gas that is dissolved in water. It also refers to a measure of the amount of oxygen available for biochemical activity in water body, and as indicator of the quality of that water.

Glossary

Ecosystem
An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.

Effluent
Sewage discharged into the environment, whether treated or not.

Embayment
A bay or a physical conformation resembling a bay.

Estuary
A partially enclosed body of water where fresh and salt water meet.

Eutrophication
A suite of changes in the condition of a water body that begins with excessive stimulation of growth of algae from nutrient inputs and leads to reduction in dissolved oxygen concentrations and sometimes to the death of organisms.

Floor Area Ratio (FAR)
A measure of building density calculated by dividing building square feet by lot area.

Flow Neutral Regulation
A sewer connection regulation that limits the amount of waste-water flow from a parcel to a pre-existing allowed flow.

Flushing Rate
The time it takes for an entire volume of water to be ex-changed, usually expressed in days or years.

Ground Water
Water below the land surface in a saturated zone.

Ground Water Discharge Permit Program
A Massachusetts regulation (314 CMR 5.00) that requires a permit for discharges of 10,000 gallons per day or more of pollutants to ground water.

Influent
Water volume flow rate or mass loading of a pollutant or other constituent into a water body or wastewater treatment plant.

Innovative/Alternative (I/A) Septic System
Any septic system or part of one that is not designed or constructed in a way consistent with a conventional Title 5 system. A conventional system has a septic tank, a distribution box or dosing mechanism, a soil-absorption system, and a reserve area. Some examples of alternative systems are recirculating sand filters, aerobic treatment units, peat filters, humus/composting toilets, and intermittent sand filters. Some I/A technologies are used to reduce nitrogen in nitrogen sensitive areas.

Interim Wellhead Protection Area (IWPA)
A public water system using wells or well fields that lack Massachusetts Department of Environmental Protection (DEP)-approved Zone IIs. The IWPA is a half-mile radius measured from the well or wellfield for sources with an approved pumping rate of 100,000 gallons per day or greater.

Loading, Load, Loading Rate
The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight (mass) per unit time.

Glossary

Local Residence Time
The average time for water to migrate from a point in a sub-embayment to a point outside the sub-embayment.

Low Impact Development (LID)
An approach to land development (or redevelopment) that works with nature to manage stormwater as close to its source as possible. Includes principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treats stormwater as a resource rather than a waste product.

Massachusetts Estuaries Project (MEP)
A project of the Massachusetts Department of Environmental Protection (DEP) and the School for Marine Science and Technology at the University of Massachusetts, Dartmouth, that provides water quality, nutrient loading, and hydrodynamic information for 89 estuaries in southeastern Massachusetts. This information is combined in a linked watershed/estuary model that predicts the water quality changes that result from land use management decisions.

Massachusetts Groundwater Discharge Program
A state permit program to regulate effluent flows in excess of 10,000 gallons per day.

Milligrams Per Liter (mg/L)
A unit of measurement expressing the concentration of a constituent in solution as the weight (mass) of solute (1 milligram) per unit volume (1 liter) of water; equivalent to 1 part per million (ppm) for a water density. 1 g cm-3. 1 mg/L = 1000 ug/L; 1 g/L = 1000 mg/L.

Million Gallons Per Day (mgd)
Rate of water volume discharge representing a volume of 1 million gallons of water passing across a given location in a time interval of 1 day. A flow rate of 1 mgd = 1.54723 cubic feet per second (cfs) = 0.04381 cubic meters per second (cms).

National Pollutant Discharge Elimination System (NPDES)
A federal permit program under the Clean Water Act that regulates the discharge of pollutants into water bodies.

Natural Attenuation of Nitrogen
The naturally occurring retention or attenuation of nitrogen in wetlands or ponds.

Natural Resource Protection Zoning
A relatively new form of zoning that is a variation of a clustered subdivision, but with several enhancements. The number of allowed dwelling units is determined by a calculation that first eliminates the amount of important natural resource lands from the determination of the number of allowed units. The net acreage is then divided by the base density to determine the number of buildable units.

Nitrate
The nitrogen species in marine ecosystems that is most responsible for eutrophication, considered a broad indicator of contamination of ground water.

Nitrite
An intermediate oxidation state of nitrogen, between nitrate and ammonia.

Nitrogen
An element abundant in the atmosphere as dinitrogen gas. When combined with oxygen to form nitrate (NO3), it can cause excessive algal growth in marine waters, which can lead to eutrophication.

Nitrogen Loading
The input of nitrogen to estuaries and embayments from natural and human sources.

Nitrogen Removal Credit
Under Title 5, an innovative alternative septic systems that achieves an effluent nitrogen concentration of 19 milligrams per liter for a residential property and 25 milligrams per liter for a commercial property may qualify for a Nitrogen Removal Credit. The credit allows for an increase in design flow per acre in designated Nitrogen Sensitive Areas such as Zone IIs to public water supply wells, in other areas that have formally been designated as Nitrogen Sensitive Areas, and for new construction in areas that have both private wells and on-site septic systems.

Nitrogen Sensitive Area
A Massachusetts regulatory designation of an area as particularly sensitive to pollution from on-site wastewater systems and therefore requiring nitrogen-loading restrictions; includes Interim Wellhead Protection Areas and Zone IIs of public water supplies, areas with private wells, and Nitrogen Sensitive embayments or other areas that are designated as nitrogen sensitive under Title 5, based on appropriate scientific evidence.

Non-Conforming Use or Structure
A use or structure that no longer conforms to current zoning, but did conform when first built or established.

Non-Point Source of Pollution
Pollution from many diffuse sources that is carried to surface waters by runoff or ground water. Non-point source pollution is typically caused by sediment, nutrients, and organic and toxic substances originating from land use activities and/or the atmosphere. Any source of water pollution that does not meet the legal definition of a point source.

Nutrient Loading
The introduction of excessive amounts of nutrients, such as nitrogen or phosphorus, from wastewater or fertilizers, which ultimately reach ponds or estuaries.

Nutrient Management Regulations
Regulations that establish limits on the amount of flow from on-site septic systems serving new development and redevelopment or use changes.

Nutrients
Any substance required by plants and animals for normal growth and maintenance; for example, nitrogen and phosphorus.

On-Site Treatment and Disposal System
A natural system or mechanical device used to collect, treat, and discharge or reclaim wastewater from an individual dwelling without the use of community-wide sewers or a centralized treatment facility. It includes a septic tank and a leach field.

Organic Matter
The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.

Organic Nitrogen
Organic form of nitrogen bound to organic matter.

Outfall
Location point where wastewater or stormwater flows from a conduit, stream, or drainage ditch into natural waters.

Glossary

Outstanding Resource Waters
A Massachusetts Department of Environmental Protection (DEP) designation assigned to certain water bodies based on their outstanding socio-economic, recreational, ecological, and/or aesthetic values.

Oxygen Demand
Measure of the dissolved oxygen used by a system (microorganisms) and or chemical compounds in the oxidation of organic matter. See also biochemical oxygen demand.

Oxygen Depletion
Deficit of dissolved oxygen in a natural waters system due to oxidation of natural and anthropogenic organic matter.

Parts Per Million (PPM)
Measure of concentration of 1 part solute to 1 million parts water (by weight). See milligrams per liter.

Pathogen
An agent such as a virus, bacterium, or fungus capable of causing disease.

Permeable Reactive Barrier (PRB)
A carbon-containing reactive substance that promotes denitrification.

pH
A measure of acidity indicated by the logarithm of the reciprocal of the hydrogen ion concentration (activity) of a solution. pH values less than 7 are acidic; values greater than 7 are basic; pH of 7 is neutral. pH of natural waters typically ranges from 6-8.

Phosphorus
A nutrient essential for plant growth that can play a key role in stimulating the growth of aquatic plants in streams, rivers and lakes.

Phytoremediation
The use of plants to take up nutrients, contaminants, or other substances from soils, ground water, and surface water in order to restore ecosystem health.

Point Source of Pollution
As defined by the US Environmental Protection Agency (EPA), any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.

Pollutant
A contaminant in a concentration or amount that adversely alters the physical, chemical, or biological properties of a natural environment. The term include pathogens, toxic metals, carcinogens, oxygen demanding substances, or other harmful substances.

Publicly Owned Treatment Works
Municipal wastewater treatment plant owned and operated by a (POTW) public governmental entity such as a town or city.

Public-Supply Withdrawals
Water withdrawn from surface water or groundwater by public or private water suppliers for use within a community. Water is used for domestic, commercial, industrial and public water uses such as fire fighting.

Recharge
The return of water to an underground aquifer by natural or artificial means.

Residence Time
The average time required for a particle of water or a pollutant to migrate through an estuary.

Salinity
The measure of the salt content of water. ,measured by weight as parts per thousand (ppt). Salinity concentrations range from 0.5-1 ppt for tidal fresh waters; 20-25 ppt for estuarine waters; 30 ppt for coastal waters to 35 ppt for the open ocean.

Secchi Depth
A measure of the light penetration into the water column. Light penetration is influenced by turbidity.

Septage
Material physically removed from any part of an on-site system, including, but not limited to, the solids, semi-solids, scum, sludge, and liquid contents of a septic tank, privy, chemical toilet, cesspool, holding tank, or other sewage waste receptacle. It does not include any material that is hazardous waste.

Septic Tank
A buried tank designed to receive and pre-treat wastewater from individual homes or facilities by separating settleable and floatable solids from wastewater. It is one component of an on-site wastewater treatment and disposal system.

Setbacks
A zoning term used to refer to the distance between a building and property lines.

Sewage
The water-carried human or animal wastes from residences, buildings, industrial establishments, or other places, together with such ground water infiltration and surface water as may be present. The liquid and solid waste carried off in sewers or drains.

Sewer
An artificial, usually underground, conduit for carrying off sewage or rainwater.

Sewerage
The removal of wastewater and refuse by means of sewers.

Sewershed
The properties within the area of service of a sewer system.

State Revolving Fund (SRF)
A Massachusetts program that helps with the financing of water pollution abatement projects. Two types of funding are provided through this program: the Clean Water and Drinking Water State Revolving Fund grants.

Station (Monitoring)
Specific location in a waterbody chosen to collect water samples for the measurement of water quality constituents. Stations are identified by an alphanumeric code identifying the agency source responsible for the collection of the data and a unique identifier code designating the location. Station measurements can be recorded from either discrete grab samples or continuous automated data acquisition systems. Station locations are typically sampled by state, federal or local agencies at periodic intervals (e.g., weekly, monthly, annual etc.) as part of a routine water quality monitoring program to track trends. Station locations can also be sampled only for a period of time needed to collect data for an intensive survey or a special monitoring program.

Stormwater Runoff
Rainfall and snow melt from diffuse (non-point) sources such as roofs, roadways, driveways, and other impervious surfaces.

Glossary

Sub-Embayment
A cove within an embayment.

Surface Waters
Water that is present above the substrate or soil surface. Usually refers to natural waterbodies such as streams, rivers, lakes and impoundments, and estuaries and coastal ocean.

System Residence Time
The average time for water to migrate through an entire estuarine system.

Tidal Flushing
The exchange of water from an estuarine system to the water body into which it empties.

Title 5
A Massachusetts state regulation (310 CMR 15.00) governing the siting, construction, inspection, upgrade, and expansion of on-site sewage treatment and disposal systems and the transport and disposal of septage.

Total Coliform Bacteria
A particular group of bacteria that are used as indicators of possible sewage pollution.

Total Maximum Daily Load (TMDL)
The greatest amount of a pollutant that a water body can accept and still meet water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation, and fishing.

Transfer of Development Rights (TDR)
A land use regulation that allows development rights to be transferred from an area where additional development is not desired, to an area where additional development is desired.

Wastewater Flow
The wastewater from septic systems that leaches into groundwater and flows through ground water into receiving waters such as a pond or estuary.

Waste Load Allocation (WLA)
The portion of a receiving water's total maximum daily load that is allocated to one of its existing or future point sources of pollution.

Wastewater Treatment
Chemical, biological, and mechanical processes applied to an industrial or municipal discharge or to any other sources of contaminated water in order to remove, reduce, or neutralize contaminants prior to discharge to a receiving water.

Water Pollution
Any condition of a waterbody that reflects unacceptable water quality or ecological conditions. Water pollution is usually the result of discharges of waste material from human activities into a waterbody.

Water Quality
Numerical description of the biological, chemical, and physical conditions of a water body. It is a measure of a water body to support beneficial uses.

Watershed
An area of land that drains to a common receiving body of water.

Zone I
The protective radius required around a public water supply well or wellfield.

Zone II or Zone of Contribution

The area of an aquifer that contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated (180 days of pumping at approved yield, with no recharge from precipitation).

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Cape Cod Area Wide Water Quality Management Plan Update
June 2015

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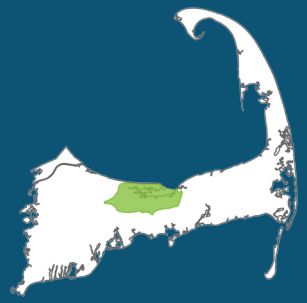
Appendix B

CCC Barnstable Harbor Watershed Report

WATERSHED REPORT: MID CAPE

Barnstable Harbor

BARNSTABLE, YARMOUTH & SANDWICH



WATER THREAT LEVEL

LOW



Barnstable Harbor Watershed

Introduction to the Watershed Reports

In 2001, the Massachusetts Estuaries Project (MEP) was established to evaluate the health of 89 coastal embayment ecosystems across southeastern Massachusetts. A collaboration between coastal communities, the Massachusetts Department of Environmental Protection (MassDEP), the School of Marine Science and Technology (SMAST) at the University of Massachusetts-Dartmouth, the US Environmental Protection Agency (US EPA), the United States Geological Survey (USGS), the Massachusetts Executive Office of Energy and Environmental Affairs (EEA), and the Cape Cod Commission, the purpose of the MEP is to identify nitrogen thresholds and necessary nutrient reductions to support healthy ecosystems.

The Cape Cod 208 Plan Update, certified and approved by the Governor of the Commonwealth of Massachusetts and the US EPA in 2015, provides an opportunity and a path forward to implement responsible plans for the restoration of the waters that define Cape Cod.

On Cape Cod there are 53 embayment watersheds with physical characteristics that make them susceptible to nitrogen impacts. In its 2003 report, "The Massachusetts Estuaries Project – Embayment Restoration and Guidance for Implementation Strategies", MassDEP identifies the 46 Cape Cod embayments included in the

MEP. Thirty-three embayments studied to date require nitrogen reduction to achieve healthy ecosystem function. A Total Maximum Daily Load (TMDL) has been established (or a draft load has been identified and is under review) for these watersheds. For those embayments not studied, the 208 Plan Update recommends planning for a 25% reduction in nitrogen, as a placeholder, until information becomes available.

The 208 Plan Update directs Waste Treatment Management Agencies (WMAs) to develop watershed reports within 12 months of certification of the Plan Update. The Watershed Reports outline potential "bookend" scenarios for each watershed that include two scenarios to meet water quality goals in the watershed – a traditional scenario, which relies completely on the typical collection and centralized treatment of wastewater, and a non-traditional scenario, which uses remediation, restoration, and on-site reduction techniques to remove nutrients from raw and treated wastewater, groundwater and affected waterbodies.

The intent of the Watershed Reports is to outline two distinct approaches for addressing the nutrient problem. The reports are not intended to identify preferred and detailed plans for each watershed, but to facilitate discussions regarding effective and efficient solutions, particularly in watersheds shared by more than one town. In some cases, towns have provided information on collection areas and non-traditional technologies that have been specifically considered by that town.

The 208 Update developed a regionally consistent database of the nitrogen load entering each watershed. This data set includes estimates of wastewater, stormwater and fertilizer loads - similar to methodologies used by the MEP. Using this regionally consistent database, the Watershed MVP tool (wMVP) was developed so that different strategies (i.e., bookend scenarios) to reduce excess nitrogen load could be evaluated. The Watershed Reports use the MEP recommendations for the required nitrogen load reductions necessary to meet the threshold loads (that serve as the basis for nitrogen management), and then use the wMVP and the regionally consistent database values to develop bookend scenarios. There are variations of load between the MEP and wMVP, primarily due to differences in comparing older and newer databases.

Terms Defined

Total nitrogen load: the nitrogen load from the watershed contributed by septic, wastewater, fertilizer, stormwater, golf course, landfill, and natural sources.

Attenuated nitrogen load: the nitrogen load from the watershed that reaches the embayment after the effect of natural attenuation in wetlands, ponds or streams.

Threshold: the amount of nitrogen that a water body can receive from its watershed and still meet water quality goals; this number is based on MEP technical reports or Total Maximum Daily Load (TMDL) reports.

Reduction target: an approximation of the amount of nitrogen that needs to be removed from the watershed to achieve the threshold; this number is calculated by subtracting the threshold number from the attenuated total watershed load, and is for planning purposes only.

Percent contribution: the percent of attenuated nitrogen load that a town contributes to the watershed.

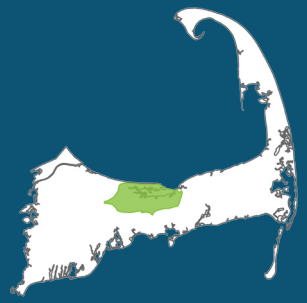
Kilogram responsibility: is calculated by applying the percent contribution to the reduction target and indicates the amount of nitrogen, in kg, that a community is responsible for addressing.

Total Maximum Daily Load: a regulatory term in the Clean Water Act, describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. Establishing a TMDL is necessary when a water body has been listed on the 303D list of impaired waters.

WATERSHED REPORT: MID CAPE

Barnstable Harbor

BARNSTABLE, YARMOUTH & SANDWICH



WATER THREAT LEVEL

LOW

The Barnstable Harbor estuary and embayment system is an estuary with its shoreline primarily located in the Town of Barnstable with a portion in Yarmouthport. Barnstable Harbor is a large embayment that receives tidal flow from Cape Cod Bay, with a 9-foot fluctuation, and extends nearly 5 miles towards the extensive Barnstable marsh. The bay supports a variety of recreational uses including boating, swimming, shell fishing and fin fishing.

The Problem

For the purposes of the Section 208 Plan Update, areas of wastewater need are primarily defined by the amount of nitrogen reduction required as defined by the Total Maximum Daily Load (TMDL) or Massachusetts Estuaries Project (MEP) technical report. An MEP report has not yet been completed for the Barnstable Harbor watershed. Due to its large tidal flow it is not expected to be severely overloaded with respect to nitrogen except for some of the upper reaches.

- **MEP TECHNICAL REPORT STATUS:** Data Collection Phase
- **TMDL STATUS:** In Progress

The Commission compiled the following updated water use and nitrogen loads using the regional wMVP database (see page 2), enabling a current estimate of nitrogen loading.

- **TOTAL WASTEWATER FLOW:** 291 MGY (million gal per year)
- **TOTAL UNATTENUATED NITROGEN LOAD:** 42,646 Kg/Y (kilograms per year)
- **ATTENUATED NITROGEN LOAD:** Not assessed

CONTRIBUTING TOWNS

Percent contributions listed below are the aggregate sub-embayment contributions identified in Appendix 8C of the Cape Cod Section 208 Plan Update (contributions are based on attenuated load where available). See Appendix 8C for detailed town allocations by sub-embayment.

- **BARNSTABLE:** 82%
- **YARMOUTH:** 14%
- **SANDWICH:** 4%

BARNSTABLE HARBOR ESTUARY

- **EMBAYMENT AREA:** 2,793 acres
- **EMBAYMENT VOLUME:** Unknown
- **2014 INTEGRATED LIST STATUS:** Category 5 for fecal coliform
  - Category 5: Waters requiring a TMDL
  - www.mass.gov/eea/docs/dep/water/resources/07v5/14list2.pdf

BARNSTABLE HARBOR WATERSHED

General watershed characteristics according to the current wMVP regional database (see figure on page 1 for watershed boundary) follow.

- **WATERSHED CHARACTERISTICS**
  - Acres: 17,043
  - Parcels: 5,542
  - % Developed Residential Parcels: 70%
  - Parcel Density: 3 acres per parcel

Freshwater Sources

PONDS

- **IDENTIFIED SURFACE WATERS:** 63
- **NUMBER OF NAMED FRESHWATER PONDS:** 18
- **PONDS WITH PRELIMINARY TROPHIC CHARACTERIZATION:** 8
- **2014 INTEGRATED LIST STATUS FOR NUTRIENTS:** None listed

Barnstable and Yarmouth have participated in the Pond and Lake Stewardship (PALS) program that has helped establish baseline water quality.

STREAMS

- **SIGNIFICANT FRESHWATER STREAM OUTLETS:** 3

  Scorton Creek, Sandwich
  - Average Flow: Not Assessed
  - Average Nitrate Concentrations: Not Assessed

  Bridge Creek, Barnstable
  - Average Flow: Not Assessed
  - Average Nitrate Concentrations: Not Assessed

  Brickyard Creek, Barnstable
  - Average Flow: Not Assessed
  - Average Nitrate Concentrations: Not Assessed

Nitrate concentrations higher than 0.05 mg/L background concentrations, evident in public supply wells located in pristine areas, provide evidence of the impact of non-point source pollution on the aquifer and receiving coastal water bodies.

DRINKING WATER SOURCES

- **WATER DISTRICTS:** 4
  - Barnstable Fire District
  - Centerville Osterville Marstons Mills Fire District
  - Hyannis Water Division
  - Yarmouth Water Division
- **GRAVEL PACKED WELLS:** 3
  - 1 has nitrate concentrations between 0.5 and 1 mg/L
  - 1 has nitrate concentrations between 1 and 2.5 mg/L
  - 1 has no nitrate concentration data
- **SMALL VOLUME WELLS:** 5
  - West Barnstable and East Sandwich are served exclusively by private wells.

Drinking water data from Cape Cod Commission and MassDEP data sources – nitrate values obtained from drinking water wells are from 2009-2012. The state and federal drinking water limit for nitrate is 10 mg/L. The Cape Cod Commission nitrate loading standard is 5 mg/l.

Degree of Impairment

Since there is no evidence of water quality impairment at this time, wastewater needs are determined based upon other factors, such as Title5 compliance.

Barnstable Harbor is listed as a Category 5 impaired water body for fecal coliform on the 2014 Integrated List of Impaired Waters.

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Traditional & Non-Traditional Scenarios

SCENARIO DEVELOPMENT

Through the 208 Stakeholder process, the Commission developed "bookend" scenarios – one looking at a possible solution using traditional collection and treatment, the other examining a possible suite of non-traditional technologies – to address the nitrogen management needs in each watershed. These bookend scenarios provide guidance for communities as they continue to discuss alternatives, priorities, and opportunities for identifying well-considered solutions that will address communities' needs and interests.

REGIONAL DATA

In preparation for this effort, the Commission collected regionally consistent data for the purposes of watershed scenario development. Both parcel data and water use data was identified and collected for the entire region. While the scientific basis for planning is the thresholds identified in the MEP technical reports, each report uses data from different years, and in some cases the MEP data used are 10 or more years old. In addition, there are watersheds on Cape Cod without the benefit of an MEP report; therefore, similar data was not available for planning purposes.

The updated regional data set was used to estimate wastewater, stormwater and fertilizer loads, using the same methodologies as the MEP. This approach allows for a reevaluation of existing development, which may have changed in the last 10 years. Parcel data included in the regional database is from 2010-2012 and water use data is from 2008-2011, depending on the water supplier and based on best available data. This approach allows for regionally consistent watershed scenario development.

WATERSHED SCENARIOS

The watershed scenarios that follow outline possibilities for the watershed. A series of non-traditional technologies that might be applicable are included, as well as the amount of residential load that would need to be collected if a traditional collection system and treatment facility was implemented. The pie charts show the load to be collected for treated effluent disposal both inside and outside the watershed.

Site specific analyses of collection areas may result in the need to collect wastewater from more or fewer parcels to meet the nitrogen reduction target. The scenarios presented are conceptual and are meant to inform discussions regarding effective and efficient solutions; they are not specific recommendations and should be viewed as resource information for additional and more detailed wastewater management planning.

TOTAL UNATTENUATED NITROGEN LOAD VALUES (FROM WMVP)

Barnstable Harbor Nitrogen Sources	Total Unattenuated Watershed Nitrogen Load (kg-N/yr)
Wastewater[1]	28,965
Fertilizer[2]	4,717
Stormwater	5,521
Other[3]	3,443
TOTAL WATERSHED LOAD	42,646
Total Watershed Threshold[4]	31,985
TOTAL UNATTENUATED LOAD TO BE REMOVED	10,662

1. Includes nitrogen loads from septic systems and wastewater treatment facilities.
2. Includes nitrogen loads from lawns, cranberry bogs, and golf courses.
3. Includes nitrogen loads from landfills and atmospheric deposition to vacant land.
4. Assumes 25% reduction is needed, as no MEP report has been completed for this watershed and no threshold has been established.

Traditional & Non-Traditional Scenarios

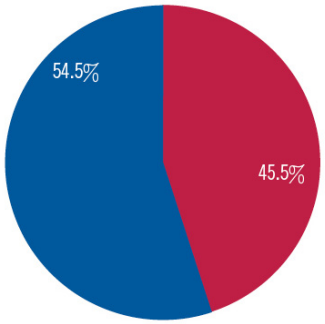
Non-Traditional

UNIT OF APPLIED TECHNOLOGY	ATTENUATED NITROGEN REMOVED IN KG/Y
25 % Nitrogen Reduction - Fertilizer Management	1,179
25 % Nitrogen Reduction - Stormwater Mitigation	1,380
2 Acres - Constructed Wetlands (Collection System)	1,000
5,600 Linear Feet - Permeable Reactive Barrier (PRB) (Capture load calculated by wMVP: 528.3 kg/Y)	383
150 Acres - Fertigation - Turf	600
29 Acres - Aquaculture/Oyster Beds	7,125
TOTAL	**10,668**

A summary of the approach and methodology that was applied using non-traditional technologies follows at the end of this report.

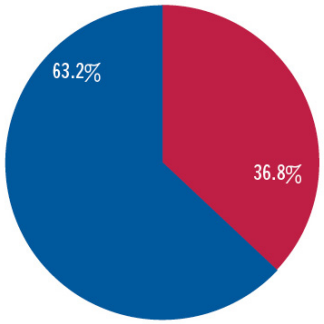
Traditional

CENTRALIZED TREATMENT WITH DISPOSAL INSIDE THE WATERSHED

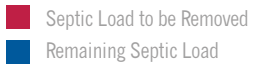


Assumes load to be collected and treated is disposed in the watershed, requiring additional collection to offset the load.

CENTRALIZED TREATMENT WITH DISPOSAL OUTSIDE THE WATERSHED



Assumes that the load to be collected and treated is removed from the watershed so no offset is required.



Town of Yarmouth Local Progress

In 2010, the Town of Yarmouth submitted its Comprehensive Wastewater Management Plan (CWMP) as a Draft Environmental Impact Report (DEIR). The draft CWMP targeted areas that would require wastewater collection to restore water quality in the Lewis Bay and Parkers River watersheds and deal with the Title 5 constraints on economic redevelopment in the area of Route 28. The town's plan included approximately 125 miles of sewer lines and the collection of 2.75 million gallons per day (MGD) of wastewater to be treated at a single facility in the Parkers River watershed. The project would ultimately serve 9,580 properties by 2035. Phase 1 of the plan would begin with the treatment facility and main trunk line sewer to serve Route 28 and portions of the Parkers River and Lewis Bay watershed.

The plan relies on gravity, pressure, and vacuum sewers. The MEP nitrogen reduction goals were the primary factor in choosing sewering locations. The phasing of these sewered areas also takes the town's economic goals into consideration.

The town submitted its Final Environmental Impact Report (FEIR) and received Massachusetts Environmental Policy Act (MEPA) approval in July 2011, but did not complete the Cape Cod Commission Development of Regional Impact (DRI) process before going to September 2011 Town Meeting to seek Phase 1 design and construction funds. Phases 1 through 5 were scheduled to be implemented over a 25-year period. The estimated cost of the total plan was $275 million. The first phase had an estimated cost of $55 million. Town Meeting did not approve the expenditure. The town withdrew the CWMP from the DRI review process.

Wastewater planning in the community had effectively come to a stop prior to the development of the 208 Plan Update.

In January 2016 town staff met with the Board of Selectmen to discuss a new financing plan for implementation of a program that would meet water quality standards in all of their watersheds.

The recommended plan includes a combination of traditional sewering methods with centralized treatment facilities as well as non-traditional nitrogen management options including a permeable reactive barrier (PRB) at the Buck Island Road effluent recharge site. The Town of Yarmouth is proposing a phased wastewater program that includes a collection system, a conveyance system and a centralized treatment facility, each constructed over several years. In addition to the proposed sewering, the recommended plan involves public outreach to promote nitrogen reduction and to prevent sewer system inflow, zoning modifications for growth management and establishment of the activity centers, development of sewer ordinances, and continued maintenance of Title 5 and I/A systems in the northern and western areas of the town that will not be served by the proposed wastewater collection system. The town also plans to implement stormwater and fertilizer improvement programs. As suggested in the 208 Plan Update, up to a 25% nitrogen reduction credit can be obtained by towns that implement stormwater and fertilizer management programs to reduce nitrogen contributions to each watershed.

During the spring 2016 town meeting, the town approved $200,000 for additional CWMP planning.

In April 2016, Yarmouth submitted a request for assistance to continue CWMP development and town staff met with the Commission to discuss the request in early May.

In June 2016, Yarmouth received $35,000 from the Commission for the Towns of Dennis, Harwich and Yarmouth for a regional treatment facility cost study. Funding was part of $142,149 in local grants made by the Commission in support of 208 Plan implementation.

At the Spring 2017 Town Meeting appropriated $200,000 for wastewater planning and engineering services including engineering studies and evaluation of recharge sites; updating, modification, and pre-implementation services for the Comprehensive Wastewater Management Plan and support for related filings with the Massachusetts Environmental Policy Act office and the Cape Cod Commission.

Town of Sandwich Local Progress

The Town of Sandwich has an established water quality committee to oversee water quality and wastewater planning efforts. In October 2015 town staff and their consultant (Wright-Pierce) met with Cape Cod Commission staff to discuss watershed planning, decision support tools, and scenario development for Sandwich watersheds. In the same month the town was approached by Mashpee regarding approaches for Popponesset Bay, and a potential watershed permit, and has agreed to participate with Mashpee and Barnstable in this shared effort. It is expected that Barnstable, Mashpee, and Sandwich will collaborate on the first watershed permit in the region in close coordination with the Cape Cod Commission and the Massachusetts Department of Environmental Protection.

Previously the committee developed a scope of work for a Comprehensive Wastewater Management Plan (CWMP) and submitted the scope under the Sagamore Lens Natural Resource Damages Assessment, related to past groundwater contamination at the Textron facility at Joint Base Cape Cod (JBCC). The town received an award of $400,000 t0 conduct its water/wastewater plan and completed a comprehensive needs assessment, as well as an interim wastewater solutions plan to accommodate economic development in the South Sandwich Village Center.

The town spent several years working with a private developer on a development project that included a public-private wastewater component for the construction of a facility that would accommodate the private project, in addition to some public wastewater needs. That project will not be completed, but the town is again seeking a private partner to create new economic growth and to potentially participate in infrastructure development.

The town has participated in discussions at JBCC about the potential use of its existing wastewater infrastructure as a regional option for the Upper Cape towns.

In February 2016 the Town of Sandwich requested a meeting with Commission staff to discuss watershed scenarios and potential modifications to watersheds in which Sandwich has jurisdiction. The town provided collection footprints and assumptions for a single treatment facility to serve all three watersheds (Popponesset Bay, Three Bays, and Waquoit Bay), consistent with the Sandwich CWMP, and identified locations for non-traditional approaches, in addition to credits for stormwater and fertilizer reduction. The Town proposes a 25% fertilizer management credit and a 6.25% stormwater management credit. While the proposed interventions, alone, do not meet the nitrogen allocations identified in Appendix 8C of the 208 Plan Update, the town has expressed a preference to rely on nutrient trading or cost sharing to reduce the load allocated to the downgradient towns in the shared watersheds of Popponesset Bay, Three Bays and Waquoit Bay, where nitrogen reductions can be more cost effectively attained.

Town of Barnstable Local Progress

The Cape Cod Commission and the Town of Barnstable met and discussed the use of WatershedMVP to evaluate targeted watershed approaches for each of the watersheds in which they have jurisdiction. In 2015, the town reformulated its Citizen's Advisory Committee (CAC) for wastewater planning to better address local needs. In addition to local participation, the newly formed committee (the Water Resources Advisory Committee or WRAC) includes state and regional representatives. Town staff provided modifications to Commission-developed watershed scenarios and presented those scenarios to their WRAC for review and discussion.

Barnstable is also working closely with Mashpee and Sandwich on a watershed permit for the Popponesset Bay watershed.

The Town of Barnstable operates the Hyannis Water Pollution Control Facility (WPCF), located off Bearses Way in Hyannis, which is the primary wastewater treatment facility serving approximately 2,900 properties in Hyannis and Barnstable village. The treatment facility has been upgraded and permitted to treat additional flows up to a total of 4.2 million gallons per day (MGD), upon meeting requirements of an adaptive management plan approved by the Commission in 2007. Property along Route 132 was acquired by the town in 2002 to potentially accommodate future disposal needs. The site is approved under a 2006 Massachusetts Environmental Policy Act (MEPA) certificate to discharge up to 0.5 MGD. The site is not presently in use. However, a force main and sewer has been extended to the site from the WPCF.

The WPCF treats an average daily flow of 1.46 MGD and a maximum monthly average flow of 1.94 MGD. Treatment performance has averaged 5 milligrams per liter (mg/L) total nitrogen in the treated effluent and the facility has a discharge limit of 5 mg/L under the 2007 Development of Regional Impact (DRI) decision and a limit of 10 mg/L under a Groundwater Discharge Permit (GWDP). The facility is also equipped with sludge thickening, storage and dewatering facilities sized for the current process conditions.

The Town of Barnstable also operates two smaller facilities – the Marstons Mills Wastewater Treatment Facility (WWTF) and the Red Lily Pond Cluster System. The Marstons Mills WWTF is limited to a discharge flow of 42,900 gallons per day (GPD) and is intended to service the Barnstable United Elementary School and the Village at Marstons Mills affordable housing development. The Red Lily Pond Cluster System currently serves 17 homes. According to the comprehensive wastewater management plan (CWMP) approved in 2007, no performance sampling of the system occurs and the system is assumed to produce comparable effluent to any conventional single family septic system.

In addition to municipally-owned facilities, there are two privately-owned treatment facilities treating wastewater from the Cotuit Landing shopping plaza and the Cape Regency nursing and rehabilitation facility. These facilities provide high levels of wastewater treatment. The treatment facility at Cotuit Landing was designed with additional treatment capacity beyond the expected needs of the shopping plaza for potential treatment of flows from neighboring properties.

Barnstable is working on a town-wide nutrient management plan that will provide the basis of its CWMP. The plan will address nitrogen and other needs in watersheds draining to Three Bays, Centerville River, and Lewis Bay. A nitrogen total maximum daily load (TMDL) for Barnstable Harbor has not been approved by US EPA. The MEPA certificate scope for the Final Environmental Impact Report (FEIR) includes engagement in a targeted watershed approach, consistent with the 208 Plan Update.

In the fall of 2014, Barnstable adopted local nitrogen-oriented fertilizer management regulations consistent with the Cape-wide Fertilizer Management District of Critical Planning Concern (DCPC).

In 2015, the Town submitted a Statement of Interest to the US EPA for a hydrogeologic site characterization as an initial step toward piloting a permeable reactive barrier in the town. One of three sites proposed by the Town was selected for characterization. The work was completed in 2016. The draft report is presently being reviewed by the Town.

In June 2016, Barnstable received $28,850 from the Commission to fund upgrades to three stormwater treatment BMPs. Funding was part of $142,149 in local grants made available to communities by the Commission in support of 208 Plan implementation.

Methodology for Selecting Non-Traditional Technology Scenarios

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology were derived from the Technologies Matrix. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology are noted below, based on the Technologies Matrix or newer data. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

Regional credits were developed for potential stormwater retrofits and fertilizer reductions. They were calculated as a percent reduction of existing nitrogen loads as identified in the MEP reports and updated GIS data developed by the Cape Cod Commission.

- **STORMWATER MANAGEMENT:** Most Cape communities have already begun the process of identifying significant untreated stormwater discharges and developing appropriate mitigation projects. With the prospect of the MS4 regulatory requirements it was assumed that additional mitigation efforts would be implemented. Based upon the evidence developed by the University of New Hampshire Stormwater Center that several vegetated stormwater management practices (including bioretention and constructed wetlands) are able to achieve nitrogen reductions of 50% or more and the assumption that only a portion (estimated at 50%) of identified sites would be retrofitted a 25% nitrogen reduction credit was assumed for each watershed. Specific locations and number of locations were not identified; this was deferred to individual towns to consider as part of the suite of nitrogen management strategies.
- **FERTILIZER REDUCTIONS:** Based upon the success of most Cape Cod towns to implement either regulatory or non-regulatory fertilizer management programs and the efforts of the Cape Cod Extension Service in educating homeowners a 25% reduction in fertilizer applications was assumed for each watershed.

Regional GIS screening methods were developed to identify locations for some non-traditional technologies. A GIS viewer was developed as an on-line tool for staff and consultants to utilize during the watershed planning process.

- **CONSTRUCTED WETLANDS/ PHYTOREMEDIATION:** A GIS-based screening method was developed by the Cape Cod Commission to identify and rank parcels of land that have potential for the location of constructed wetlands and phytoremediation. The ranking utilized parcel size and ownership, depth to groundwater, suitable soils, distance from wetlands, and undeveloped parcels. A nitrogen removal rate of 500 kg/Y/acre and 532 kg/Y/acre was used for Constructed Wetlands and Phytoremediation, respectively.
- **PERMEABLE REACTIVE BARRIERS (PRBS):** A GIS-based screening method was developed to identify existing roads that are proximate to receiving waters, downgradient of high density development, run perpendicular to groundwater flow (to have the highest potential to intercept nutrients in groundwater), and where the depth to groundwater is relatively shallow to maximize the area of saturated thickness treated in the aquifer.

Methodology for Selecting Non-Traditional Technology Scenarios

- **FERTIGATION WELLS:** Golf courses were mapped to identify areas where fertigation wells could be utilized to recapture nitrogen-enriched groundwater and re-apply it to the managed turf areas to serve both irrigation and fertilization needs. Most golf courses were assumed to be eighteen holes with a fertilized area of 75 acres. Fertigation water was assumed to have an average concentration of 5 mg/liter. An uptake/attenuation rate of 80% was applied resulting in an assumed nitrogen reduction of 300 kg/year for each golf course with effectively located fertigation wells. In some cases other irrigated areas (such as athletic fields and cemeteries) were identified as potential fertigation locations. Assuming the use of 730 gpd/acre for turf areas, a nitrogen removal rate of 4 kg/y/acre was used for fertigation of turf areas. Assuming a higher flow rate of 2,200 gpd/acre for cranberry bogs, a 12 kg/y/acre removal rate was used for fertigation of cranberry bogs.

The MVP tool and other site-specific tools were utilized to quantify nitrogen load reductions for several potential NT interventions.

- **PERMEABLE REACTIVE BARRIERS:** for each PRB that was identified during the prior GIS-screening process an approximate capture area was identified using available water table maps and the wMVP tool. Upgradient contributing areas were digitized within wMVP and the nitrogen load was calculated. A nitrogen reduction of 72.5% was applied (calculated as an average of the reported attenuation range from the Technologies Matrix).
- **CONSTRUCTED WETLANDS (WITH COLLECTION):** Constructed wetlands were considered as a tertiary, polishing treatment for existing wastewater treatment plants. This included small-scale wastewater treatment systems. A nitrogen removal rate of 500 kg/Y/acre was used.
- **AQUACULTURE/OYSTER REEFS:** Potential areas for aquaculture and/or oyster reef restoration were considered based upon discussions with town representatives and review of maps to identify potential areas for these operations without significant conflicts to navigation. In some cases actual recent aquaculture expansions were included where they were developed after the MEP reports were prepared. An assumption of 1 million oysters per acre was used with a nitrogen removal rate of 250 kg/Y/acre.
- **FLOATING CONSTRUCTED WETLANDS:** Potential areas for floating wetlands were considered in areas where no conflicts with navigation or swimming areas were identified. A nitrogen removal rate of 0.4 kg/Y/sq foot was used.
- **INLET WIDENING AND COASTAL HABITAT RESTORATION:** Only considered in areas where these projects were identified by towns or state agencies and where detailed hydrologic investigations and modeling had been performed due to wide variations in nitrate load reduction, flushing impacts, impacts on flooding, and costs (dredging only, replacing infrastructure, removing and replacing roadways or bridges, etc.). Nitrogen removal rates were based on MEP or other studies.
- **INNOVATIVE & ALTERNATIVE SEPTIC SYSTEMS AND ECOTOILETS:** In most cases specific locations for these technologies were not identified. Rather general estimates for the percent adoption were provided based upon discussions with the stakeholder groups and their views on potential adoption rates. In some watersheds a 5% adoption rate was included based upon this stakeholder input. In a limited number of instances specific locations for these technologies were included based upon town input and suggestions. A nitrogen removal rate of 1.658 kg/Y for each system was used for I&A Septic Systems, and 2.984 kg/Y for enhanced I&A systems. A removal rate of 2.542 kg/Y was used for each home installation of an Ecotoilet, and 0.467 kg/Y for installation of urine diversion toilets in public settings.

Finally, the locations of specific technologies were discussed during the 208 stakeholder engagement process. Stakeholders across the Cape 'groundtruthed' potential NT locations and NT scenarios were adjusted accordingly.

Appendix C

CCC Centerville River Watershed Report

WATERSHED REPORT: MID CAPE

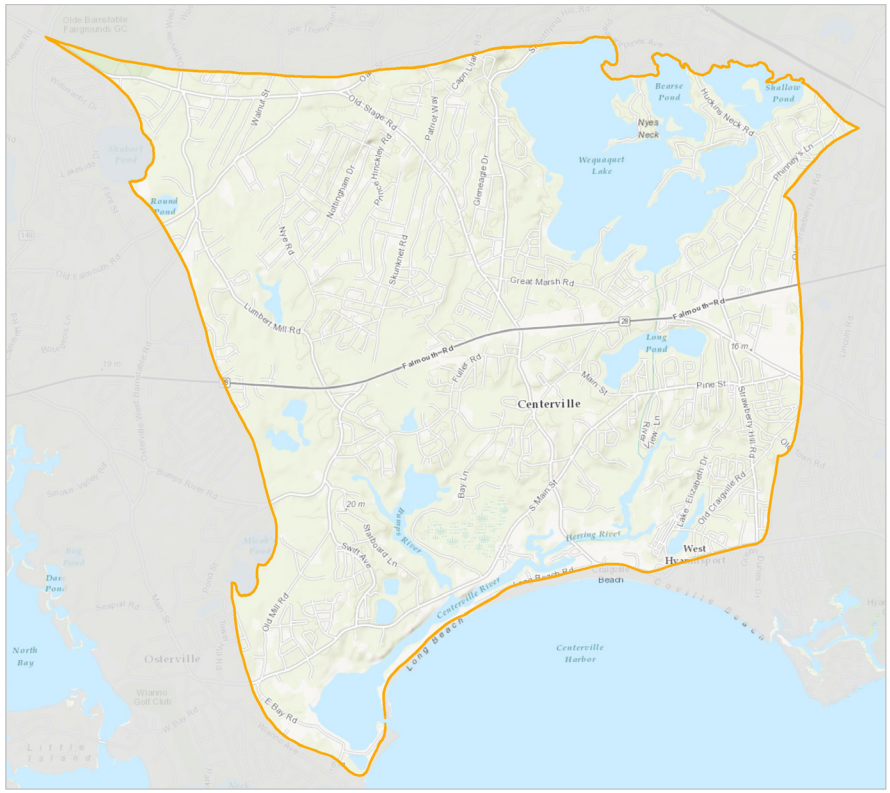
Centerville River

BARNSTABLE



WATER THREAT LEVEL

MODERATE



Centerville River Watershed

Introduction to the Watershed Reports

In 2001, the Massachusetts Estuaries Project (MEP) was established to evaluate the health of 89 coastal embayment ecosystems across southeastern Massachusetts. A collaboration between coastal communities, the Massachusetts Department of Environmental Protection (MassDEP), the School of Marine Science and Technology (SMAST) at the University of Massachusetts-Dartmouth, the US Environmental Protection Agency (US EPA), the United States Geological Survey (USGS), the Massachusetts Executive Office of Energy and Environmental Affairs (EEA), and the Cape Cod Commission, the purpose of the MEP is to identify nitrogen thresholds and necessary nutrient reductions to support healthy ecosystems.

The Cape Cod 208 Plan Update, certified and approved by the Governor of the Commonwealth of Massachusetts and the US EPA in 2015, provides an opportunity and a path forward to implement responsible plans for the restoration of the waters that define Cape Cod.

On Cape Cod there are 53 embayment watersheds with physical characteristics that make them susceptible to nitrogen impacts. In its 2003 report, "The Massachusetts Estuaries Project – Embayment Restoration and Guidance for Implementation Strategies", MassDEP identifies the 46 Cape Cod embayments included in the

MEP. Thirty-three embayments studied to date require nitrogen reduction to achieve healthy ecosystem function. A Total Maximum Daily Load (TMDL) has been established (or a draft load has been identified and is under review) for these watersheds. For those embayments not studied, the 208 Plan Update recommends planning for a 25% reduction in nitrogen, as a placeholder, until information becomes available.

The 208 Plan Update directs Waste Treatment Management Agencies (WMAs) to develop watershed reports within 12 months of certification of the Plan Update. The Watershed Reports outline potential "bookend" scenarios for each watershed that include two scenarios to meet water quality goals in the watershed – a traditional scenario, which relies completely on the typical collection and centralized treatment of wastewater, and a non-traditional scenario, which uses remediation, restoration, and on-site reduction techniques to remove nutrients from raw and treated wastewater, groundwater and affected waterbodies.

The intent of the Watershed Reports is to outline two distinct approaches for addressing the nutrient problem. The reports are not intended to identify preferred and detailed plans for each watershed, but to facilitate discussions regarding effective and efficient solutions, particularly in watersheds shared by more than one town. In some cases, towns have provided information on collection areas and non-traditional technologies that have been specifically considered by that town.

The 208 Update developed a regionally consistent database of the nitrogen load entering each watershed. This data set includes estimates of wastewater, stormwater and fertilizer loads - similar to methodologies used by the MEP. Using this regionally consistent database, the Watershed MVP tool (wMVP) was developed so that different strategies (i.e., bookend scenarios) to reduce excess nitrogen load could be evaluated. The Watershed Reports use the MEP recommendations for the required nitrogen load reductions necessary to meet the threshold loads (that serve as the basis for nitrogen management), and then use the wMVP and the regionally consistent database values to develop bookend scenarios. There are variations of load between the MEP and wMVP, primarily due to differences in comparing older and newer databases.

Terms Defined

Total nitrogen load: the nitrogen load from the watershed contributed by septic, wastewater, fertilizer, stormwater, golf course, landfill, and natural sources.

Attenuated nitrogen load: the nitrogen load from the watershed that reaches the embayment after the effect of natural attenuation in wetlands, ponds or streams.

Threshold: the amount of nitrogen that a water body can receive from its watershed and still meet water quality goals; this number is based on MEP technical reports or Total Maximum Daily Load (TMDL) reports.

Reduction target: an approximation of the amount of nitrogen that needs to be removed from the watershed to achieve the threshold; this number is calculated by subtracting the threshold number from the attenuated total watershed load, and is for planning purposes only.

Percent contribution: the percent of attenuated nitrogen load that a town contributes to the watershed.

Kilogram responsibility: is calculated by applying the percent contribution to the reduction target and indicates the amount of nitrogen, in kg, that a community is responsible for addressing.

Total Maximum Daily Load: a regulatory term in the Clean Water Act, describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. Establishing a TMDL is necessary when a water body has been listed on the 303D list of impaired waters.

Centerville River

BARNSTABLE



WATER THREAT LEVEL
MODERATE

The Centerville River estuary and embayment system is located wholly within the Town of Barnstable. It is comprised of a number of sub-basins, such as East Bay and Scudder Bay/Bumps River and supports a variety of recreational uses including boating, swimming, shell fishing and fin fishing.

The Problem

The Massachusetts Estuaries Project (MEP) technical report (available at http://www.mass.gov/eea/agencies/massdep/water/watersheds/the-massachusetts-estuaries-project-and-reports.html) indicates that the Centerville River system exceeds its critical threshold for nitrogen, resulting in impaired water quality. A MEP technical report has been completed and a Total Maximum Daily Load (TMDL) for nitrogen has been developed and approved.

- **MEP TECHNICAL REPORT STATUS:** Final
- **TMDL STATUS:** Final TMDL

Watershed nitrogen load characteristics were published in the 2006 MEP report for Centerville River, reflecting current conditions at the time of writing:

- **TOTAL ATTENUATED NITROGEN LOAD:** 48,245 Kg/Y (MEP Chapter VIII)
- **SOURCES OF ATTENUATED WATERSHED NITROGEN LOAD:**
  - 87% Septic Systems
  - 6% Fertilizer
  - 7% Stormwater From Impervious Surfaces

Since the MEP report, the Commission compiled the following updated water use and nitrogen loads using the regional wMVP database, enabling a more current estimate of nitrogen loading (see figure on page 1 for watershed boundary delineation):

- **TOTAL WASTEWATER FLOW:** 427 MGY (million gal per year)
  - Treated Wastewater Flow: 4 MGY
  - Septic Flow: 423 MGY
- **TOTAL ATTENUATED NITROGEN LOAD (WMVP):** 44,573 Kg/Y

CONTRIBUTING TOWNS

Percent contributions listed below are the aggregate sub-embayment contributions identified in Appendix 8C of the Cape Cod Section 208 Plan Update (contributions are based on attenuated load where available). See Appendix 8C for detailed town allocations by sub-embayment.

- **BARNSTABLE:** 100%

THE MEP RESTORATION SCENARIO:

- **WATERSHED TOTAL NITROGEN REDUCTION TARGET:** 28%
- **WATERSHED SEPTIC REDUCTION TARGET:** 34% (The scenario represents the aggregated sub-embayment percent removal targets from the MEP technical report)

CENTERVILLE RIVER ESTUARY

- **EMBAYMENT AREA:** 218 acres
- **EMBAYMENT VOLUME:** 39.8 million cubic feet
- **2014 INTEGRATED LIST STATUS:** Category 4a
  - Bumps River: fecal coliform
  - Centerville River: fecal coliform, estuarine bioassessments and nitrogen
  - Category 4a, TMDL is completed
  - www.mass.gov/eea/docs/dep/water/resources/07v5/14list2.pdf

CENTERVILLE RIVER WATERSHED

General watershed characteristics according to the current wMVP regional database (see figure on page 1 for watershed boundary) follow.

- **WATERSHED CHARACTERISTICS**
  - Acres: 6,739
  - Parcels: 7,491
  - % Developed Residential Parcels: 88%
  - Parcel Density: 0.9 acres per parcel

Freshwater Sources

PONDS

- **IDENTIFIED SURFACE WATERS:** 39
- **NUMBER OF NAMED FRESHWATER PONDS:** 14
- **PONDS WITH PRELIMINARY TROPHIC CHARACTERIZATION:** 8
- **2014 INTEGRATED LIST STATUS:** 6 ponds listed in Category 5 requiring a TMDL.

Three ponds within the adjacent Three Bays watershed (Shubael Pond, Micahs Pond and Joshuas Pond) also contribute to Centerville River. The recent comprehensive wastewater management plan (CWMP) included the preparation of a Pond Action Report.

Yarmouth has participated in the Pond and Lake Stewardship (PALS) program that has helped establish baseline water quality.

STREAMS

- **SIGNIFICANT FRESHWATER STREAM OUTLETS:** 4

Skunknett River:
- Average Flow: 13,925 cubic meters per day (m3/d)
- Average Nitrate Concentrations: 1.113 milligrams per liter (mg/L)

Bumps River:
- Average Flow: 5,679 m3/d
- Average Nitrate Concentrations: 2.207 mg/L

Long Pond Stream:
- Average Flow: 6,518 m3/d
- Average Nitrate Concentrations: 0.199 mg/L

Lake Elizabeth:
- Average Flow: 1,547 m3/d
- Average Nitrate Concentrations: 0.937 mg/L

Stream data from MEP technical report. Nitrate concentrations higher than 0.05 mg/L background concentrations, evident in public supply wells located in pristine areas, provide evidence of the impact of non-point source pollution on the aquifer and receiving coastal water bodies.

DRINKING WATER SOURCES

- **WATER DISTRICTS:** 2
  - Hyannis Water District
  - Centerville-Osterville-Marstons Mills (COMM) Water District
- **GRAVEL PACKED WELLS:** 6
  - 1 has nitrate concentrations between 1 and 2.5 mg/L
  - 5 have nitrate concentrations between 2.5 and 5 mg/L
- **SMALL VOLUME WELLS:** 0

Drinking water data from Cape Cod Commission and MassDEP data sources – nitrate values obtained from drinking water wells are from 2009-2012. The state and federal drinking water limit for nitrate is 10 mg/L. The Cape Cod Commission nitrate loading standard is 5 mg/l.

Degree of Impairment and Areas of Need

For the purposes of the 208 Plan Update, areas of need are primarily defined by the amount of nitrogen reduction required as defined by the TMDL and/or MEP technical report. For the Centerville River, this amount is 34% of the septic load or 28% of the total attenuated nitrogen load. The MEP technical report also provides a specific targeted amount of nitrogen reduction required by subwatershed, (see the figures: Subwatersheds with Total and Septic Attenuated Nitrogen Removal Targets).

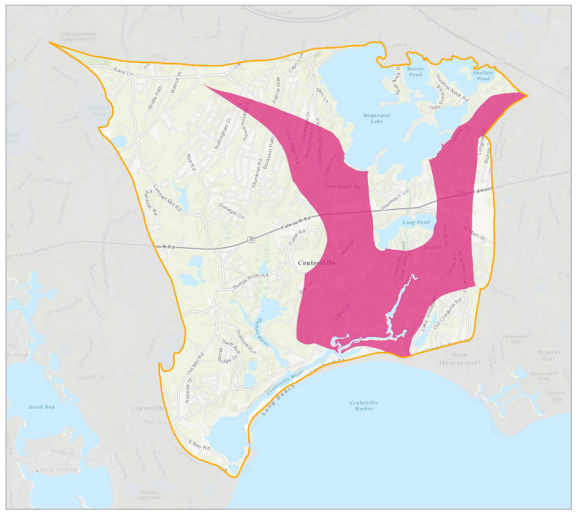
The nitrogen load from the watershed exceeds the threshold for the Centerville River, resulting in impaired water quality. Lower portions of Centerville River have generally good water quality supported by tidal flushing and significant attenuation to contributing areas, while the upper reach of Centerville

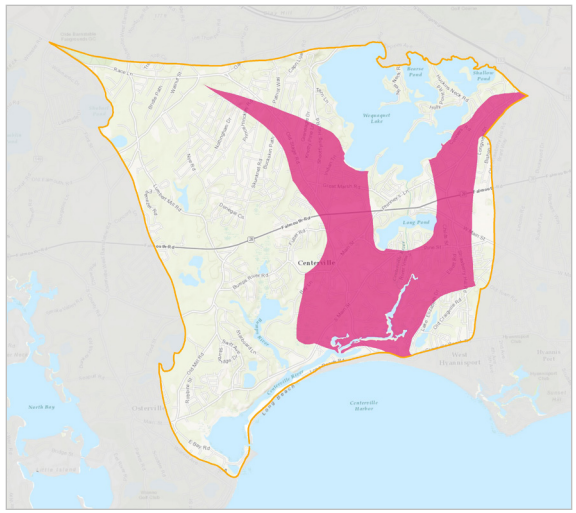
River, Centerville River East, has decreased water quality. The ecological health of a water body is determined from water quality, extent of eelgrass, assortment of benthic fauna, and dissolved oxygen and ranges from severe degradation, significantly impaired, moderately impaired, or healthy habitat conditions.

ECOLOGICAL CHARACTERISTICS AND WATER QUALITY

The MEP report provides the following characterization of the estuary's health:

- **OVERALL ECOLOGIC CONDITION:** Healthy to Significantly Impaired
- **UPPER CENTERVILLE RIVER:** Healthy
- **MID CENTERVILLE RIVER:** Healthy to Moderately Impaired
- **LOWER CENTERVILLE RIVER:** Healthy to Significantly Impaired
- **EAST BAY:** Moderately to Significantly Impaired
- **BUMPS RIVER:** Healthy
- **SCUDDER BAY:** Moderately Impaired
- **SENTINEL STATION:**
  - Total Nitrogen Concentration Threshold: 0.37 mg/L
  - Total Nitrogen Concentration Existing: 0.41 mg/L (As reported at the MEP sentinel water-quality monitoring station.)





0.1% - 9%
9.1% - 38%
38.1% - 62%
62.1% - 86%
86.1% - 100%

Subwatersheds with Total Attenuated Watershed Removal Targets

(Left) Benthic and atmospheric loads directly on embayments are not included.

Subwatersheds with Septic Attenuated Nitrogen Removal Targets

(Right)

Traditional & Non-Traditional Scenarios

SCENARIO DEVELOPMENT

Through the 208 Stakeholder process, the Commission developed "bookend" scenarios – one looking at a possible solution using traditional collection and treatment, the other examining a possible suite of non-traditional technologies – to address the nitrogen management needs in each watershed. These bookend scenarios provide guidance for communities as they continue to discuss alternatives, priorities, and opportunities for identifying well-considered solutions that will address communities' needs and interests.

REGIONAL DATA

In preparation for this effort, the Commission collected regionally consistent data for the purposes of watershed scenario development. Both parcel data and water use data was identified and collected for the entire region. While the scientific basis for planning is the thresholds identified in the MEP technical reports, each report uses data from different years, and in some cases the MEP data used are 10 or more years old. In addition, there are watersheds on Cape Cod without the benefit of an MEP report; therefore, similar data was not available for planning purposes.

The updated regional data set was used to estimate wastewater, stormwater and fertilizer loads, using the same methodologies as the MEP. This approach allows for a reevaluation of existing development, which may have changed in the last 10 years. Parcel data included in the regional database is from 2010-2012 and water use data is from 2008-2011, depending on the water supplier and based on best available data. This approach allows for regionally consistent watershed scenario development.

WATERSHED SCENARIOS

The watershed scenarios that follow outline possibilities for the watershed. A series of non-traditional technologies that might be applicable are included, as well as the amount of residential load that would need to be collected if a traditional collection system and treatment facility was implemented. The pie charts show the load to be collected for treated effluent disposal both inside and outside the watershed.

Site specific analyses of collection areas may result in the need to collect wastewater from more or fewer parcels to meet the nitrogen reduction target. The scenarios presented are conceptual and are meant to inform discussions regarding effective and efficient solutions; they are not specific recommendations and should be viewed as resource information for additional and more detailed wastewater management planning.

In Centerville River, the Town of Barnstable has done additional and more detailed planning. Included in the last section of this report is a description of their efforts, along with details of plans developed to date.

TOTAL ATTENUATED WATERSHED NITROGEN LOAD VALUES (FROM WMVP)

Centerville River Nitrogen Sources	Total Attenuated Watershed Nitrogen Load (kg-N/yr)
Wastewater[1]	36,000
Fertilizer[2]	3,166
Stormwater	4,475
Other[3]	932
TOTAL WATERSHED LOAD	44,573
Total Watershed Threshold	34,833
TOTAL ATTENUATED LOAD TO BE REMOVED	9,740

1. Includes nitrogen loads from septic systems and wastewater treatment facilities.
2. Includes nitrogen loads from lawns, cranberry bogs, and golf courses.
3. Includes nitrogen loads from landfills and atmospheric deposition to vacant land.

Traditional & Non-Traditional Scenarios

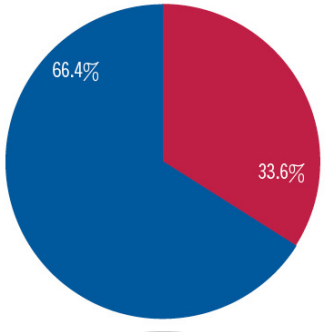
Non-Traditional

UNIT OF APPLIED TECHNOLOGY	ATTENUATED NITROGEN REMOVED IN KG/Y
25 % Nitrogen Reduction - Fertilizer Management	792
25 % Nitrogen Reduction - Stormwater Mitigation	1,119
6 Acres - Constructed Wetlands (Collection System)	3,000
5,600 Linear Feet - Permeable Reactive Barrier (PRB) (Capture load calculated by wMVP: 6,863.4 kg/Y)	4,976
150 Acres - Fertigation - Turf	600
9 Acres - Aquaculture/Oyster Beds	2,200
1,285 People Per Year - UD School or Public Facility	600
TOTAL	**13,287**

A summary of the approach and methodology that was applied using non-traditional technologies follows at the end of this report.

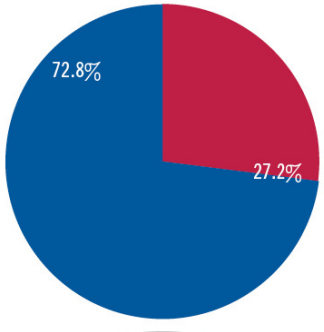
Traditional

CENTRALIZED TREATMENT WITH DISPOSAL INSIDE THE WATERSHED

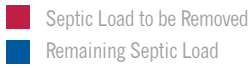


Assumes load to be collected and treated is disposed in the watershed, requiring additional collection to offset the load.

CENTRALIZED TREATMENT WITH DISPOSAL OUTSIDE THE WATERSHED



Assumes that the load to be collected and treated is removed from the watershed so no offset is required.



Town of Barnstable Local Progress

The Cape Cod Commission and the Town of Barnstable met and discussed the use of WatershedMVP to evaluate targeted watershed approaches for each of the watersheds in which they have jurisdiction. In 2015, the town reformulated its Citizen's Advisory Committee (CAC) for wastewater planning to better address local needs. In addition to local participation, the newly formed committee (the Water Resources Advisory Committee or WRAC) includes state and regional representatives. Town staff provided modifications to Commission-developed watershed scenarios and presented those scenarios to their WRAC for review and discussion. Those scenarios are included in this report.

Barnstable is also working closely with Mashpee and Sandwich on a watershed permit for the Popponesset Bay watershed.

The Town of Barnstable operates the Hyannis Water Pollution Control Facility (WPCF), located off Bearses Way in Hyannis, which is the primary wastewater treatment facility serving approximately 2,900 properties in Hyannis and Barnstable village. The treatment facility has been upgraded and permitted to treat additional flows up to a total of 4.2 million gallons per day (MGD), upon meeting requirements of an adaptive management plan approved by the Commission in 2007. Property along Route 132 was acquired by the town in 2002 to potentially accommodate future disposal needs. The site is approved under a 2006 Massachusetts Environmental Policy Act (MEPA) certificate to discharge up to 0.5 MGD. The site is not presently in use. However, a force main and sewer has been extended to the site from the WPCF.

The WPCF treats an average daily flow of 1.46 MGD and a maximum monthly average flow of 1.94 MGD. Treatment performance has averaged 5 milligrams per liter (mg/L) total nitrogen in the treated effluent and the facility has a discharge limit of 5 mg/L under the 2007 Development of Regional Impact (DRI) decision and a limit of 10 mg/L under a Groundwater Discharge Permit (GWDP). The facility is also equipped with sludge thickening, storage and dewatering facilities sized for the current process conditions.

The Town of Barnstable also operates two smaller facilities – the Marstons Mills Wastewater Treatment Facility (WWTF) and the Red Lily Pond Cluster System. The Marstons Mills WWTF is limited to a discharge flow of 42,900 gallons per day (GPD) and is intended to service the Barnstable United Elementary School and the Village at Marstons Mills affordable housing development. The Red Lily Pond Cluster System currently serves 17 homes. According to the comprehensive wastewater management plan (CWMP) approved in 2007, no performance sampling of the system occurs and the system is assumed to produce comparable effluent to any conventional single family septic system.

In addition to municipally-owned facilities, there are two privately-owned treatment facilities treating wastewater from the Cotuit Landing shopping plaza and the Cape Regency nursing and rehabilitation facility. These facilities provide high levels of wastewater treatment. The treatment facility at Cotuit Landing was designed with additional treatment capacity beyond the expected needs of the shopping plaza for potential treatment of flows from neighboring properties.

Barnstable is working on a town-wide nutrient management plan that will provide the basis of its CWMP. The plan will address nitrogen and other needs in watersheds draining to Three Bays, Centerville River, and Lewis Bay. A nitrogen total maximum daily load (TMDL) for Barnstable Harbor has not been approved by US EPA. The MEPA certificate scope for the Final Environmental Impact Report (FEIR) includes engagement in a targeted watershed approach, consistent with the 208 Plan Update.

In the fall of 2014, Barnstable adopted local nitrogen-oriented fertilizer management regulations consistent with the Cape-wide Fertilizer Management District of Critical Planning Concern (DCPC).

In 2015, the Town submitted a Statement of Interest to the US EPA for a hydrogeologic site characterization as an initial step toward piloting a permeable reactive barrier in the town. One of three sites proposed by the Town was selected for characterization. The work was completed in 2016. The draft report is presently being reviewed by the Town.

In June 2016, Barnstable received $28,850 from the Commission to fund upgrades to three stormwater treatment BMPs. Funding was part of $142,149 in local grants made available to communities by the Commission in support of 208 Plan implementation.

Town of Barnstable Watershed Scenario Details

Centerville River	CREDITS		REDUCTION TECHNOLOGIES			REMEDIATION AND RESTORATION TECHNOLOGIES			REMOVAL
NAME OF TECHNOLOGY	% Nitrogen Reduction	Load Reduction (kg-N/yr)	# Properties / Units	Flow Collected (gpd)	Load Reduction (kg-N/yr)	# Units Proposed	Unit Metric	Load Reduction (kg-N/yr)	Total Scenario Load Reduction (kg-N/yr)
Traditional Scenario									15,256
Centralized Sewer			3,183	491,518	15,256				
Non-Traditional Scenario									15,059
Fertilizer Management	25%	764							
Stormwater Mitigation	25%	1,119							
Constructed Wetlands (No Collection System)						6	Acres	3,000	
Permeable Reactive Barrier (PRB)						9,952	Linear Feet	4,976	
Fertigation - Turf						143	Acres	600	
Aquaculture/Oyster Beds						9	Acres	2,200	
Floating Constructed Wetlands						9,000	Square Feet	1,800	
Ecotoilets (UD & Compost)			140	Units	600				

Scenario Maps

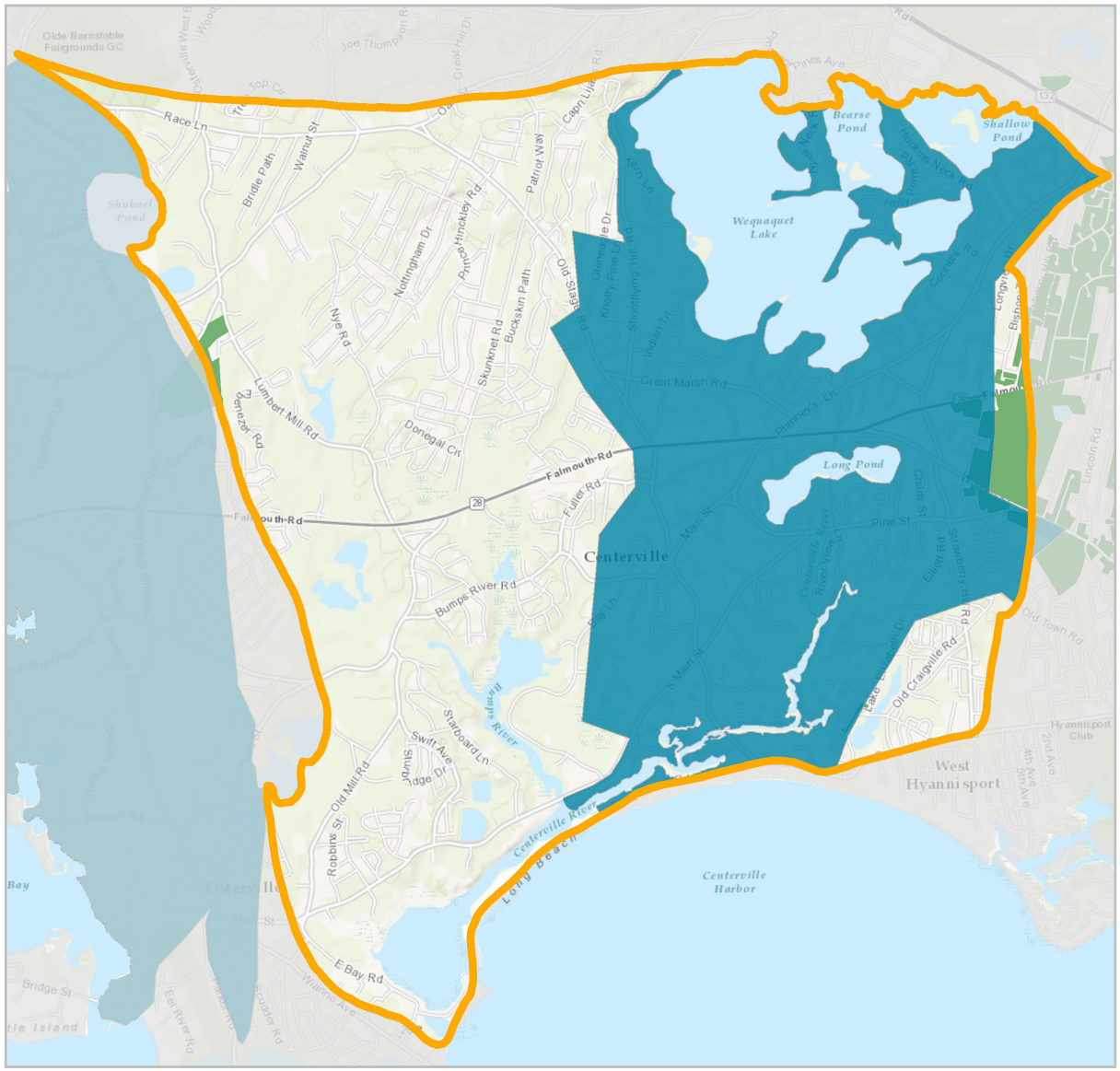
Centerville River Watershed
Traditional Scenario

BARNSTABLE

Representative locations of conceptually proposed infrastructure

Legend

- Town Lines
- Sewered Areas
- Embayment Watersheds
- Proposed Sewershed



Scenario Maps

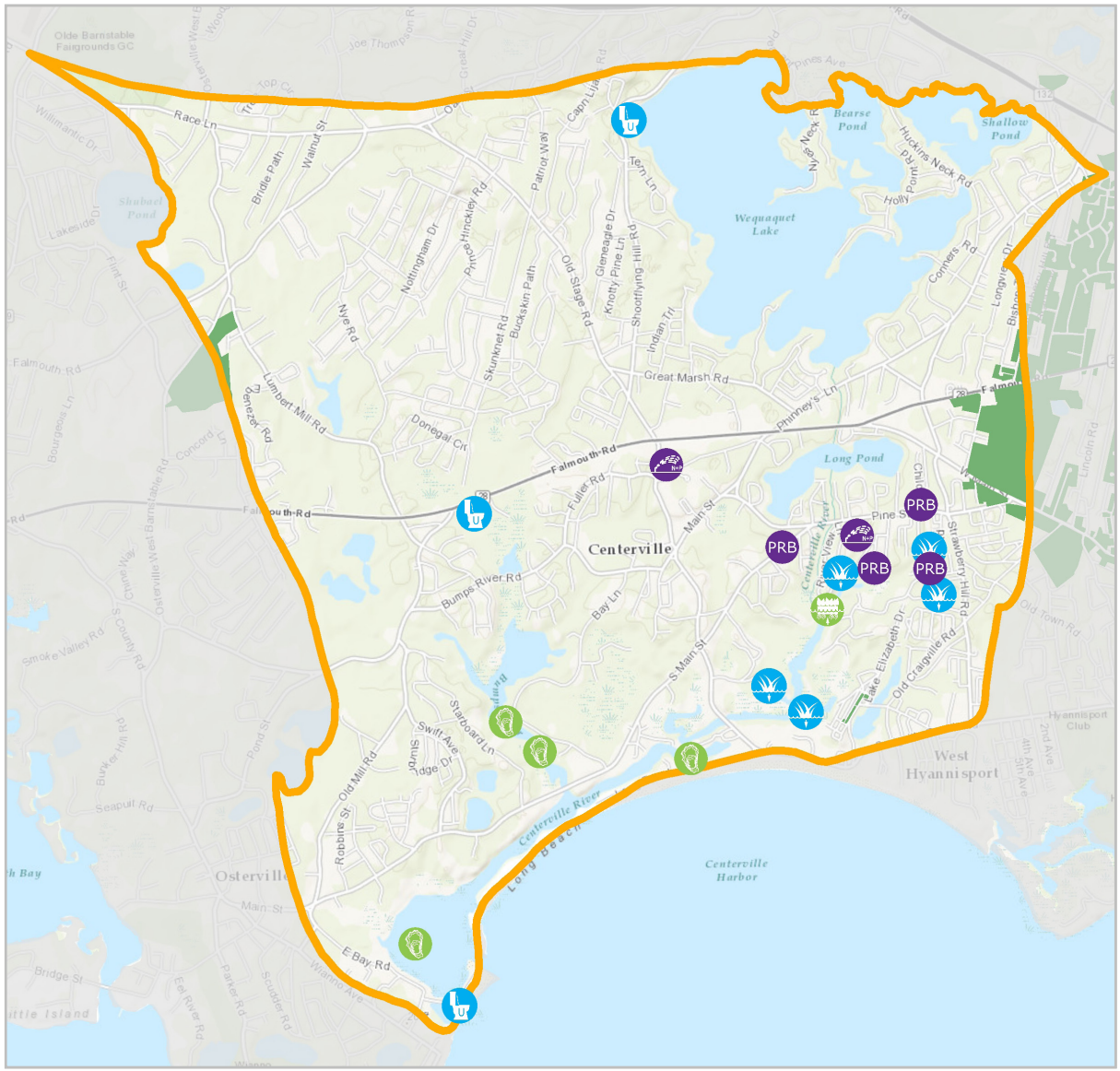
Centerville River Watershed
Non-Traditional Scenario

BARNSTABLE

Representative locations of conceptually proposed infrastructure

Legend

- Eco-Toilets
- Fertigation
- Floating Constructed Wetlands
- Constructed Wetland
- Permeable Reactive Barrier
- Aquaculture
- Town Lines
- Embayment Watersheds
- Sewered Areas



Methodology for Selecting Non-Traditional Technology Scenarios

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology were derived from the Technologies Matrix. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology are noted below, based on the Technologies Matrix or newer data. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

Regional credits were developed for potential stormwater retrofits and fertilizer reductions. They were calculated as a percent reduction of existing nitrogen loads as identified in the MEP reports and updated GIS data developed by the Cape Cod Commission.

- **STORMWATER MANAGEMENT:** Most Cape communities have already begun the process of identifying significant untreated stormwater discharges and developing appropriate mitigation projects. With the prospect of the MS4 regulatory requirements it was assumed that additional mitigation efforts would be implemented. Based upon the evidence developed by the University of New Hampshire Stormwater Center that several vegetated stormwater management practices (including bioretention and constructed wetlands) are able to achieve nitrogen reductions of 50% or more and the assumption that only a portion (estimated at 50%) of identified sites would be retrofitted a 25% nitrogen reduction credit was assumed for each watershed. Specific locations and number of locations were not identified; this was deferred to individual towns to consider as part of the suite of nitrogen management strategies.
- **FERTILIZER REDUCTIONS:** Based upon the success of most Cape Cod towns to implement either regulatory or non-regulatory fertilizer management programs and the efforts of the Cape Cod Extension Service in educating homeowners a 25% reduction in fertilizer applications was assumed for each watershed.

Regional GIS screening methods were developed to identify locations for some non-traditional technologies. A GIS viewer was developed as an on-line tool for staff and consultants to utilize during the watershed planning process.

- **CONSTRUCTED WETLANDS/ PHYTOREMEDIATION:** A GIS-based screening method was developed by the Cape Cod Commission to identify and rank parcels of land that have potential for the location of constructed wetlands and phytoremediation. The ranking utilized parcel size and ownership, depth to groundwater, suitable soils, distance from wetlands, and undeveloped parcels. A nitrogen removal rate of 500 kg/Y/acre and 532 kg/Y/acre was used for Constructed Wetlands and Phytoremediation, respectively.
- **PERMEABLE REACTIVE BARRIERS (PRBS):** A GIS-based screening method was developed to identify existing roads that are proximate to receiving waters, downgradient of high density development, run perpendicular to groundwater flow (to have the highest potential to intercept nutrients in groundwater), and where the depth to groundwater is relatively shallow to maximize the area of saturated thickness treated in the aquifer.

Methodology for Selecting Non-Traditional Technology Scenarios

- **FERTIGATION WELLS:** Golf courses were mapped to identify areas where fertigation wells could be utilized to recapture nitrogen-enriched groundwater and re-apply it to the managed turf areas to serve both irrigation and fertilization needs. Most golf courses were assumed to be eighteen holes with a fertilized area of 75 acres. Fertigation water was assumed to have an average concentration of 5 mg/liter. An uptake/attenuation rate of 80% was applied resulting in an assumed nitrogen reduction of 300 kg/year for each golf course with effectively located fertigation wells. In some cases other irrigated areas (such as athletic fields and cemeteries) were identified as potential fertigation locations. A nitrogen removal rate of 4 kg/Y/acre was used.

The MVP tool and other site-specific tools were utilized to quantify nitrogen load reductions for several potential NT interventions.

- **PERMEABLE REACTIVE BARRIERS:** for each PRB that was identified during the prior GIS-screening process an approximate capture area was identified using available water table maps and the wMVP tool. Upgradient contributing areas were digitized within wMVP and the nitrogen load was calculated. A nitrogen reduction of 72.5% was applied (calculated as an average of the reported attenuation range from the Technologies Matrix).
- **CONSTRUCTED WETLANDS (WITH COLLECTION):** Constructed wetlands were considered as a tertiary, polishing treatment for existing wastewater treatment plants. This included small-scale wastewater treatment systems. A nitrogen removal rate of 500 kg/Y/acre was used.
- **AQUACULTURE/OYSTER REEFS:** Potential areas for aquaculture and/or oyster reef restoration were considered based upon discussions with town representatives and review of maps to identify potential areas for these operations without significant conflicts to navigation. In some cases actual recent aquaculture expansions were included where they were developed after the MEP reports were prepared. An assumption of 1 million oysters per acre was used with a nitrogen removal rate of 250 kg/Y/acres.
- **FLOATING CONSTRUCTED WETLANDS:** Potential areas for floating wetlands were considered in areas where no conflicts with navigation or swimming areas were identified. A nitrogen removal rate of 0.4 kg/Y/sq foot was used.
- **INLET WIDENING AND COASTAL HABITAT RESTORATION:** Only considered in areas where these projects were identified by towns or state agencies and where detailed hydrologic investigations and modeling had been performed due to wide variations in nitrate load reduction, flushing impacts, impacts on flooding, and costs (dredging only, replacing infrastructure, removing and replacing roadways or bridges, etc.). Nitrogen removal rates were based on MEP or other studies.
- **INNOVATIVE & ALTERNATIVE SEPTIC SYSTEMS AND ECOTOILETS:** In most cases specific locations for these technologies were not identified. Rather general estimates for the percent adoption were provided based upon discussions with the stakeholder groups and their views on potential adoption rates. In some watersheds a 5% adoption rate was included based upon this stakeholder input. In a limited number of instances specific locations for these technologies were included based upon town input and suggestions. A nitrogen removal rate of 1.658 kg/Y for each system was used for I&A Septic Systems, and 2.984 kg/Y for enhanced I&A systems. A removal rate of 2.542 kg/Y was used for each home installation of an Ecotoilet, and 0.467 kg/Y for installation of urine diversion toilets in public settings.

Finally, the locations of specific technologies were discussed during the 208 stakeholder engagement process. Stakeholders across the Cape 'groundtruthed' potential NT locations and NT scenarios were adjusted accordingly.

Appendix D

CCC Lewis Bay Watershed Report

WATERSHED REPORT: MID CAPE

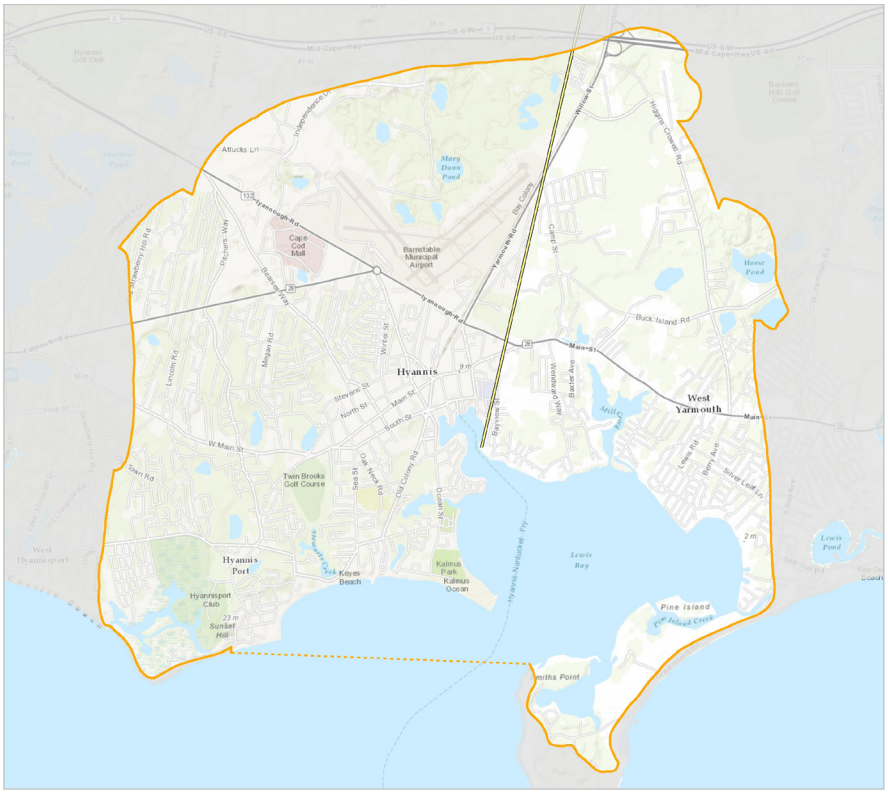
Lewis Bay

BARNSTABLE & YARMOUTH



WATER THREAT LEVEL

MODERATE



Lewis Bay Watershed

Introduction to the Watershed Reports

In 2001, the Massachusetts Estuaries Project (MEP) was established to evaluate the health of 89 coastal embayment ecosystems across southeastern Massachusetts. A collaboration between coastal communities, the Massachusetts Department of Environmental Protection (MassDEP), the School of Marine Science and Technology (SMAST) at the University of Massachusetts-Dartmouth, the US Environmental Protection Agency (US EPA), the United States Geological Survey (USGS), the Massachusetts Executive Office of Energy and Environmental Affairs (EEA), and the Cape Cod Commission, the purpose of the MEP is to identify nitrogen thresholds and necessary nutrient reductions to support healthy ecosystems.

The Cape Cod 208 Plan Update, certified and approved by the Governor of the Commonwealth of Massachusetts and the US EPA in 2015, provides an opportunity and a path forward to implement responsible plans for the restoration of the waters that define Cape Cod.

On Cape Cod there are 53 embayment watersheds with physical characteristics that make them susceptible to nitrogen impacts. In its 2003 report, "The Massachusetts Estuaries Project – Embayment Restoration and Guidance for Implementation Strategies", MassDEP identifies the 46 Cape Cod embayments included in the

MEP. Thirty-three embayments studied to date require nitrogen reduction to achieve healthy ecosystem function. A Total Maximum Daily Load (TMDL) has been established (or a draft load has been identified and is under review) for these watersheds. For those embayments not studied, the 208 Plan Update recommends planning for a 25% reduction in nitrogen, as a placeholder, until information becomes available.

The 208 Plan Update directs Waste Treatment Management Agencies (WMAs) to develop watershed reports within 12 months of certification of the Plan Update. The Watershed Reports outline potential "bookend" scenarios for each watershed that include two scenarios to meet water quality goals in the watershed – a traditional scenario, which relies completely on the typical collection and centralized treatment of wastewater, and a non-traditional scenario, which uses remediation, restoration, and on-site reduction techniques to remove nutrients from raw and treated wastewater, groundwater and affected waterbodies.

The intent of the Watershed Reports is to outline two distinct approaches for addressing the nutrient problem. The reports are not intended to identify preferred and detailed plans for each watershed, but to facilitate discussions regarding effective and efficient solutions, particularly in watersheds shared by more than one town. In some cases, towns have provided information on collection areas and non-traditional technologies that have been specifically considered by that town.

The 208 Update developed a regionally consistent database of the nitrogen load entering each watershed. This data set includes estimates of wastewater, stormwater and fertilizer loads - similar to methodologies used by the MEP. Using this regionally consistent database, the Watershed MVP tool (wMVP) was developed so that different strategies (i.e., bookend scenarios) to reduce excess nitrogen load could be evaluated. The Watershed Reports use the MEP recommendations for the required nitrogen load reductions necessary to meet the threshold loads (that serve as the basis for nitrogen management), and then use the wMVP and the regionally consistent database values to develop bookend scenarios. There are variations of load between the MEP and wMVP, primarily due to differences in comparing older and newer databases.

Terms Defined

Total nitrogen load: the nitrogen load from the watershed contributed by septic, wastewater, fertilizer, stormwater, golf course, landfill, and natural sources.

Attenuated nitrogen load: the nitrogen load from the watershed that reaches the embayment after the effect of natural attenuation in wetlands, ponds or streams.

Threshold: the amount of nitrogen that a water body can receive from its watershed and still meet water quality goals; this number is based on MEP technical reports or Total Maximum Daily Load (TMDL) reports.

Reduction target: an approximation of the amount of nitrogen that needs to be removed from the watershed to achieve the threshold; this number is calculated by subtracting the threshold number from the attenuated total watershed load, and is for planning purposes only.

Percent contribution: the percent of attenuated nitrogen load that a town contributes to the watershed.

Kilogram responsibility: is calculated by applying the percent contribution to the reduction target and indicates the amount of nitrogen, in kg, that a community is responsible for addressing.

Total Maximum Daily Load: a regulatory term in the Clean Water Act, describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. Establishing a TMDL is necessary when a water body has been listed on the 303D list of impaired waters.

Lewis Bay

BARNSTABLE & YARMOUTH



WATER THREAT LEVEL
MODERATE

The Lewis Bay estuary and embayment system shoreline is located in the Towns of Barnstable and Yarmouth. It is comprised of several primary segments that include Hyannis Inner Harbor, Mill Creek, Snows Creek and Stewarts Creek. Lewis Bay is guarded by Great Island which contains Uncle Roberts Cove and Pine Island Creek. The Bay supports commercial fishing and a variety of recreational uses including boating, swimming, shell fishing and fin fishing.

The Problem

The Massachusetts Estuaries Project (MEP) technical report (available at http://www.mass.gov/eea/agencies/massdep/water/watersheds/the-massachusetts-estuaries-project-and-reports.html) indicates that the Lewis Bay system exceeds its critical threshold for nitrogen, resulting in impaired water quality. A MEP technical report has been completed and a Total Maximum Daily Load (TMDL) for nitrogen has been developed and approved. The MEP technical report indicates that the cause of eutrophication to the system is excess nitrogen from the contributing watershed.

- **MEP TECHNICAL REPORT STATUS:** Final
- **TMDL STATUS:** Final TMDL issued March 3, 2015 www.mass.gov/eea/docs/dep/water/resources/a-thru-m/lewisbay.pdf

Watershed nitrogen load characteristics were published in the 2008 MEP report for Lewis Bay, reflecting current conditions at the time of writing:

- **TOTAL ATTENUATED NITROGEN LOAD:** 48,877 Kg/Y (MEP Chapter VIII)
- **SOURCES OF ATTENUATED WATERSHED NITROGEN LOAD:**
  - 63% Septic Systems
  - 6% Fertilizer
  - 9% Stormwater from Impervious Surfaces
  - 22% Wastewater Treatment Facilities

Since the MEP report, the Commission compiled the following updated water use and nitrogen loads using the regional wMVP database (see page 2), enabling a more current estimate of nitrogen loading. Towns have also submitted watershed characteristics that may differ from wMVP. Differences may be explained by different source years of water use data, or other assumptions. Both values are presented, when provided:

- **REGIONAL DATABASE (WMVP)**
  See figure on page 1 for watershed boundary delineation
  - Total Wastewater Flow: 1.1 BGY (billion gallons per year)
  - Treated Wastewater Flow: 657 MGY
  - Septic Flow: 475 MGY
  - Total Attenuated Nitrogen Load: 55,338 Kg/Y
- **TOWN OF YARMOUTH/CDM REPORTED VALUE**
  - Treated Wastewater Flow: 632 MGY

CONTRIBUTING TOWNS

Percent contributions listed below are the aggregate sub-embayment contributions identified in Appendix 8C of the

Cape Cod Section 208 Plan Update (contributions are based on attenuated load where available). See Appendix 8C for detailed town allocations by sub-embayment.

- **BARNSTABLE:** 66%
- **YARMOUTH:** 34%

THE MEP RESTORATION SCENARIO:

- **WATERSHED TOTAL NITROGEN REDUCTION TARGET:** 27%
- **WATERSHED SEPTIC REDUCTION TARGET:** 39% (The scenario represents the aggregated sub-embayment percent removal targets from the MEP technical report)

LEWIS BAY ESTUARY

- **EMBAYMENT AREA:** 1,737 acres
- **EMBAYMENT VOLUME:** 452 million cubic feet
- **2014 INTEGRATED LIST STATUS:**
  - Snows Creek: Category 4a for fecal coliform
  - Lewis Bay: Category 4a, 5 for fecal coliform and estuarine bioassessments
  - Mill Creek: Category 5 for fecal coliform and nitrogen
  - Category 4a - TMDL is completed; Category 5 - Waters requiring a TMDL
  - www.mass.gov/eea/docs/dep/water/resources/07v5/14list2.pdf

LEWIS BAY WATERSHED

General watershed characteristics according to the current wMVP regional database (see figure on page 1 for watershed boundary) follow. Towns have also submitted watershed characteristics that may differ from wMVP. Differences may be explained by changes due to development in the intervening years, or other assumptions. Both values are presented, when provided:

- **WATERSHED CHARACTERISTICS**

Regional Database (wMVP):

- Acres: 8,704
- Parcels: 9,531
- Residential Parcels: 77%
- Parcel Density: 0.91 acres per parcel (approx.)

Town of Yarmouth/CDM Reported Values:

- Acres: 8,759
- Parcels: 8,805
- Residential Parcels: 84%
- Parcel Density: 0.99 acres per parcel (approx.)

Freshwater Sources

PONDS

- **IDENTIFIED SURFACE WATERS:** 71
- **NUMBER OF NAMED FRESHWATER PONDS:** 8
- **PONDS WITH PRELIMINARY TROPHIC CHARACTERIZATION:** 6
- **2014 INTEGRATED LIST STATUS:** None listed

Barnstable and Yarmouth have participated in the Pond and Lake Stewardship (PALS) program that has helped establish baseline water quality. Barnstable completed a Pond Action Report as part of its 2012 Draft Comprehensive Wastewater Management Plan (CWMP).

STREAMS

- **SIGNIFICANT FRESHWATER STREAM OUTLETS:** 6

Halls Creek:

- Average Flow: 1,185 cubic meters per day (m3/d)
- Average Nitrate Concentrations: 0.85 milligrams per liter (mg/L)

Stewarts Creek:

- Average Flow: 31,966 m3/d
- Average Nitrate Concentrations: 1.17 mg/L

Snow's Creek:

- Average Flow: 5,298 m3/d
- Average Nitrate Concentrations: 1.14 mg/L

Hospital Bog:

- Average Flow: 1,318 m3/d
- Average Nitrate Concentrations: 0.64 mg/L

Mill Pond:

- Average Flow: 15,655 m3/d
- Average Nitrate Concentrations: 0.61 mg/L

Chase Brook:

- Average Flow: 3,255 m3/d
- Average Nitrate Concentrations: 0.45 mg/L

Stream data from MEP technical report. Nitrate concentrations higher than 0.05 mg/L background concentrations, evident in public supply wells located in pristine areas, provide evidence of the impact of non-point source pollution on the aquifer and receiving coastal water bodies.

DRINKING WATER SOURCES

Town submitted watershed reports (by Yarmouth) included watershed characteristics that slightly differ from the regional database, both values are reported below.

- **WATER DISTRICTS:** 2
  - Hyannis Water Division
  - Yarmouth Water Department
- **GRAVEL PACKED WELLS:**

Regional Database Gravel Packed Wells: 22
- 12 have nitrate concentrations between 0 and 0.5 mg/L
- 4 have nitrate concentrations between 0.5 and 1 mg/L
- 3 have nitrate concentrations between 2.5 and 5 mg/L
- 3 have no nitrate concentration data

Town Reported Gravel Packed Wells: 14
- 11 have average nitrate concentrations between 0 and 1 mg/L
- 3 have no nitrate concentration data

- **SMALL VOLUME WELLS:** 0

Each of the Towns has acquired significant portions of land in their Zone IIs for water quality protection which together with adopted land use controls recommended from the 1978 Section 208 Plan has resulted in excellent water quality. The wells with high nitrate concentrations are coincident with high density development and indicative of septic and wastewater impacts to groundwater quality.

Drinking water data from Cape Cod Commission and MassDEP data sources – nitrate values obtained from drinking water wells are from 2009-2012. The state and federal drinking water limit for nitrate is 10 mg/L. The Cape Cod Commission nitrate loading standard is 5 mg/l.

Degree of Impairment and Areas of Need

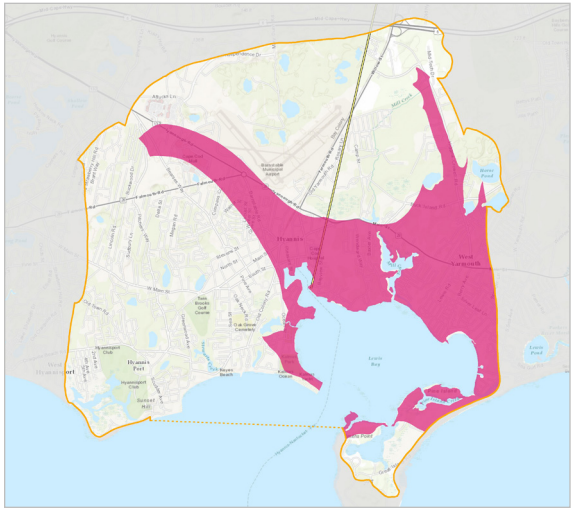
For the purposes of the Section 208 Plan Update areas of need are primarily defined by the amount of nitrogen reduction required as defined by the TMDL and/or MEP technical report. The aggregated watershed removal rates are 27% and 39% for total attenuated watershed and septic attenuated nitrogen loads, respectively. More specifically, the targeted amount of nitrogen reduction required by subwatershed ranges from 68% to 80% removal as indicated in the figures, Subwatersheds with Subwatersheds with Total and Septic Attenuated Nitrogen Removal Targets.

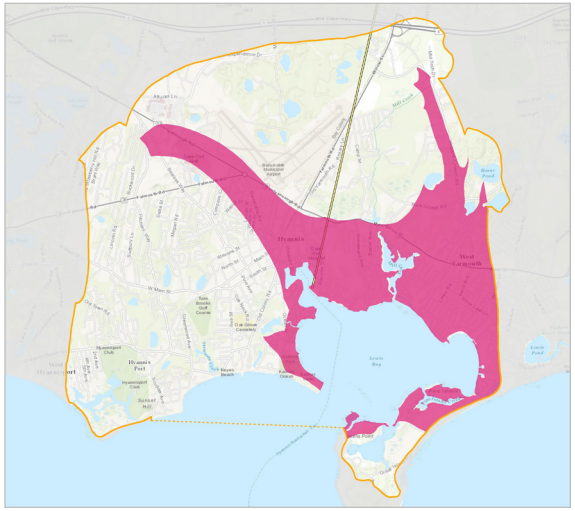
The Lewis Bay subwatershed in Yarmouth requires 80% septic nitrogen removal.

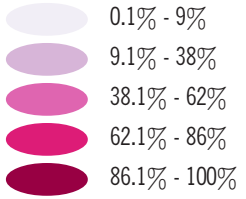
The nitrogen load from the watershed exceeds the threshold for Lewis Bay, resulting in impaired water quality. The upper headwaters of Lewis Bay are particularly impaired. The ecological health of a water body is determined from water quality, extent of eelgrass, assortment of benthic fauna, and dissolved oxygen and ranges from severe degradation, significantly impaired, moderately impaired, or healthy habitat conditions.

ECOLOGICAL CHARACTERISTICS AND WATER QUALITY

The MEP report provides the following characterization of the estuary's health:







Subwatersheds with
Total Attenuated Watershed Removal Targets

(Left) Benthic and atmospheric loads directly on embayments are not included.

Subwatersheds with
Septic Attenuated Nitrogen Removal Targets

(Right)

WATERSHED REPORT: Lewis Bay

- **OVERALL ECOLOGIC CONDITION:** Healthy to Significantly Impaired
- **OUTER LEWIS BAY:** Significantly Impaired
- **INNER LEWIS BAY:** Significantly Impaired
- **UNCLE ROBERTS COVE:** Significantly Impaired
- **HYANNIS INNER HARBOR:** Moderately Impaired
- **MILL CREEK:** Moderately Impaired
- **HALLS CREEK:** Healthy
- **SENTINEL STATION:**
  - Total Nitrogen Concentration Threshold: 0.378 mg/L
  - Total Nitrogen Concentration Existing: 0.407 mg/L (As reported at the MEP sentinel water-quality monitoring station)

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Traditional & Non-Traditional Scenarios

SCENARIO DEVELOPMENT

Through the 208 Stakeholder process, the Commission developed "bookend" scenarios – one looking at a possible solution using traditional collection and treatment, the other examining a possible suite of non-traditional technologies – to address the nitrogen management needs in each watershed. These bookend scenarios provide guidance for communities as they continue to discuss alternatives, priorities, and opportunities for identifying well-considered solutions that will address communities' needs and interests.

REGIONAL DATA

In preparation for this effort, the Commission collected regionally consistent data for the purposes of watershed scenario development. Both parcel data and water use data was identified and collected for the entire region. While the scientific basis for planning is the thresholds identified in the MEP technical reports, each report uses data from different years, and in some cases the MEP data used are 10 or more years old. In addition, there are watersheds on Cape Cod without the benefit of an MEP report; therefore, similar data was not available for planning purposes.

The updated regional data set was used to estimate wastewater, stormwater and fertilizer loads, using the same methodologies as the MEP. This approach allows for a reevaluation of existing development, which may have changed in the last 10 years. Parcel data included in the regional database is from 2010-2012 and water use data is from 2008-2011, depending on the water supplier and based on best available data. This approach allows for regionally consistent watershed scenario development.

WATERSHED SCENARIOS

The watershed scenarios that follow outline possibilities for the watershed. A series of non-traditional technologies that might be applicable are included, as well as the amount of residential load that would need to be collected if a traditional collection system and treatment facility was implemented. The pie charts show the load to be collected for treated effluent disposal both inside and outside the watershed.

Site specific analyses of collection areas may result in the need to collect wastewater from more or fewer parcels to meet the nitrogen reduction target. The scenarios presented are conceptual and are meant to inform discussions regarding effective and efficient solutions; they are not specific recommendations and should be viewed as resource information for additional and more detailed wastewater management planning.

In Lewis Bay, the Towns of Barnstable and Yarmouth have done additional and more detailed planning. Included in the last section of this report is a description of their efforts, along with details of plans developed to date.

TOTAL ATTENUATED WATERSHED NITROGEN LOAD VALUES (FROM WMVP)

Lewis Bay Nitrogen Sources	Total Attenuated Watershed Nitrogen Load (kg-N/yr)
Wastewater[1]	42,815
Fertilizer[2]	3,389
Stormwater	8,029
Other[3]	1,105
TOTAL WATERSHED LOAD	55,338
Total Watershed Threshold	35,705
TOTAL ATTENUATED LOAD TO BE REMOVED	19,633

1. Includes nitrogen loads from septic systems and wastewater treatment facilities. 2. Includes nitrogen loads from lawns, cranberry bogs, and golf courses. 3. Includes nitrogen loads from landfills and atmospheric deposition to vacant land.

The attenuated watershed loads, threshold, and both traditional and non-traditional scenarios presented in this report exclude Halls Creek because Halls Creek has its own

Traditional & Non-Traditional Scenarios

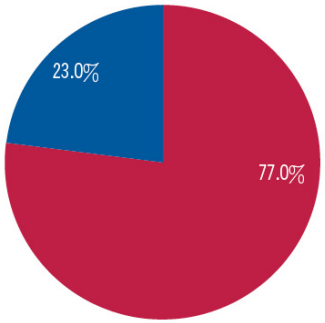
Non-Traditional

UNIT OF APPLIED TECHNOLOGY	ATTENUATED NITROGEN REMOVED IN KG/Y
25 % Nitrogen Reduction - Fertilizer Management	847
25 % Nitrogen Reduction - Stormwater Mitigation	2,007
1 Acres - Constructed Wetlands (Collection System)	500
15,200 Linear Feet - Permeable Reactive Barrier (PRB) (Capture load calculated by wMVP: 12,106.2 kg/Y)	8,777
38 Acres - Aquaculture/Oyster Beds	9,570
TOTAL	**21,701**

A summary of the approach and methodology that was applied using non-traditional technologies follows at the end of this report.

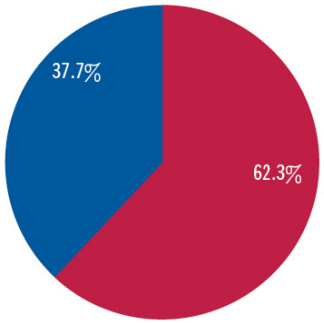
Traditional

CENTRALIZED TREATMENT WITH DISPOSAL INSIDE THE WATERSHED

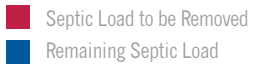


Assumes load to be collected and treated is disposed in the watershed, requiring additional collection to offset the load.

CENTRALIZED TREATMENT WITH DISPOSAL OUTSIDE THE WATERSHED



Assumes that the load to be collected and treated is removed from the watershed so no offset is required.



Town of Barnstable Local Progress

The Cape Cod Commission and the Town of Barnstable met and discussed the use of WatershedMVP to evaluate targeted watershed approaches for each of the watersheds in which they have jurisdiction. In 2015, the town reformulated its Citizen's Advisory Committee (CAC) for wastewater planning to better address local needs. In addition to local participation, the newly formed committee (the Water Resources Advisory Committee or WRAC) includes state and regional representatives. Town staff provided modifications to Commission-developed watershed scenarios and presented those scenarios to their WRAC for review and discussion. Those scenarios are included in this report.

Barnstable is also working closely with Mashpee and Sandwich on a watershed permit for the Popponesset Bay watershed.

The Town of Barnstable operates the Hyannis Water Pollution Control Facility (WPCF), located off Bearses Way in Hyannis, which is the primary wastewater treatment facility serving approximately 2,900 properties in Hyannis and Barnstable village. The treatment facility has been upgraded and permitted to treat additional flows up to a total of 4.2 million gallons per day (MGD), upon meeting requirements of an adaptive management plan approved by the Commission in 2007. Property along Route 132 was acquired by the town in 2002 to potentially accommodate future disposal needs. The site is approved under a 2006 Massachusetts Environmental Policy Act (MEPA) certificate to discharge up to 0.5 MGD. The site is not presently in use. However, a force main and sewer has been extended to the site from the WPCF.

The WPCF treats an average daily flow of 1.46 MGD and a maximum monthly average flow of 1.94 MGD. Treatment performance has averaged 5 milligrams per liter (mg/L) total nitrogen in the treated effluent and the facility has a discharge limit of 5 mg/L under the 2007 Development of Regional Impact (DRI) decision and a limit of 10 mg/L under a Groundwater Discharge Permit (GWDP). The facility is also equipped with sludge thickening, storage and dewatering facilities sized for the current process conditions.

The Town of Barnstable also operates two smaller facilities – the Marstons Mills Wastewater Treatment Facility (WWTF) and the Red Lily Pond Cluster System. The Marstons Mills WWTF is limited to a discharge flow of 42,900 gallons per day (GPD) and is intended to service the Barnstable United Elementary School and the Village at Marstons Mills affordable housing development. The Red Lily Pond Cluster System currently serves 17 homes. According to the comprehensive wastewater management plan (CWMP) approved in 2007, no performance sampling of the system occurs and the system is assumed to produce comparable effluent to any conventional single family septic system.

In addition to municipally-owned facilities, there are two privately-owned treatment facilities treating wastewater from the Cotuit Landing shopping plaza and the Cape Regency nursing and rehabilitation facility. These facilities provide high levels of wastewater treatment. The treatment facility at Cotuit Landing was designed with additional treatment capacity beyond the expected needs of the shopping plaza for potential treatment of flows from neighboring properties.

Barnstable is working on a town-wide nutrient management plan that will provide the basis of its CWMP. The plan will address nitrogen and other needs in watersheds draining to Three Bays, Centerville River, and Lewis Bay. A nitrogen total maximum daily load (TMDL) for Barnstable Harbor has not been approved by US EPA. The MEPA certificate scope for the Final Environmental Impact Report (FEIR) includes engagement in a targeted watershed approach, consistent with the 208 Plan Update.

In the fall of 2014, Barnstable adopted local nitrogen-oriented fertilizer management regulations consistent with the Cape-wide Fertilizer Management District of Critical Planning Concern (DCPC).

Since the approval of the 208 Plan Update, the Commission has been working for several months with Barnstable and Yarmouth to develop a targeted watershed scope of work for the Lewis Bay watershed to address excess nitrogen entering the system. In addition, the town was a recipient of a technical assistance grant through the Southeast New England Coastal Watershed Restoration Program (SNEP) and a stormwater best

Town of Barnstable Watershed Scenario Details

Lewis Bay	CREDITS		REDUCTION TECHNOLOGIES			REMEDIATION AND RESTORATION TECHNOLOGIES			REMOVAL
NAME OF TECHNOLOGY	% Nitrogen Reduction	Load Reduction (kg-N/yr)	# Properties / Units	Flow Collected (gpd)	Load Reduction (kg-N/yr)	# Units Proposed	Unit Metric	Load Reduction (kg-N/yr)	Total Scenario Load Reduction (kg-N/yr)
Scenario									2,804
Centralized Sewer			303	82,823	2,804				

management practice (BMP) was constructed in the Lewis Bay watershed in the spring of 2015.

In 2015, the Town submitted a Statement of Interest to the US EPA for a hydrogeologic site characterization as an initial step toward piloting a permeable reactive barrier in the town. One of three sites proposed by the Town was selected for characterization. The work was completed in 2016. The draft report is presently being reviewed by the Town.

In June 2016, Barnstable received $28,850 from the Commission to fund upgrades to three stormwater treatment BMPs. Funding was part of $142,149 in local grants made available to communities by the Commission in support of 208 Plan implementation.

Town of Yarmouth Local Progress

In 2010, the Town of Yarmouth submitted its Comprehensive Wastewater Management Plan (CWMP) as a Draft Environmental Impact Report (DEIR). The draft CWMP targeted areas that would require wastewater collection to restore water quality in the Lewis Bay and Parkers River watersheds and deal with the Title 5 constraints on economic redevelopment in the area of Route 28. The town's plan included approximately 125 miles of sewer lines and the collection of 2.75 million gallons per day (MGD) of wastewater to be treated at a single facility in the Parkers River watershed. The project would ultimately serve 9,580 properties by 2035. Phase 1 of the plan would begin with the treatment facility and main trunk line sewer to serve Route 28 and portions of the Parkers River and Lewis Bay watershed.

The plan relies on gravity, pressure, and vacuum sewers. The MEP nitrogen reduction goals were the primary factor in choosing sewering locations. The phasing of these sewered areas also takes the town's economic goals into consideration.

The town submitted its Final Environmental Impact Report (FEIR) and received Massachusetts Environmental Policy Act (MEPA) approval in July 2011, but did not complete the Cape Cod Commission Development of Regional Impact (DRI) process before going to September 2011 Town Meeting to seek Phase 1 design and construction funds. Phases 1 through 5 were scheduled to be implemented over a 25-year period. The estimated cost of the total plan was $275 million. The first phase had an estimated cost of $55 million. Town Meeting did not approve the expenditure. The town withdrew the CWMP from the DRI review process.

Wastewater planning in the community had effectively come to a stop prior to the development of the 208 Plan Update.

In January 2016 town staff met with the Board of Selectmen to discuss a new financing plan for implementation of a program that would meet water quality standards in all of their watersheds.

The recommended plan includes a combination of traditional sewering methods with centralized treatment facilities as well as non-traditional nitrogen management options including a permeable reactive barrier (PRB) at the Buck Island Road effluent recharge site. The Town of Yarmouth is proposing a phased wastewater program that includes a collection system, a conveyance system and a centralized treatment facility, each constructed over several years. In addition to the proposed sewering, the recommended plan involves public outreach to promote nitrogen reduction and to prevent sewer system inflow, zoning modifications for growth management and establishment of the activity centers, development of sewer ordinances, and continued maintenance of Title 5 and I/A systems in the northern and western areas of the town that will not be served by the proposed wastewater collection system. The town also plans to implement stormwater and fertilizer improvement programs. As suggested in the 208 Plan Update, up to a 25% nitrogen reduction credit can be obtained by towns that implement stormwater and fertilizer management programs to reduce nitrogen contributions to each watershed. To achieve a 25% nitrogen reduction from stormwater in the Lewis Bay watershed, 50% of the total roads in the watershed are assumed to require stormwater best management practices (BMPs). Yarmouth plans to achieve 25% nitrogen reduction in fertilizers by implementing a town-wide fertilizer education program.

During the spring 2016 town meeting, the town approved $200,000 for additional CWMP planning.

In April 2016, Yarmouth submitted a request for assistance to continue CWMP development and town staff met with the Commission to discuss the request in early May.

In June 2016, Yarmouth received $35,000 from the Commission for the Towns of Dennis, Harwich and Yarmouth for a regional treatment facility cost study. Funding was part of $142,149 in local grants made by the Commission in support of 208 Plan implementation.

At the Spring 2017 Town Meeting appropriated $200,000 for wastewater planning and engineering services including engineering studies and evaluation of recharge sites; updating, modification, and pre-implementation services for the Comprehensive Wastewater Management Plan and support for related filings with the Massachusetts Environmental Policy Act office and the Cape Cod Commission.

Town of Yarmouth Watershed Scenario Details

Lewis Bay	CREDITS		REDUCTION TECHNOLOGIES			REMEDIATION AND RESTORATION TECHNOLOGIES			REMOVAL
NAME OF TECHNOLOGY	% Nitrogen Reduction	Load Reduction (kg-N/yr)	# Properties / Units	Flow Collected (gpd)	Load Reduction (kg-N/yr)	# Units Proposed	Unit Metric	Load Reduction (kg-N/yr)	Total Scenario Load Reduction (kg-N/yr)
Traditional Scenario									13,800**
Fertilizer Management	25%	Not reported**							
Stormwater Mitigation	25%	Not reported**							
Centralized Sewer			2,209	582,376	13,800				

NOTES:

* Average daily flow collected includes buildout and estimated inflow and infiltration.

** This total value does not include fertilizer management and stormwater management credits which were not calculated as part of the recommended program. Values for both are shown in the Cape Cod Commission's Non-Traditional summary on pg. 9; however, these values are for all of Bass River Watershed. These credits will be built into the updated recommended plan for Yarmouth when the Notice of Project Change (NPC) is submitted for the Final CWMP.

Scenario Maps

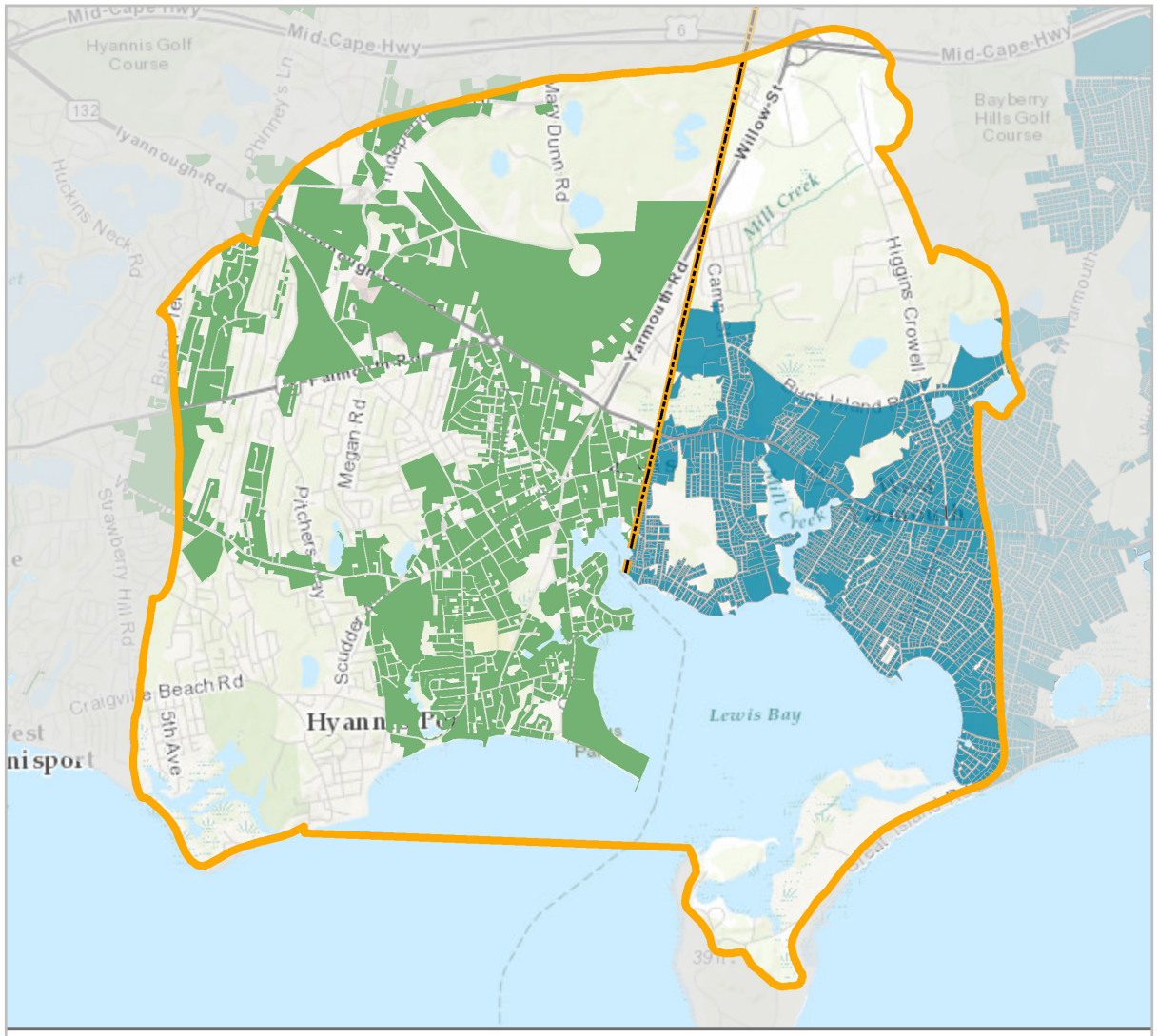
Lewis Bay Watershed Scenario

BARNSTABLE & YARMOUTH

Representative locations of conceptually proposed infrastructure

Legend

- Town Lines
- Sewered Areas
- Embayment Watersheds
- Proposed Sewershed



September 2016 Watershed Scenario Map

Methodology for Selecting Non-Traditional Technology Scenarios

- **FERTIGATION WELLS:** Golf courses were mapped to identify areas where fertigation wells could be utilized to recapture nitrogen-enriched groundwater and re-apply it to the managed turf areas to serve both irrigation and fertilization needs. Most golf courses were assumed to be eighteen holes with a fertilized area of 75 acres. Fertigation water was assumed to have an average concentration of 5 mg/liter. An uptake/attenuation rate of 80% was applied resulting in an assumed nitrogen reduction of 300 kg/year for each golf course with effectively located fertigation wells. In some cases other irrigated areas (such as athletic fields and cemeteries) were identified as potential fertigation locations. A nitrogen removal rate of 4 kg/Y/acre was used.

The MVP tool and other site-specific tools were utilized to quantify nitrogen load reductions for several potential NT interventions.

- **PERMEABLE REACTIVE BARRIERS:** for each PRB that was identified during the prior GIS-screening process an approximate capture area was identified using available water table maps and the wMVP tool. Upgradient contributing areas were digitized within wMVP and the nitrogen load was calculated. A nitrogen reduction of 72.5% was applied (calculated as an average of the reported attenuation range from the Technologies Matrix).
- **CONSTRUCTED WETLANDS (WITH COLLECTION):** Constructed wetlands were considered as a tertiary, polishing treatment for existing wastewater treatment plants. This included small-scale wastewater treatment systems. A nitrogen removal rate of 500 kg/Y/acre was used.
- **AQUACULTURE/OYSTER REEFS:** Potential areas for aquaculture and/or oyster reef restoration were considered based upon discussions with town representatives and review of maps to identify potential areas for these operations without significant conflicts to navigation. In some cases actual recent aquaculture expansions were included where they were developed after the MEP reports were prepared. An assumption of 1 million oysters per acre was used with a nitrogen removal rate of 250 kg/Y/acres.
- **FLOATING CONSTRUCTED WETLANDS:** Potential areas for floating wetlands were considered in areas where no conflicts with navigation or swimming areas were identified. A nitrogen removal rate of 0.4 kg/Y/sq foot was used.
- **INLET WIDENING AND COASTAL HABITAT RESTORATION:** Only considered in areas where these projects were identified by towns or state agencies and where detailed hydrologic investigations and modeling had been performed due to wide variations in nitrate load reduction, flushing impacts, impacts on flooding, and costs (dredging only, replacing infrastructure, removing and replacing roadways or bridges, etc.). Nitrogen removal rates were based on MEP or other studies.
- **INNOVATIVE & ALTERNATIVE SEPTIC SYSTEMS AND ECOTOILETS:** In most cases specific locations for these technologies were not identified. Rather general estimates for the percent adoption were provided based upon discussions with the stakeholder groups and their views on potential adoption rates. In some watersheds a 5% adoption rate was included based upon this stakeholder input. In a limited number of instances specific locations for these technologies were included based upon town input and suggestions. A nitrogen removal rate of 1.658 kg/Y for each system was used for I&A Septic Systems, and 2.984 kg/Y for enhanced I&A systems. A removal rate of 2.542 kg/Y was used for each home installation of an Ecotoilet, and 0.467 kg/Y for installation of urine diversion toilets in public settings.

Finally, the locations of specific technologies were discussed during the 208 stakeholder engagement process. Stakeholders across the Cape 'groundtruthed' potential NT locations and NT scenarios were adjusted accordingly.

Methodology for Selecting Non-Traditional Technology Scenarios

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology were derived from the Technologies Matrix. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology are noted below, based on the Technologies Matrix or newer data. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

Regional credits were developed for potential stormwater retrofits and fertilizer reductions. They were calculated as a percent reduction of existing nitrogen loads as identified in the MEP reports and updated GIS data developed by the Cape Cod Commission.

- **STORMWATER MANAGEMENT:** Most Cape communities have already begun the process of identifying significant untreated stormwater discharges and developing appropriate mitigation projects. With the prospect of the MS4 regulatory requirements it was assumed that additional mitigation efforts would be implemented. Based upon the evidence developed by the University of New Hampshire Stormwater Center that several vegetated stormwater management practices (including bioretention and constructed wetlands) are able to achieve nitrogen reductions of 50% or more and the assumption that only a portion (estimated at 50%) of identified sites would be retrofitted a 25% nitrogen reduction credit was assumed for each watershed. Specific locations and number of locations were not identified; this was deferred to individual towns to consider as part of the suite of nitrogen management strategies.
- **FERTILIZER REDUCTIONS:** Based upon the success of most Cape Cod towns to implement either regulatory or non-regulatory fertilizer management programs and the efforts of the Cape Cod Extension Service in educating homeowners a 25% reduction in fertilizer applications was assumed for each watershed.

Regional GIS screening methods were developed to identify locations for some non-traditional technologies. A GIS viewer was developed as an on-line tool for staff and consultants to utilize during the watershed planning process.

- **CONSTRUCTED WETLANDS/ PHYTOREMEDIATION:** A GIS-based screening method was developed by the Cape Cod Commission to identify and rank parcels of land that have potential for the location of constructed wetlands and phytoremediation. The ranking utilized parcel size and ownership, depth to groundwater, suitable soils, distance from wetlands, and undeveloped parcels. A nitrogen removal rate of 500 kg/Y/acre and 532 kg/Y/acre was used for Constructed Wetlands and Phytoremediation, respectively.
- **PERMEABLE REACTIVE BARRIERS (PRBS):** A GIS-based screening method was developed to identify existing roads that are proximate to receiving waters, downgradient of high density development, run perpendicular to groundwater flow (to have the highest potential to intercept nutrients in groundwater), and where the depth to groundwater is relatively shallow to maximize the area of saturated thickness treated in the aquifer.

Appendix E

CCC Three Bays Watershed Report

WATERSHED REPORT: MID CAPE

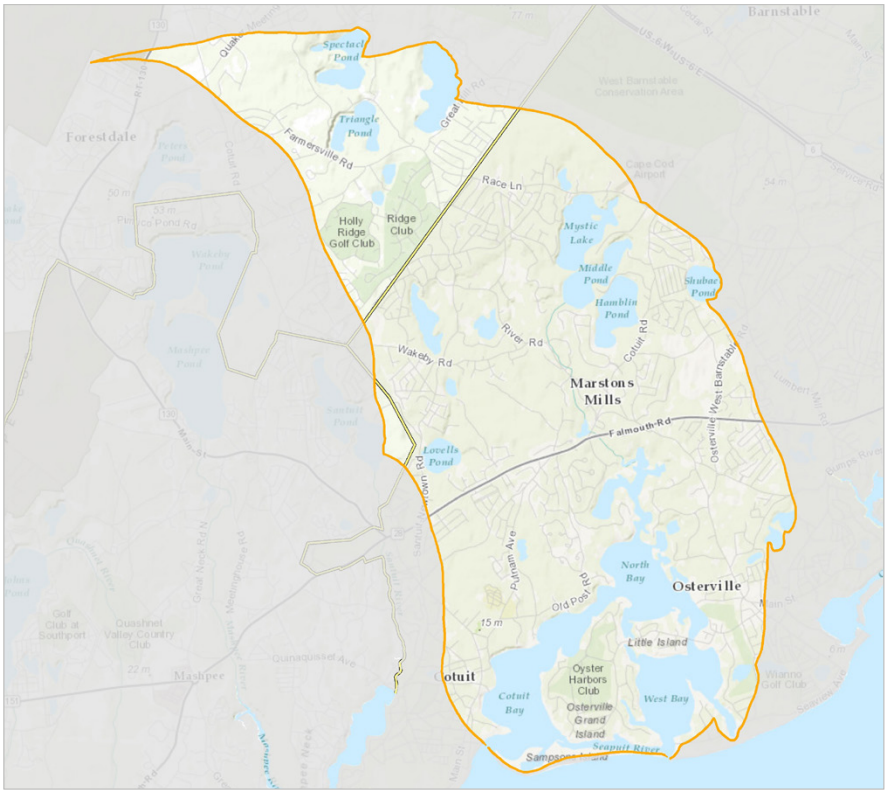
Three Bays

BARNSTABLE & SANDWICH



WATER THREAT LEVEL

HIGH



Three Bays Watershed

Introduction to the Watershed Reports

In 2001, the Massachusetts Estuaries Project (MEP) was established to evaluate the health of 89 coastal embayment ecosystems across southeastern Massachusetts. A collaboration between coastal communities, the Massachusetts Department of Environmental Protection (MassDEP), the School of Marine Science and Technology (SMAST) at the University of Massachusetts-Dartmouth, the US Environmental Protection Agency (US EPA), the United States Geological Survey (USGS), the Massachusetts Executive Office of Energy and Environmental Affairs (EEA), and the Cape Cod Commission, the purpose of the MEP is to identify nitrogen thresholds and necessary nutrient reductions to support healthy ecosystems.

The Cape Cod 208 Plan Update, certified and approved by the Governor of the Commonwealth of Massachusetts and the US EPA in 2015, provides an opportunity and a path forward to implement responsible plans for the restoration of the waters that define Cape Cod.

On Cape Cod there are 53 embayment watersheds with physical characteristics that make them susceptible to nitrogen impacts. In its 2003 report, "The Massachusetts Estuaries Project – Embayment Restoration and Guidance for Implementation Strategies", MassDEP identifies the 46 Cape Cod embayments included in the

MEP. Thirty-three embayments studied to date require nitrogen reduction to achieve healthy ecosystem function. A Total Maximum Daily Load (TMDL) has been established (or a draft load has been identified and is under review) for these watersheds. For those embayments not studied, the 208 Plan Update recommends planning for a 25% reduction in nitrogen, as a placeholder, until information becomes available.

The 208 Plan Update directs Waste Treatment Management Agencies (WMAs) to develop watershed reports within 12 months of certification of the Plan Update. The Watershed Reports outline potential "bookend" scenarios for each watershed that include two scenarios to meet water quality goals in the watershed – a traditional scenario, which relies completely on the typical collection and centralized treatment of wastewater, and a non-traditional scenario, which uses remediation, restoration, and on-site reduction techniques to remove nutrients from raw and treated wastewater, groundwater and affected waterbodies.

The intent of the Watershed Reports is to outline two distinct approaches for addressing the nutrient problem. The reports are not intended to identify preferred and detailed plans for each watershed, but to facilitate discussions regarding effective and efficient solutions, particularly in watersheds shared by more than one town. In some cases, towns have provided information on collection areas and non-traditional technologies that have been specifically considered by that town.

The 208 Update developed a regionally consistent database of the nitrogen load entering each watershed. This data set includes estimates of wastewater, stormwater and fertilizer loads - similar to methodologies used by the MEP. Using this regionally consistent database, the Watershed MVP tool (wMVP) was developed so that different strategies (i.e., bookend scenarios) to reduce excess nitrogen load could be evaluated. The Watershed Reports use the MEP recommendations for the required nitrogen load reductions necessary to meet the threshold loads (that serve as the basis for nitrogen management), and then use the wMVP and the regionally consistent database values to develop bookend scenarios. There are variations of load between the MEP and wMVP, primarily due to differences in comparing older and newer databases.

Terms Defined

Total nitrogen load: the nitrogen load from the watershed contributed by septic, wastewater, fertilizer, stormwater, golf course, landfill, and natural sources.

Attenuated nitrogen load: the nitrogen load from the watershed that reaches the embayment after the effect of natural attenuation in wetlands, ponds or streams.

Threshold: the amount of nitrogen that a water body can receive from its watershed and still meet water quality goals; this number is based on MEP technical reports or Total Maximum Daily Load (TMDL) reports.

Reduction target: an approximation of the amount of nitrogen that needs to be removed from the watershed to achieve the threshold; this number is calculated by subtracting the threshold number from the attenuated total watershed load, and is for planning purposes only.

Percent contribution: the percent of attenuated nitrogen load that a town contributes to the watershed.

Kilogram responsibility: is calculated by applying the percent contribution to the reduction target and indicates the amount of nitrogen, in kg, that a community is responsible for addressing.

Total Maximum Daily Load: a regulatory term in the Clean Water Act, describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. Establishing a TMDL is necessary when a water body has been listed on the 303D list of impaired waters.

Three Bays

BARNSTABLE & SANDWICH



WATER THREAT LEVEL
HIGH

The Three Bays estuary and embayment system is located in the Town of Barnstable. It is comprised of three primary segments that include West Bay, North Bay and Cotuit Bay. Sub-systems include Prince's Cove that flows into North Bay, the Narrows that flows between North Bay and Cotuit Bay and Eel River that flows into West Bay. The embayment is guarded by Sampson's Island/Dead Neck which defines the inner Seapuit River waterway between Cotuit Bay and West Bay. Three Bays supports a variety of recreational uses including boating, swimming, shell fishing and fin fishing

The Problem

The Massachusetts Estuaries Project (MEP) technical report (available at http://www.mass.gov/eea/agencies/massdep/water/watersheds/the-massachusetts-estuaries-project-and-reports.html) indicates that the Three Bays system exceeds its critical threshold for nitrogen, resulting in impaired water quality. A MEP technical report has been completed and a Total Maximum Daily Load (TMDL) for nitrogen has been developed and approved.

- **MEP TECHNICAL REPORT STATUS:** Final
- **TMDL STATUS:** Final TMDL

Watershed nitrogen load characteristics were published in the 2006 MEP report, reflecting current conditions at the time of writing:

- **TOTAL ATTENUATED NITROGEN LOAD (MEP CHAPTER VIII):** 47,727 Kg/Y
- **SOURCES OF ATTENUATED WATERSHED NITROGEN LOAD:**
  - 85% Septic Systems
  - 10% Fertilizer
  - 5% Stormwater From Impervious Surfaces

Since the MEP report, the Commission compiled the following updated water use and nitrogen loads using the regional wMVP database, enabling a more current estimate of nitrogen loading (see figure on page 1 for watershed boundary delineation):

- **TOTAL WASTEWATER FLOW:** 528 MGY (million gal per year)
  - Treated Wastewater Flow: 8 MGY
  - Septic Flow: 520 MGY
- **TOTAL ATTENUATED NITROGEN LOAD (WMVP):** 46,221Kg/Y

CONTRIBUTING TOWNS

Percent contributions listed below are the aggregate sub-embayment contributions identified in Appendix 8C of the Cape Cod Section 208 Plan Update (contributions are based on attenuated load where available). See Appendix 8C for detailed town allocations by sub-embayment.

- **BARNSTABLE:** 93%
- **SANDWICH:** 7%
- **MASHPEE:** <1%*

*Under existing conditions, the load contributed by Mashpee is so small that reductions are not necessary at this time; however, growth management measures should be taken to ensure that the contribution does not increase. Contributions will be reevaluated at least every five years, based on updated data.

THE MEP RESTORATION SCENARIO

- **WATERSHED TOTAL NITROGEN REDUCTION TARGET:** 46%
- **WATERSHED SEPTIC REDUCTION TARGET:** 60%
  (The scenario represents the aggregated sub-embayment percent removal targets from the MEP technical report)

THREE BAYS ESTUARY

- **EMBAYMENT AREA:** 1,251 acres
- **EMBAYMENT VOLUME:** 429 million cubic feet
- **2014 INTEGRATED LIST STATUS:** Category 4a for nitrogen and fecal coliform
  - Category 4a: TMDL is completed
  - www.mass.gov/eea/docs/dep/water/resources/07v5/14list2.pdf

THREE BAYS WATERSHED

General watershed characteristics according to the current wMVP regional database (see figure on page 1 for watershed boundary) follow.

- **WATERSHED CHARACTERISTICS**
  - Acres: 12,458
  - Parcels: 7,670
  - % Developed Residential Parcels: 85%
  - Parcel Density: 1.6 acres per parcel (approx.)

Freshwater Sources

PONDS

- **IDENTIFIED SURFACE WATERS:** 54
- **NUMBER OF NAMED FRESHWATER PONDS:** 21
- **PONDS WITH PRELIMINARY TROPHIC CHARACTERIZATION:** 19
- **2014 INTEGRATED LIST STATUS:** 6 listed
  - Hamblin Pond
  - Lovells Pond
  - Middle Pond
  - Mystic Lake
  - Lawrence Pond
  - Shubael Pond

Barnstable has participated in the Pond and Lake Stewardship (PALS) program that has helped establish baseline water quality.

The Town of Barnstable has completed a Pond Action Report as part of its 2012 draft Comprehensive Wastewater Management Plan (CWMP). In addition, the Town has worked with watershed associations to implement alum treatments for Hamblin and Mystic Ponds and Lovells Pond treatment is scheduled. The Town regularly treats several ponds with Sonar, an herbicide to combat invasive weeds.

STREAMS

- **SIGNIFICANT FRESHWATER STREAM OUTLETS:** 2

  Marstons Mills River:
  - Average Flow: 16,000 cubic meters per day (m3/d)
  - Average Nitrate Concentrations: 0.48 milligrams per liter (mg/L)

  Little River:
  - Average Flow: 3,500 m3/d
  - Average Nitrate Concentrations: 0.86 mg/L

Stream data from MEP technical report. Nitrate concentrations higher than 0.05 mg/L background concentrations, evident in public supply wells located in pristine areas, provide evidence of the impact of non-point source pollution on the aquifer and receiving coastal water bodies.

DRINKING WATER SOURCES

- **WATER DISTRICTS:** 3
  - Sandwich Water District
  - Centerville-Osterville-Marstons Mills (COMM) Water District
  - Cotuit Water District
- **GRAVEL PACKED WELLS:** 26
  - 6 have nitrate concentrations between 0 and 0.5 mg/L
  - 7 have nitrate concentrations between 0.5 and 1 mg/L
  - 7 have nitrate concentrations between 1 and 2.5 mg/L
  - 2 have nitrate concentrations between 2.5 and 5 mg/L
  - 4 have no nitrate concentration data
- **SMALL VOLUME WELLS:** 9

Each of the water districts and land trusts have acquired significant portions of land in their Zone IIs for water quality protection which, together with adopted land use controls recommended from the 1978 Section 208 Plan, has resulted in excellent water quality.

Drinking water data from Cape Cod Commission and MassDEP data sources – nitrate values obtained from drinking water wells are from 2009-2012. The state and federal drinking water limit for nitrate is 10 mg/L. The Cape Cod Commission nitrate loading standard is 5 mg/l.

Degree of Impairment and Areas of Need

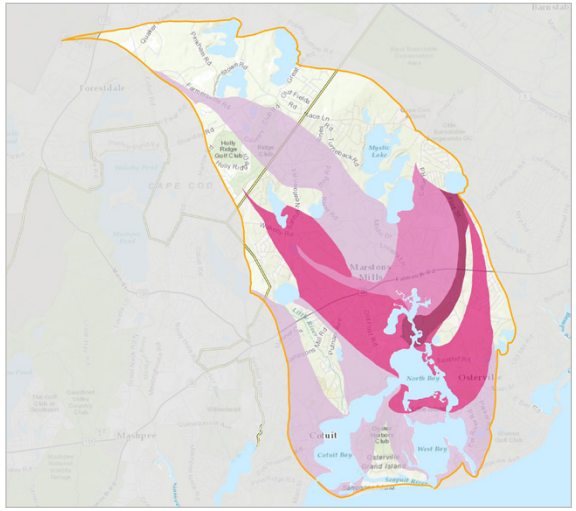
For the purposes of the Section 208 Plan Update areas of need are primarily defined by the amount of nitrogen reduction required as defined by the TMDL and/or MEP technical report. The aggregated watershed removal rates are 46% and 60% for total attenuated nitrogen and septic nitrogen, respectively. More specifically, the targeted amount of nitrogen reduction required by subwatershed ranges from 20 to 80% removal, as indicated in the figures, Subwatersheds with Total Attenuated Watershed Removal Targets and Subwatersheds with Septic Attenuated Nitrogen Removal Targets.

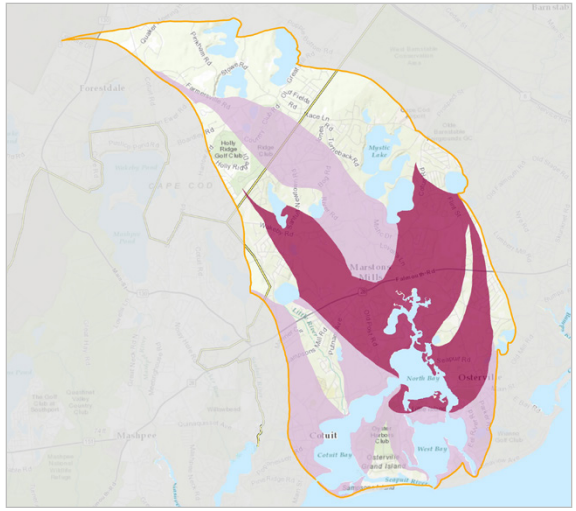
The nitrogen load from the watershed exceeds the TMDL for Three Bays, resulting in impaired water quality. The ecological health of a water body is determined from water quality, extent of eelgrass, assortment of benthic fauna, and dissolved oxygen and ranges from severe degradation, significantly impaired, moderately impaired, or healthy habitat conditions. The upper head waters of Three Bays are particularly impaired and the upper Prince Cove segment experiences occasional severe eutrophic conditions affecting recreational activities.

ECOLOGICAL CHARACTERISTICS AND WATER QUALITY

The MEP report provides the following characterization of the estuary's health:

- **OVERALL ECOLOGIC CONDITION:** Moderately Impaired to Severely Degraded
- **PRINCES COVE:** Significantly Impaired to Severely Degraded
- **WARRENS COVE:** Severely Degraded
- **UPPER NORTH BAY:** Significantly Impaired to Severely Degraded
- **LOWER NORTH BAY:** Moderately to Significantly Impaired
- **COTUIT BAY:** Moderately Impaired
- **WEST BAY:** Moderately Impaired
- **EEL POND:** Moderately to Significantly Impaired
- **SENTINEL STATION:**
  - Total Nitrogen Concentration Threshold: 0.38 mg/L
  - Total Nitrogen Concentration Existing: 0.5 mg/L (As reported at the MEP sentinel water-quality monitoring station)





0.1% - 9%
9.1% - 38%
38.1% - 62%
62.1% - 86%
86.1% - 100%

Subwatersheds with
Total Attenuated Watershed Removal Targets

(Left) Benthic and atmospheric loads directly on embayments are not included.

Subwatersheds with
Septic Attenuated Nitrogen Removal Targets

(Right)

Traditional & Non-Traditional Scenarios

SCENARIO DEVELOPMENT

Through the 208 Stakeholder process, the Commission developed "bookend" scenarios – one looking at a possible solution using traditional collection and treatment, the other examining a possible suite of non-traditional technologies – to address the nitrogen management needs in each watershed. These bookend scenarios provide guidance for communities as they continue to discuss alternatives, priorities, and opportunities for identifying well-considered solutions that will address communities' needs and interests.

REGIONAL DATA

In preparation for this effort, the Commission collected regionally consistent data for the purposes of watershed scenario development. Both parcel data and water use data was identified and collected for the entire region. While the scientific basis for planning is the thresholds identified in the MEP technical reports, each report uses data from different years, and in some cases the MEP data used are 10 or more years old. In addition, there are watersheds on Cape Cod without the benefit of an MEP report; therefore, similar data was not available for planning purposes.

The updated regional data set was used to estimate wastewater, stormwater and fertilizer loads, using the same methodologies as the MEP. This approach allows for a reevaluation of existing development, which may have changed in the last 10 years. Parcel data included in the regional database is from 2010-2012 and water use data is from 2008-2011, depending on the water supplier and based on best available data. This approach allows for regionally consistent watershed scenario development.

WATERSHED SCENARIOS

The watershed scenarios that follow outline possibilities for the watershed. A series of non-traditional technologies that might be applicable are included, as well as the amount of residential load that would need to be collected if a traditional collection system and treatment facility was implemented. The pie charts show the load to be collected for treated effluent disposal both inside and outside the watershed.

Site specific analyses of collection areas may result in the need to collect wastewater from more or fewer parcels to meet the nitrogen reduction target. The scenarios presented are conceptual and are meant to inform discussions regarding effective and efficient solutions; they are not specific recommendations and should be viewed as resource information for additional and more detailed wastewater management planning.

In Three Bays, the Towns of Barnstable and Sandwich have done additional and more detailed planning. Included in the last section of this report is a description of their efforts, along with details of plans developed to date.

TOTAL ATTENUATED WATERSHED NITROGEN LOAD VALUES (FROM WMVP)

Three Bays Nitrogen Sources	Total Attenuated Watershed Nitrogen Load (kg-N/yr)
Wastewater[1]	34,376
Fertilizer[2]	5,070
Stormwater	4,361
Other[3]	2,414
TOTAL WATERSHED LOAD	46,221
Total Watershed Threshold	25,643
TOTAL ATTENUATED LOAD TO BE REMOVED	20,578

1. Includes nitrogen loads from septic systems and wastewater treatment facilities.
2. Includes nitrogen loads from lawns, cranberry bogs, and golf courses.
3. Includes nitrogen loads from landfills and atmospheric deposition to vacant land.

Traditional & Non-Traditional Scenarios

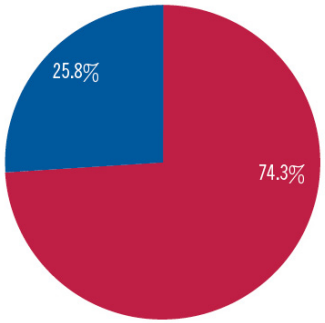
Non-Traditional

UNIT OF APPLIED TECHNOLOGY	ATTENUATED NITROGEN REMOVED IN KG/Y
25 % Nitrogen Reduction - Fertilizer Management	1,268
25 % Nitrogen Reduction - Stormwater Mitigation	1,090
3,000 Linear Feet - Permeable Reactive Barrier (PRB) (Capture load calculated by wMVP: 3,907.6 kg/Y)	2,833
225 Acres - Fertigation - Turf	660
66,000 Cubic Yards - Dredging/Inlet Widening	1,590
41 Acres - Aquaculture/Oyster Beds	10,200
4,700 Square Feet - Floating Constructed Wetlands	1,472
269 Units - Ecotoilets (UD & Compost)	684
336 People Per Year - UD School or Public Facility	157
TOTAL	**19,954**

A summary of the approach and methodology that was applied using non-traditional technologies follows at the end of this report.

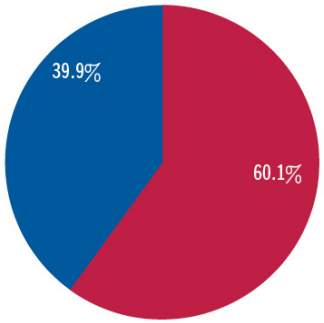
Traditional

CENTRALIZED TREATMENT WITH DISPOSAL INSIDE THE WATERSHED

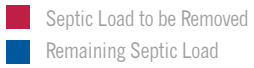


Assumes load to be collected and treated is disposed in the watershed, requiring additional collection to offset the load.

CENTRALIZED TREATMENT WITH DISPOSAL OUTSIDE THE WATERSHED



Assumes that the load to be collected and treated is removed from the watershed so no offset is required.



Town of Barnstable Local Progress

The Cape Cod Commission and the Town of Barnstable met and discussed the use of WatershedMVP to evaluate targeted watershed approaches for each of the watersheds in which they have jurisdiction. In 2015, the town reformulated its Citizen's Advisory Committee (CAC) for wastewater planning to better address local needs. In addition to local participation, the newly formed committee (the Water Resources Advisory Committee or WRAC) includes state and regional representatives. Town staff provided modifications to Commission-developed watershed scenarios and presented those scenarios to their WRAC for review and discussion. Those scenarios are included in this report.

Barnstable is also working closely with Mashpee and Sandwich on a watershed permit for the Popponesset Bay watershed.

The Town of Barnstable operates the Hyannis Water Pollution Control Facility (WPCF), located off Bearses Way in Hyannis, which is the primary wastewater treatment facility serving approximately 2,900 properties in Hyannis and Barnstable village. The treatment facility has been upgraded and permitted to treat additional flows up to a total of 4.2 million gallons per day (MGD), upon meeting requirements of an adaptive management plan approved by the Commission in 2007. Property along Route 132 was acquired by the town in 2002 to potentially accommodate future disposal needs. The site is approved under a 2006 Massachusetts Environmental Policy Act (MEPA) certificate to discharge up to 0.5 MGD. The site is not presently in use. However, a force main and sewer has been extended to the site from the WPCF.

The WPCF treats an average daily flow of 1.46 MGD and a maximum monthly average flow of 1.94 MGD. Treatment performance has averaged 5 milligrams per liter (mg/L) total nitrogen in the treated effluent and the facility has a discharge limit of 5 mg/L under the 2007 Development of Regional Impact (DRI) decision and a limit of 10 mg/L under a Groundwater Discharge Permit (GWDP). The facility is also equipped with sludge thickening, storage and dewatering facilities sized for the current process conditions.

The Town of Barnstable also operates two smaller facilities – the Marstons Mills Wastewater Treatment Facility (WWTF) and the Red Lily Pond Cluster System. The Marstons Mills WWTF is limited to a discharge flow of 42,900 gallons per day (GPD) and is intended to service the Barnstable United Elementary School and the Village at Marstons Mills affordable housing development. The Red Lily Pond Cluster System currently serves 17 homes. According to the comprehensive wastewater management plan (CWMP) approved in 2007, no performance sampling of the system occurs and the system is assumed to produce comparable effluent to any conventional single family septic system.

In addition to municipally-owned facilities, there are two privately-owned treatment facilities treating wastewater from the Cotuit Landing shopping plaza and the Cape Regency nursing and rehabilitation facility. These facilities provide high levels of wastewater treatment. The treatment facility at Cotuit Landing was designed with additional treatment capacity beyond the expected needs of the shopping plaza for potential treatment of flows from neighboring properties.

Barnstable is working on a town-wide nutrient management plan that will provide the basis of its CWMP. The plan will address nitrogen and other needs in watersheds draining to Three Bays, Centerville River, and Lewis Bay. A nitrogen total maximum daily load (TMDL) for Barnstable Harbor has not been approved by US EPA. The MEPA certificate scope for the Final Environmental Impact Report (FEIR) includes engagement in a targeted watershed approach, consistent with the 208 Plan Update.

In the fall of 2014, Barnstable adopted local nitrogen-oriented fertilizer management regulations consistent with the Cape-wide Fertilizer Management District of Critical Planning Concern (DCPC).

In 2015, the Town submitted a Statement of Interest to the US EPA for a hydrogeologic site characterization as an initial step toward piloting a permeable reactive barrier in the town. One of three sites proposed by the Town was selected for characterization. The work was completed in 2016. The draft report is presently being reviewed by the Town.

Throughout 2015 and 2016, Three Bays Preservation, Inc, worked with the Commission and town staff to develop conceptual plans for priority non-traditional projects within the Three Bays watershed. Detailed assessments of five priority projects were completed and designs were developed. The project sough to identify pilot projects where technologies could be implemented on a small scale and monitored to determine their effectiveness.

Town of Barnstable Watershed Scenario Details

Three Bays	CREDITS		REDUCTION TECHNOLOGIES			REMEDIATION AND RESTORATION TECHNOLOGIES			REMOVAL
NAME OF TECHNOLOGY	% Nitrogen Reduction	Load Reduction (kg-N/yr)	# Properties / Units	Flow Collected (gpd)	Load Reduction (kg-N/yr)	# Units Proposed	Unit Metric	Load Reduction (kg-N/yr)	Total Scenario Load Reduction (kg-N/yr)
Traditional Scenario									19,700
Centralized Sewer - Outside Disposal			3,930	710,000	19,700				
Non-Traditional Scenario									19,043
Fertilizer Management	25%	498							
Stormwater Mitigation	25%	1,008							
Permeable Reactive Barrier (PRB)						3,000	Linear Feet	2,833	
Fertigation - Golf Course						188	Acres	600	
Aquaculture/Oyster Beds						43	Acres	10,200	
Coastal Habitat Restoration						66,000	Cubic Yards	1,590	
Floating Constructed Wetlands						4,700	Square Feet	1,472	
Ecotoilets (UD & Compost)			113	Units	684				
UD School or Public Facility			69	People Per Year	157				

In June 2016, Barnstable received $28,850 from the Commission to fund upgrades to three stormwater treatment BMPs. Funding was part of $142,149 in local grants made available to communities by the Commission in support of 208 Plan implementation.

Town of Sandwich Local Progress

The Town of Sandwich has an established water quality committee to oversee water quality and wastewater planning efforts. In October 2015 town staff and their consultant (Wright-Pierce) met with Cape Cod Commission staff to discuss watershed planning, decision support tools, and scenario development for Sandwich watersheds. In the same month the town was approached by Mashpee regarding approaches for Popponesset Bay, and a potential watershed permit, and has agreed to participate with Mashpee and Barnstable in this shared effort. It is expected that Barnstable, Mashpee, and Sandwich will collaborate on the first watershed permit in the region in close coordination with the Cape Cod Commission and the Massachusetts Department of Environmental Protection.

Previously the committee developed a scope of work for a Comprehensive Wastewater Management Plan (CWMP) and submitted the scope under the Sagamore Lens Natural Resource Damages Assessment, related to past groundwater contamination at the Textron facility at Joint Base Cape Cod (JBCC). The town received an award of $400,000 t0 conduct its water/wastewater plan and completed a comprehensive needs assessment, as well as an interim wastewater solutions plan to accommodate economic development in the South Sandwich Village Center.

The town spent several years working with a private developer on a development project that included a public-private wastewater component for the construction of a facility that would accommodate the private project, in addition to some public wastewater needs. That project will not be completed, but the town is again seeking a private partner to create new economic growth and to potentially participate in infrastructure development.

The town has participated in discussions at JBCC about the potential use of its existing wastewater infrastructure as a regional option for the Upper Cape towns.

In February 2016 the Town of Sandwich requested a meeting with Commission staff to discuss watershed scenarios and potential modifications to watersheds in which Sandwich has jurisdiction. The town provided collection footprints and assumptions for a single treatment facility to serve all three watersheds (Popponesset Bay, Three Bays, and Waquoit Bay), consistent with the Sandwich CWMP, and identified locations for non-traditional approaches, in addition to credits for stormwater and fertilizer reduction. The Town proposes a 25% fertilizer management credit and a 6.25% stormwater management credit. While the proposed interventions, alone, do not meet the nitrogen allocations identified in Appendix 8C of the 208 Plan Update, the town has expressed a preference to rely on nutrient trading or cost sharing to reduce the load allocated to the downgradient towns in the shared watersheds of Popponesset Bay, Three Bays and Waquoit Bay, where nitrogen reductions can be more cost effectively attained.

Town of Sandwich Watershed Scenario Details

Three Bays	CREDITS		REDUCTION TECHNOLOGIES			REMEDIATION AND RESTORATION TECHNOLOGIES			REMOVAL
NAME OF TECHNOLOGY	% Nitrogen Reduction	Load Reduction (kg-N/yr)	# Properties / Units	Flow Collected (gpd)	Load Reduction (kg-N/yr)	# Units Proposed	Unit Metric	Load Reduction (kg-N/yr)	Total Scenario Load Reduction (kg-N/yr)
Traditional Scenario									1,170
Centralized Sewer - Outside Disposal			780	162,623	1,170				
Non-Traditional Scenario*									410
Fertilizer Management	25%	35							
Stormwater Mitigation	6.25%	16							
Fertigation - Turf						75	Acres	118	
Golf Course Fertilizer Reduction						5,991	Pounds**	241	

NOTES:

* The Town of Sandwich will rely on nutrient trading as an additional measure to meet the TMDL, if necessary.

** Golf course fertilizer use was reduced by a total of 5,991 lbs/year (unattenuated), the corresponding nitrogen reduction is 241 kg/year (attenuated).

Scenario Maps

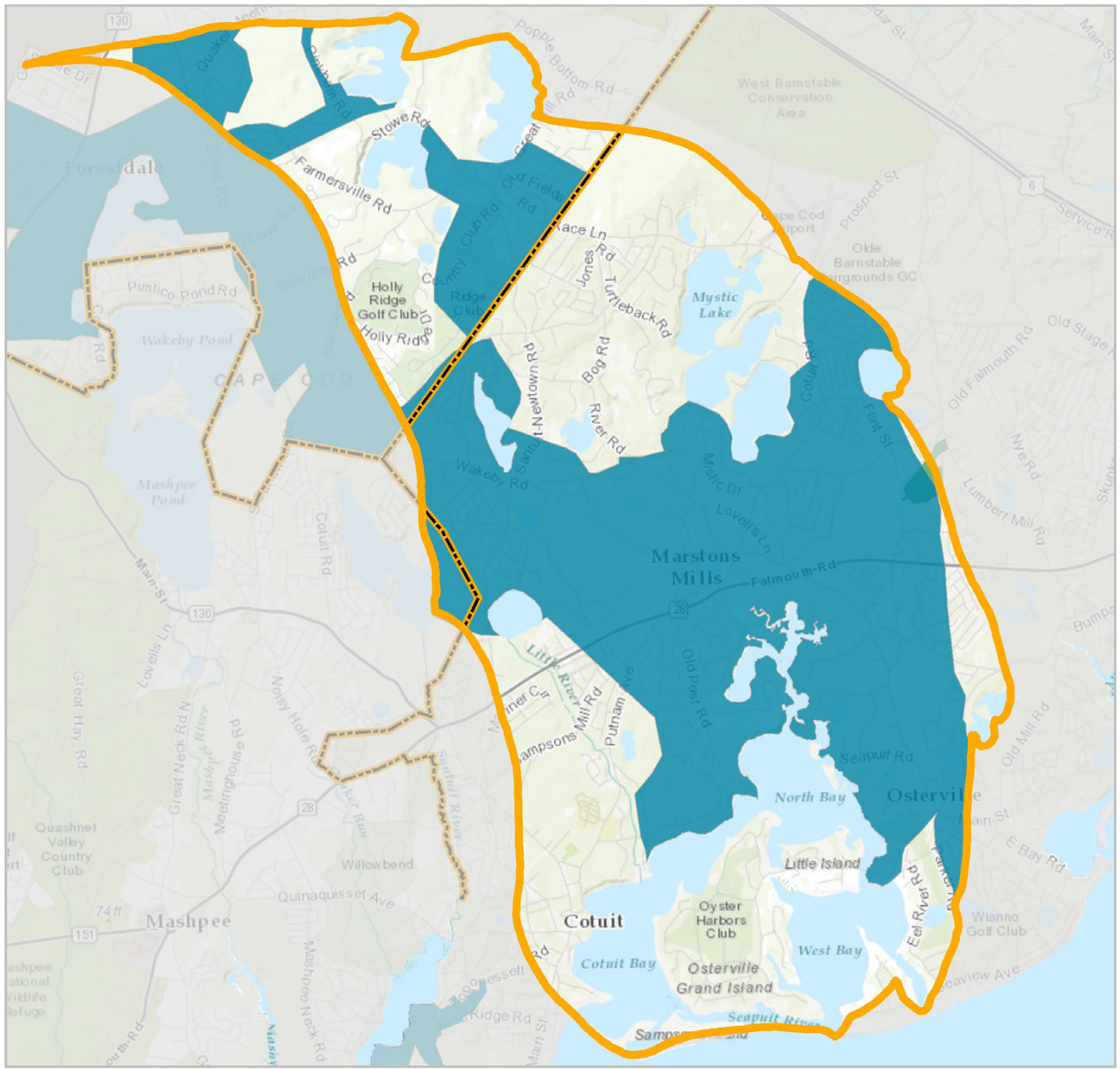
Three Bays Watershed
Traditional Scenario

BARNSTABLE & SANDWICH

Representative locations of conceptually proposed infrastructure

Legend

- Town Lines
- Sewered Areas
- Embayment Watersheds
- Proposed Sewershed



Scenario Maps

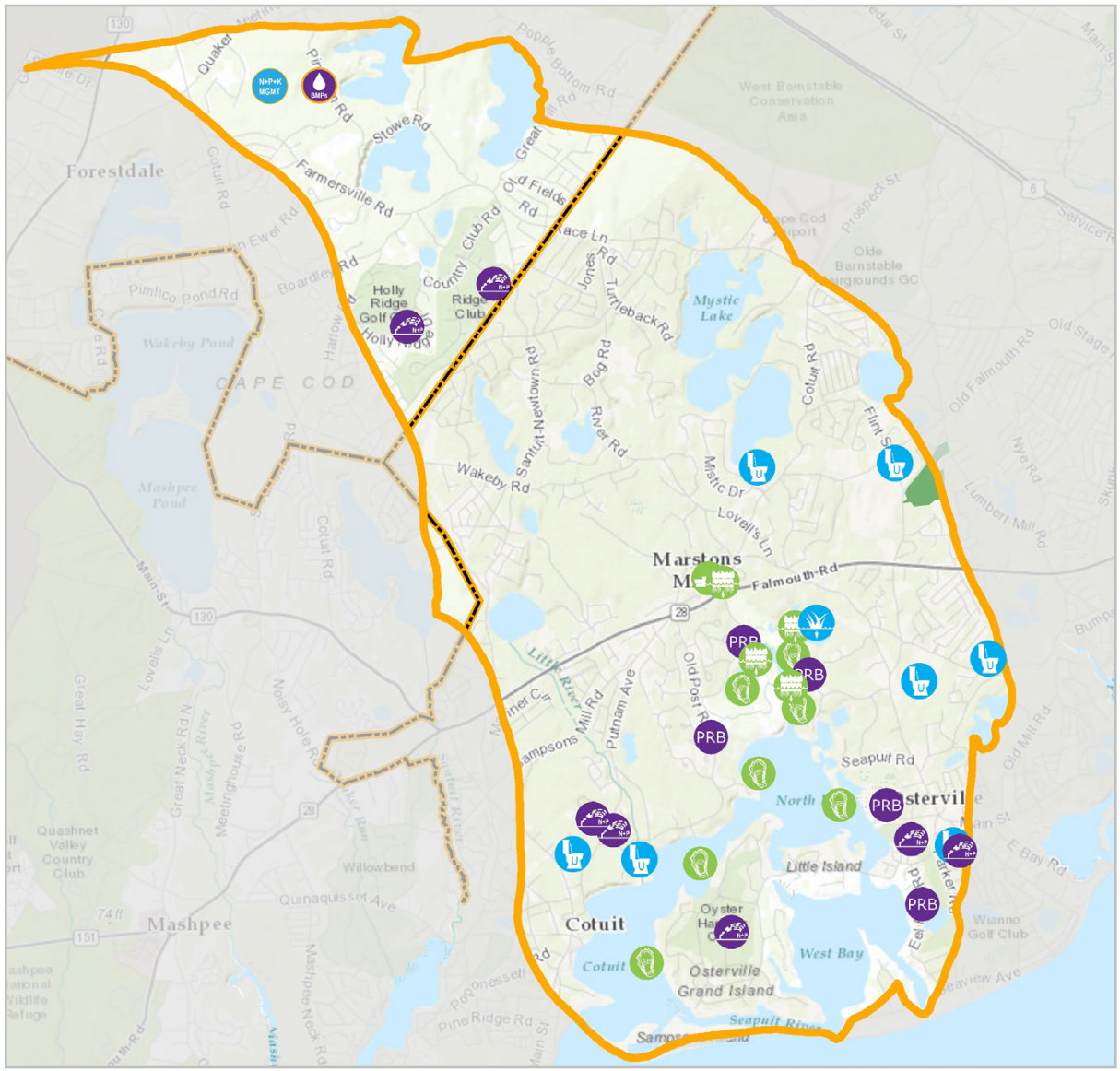
Three Bays Watershed
Non-Traditional Scenario

BARNSTABLE & SANDWICH

Representative locations of conceptually proposed infrastructure

Legend

- Dredging
- Fertilizer Management
- Stormwater Management
- Eco-Toilets
- Fertigation
- Floating Constructed Wetlands
- Constructed Wetland
- Permeable Reactive Barrier
- Aquaculture
- Town Lines
- Embayment Watersheds
- Sewered Areas



Methodology for Selecting Non-Traditional Technology Scenarios

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology were derived from the Technologies Matrix. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology are noted below, based on the Technologies Matrix or newer data. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

Regional credits were developed for potential stormwater retrofits and fertilizer reductions. They were calculated as a percent reduction of existing nitrogen loads as identified in the MEP reports and updated GIS data developed by the Cape Cod Commission.

- **STORMWATER MANAGEMENT:** Most Cape communities have already begun the process of identifying significant untreated stormwater discharges and developing appropriate mitigation projects. With the prospect of the MS4 regulatory requirements it was assumed that additional mitigation efforts would be implemented. Based upon the evidence developed by the University of New Hampshire Stormwater Center that several vegetated stormwater management practices (including bioretention and constructed wetlands) are able to achieve nitrogen reductions of 50% or more and the assumption that only a portion (estimated at 50%) of identified sites would be retrofitted a 25% nitrogen reduction credit was assumed for each watershed. Specific locations and number of locations were not identified; this was deferred to individual towns to consider as part of the suite of nitrogen management strategies.
- **FERTILIZER REDUCTIONS:** Based upon the success of most Cape Cod towns to implement either regulatory or non-regulatory fertilizer management programs and the efforts of the Cape Cod Extension Service in educating homeowners a 25% reduction in fertilizer applications was assumed for each watershed.

Regional GIS screening methods were developed to identify locations for some non-traditional technologies. A GIS viewer was developed as an on-line tool for staff and consultants to utilize during the watershed planning process.

- **CONSTRUCTED WETLANDS/ PHYTOREMEDIATION:** A GIS-based screening method was developed by the Cape Cod Commission to identify and rank parcels of land that have potential for the location of constructed wetlands and phytoremediation. The ranking utilized parcel size and ownership, depth to groundwater, suitable soils, distance from wetlands, and undeveloped parcels. A nitrogen removal rate of 500 kg/Y/acre and 532 kg/Y/acre was used for Constructed Wetlands and Phytoremediation, respectively.
- **PERMEABLE REACTIVE BARRIERS (PRBS):** A GIS-based screening method was developed to identify existing roads that are proximate to receiving waters, downgradient of high density development, run perpendicular to groundwater flow (to have the highest potential to intercept nutrients in groundwater), and where the depth to groundwater is relatively shallow to maximize the area of saturated thickness treated in the aquifer.

Methodology for Selecting Non-Traditional Technology Scenarios

- **FERTIGATION WELLS:** Golf courses were mapped to identify areas where fertigation wells could be utilized to recapture nitrogen-enriched groundwater and re-apply it to the managed turf areas to serve both irrigation and fertilization needs. Most golf courses were assumed to be eighteen holes with a fertilized area of 75 acres. Fertigation water was assumed to have an average concentration of 5 mg/liter. An uptake/attenuation rate of 80% was applied resulting in an assumed nitrogen reduction of 300 kg/year for each golf course with effectively located fertigation wells. In some cases other irrigated areas (such as athletic fields and cemeteries) were identified as potential fertigation locations. A nitrogen removal rate of 4 kg/Y/acre was used.

The MVP tool and other site-specific tools were utilized to quantify nitrogen load reductions for several potential NT interventions.

- **PERMEABLE REACTIVE BARRIERS:** for each PRB that was identified during the prior GIS-screening process an approximate capture area was identified using available water table maps and the wMVP tool. Upgradient contributing areas were digitized within wMVP and the nitrogen load was calculated. A nitrogen reduction of 72.5% was applied (calculated as an average of the reported attenuation range from the Technologies Matrix).
- **CONSTRUCTED WETLANDS (WITH COLLECTION):** Constructed wetlands were considered as a tertiary, polishing treatment for existing wastewater treatment plants. This included small-scale wastewater treatment systems. A nitrogen removal rate of 500 kg/Y/acre was used.
- **AQUACULTURE/OYSTER REEFS:** Potential areas for aquaculture and/or oyster reef restoration were considered based upon discussions with town representatives and review of maps to identify potential areas for these operations without significant conflicts to navigation. In some cases actual recent aquaculture expansions were included where they were developed after the MEP reports were prepared. An assumption of 1 million oysters per acre was used with a nitrogen removal rate of 250 kg/Y/acres.
- **FLOATING CONSTRUCTED WETLANDS:** Potential areas for floating wetlands were considered in areas where no conflicts with navigation or swimming areas were identified. A nitrogen removal rate of 0.4 kg/Y/sq foot was used.
- **INLET WIDENING AND COASTAL HABITAT RESTORATION:** Only considered in areas where these projects were identified by towns or state agencies and where detailed hydrologic investigations and modeling had been performed due to wide variations in nitrate load reduction, flushing impacts, impacts on flooding, and costs (dredging only, replacing infrastructure, removing and replacing roadways or bridges, etc.). Nitrogen removal rates were based on MEP or other studies.
- **INNOVATIVE & ALTERNATIVE SEPTIC SYSTEMS AND ECOTOILETS:** In most cases specific locations for these technologies were not identified. Rather general estimates for the percent adoption were provided based upon discussions with the stakeholder groups and their views on potential adoption rates. In some watersheds a 5% adoption rate was included based upon this stakeholder input. In a limited number of instances specific locations for these technologies were included based upon town input and suggestions. A nitrogen removal rate of 1.658 kg/Y for each system was used for I&A Septic Systems, and 2.984 kg/Y for enhanced I&A systems. A removal rate of 2.542 kg/Y was used for each home installation of an Ecotoilet, and 0.467 kg/Y for installation of urine diversion toilets in public settings.

Finally, the locations of specific technologies were discussed during the 208 stakeholder engagement process. Stakeholders across the Cape 'groundtruthed' potential NT locations and NT scenarios were adjusted accordingly.

Appendix F

CCC Popponesset Bay Watershed Report

WATERSHED REPORT: UPPER CAPE

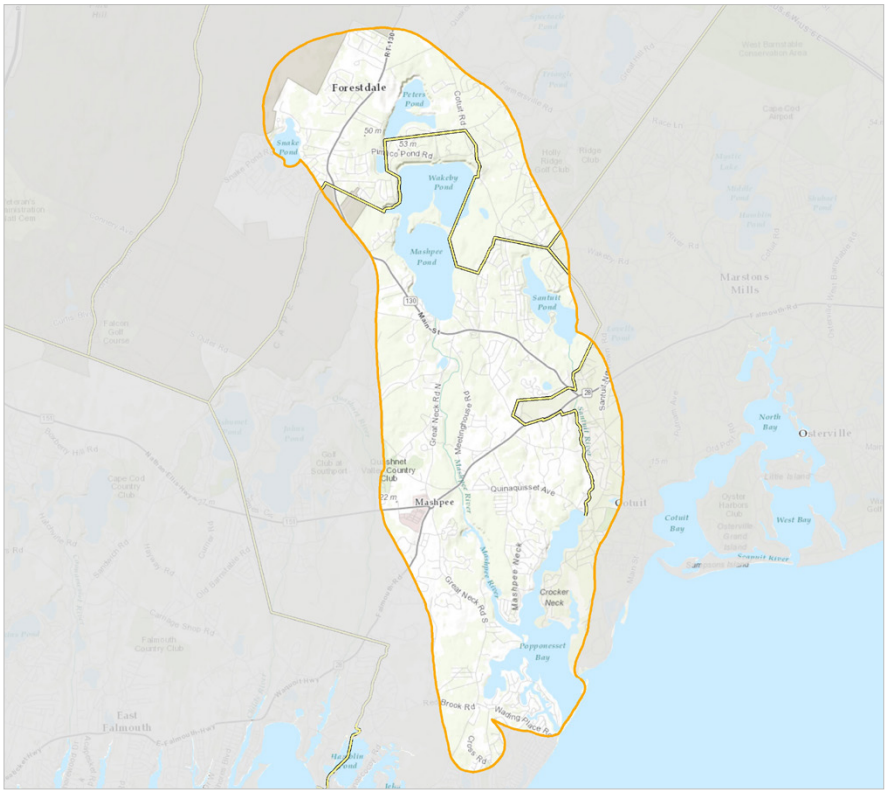
Popponesset Bay

MASHPEE, BARNSTABLE & SANDWICH



WATER THREAT LEVEL

HIGH



Popponesset Bay Watershed

Introduction to the Watershed Reports

In 2001, the Massachusetts Estuaries Project (MEP) was established to evaluate the health of 89 coastal embayment ecosystems across southeastern Massachusetts. A collaboration between coastal communities, the Massachusetts Department of Environmental Protection (MassDEP), the School of Marine Science and Technology (SMAST) at the University of Massachusetts-Dartmouth, the US Environmental Protection Agency (US EPA), the United States Geological Survey (USGS), the Massachusetts Executive Office of Energy and Environmental Affairs (EEA), and the Cape Cod Commission, the purpose of the MEP is to identify nitrogen thresholds and necessary nutrient reductions to support healthy ecosystems.

The Cape Cod 208 Plan Update, certified and approved by the Governor of the Commonwealth of Massachusetts and the US EPA in 2015, provides an opportunity and a path forward to implement responsible plans for the restoration of the waters that define Cape Cod.

On Cape Cod there are 53 embayment watersheds with physical characteristics that make them susceptible to nitrogen impacts. In its 2003 report, "The Massachusetts Estuaries Project – Embayment Restoration and Guidance for Implementation Strategies", MassDEP identifies the 46 Cape Cod embayments included in the

MEP. Thirty-three embayments studied to date require nitrogen reduction to achieve healthy ecosystem function. A Total Maximum Daily Load (TMDL) has been established (or a draft load has been identified and is under review) for these watersheds. For those embayments not studied, the 208 Plan Update recommends planning for a 25% reduction in nitrogen, as a placeholder, until information becomes available.

The 208 Plan Update directs Waste Treatment Management Agencies (WMAs) to develop watershed reports within 12 months of certification of the Plan Update. The Watershed Reports outline potential "bookend" scenarios for each watershed that include two scenarios to meet water quality goals in the watershed – a traditional scenario, which relies completely on the typical collection and centralized treatment of wastewater, and a non-traditional scenario, which uses remediation, restoration, and on-site reduction techniques to remove nutrients from raw and treated wastewater, groundwater and affected waterbodies.

The intent of the Watershed Reports is to outline two distinct approaches for addressing the nutrient problem. The reports are not intended to identify preferred and detailed plans for each watershed, but to facilitate discussions regarding effective and efficient solutions, particularly in watersheds shared by more than one town. In some cases, towns have provided information on collection areas and non-traditional technologies that have been specifically considered by that town.

The 208 Update developed a regionally consistent database of the nitrogen load entering each watershed. This data set includes estimates of wastewater, stormwater and fertilizer loads - similar to methodologies used by the MEP. Using this regionally consistent database, the Watershed MVP tool (wMVP) was developed so that different strategies (i.e., bookend scenarios) to reduce excess nitrogen load could be evaluated. The Watershed Reports use the MEP recommendations for the required nitrogen load reductions necessary to meet the threshold loads (that serve as the basis for nitrogen management), and then use the wMVP and the regionally consistent database values to develop bookend scenarios. There are variations of load between the MEP and wMVP, primarily due to differences in comparing older and newer databases.

Terms Defined

Total nitrogen load: the nitrogen load from the watershed contributed by septic, wastewater, fertilizer, stormwater, golf course, landfill, and natural sources.

Attenuated nitrogen load: the nitrogen load from the watershed that reaches the embayment after the effect of natural attenuation in wetlands, ponds or streams.

Threshold: the amount of nitrogen that a water body can receive from its watershed and still meet water quality goals; this number is based on MEP technical reports or Total Maximum Daily Load (TMDL) reports.

Reduction target: an approximation of the amount of nitrogen that needs to be removed from the watershed to achieve the threshold; this number is calculated by subtracting the threshold number from the attenuated total watershed load, and is for planning purposes only.

Percent contribution: the percent of attenuated nitrogen load that a town contributes to the watershed.

Kilogram responsibility: is calculated by applying the percent contribution to the reduction target and indicates the amount of nitrogen, in kg, that a community is responsible for addressing.

Total Maximum Daily Load: a regulatory term in the Clean Water Act, describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. Establishing a TMDL is necessary when a water body has been listed on the 303D list of impaired waters.

WATERSHED REPORT: UPPER CAPE

Popponesset Bay

MASHPEE, BARNSTABLE & SANDWICH



WATER THREAT LEVEL

HIGH

The Popponesset Bay estuary is located in the Towns of Mashpee and Barnstable. It is a large shallow embayment that extends from Nantucket Sound nearly three miles to its groundwater fed headwaters. The embayment includes four distinct sub-systems - Shoestring Bay, the Mashpee River, Ockway Bay and Popponesset Creek. The estuary supports a variety of recreational uses including boating, swimming, shell fishing and fin fishing.

The Problem

The Massachusetts Estuaries Project (MEP) technical report (available at http://www.mass.gov/eea/agencies/massdep/water/watersheds/the-massachusetts-estuaries-project-and-reports.html) indicates the Popponesset Bay system exceeds its critical threshold for nitrogen, resulting in impaired water quality. Popponesset Bay is one of the first to have received a MEP technical report. A MEP technical report has been completed and a Total Maximum Daily Load (TMDL) for nitrogen has been developed and approved.

- **MEP TECHNICAL REPORT STATUS:** Final
- **TMDL STATUS:** Final TMDL

Watershed nitrogen load characteristics were published in the 2004 MEP report, reflecting current conditions at the time of writing:

- **TOTAL ATTENUATED NITROGEN LOAD (MEP CHAPTER VIII):** 28,813 kg/Y
- **SOURCES OF ATTENUATED WATERSHED NITROGEN LOAD:**
  - 82% Septic Systems
  - 10% Fertilizer
  - 7% Stormwater From Impervious Surfaces
  - 1% Wastewater Treatment Facilities

Since the MEP report, the Commission compiled the following updated water use and nitrogen loads using the regional wMVP database, enabling a more current estimate of nitrogen loading (see figure on page 1 for watershed boundary delineation):

- **TOTAL WASTEWATER FLOW:** 456 MGY (million gal per year)
  - Treated Wastewater Flow: 61 MGY
  - Septic Flow: 395 MGY
- **TOTAL ATTENUATED NITROGEN LOAD (WMVP):** 31,961 kg/Y

CONTRIBUTING TOWNS

Percent contributions listed below are the aggregate sub-embayment contributions identified in Appendix 8C of the Cape Cod Section 208 Plan Update (contributions are based on attenuated load where available). See Appendix 8C for detailed town allocations by sub-embayment.

A portion of the land area in Sandwich and Mashpee is not in the control of the towns as it is part of Joint Base Cape Cod (JBCC), which is served by a wastewater treatment facility and discharged outside of the watershed.

- **MASHPEE:** 75%
- **BARNSTABLE:** 17%
- **SANDWICH:** 8%

The Towns of Barnstable, Mashpee, and Sandwich are currently working through the development of an Inter-Municipal Agreement (IMA) and draft watershed permit, and have developed updated percent contributions based on those efforts (Mashpee - 75%, Barnstable - 16%, Sandwich - 9%). The percentages agreed upon in the IMA will be the basis for the coordinated efforts of the three communities to address nitrogen impacts on Popponesset Bay.

THE MEP RESTORATION SCENARIO

- **WATERSHED TOTAL ATTENUATED NITROGEN REDUCTION TARGET:** 45%
- **WATERSHED SEPTIC REDUCTION TARGET:** 61%
  (The scenario represents the aggregated sub-embayment percent removal targets from the MEP technical report)

POPPONESSET BAY ESTUARY

- **EMBAYMENT AREA:** 720 acres
- **EMBAYMENT VOLUME:** 119 million cubic feet
- **2014 INTEGRATED LIST STATUS:** Category 4a for estuarine bioassessments and fecal coliform
  - Category 4a: TMDL is complete
  - www.mass.gov/eea/docs/dep/water/resources/07v5/14list2.pdf

POPPONESSET BAY WATERSHED

General watershed characteristics according to the current wMVP regional database (see figure on page 1 for watershed boundary) follow.

- **WATERSHED CHARACTERISTICS**
  - Acres: 13,082
  - Parcels: 7,979
  - % Developed Residential Parcels: 78%
  - Parcel Density: 1.6 acres per parcel (approx.)

Freshwater Sources

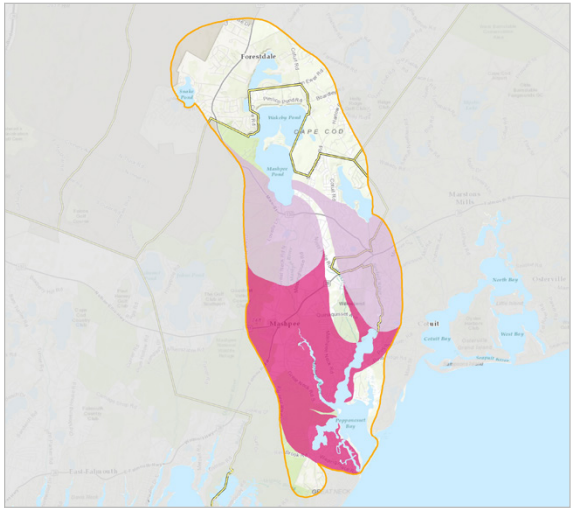
PONDS

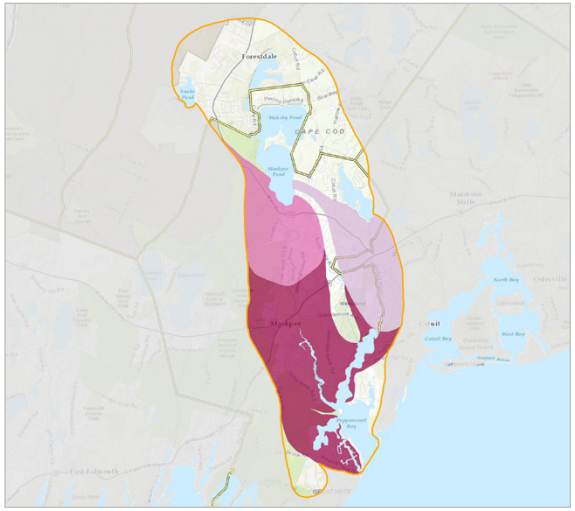
- **IDENTIFIED SURFACE WATERS:** 40
- **NUMBER OF NAMED FRESHWATER PONDS:** 13
- **PONDS WITH PRELIMINARY TROPHIC CHARACTERIZATION:** 5
- **2014 INTEGRATED LIST STATUS:** 4 listed

Mashpee recently conducted a pond assessment and installed Solar Bees in Santuit Pond in efforts to restore water quality. Mashpee and Barnstable have participated in the Pond and Lake Stewardship (PALS) program that has helped establish baseline water quality.

STREAMS

- **SIGNIFICANT FRESHWATER STREAM OUTLETS:** 2





0.1% - 9%
9.1% - 38%
38.1% - 62%
62.1% - 86%
86.1% - 100%

Subwatersheds with
Total Attenuated Watershed Removal Targets

(Left) Benthic and atmospheric loads directly on embayments are not included.

Subwatersheds with
Septic Attenuated Nitrogen Removal Targets

(Right)

Mashpee River:
- Average Flow: 26,223 cubic meters per day (m3/d)
- Average Nitrate Concentrations: .318 milligrams per liter (mg/L)

Santuit River:
- Average Flow: 13,164 m3/d
- Average Nitrate Concentrations: 0.702 mg/L

Stream data from MEP technical report. Nitrate concentrations higher than 0.05 mg/L background concentrations, evident in public supply wells located in pristine areas, provide evidence of the impact of non-point source pollution on the aquifer and receiving coastal water bodies.

DRINKING WATER SOURCES

- **WATER DISTRICTS:** 3
  - Sandwich Water District
  - Cotuit Water District
  - Mashpee Water District
- **GRAVEL PACKED WELLS:** 9
  - 2 have nitrate concentrations between 0 and 0.5 mg/L
  - 1 have nitrate concentrations between 0.5 and 1 mg/L
  - 3 have nitrate concentrations between 1 and 2.5 mg/L
  - 1 have nitrate concentrations between 2.5 and 5 mg/L
  - 2 have no nitrate concentration data
- **SMALL VOLUME WELLS:** 2

Drinking water data from Cape Cod Commission and MassDEP data sources – nitrate values obtained from drinking water wells are from 2009-2012. The state and federal drinking water limit for nitrate is 10 mg/L. The Cape Cod Commission nitrate loading standard is 5 mg/l.

The MEP report includes contributing areas to the Rock Landing community water supply wells in its watershed map. These wells are located outside the Popponesset Bay watershed.

Degree of Impairment and Areas of Need

For the purposes of the Section 208 Plan Update areas of need are primarily defined by the amount of nitrogen reduction required as defined by the TMDL and/or MEP technical report. These were referred to above as a 61% reduction in septic nitrogen and a 45% reduction in total nitrogen. More specifically, the MEP provides a targeted amount of nitrogen reduction required by subwatershed, as shown in the figures Subwatersheds with Total Attenuated Watershed Removal Targets and Subwatersheds with Septic Attenuated Nitrogen Removal Targets.

The nitrogen load from the watershed exceeds the threshold or TMDL for Popponesset Bay, resulting in impaired water quality. The ecological health of a water body is determined from water quality, extent of eelgrass, assortment of benthic fauna, and dissolved oxygen and ranges from severe degradation, significantly impaired, moderately impaired, or healthy habitat conditions

MEP ECOLOGICAL CHARACTERISTICS AND WATER QUALITY

The MEP report provides the following characterization of the estuary's health:

- **OVERALL ECOLOGIC CONDITION:** Healthy to Severely Degraded
- **LOWER POPPONESSET BAY:** Healthy to Moderately Impaired
- **OCKWAY BAY:** Significantly Impaired to Severely Degraded
- **MASHPEE RIVER:** significantly Impaired to Severely Degraded
- **SENTINEL STATION:**
  - Total Nitrogen Concentration Threshold: 0.38 mg/L
  - Total Nitrogen Concentration Existing: 0.45 mg/L (As reported at the MEP sentinel water-quality monitoring station)

Traditional & Non-Traditional Scenarios

SCENARIO DEVELOPMENT

Through the 208 Stakeholder process, the Commission developed "bookend" scenarios – one looking at a possible solution using traditional collection and treatment, the other examining a possible suite of non-traditional technologies – to address the nitrogen management needs in each watershed. These bookend scenarios provide guidance for communities as they continue to discuss alternatives, priorities, and opportunities for identifying well-considered solutions that will address communities' needs and interests.

REGIONAL DATA

In preparation for this effort, the Commission collected regionally consistent data for the purposes of watershed scenario development. Both parcel data and water use data was identified and collected for the entire region. While the scientific basis for planning is the thresholds identified in the MEP technical reports, each report uses data from different years, and in some cases the MEP data used are 10 or more years old. In addition, there are watersheds on Cape Cod without the benefit of an MEP report; therefore, similar data was not available for planning purposes.

The updated regional data set was used to estimate wastewater, stormwater and fertilizer loads, using the same methodologies as the MEP. This approach allows for a reevaluation of existing development, which may have changed in the last 10 years. Parcel data included in the regional database is from 2010-2012 and water use data is from 2008-2011, depending on the water supplier and based on best available data. This approach allows for regionally consistent watershed scenario development.

WATERSHED SCENARIOS

The watershed scenarios that follow outline possibilities for the watershed. A series of non-traditional technologies that might be applicable are included, as well as the amount of residential load that would need to be collected if a traditional collection system and treatment facility was implemented. The pie charts show the load to be collected for treated effluent disposal both inside and outside the watershed.

Site specific analyses of collection areas may result in the need to collect wastewater from more or fewer parcels to meet the nitrogen reduction target. The scenarios presented are conceptual and are meant to inform discussions regarding effective and efficient solutions; they are not specific recommendations and should be viewed as resource information for additional and more detailed wastewater management planning.

In Popponesset Bay, the Towns of Mashpee and Sandwich have done additional and more detailed planning. Included in the last section of this report is a description of their efforts, along with plan details. The Town of Mashpee scenario is based on their Final Recommended Plan and Final Environmental Impact Report established as part of their Watershed Nitrogen Management Planning efforts.

TOTAL ATTENUATED NITROGEN LOAD VALUES (FROM WMVP)

Popponesset Bay Nitrogen Sources	Total Attenuated Watershed Nitrogen Load (kg-N/yr)
Wastewater[1]	22,729
Fertilizer[2]	3,571
Stormwater	4,143
Other[3]	1,518
TOTAL WATERSHED LOAD	31,961
Total Watershed Threshold	13,852
TOTAL ATTENUATED LOAD TO BE REMOVED	18,109

1. Includes nitrogen loads from septic systems and wastewater treatment facilities.
2. Includes nitrogen loads from lawns, cranberry bogs, and golf courses.
3. Includes nitrogen loads from landfills and atmospheric deposition to vacant land.

Traditional & Non-Traditional Scenarios

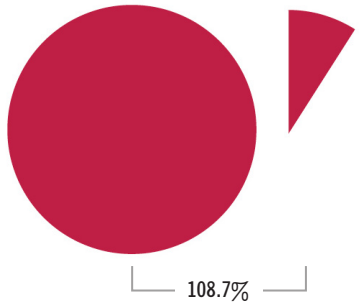
Non-Traditional

UNIT OF APPLIED TECHNOLOGY	ATTENUATED NITROGEN REMOVED IN KG/Y
25 % Nitrogen Reduction - Fertilizer Management	893
25 % Nitrogen Reduction - Stormwater Mitigation	1,036
4,000 Linear Feet - Permeable Reactive Barrier (PRB) (Capture load calculated by wMVP: 3,492.4 kg/Y)	2,532
233 Acres - Fertigation - Turf	653
35 Acres - Fertigation - Cranberry Bogs	425
27 Acres - Aquaculture/Oyster Beds	6,830
1,938 Square Feet - Floating Constructed Wetlands	775
784 Units - Ecotoilets (UD & Compost)	1,448
1,202 Units - I & A Systems	1,448
668 Units - Enhanced I & A Systems	1,448
TOTAL	**17,488**

A summary of the approach and methodology that was applied using non-traditional technologies follows at the end of this report.

Traditional

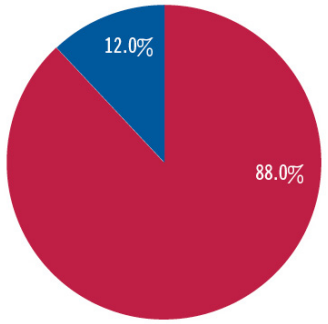
CENTRALIZED TREATMENT WITH DISPOSAL INSIDE THE WATERSHED



Assumes load to be collected and treated is disposed in the watershed, requiring additional collection to offset the load.

The watershed nitrogen threshold cannot be met by collecting 100% of the septic load in the watershed and returning the treated load to the watershed.

CENTRALIZED TREATMENT WITH DISPOSAL OUTSIDE THE WATERSHED



Assumes that the load to be collected and treated is removed from the watershed so no offset is required.

Town of Mashpee Local Progress

The Mashpee Comprehensive Wastewater Management Plan (CWMP) was scoped through a joint Massachusetts Environmental Policy Act (MEPA)/Development of Regional Impact (DRI) review as an Environmental Notification Form (ENF) in 2001. In 2007, the town submitted its Needs Assessment Report entitled, "Town of Mashpee, Popponesset Bay and Waquoit Bay-East Watersheds Needs Assessment Report." Also in 2007, the town completed a technology screening report, which was followed shortly by its draft alternative scenarios and site evaluation report in March 2008.

The Needs Assessment contains a characterization of the nine operating private sewage treatment facilities, including treatment efficiency and excess capacity. This work allowed the town to focus on three potential wastewater scenarios that were developed in 2012. These options were reviewed and served as the basis for development of their preferred alternative. The wastewater scenarios include use of the existing private plants at their planned capacity and either three or four subregional plants with consideration of shared town responsibility. Off-site disposal of effluent outside of the impaired watersheds is an important consideration for the plan's approach. The alternatives analysis included consideration of private effluent disposal sites at New Seabury, Willowbend, and others, in addition to the town's transfer facility site.

The issuance of the final Alternatives Screening Analysis in August 2013 developed the framework of the draft and final plans and identified several alternative approaches to sewering, including shellfish aquaculture and permeable reactive barriers.

In April 2014, the Sewer Commission met with Cape Cod Commission staff to begin the discussion around filing its CWMP. The Recommended Plan includes a significant aquaculture undertaking and an adaptive management approach to achieving water quality goals.

In the fall of 2014, Mashpee adopted local nitrogen-oriented fertilizer management regulations consistent with the Cape-wide Fertilizer Management District of Critical Planning Concern (DCPC).

In September 2014, the Massachusetts Secretary of Energy and Environmental Affair issued a certificate of adequacy for the Draft Environmental Impact Review (DEIR) for Mashpee's Comprehensive Watershed Nitrogen Management Plan. In the Summer of 2015, the Massachusetts Secretary of Energy and Environmental Affair issued a final certificate Mashpee's Comprehensive Watershed Nitrogen Management Plan. The plan is currently under review by the Commission, although the Commission has already notified the town that phase I of its plan is consistent with the 208 Plan Update.

At the October 2015 Mashpee Town Meeting, the town voted to appropriate $250,000 for shellfish propagation, $32,500 as the first installment on a 3-year monitoring study associated with the shellfish project, funded a full time permanent water quality technician position, $100,000 to reauthorize the Sewer Commission Facilities Study Account and hire a consultant to complete studies and develop a preliminary design for the connection of properties to existing treatment facilities, $80,000 to support the development of inter-municipal agreements with neighboring communities, as well as authorized the use of town-owned land for the purposes of developing wastewater treatment facilities.

In October 2015, the town also approached Barnstable and Sandwich regarding approaches for Popponesset Bay and a potential watershed permit. It is expected that these three towns will collaborate on the first watershed permit in the region in close coordination with the Cape Cod Commission and the Massachusetts Department of Environmental Protection. To accommodate for discussions with Barnstable and Sandwich regarding the watershed permit a DRI extension through the fall has been agreed upon.

In June 2016, Mashpee received $14,600 from the Commission for construction of a floating shellfish seed upweller system to grow quahog seed for initial implementation of their shellfish restoration plan. Funding was part of $142,149 in local grants made by the Commission in support of 208 Plan implementation.

At the Spring 2017 Town Meeting, Mashpee voted to fund monitoring of shellfish aquaculture in Popponesset Bay and Waquoit Bay in the amount of $49,500. Amendments to the Town's nutrient control bylaw were also approved.

Town of Mashpee Watershed Scenario Details

Popponesset Bay	CREDITS		REDUCTION TECHNOLOGIES			REMEDIATION AND RESTORATION TECHNOLOGIES			REMOVAL
NAME OF TECHNOLOGY	% Nitrogen Reduction	Load Reduction (kg-N/yr)	# Properties / Units	Flow Collected (MGD)	Load Reduction (kg-N/yr)	# Units Proposed	Unit Metric	Load Reduction (kg-N/yr)	Total Scenario Load Reduction (kg-N/yr)
Scenario									10,940
Centralized Sewer			1,170	0.157	4,110				
Aquaculture/Oyster Beds						16.32 M	Shellfish	6,830	

Town of Barnstable Local Progress

The Cape Cod Commission and the Town of Barnstable met and discussed the use of WatershedMVP to evaluate targeted watershed approaches for each of the watersheds in which they have jurisdiction. In 2015, the town reformulated its Citizen's Advisory Committee (CAC) for wastewater planning to better address local needs. In addition to local participation, the newly formed committee (the Water Resources Advisory Committee or WRAC) includes state and regional representatives. Town staff provided modifications to Commission-developed watershed scenarios and presented those scenarios to their WRAC for review and discussion. Those scenarios are included in this report.

The Town of Barnstable operates the Hyannis Water Pollution Control Facility (WPCF), located off Bearses Way in Hyannis, which is the primary wastewater treatment facility serving approximately 2,900 properties in Hyannis and Barnstable village. The treatment facility has been upgraded and permitted to treat additional flows up to a total of 4.2 million gallons per day (MGD), upon meeting requirements of an adaptive management plan approved by the Commission in 2007. Property along Route 132 was acquired by the town in 2002 to potentially accommodate future disposal needs. The site is approved under a 2006 Massachusetts Environmental Policy Act (MEPA) certificate to discharge up to 0.5 MGD. The site is not presently in use. However, a force main and sewer has been extended to the site from the WPCF.

The WPCF treats an average daily flow of 1.46 MGD and a maximum monthly average flow of 1.94 MGD. Treatment performance has averaged 5 milligrams per liter (mg/L) total nitrogen in the treated effluent and the facility has a discharge limit of 5 mg/L under the 2007 Development of Regional Impact (DRI) decision and a limit of 10 mg/L under a Groundwater Discharge Permit (GWDP). The facility is also equipped with sludge thickening, storage and dewatering facilities sized for the current process conditions.

The Town of Barnstable also operates two smaller facilities – the Marstons Mills Wastewater Treatment Facility (WWTF) and the Red Lily Pond Cluster System. The Marstons Mills WWTF is limited to a discharge flow of 42,900 gallons per day (GPD) and is intended to service the Barnstable United Elementary School and the Village at Marstons Mills affordable housing development. The Red Lily Pond Cluster System currently serves 17 homes. According to the comprehensive wastewater management plan (CWMP) approved in 2007, no performance sampling of the system occurs and the system is assumed to produce comparable effluent to any conventional single family septic system.

In addition to municipally-owned facilities, there are two privately-owned treatment facilities treating wastewater from the Cotuit Landing shopping plaza and the Cape Regency nursing and rehabilitation facility. These facilities provide high levels of wastewater treatment. The treatment facility at Cotuit Landing was designed with additional treatment capacity beyond the expected needs of the shopping plaza for potential treatment of flows from neighboring properties.

Barnstable is working on a town-wide nutrient management plan that will provide the basis of its CWMP. The plan will address nitrogen and other needs in watersheds draining to Three Bays, Centerville River, and Lewis Bay. A nitrogen total maximum daily load (TMDL) for Barnstable Harbor has not been approved by US EPA. The MEPA certificate scope for the Final Environmental Impact Report (FEIR) includes engagement in a targeted watershed approach, consistent with the 208 Plan Update.

In the fall of 2014, Barnstable adopted local nitrogen-oriented fertilizer management regulations consistent with the Cape-wide Fertilizer Management District of Critical Planning Concern (DCPC).

In 2015, the Town submitted a Statement of Interest to the US EPA for a hydrogeologic site characterization as an initial step toward piloting a permeable reactive barrier in the town. One of three sites proposed by the Town was selected for characterization. The work was completed in 2016. The draft report is presently being reviewed by the Town.

Also in 2015, the Town agreed to work with Mashpee and Sandwich on approaches for the Popponesset Bay watershed and a potential development of a watershed permit. It is expected that these three towns will collaborate on the first

Town of Barnstable Watershed Scenario Details

Popponesset Bay	CREDITS		REDUCTION TECHNOLOGIES			REMEDIATION AND RESTORATION TECHNOLOGIES			REMOVAL
NAME OF TECHNOLOGY	% Nitrogen Reduction	Load Reduction (kg-N/yr)	# Properties / Units	Flow Collected (gpd)	Load Reduction (kg-N/yr)	# Units Proposed	Unit Metric	Load Reduction (kg-N/yr)	Total Scenario Load Reduction (kg-N/yr)
Traditional Scenario - Disposal Outside the Watershed									2,400
Centralized Sewer			500	80,000	2,400				
Non-Traditional Scenario									826
Fertilizer Management	25%	64							
Stormwater Mitigation	25%	132							
Permeable Reactive Barrier (PRB)						654	Linear Feet	414	
I & A Systems			41	Units	108				
Enhanced I & A Systems			75	Units	108				

watershed permit in the region in close coordination with the Cape Cod Commission and the Massachusetts Department of Environmental Protection.

In June 2016, Barnstable received $28,850 from the Commission to fund upgrades to three stormwater treatment BMPs. Funding was part of $142,149 in local grants made available to communities by the Commission in support of 208 Plan implementation.

Town of Sandwich Local Progress

The Town of Sandwich has an established water quality committee to oversee water quality and wastewater planning efforts. In October 2015 town staff and their consultant (Wright-Pierce) met with Cape Cod Commission staff to discuss watershed planning, decision support tools, and scenario development for Sandwich watersheds. In the same month the town was approached by Mashpee regarding approaches for Popponesset Bay, and a potential watershed permit, and has agreed to participate with Mashpee and Barnstable in this shared effort. It is expected that Barnstable, Mashpee, and Sandwich will collaborate on the first watershed permit in the region in close coordination with the Cape Cod Commission and the Massachusetts Department of Environmental Protection.

Previously the committee developed a scope of work for a Comprehensive Wastewater Management Plan (CWMP) and submitted the scope under the Sagamore Lens Natural Resource Damages Assessment, related to past groundwater contamination at the Textron facility at Joint Base Cape Cod (JBCC). The town received an award of $400,000 t0 conduct its water/wastewater plan and completed a comprehensive needs assessment, as well as an interim wastewater solutions plan to accommodate economic development in the South Sandwich Village Center.

The town spent several years working with a private developer on a development project that included a public-private wastewater component for the construction of a facility that would accommodate the private project, in addition to some public wastewater needs. That project will not be completed, but the town is again seeking a private partner to create new economic growth and to potentially participate in infrastructure development.

The town has participated in discussions at JBCC about the potential use of its existing wastewater infrastructure as a regional option for the Upper Cape towns.

In February 2016 the Town of Sandwich requested a meeting with Commission staff to discuss watershed scenarios and potential modifications to watersheds in which Sandwich has jurisdiction. The town provided collection footprints and assumptions for a single treatment facility to serve all three watersheds (Popponesset Bay, Three Bays, and Waquoit Bay), consistent with the Sandwich CWMP, and identified locations for non-traditional approaches, in addition to credits for stormwater and fertilizer reduction. The Town proposes a 25% fertilizer management credit and a 6.25% stormwater management credit. While the proposed interventions, alone, do not meet the nitrogen allocations identified in Appendix 8C of the 208 Plan Update, the town has expressed a preference to rely on nutrient trading or cost sharing to reduce the load allocated to the downgradient towns in the shared watersheds of Popponesset Bay, Three Bays and Waquoit Bay, where nitrogen reductions can be more cost effectively attained.

Town of Sandwich Watershed Scenario Details

Popponesset Bay	CREDITS		REDUCTION TECHNOLOGIES			REMEDIATION AND RESTORATION TECHNOLOGIES			REMOVAL
NAME OF TECHNOLOGY	% Nitrogen Reduction	Load Reduction (kg-N/yr)	# Properties / Units	Flow Collected (gpd)	Load Reduction (kg-N/yr)	# Units Proposed	Unit Metric	Load Reduction (kg-N/yr)	Total Scenario Load Reduction (kg-N/yr)
Traditional Scenario - Disposal Outside the Watershed									1,820
Centralized Sewer			1,328	230,214	1,820				
Non-Traditional Scenario*									47
Fertilizer Management	25%	32							
Stormwater Mitigation	6.25%	15							

NOTES:

* The Town of Sandwich will rely on nutrient trading as an additional measure to meet the TMDL, if necessary.

Scenario Maps

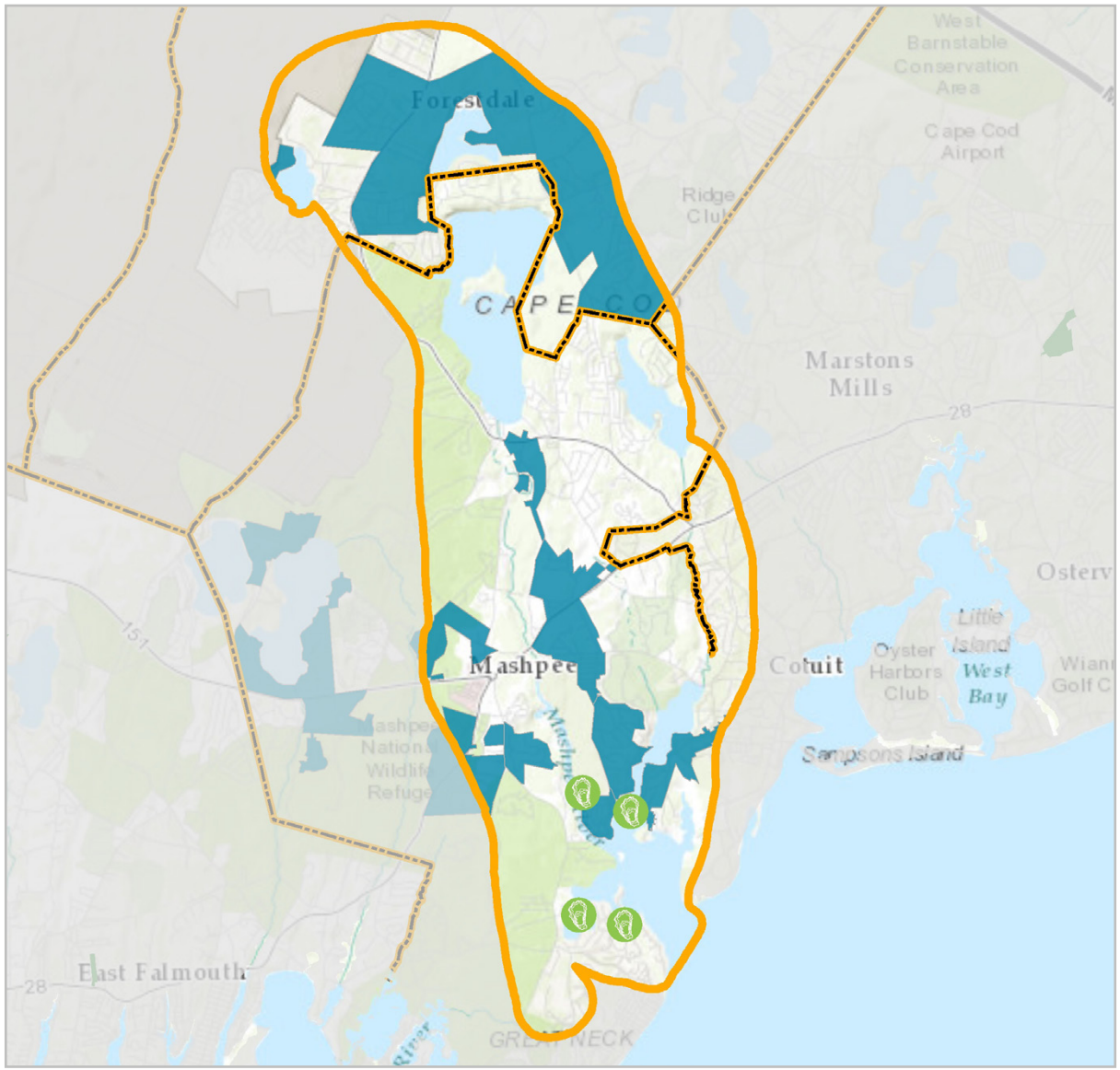
Popponesset Bay Watershed
Traditional Scenario

MASHPEE, BARNSTABLE & SANDWICH

Representative locations of conceptually proposed infrastructure

Legend

- Aquaculture
- Town Lines
- Embayment Watersheds
- Proposed Sewershed



Scenario Maps

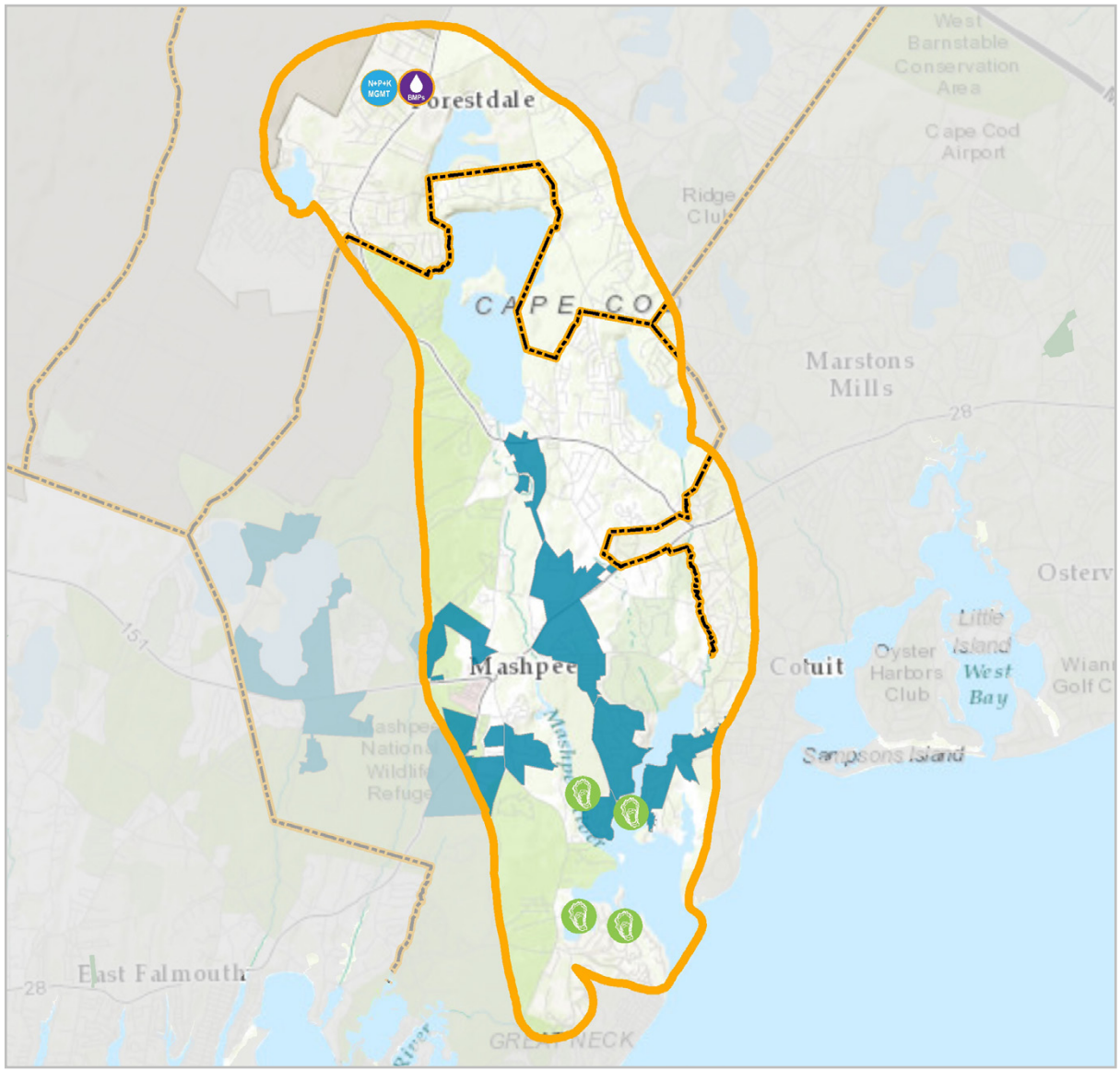
Popponesset Bay Watershed
Non-Traditional Scenario

MASHPEE, BARNSTABLE & SANDWICH

Representative locations of conceptually proposed infrastructure

Legend

- Stormwater Management
- Fertilizer Management
- Aquaculture
- Town Lines
- Embayment Watersheds
- Proposed Sewershed



Methodology for Selecting Non-Traditional Technology Scenarios

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology were derived from the Technologies Matrix. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

This section summarizes the approach and methodology that was applied during the 208 Update to develop plans for reducing nitrogen loading to estuaries using non-traditional (NT) technologies. It includes descriptions of regional credits for stormwater and fertilizer reductions, regional screening for potential sites for several technologies, and site-specific analyses for others. Nitrogen attenuation rates for each technology are noted below, based on the Technologies Matrix or newer data. The nitrogen thresholds for each embayment were determined from the Massachusetts Estuaries Project (MEP).

Regional credits were developed for potential stormwater retrofits and fertilizer reductions. They were calculated as a percent reduction of existing nitrogen loads as identified in the MEP reports and updated GIS data developed by the Cape Cod Commission.

- **STORMWATER MANAGEMENT:** Most Cape communities have already begun the process of identifying significant untreated stormwater discharges and developing appropriate mitigation projects. With the prospect of the MS4 regulatory requirements it was assumed that additional mitigation efforts would be implemented. Based upon the evidence developed by the University of New Hampshire Stormwater Center that several vegetated stormwater management practices (including bioretention and constructed wetlands) are able to achieve nitrogen reductions of 50% or more and the assumption that only a portion (estimated at 50%) of identified sites would be retrofitted a 25% nitrogen reduction credit was assumed for each watershed. Specific locations and number of locations were not identified; this was deferred to individual towns to consider as part of the suite of nitrogen management strategies.
- **FERTILIZER REDUCTIONS:** Based upon the success of most Cape Cod towns to implement either regulatory or non-regulatory fertilizer management programs and the efforts of the Cape Cod Extension Service in educating homeowners a 25% reduction in fertilizer applications was assumed for each watershed.

Regional GIS screening methods were developed to identify locations for some non-traditional technologies. A GIS viewer was developed as an on-line tool for staff and consultants to utilize during the watershed planning process.

- **CONSTRUCTED WETLANDS/ PHYTOREMEDIATION:** A GIS-based screening method was developed by the Cape Cod Commission to identify and rank parcels of land that have potential for the location of constructed wetlands and phytoremediation. The ranking utilized parcel size and ownership, depth to groundwater, suitable soils, distance from wetlands, and undeveloped parcels. A nitrogen removal rate of 500 kg/Y/acre and 532 kg/Y/acre was used for Constructed Wetlands and Phytoremediation, respectively.
- **PERMEABLE REACTIVE BARRIERS (PRBS):** A GIS-based screening method was developed to identify existing roads that are proximate to receiving waters, downgradient of high density development, run perpendicular to groundwater flow (to have the highest potential to intercept nutrients in groundwater), and where the depth to groundwater is relatively shallow to maximize the area of saturated thickness treated in the aquifer.

Methodology for Selecting Non-Traditional Technology Scenarios

- **FERTIGATION WELLS:** Golf courses were mapped to identify areas where fertigation wells could be utilized to recapture nitrogen-enriched groundwater and re-apply it to the managed turf areas to serve both irrigation and fertilization needs. Most golf courses were assumed to be eighteen holes with a fertilized area of 75 acres. Fertigation water was assumed to have an average concentration of 5 mg/liter. An uptake/attenuation rate of 80% was applied resulting in an assumed nitrogen reduction of 300 kg/year for each golf course with effectively located fertigation wells. In some cases other irrigated areas (such as athletic fields and cemeteries) were identified as potential fertigation locations. A nitrogen removal rate of 4 kg/Y/acre was used.

The MVP tool and other site-specific tools were utilized to quantify nitrogen load reductions for several potential NT interventions.

- **PERMEABLE REACTIVE BARRIERS:** for each PRB that was identified during the prior GIS-screening process an approximate capture area was identified using available water table maps and the wMVP tool. Upgradient contributing areas were digitized within wMVP and the nitrogen load was calculated. A nitrogen reduction of 72.5% was applied (calculated as an average of the reported attenuation range from the Technologies Matrix).
- **CONSTRUCTED WETLANDS (WITH COLLECTION):** Constructed wetlands were considered as a tertiary, polishing treatment for existing wastewater treatment plants. This included small-scale wastewater treatment systems. A nitrogen removal rate of 500 kg/Y/acre was used.
- **AQUACULTURE/OYSTER REEFS:** Potential areas for aquaculture and/or oyster reef restoration were considered based upon discussions with town representatives and review of maps to identify potential areas for these operations without significant conflicts to navigation. In some cases actual recent aquaculture expansions were included where they were developed after the MEP reports were prepared. An assumption of 1 million oysters per acre was used with a nitrogen removal rate of 250 kg/Y/acres.
- **FLOATING CONSTRUCTED WETLANDS:** Potential areas for floating wetlands were considered in areas where no conflicts with navigation or swimming areas were identified. A nitrogen removal rate of 0.4 kg/Y/sq foot was used.
- **INLET WIDENING AND COASTAL HABITAT RESTORATION:** Only considered in areas where these projects were identified by towns or state agencies and where detailed hydrologic investigations and modeling had been performed due to wide variations in nitrate load reduction, flushing impacts, impacts on flooding, and costs (dredging only, replacing infrastructure, removing and replacing roadways or bridges, etc.). Nitrogen removal rates were based on MEP or other studies.
- **INNOVATIVE & ALTERNATIVE SEPTIC SYSTEMS AND ECOTOILETS:** In most cases specific locations for these technologies were not identified. Rather general estimates for the percent adoption were provided based upon discussions with the stakeholder groups and their views on potential adoption rates. In some watersheds a 5% adoption rate was included based upon this stakeholder input. In a limited number of instances specific locations for these technologies were included based upon town input and suggestions. A nitrogen removal rate of 1.658 kg/Y for each system was used for I&A Septic Systems, and 2.984 kg/Y for enhanced I&A systems. A removal rate of 2.542 kg/Y was used for each home installation of an Ecotoilet, and 0.467 kg/Y for installation of urine diversion toilets in public settings.

Finally, the locations of specific technologies were discussed during the 208 stakeholder engagement process. Stakeholders across the Cape 'groundtruthed' potential NT locations and NT scenarios were adjusted accordingly.

Appendix G

CCC Rushy Marsh Watershed Report

WATERSHED REPORT: MID CAPE

Rushy Marsh

BARNSTABLE



WATER THREAT LEVEL

HIGH

Rushy Marsh is an embayment system with shoreline located entirely in the Town of Barnstable. The Rushy Marsh system is disconnected from Nantucket Sound during low tide with tidal waters entering the Marsh intermittently.

The Problem

The Massachusetts Estuaries Project (MEP) technical report (available at www.oceanscience.net/estuaries) indicates that the Rushy Marsh system exceeds its critical nitrogen threshold, resulting in impaired water quality. Although a MEP report is available, a Total Maximum Daily Load (TMDL) for nitrogen has not yet been established.

- **MEP TECHNICAL REPORT STATUS:** Final
- **TMDL STATUS:** TMDL not yet established
- **TOTAL WASTEWATER FLOW:** 1 MGY (million gal per year)
  - Treated Wastewater Flow: 0 MGY
  - Septic Flow: 1 MGY
- **UNATTENUATED TOTAL NITROGEN LOAD (MEP):** 163 Kg/Y (kilograms per year)
- **ATTENUATED TOTAL NITROGEN LOAD (MEP):** 163 Kg/Y
- **SOURCES OF CONTROLLABLE NITROGEN (MEP):**
  - 89% Septic Systems
  - 4% Lawn Fertilizer
  - 7% Stormwater From Impervious Surfaces

CONTRIBUTING TOWN

Percent contributions listed below are the aggregate sub-embayment contributions identified in Appendix 8C of the Cape Cod Section 208 Plan Update (contributions are based on attenuated load where available). See Appendix 8C for detailed town allocations by sub-embayment.

- **BARNSTABLE:** 100%

THE MEP RESTORATION SCENARIO

- **WATERSHED TOTAL NITROGEN REDUCTION TARGET:** 79%
- **WATERSHED SEPTIC REDUCTION TARGET:** 100% (The scenario represents the aggregated sub-embayment percent removal targets from the MEP technical report)

RUSHY MARSH ESTUARY

- **EMBAYMENT AREA:** 15 acres
- **EMBAYMENT VOLUME:** 3 million cubic feet
- **2014 INTEGRATED LIST STATUS:** Category 3
  - Category 3: No uses assessed
  - www.mass.gov/eea/docs/dep/water/resources/07v5/14list2.pdf

RUSHY MARSH WATERSHED

- **ACRES:** 57
- **PARCELS:** 18
- **% DEVELOPED RESIDENTIAL PARCELS:** 33%

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- **PARCEL DENSITY:** 3 acres per parcel (approx.)
- **WASTEWATER TREATMENT FACILITIES:** 0

Freshwater Sources

PONDS

- **IDENTIFIED SURFACE WATERS:** 1
- **NUMBER OF NAMED FRESHWATER PONDS:** 0
- **PONDS WITH PRELIMINARY TROPHIC CHARACTERIZATION:** 0
- **2014 INTEGRATED LIST STATUS:** None listed

Barnstable has participated in the Pond and Lake Stewardship (PALS) program that has helped establish baseline water quality. Trophic characterizations are based on most recent Commission staff assessment. The pond in this watershed does not have water quality data that allows a preliminary trophic characterization.

STREAMS

- **SIGNIFICANT FRESHWATER STREAM OUTLETS:** 0

Nitrate concentrations higher than 0.05 mg/L background concentrations, evident in public supply wells located in pristine areas, provide evidence of the impact of non-point source pollution on the aquifer and receiving coastal water bodies.

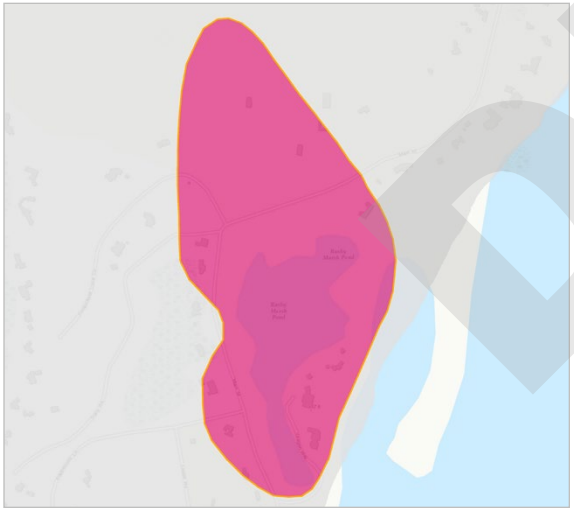
DRINKING WATER SOURCES

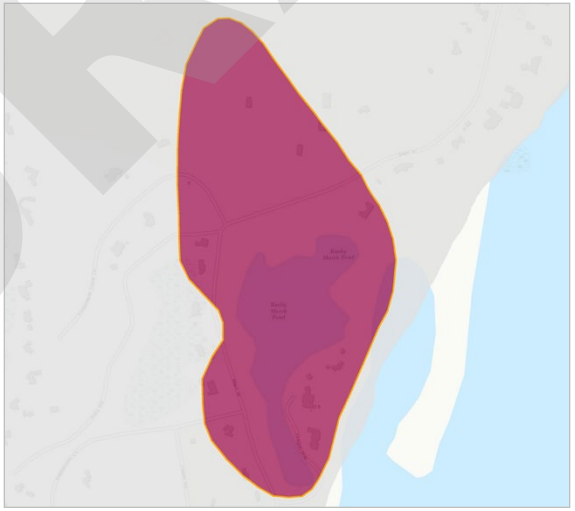
- **WATER DISTRICTS:** 1
  - Centerville-Osterville-Marstons Mills (COMM) Water District
- **GRAVEL PACKED WELLS:** 0
- **SMALL VOLUME WELLS:** 0

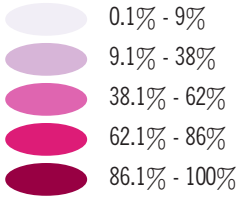
Degree of Impairment and Areas of Need

For the purposes of the Section 208 Plan Update, areas of need are primarily defined by the amount of nitrogen reduction required as defined by the TMDL and/or MEP technical report. The aggregated watershed removal rates for Rushy Marsh are 79% and 100% for total watershed load and septic nitrogen load, respectively (see figures: Subwatersheds with Total Nitrogen Removal Targets and Subwatersheds with Septic Nitrogen Removal Targets).

The nitrogen load from the watershed exceeds the threshold for Rushy Marsh, resulting in impaired water quality. The ecological health of a water body is determined from water quality, extent of eelgrass, assortment of benthic fauna, and dissolved oxygen and ranges from 1-severe degradation, 2-significantly impaired, 3-moderately impaired, 4-healthy habitat conditions.







Subwatersheds with Total Watershed Removal Targets

(Left) Benthic and atmospheric loads directly on embayments are not included.

Subwatersheds with Septic Nitrogen Removal Targets

(Right)

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ECOLOGICAL CHARACTERISTICS AND WATER QUALITY

- **OVERALL ECOLOGIC CONDITION:** Severely Degraded
- **MAIN BASIN:** Severely Degraded
- **CHANNEL:** Severely Degraded
- **SENTINEL STATION:**
  - Total Nitrogen Concentration Threshold: 0.99 mg/L
  - Total Nitrogen Concentration Existing: 1.11 mg/L (As reported at the MEP sentinel water-quality monitoring station)

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Collection & Non-Collection Scenarios

Regional Data

In 2010, the Commission sought to collect regionally consistent data for the purposes of watershed scenario development. Both parcel data and water use data was identified and collected for the entire region. While the scientific basis for planning is the thresholds identified in the MEP technical reports, each report uses data from different years, and in some cases the MEP data used is 10 or more years old. In addition, there are watersheds on Cape Cod without the benefit of an MEP report; therefore, similar data was not available for planning purposes.

The updated regional data set was used to estimate wastewater, stormwater and fertilizer loads, using the same methodologies as the MEP. This approach allows for a reevaluation of existing development, which may have changed in the last 10 years. Parcel data included in the regional database is from 2010-2012 and water use data is from 2008-2011, depending on the water district. This approach allows for regionally consistent watershed scenario development.

Watershed Scenarios

The watershed scenarios that follow outline possibilities for the watershed. A series of non-traditional technologies that might be applicable are included, as well as the amount of flow and approximate number of residential parcels that would need to be collected if a traditional collection system and treatment facility was implemented. Some assumptions were made in determining the approximate flows and parcels for collection, including a treatment factor of 5 parts per million (ppm), disposal occurring inside the watershed, and no natural attenuation, therefore prioritizing parcels with a direct impact on the water body. Site specific determinations of collection areas may result in the need to collect more or less parcels to meet the nutrient reduction target. The scenarios presented are meant to act as a starting point for discussions regarding effective and cost efficient solutions.

RUSHY MARSH NITROGEN SOURCES	TOTAL NITROGEN LOAD (kg-N/yr)
Wastewater	63
Fertilizer	3
Stormwater	12
Other	4
TOTAL	82
Total Watershed Load (including atmospheric)	82
Total Watershed Threshold	34
TOTAL LOAD TO BE REMOVED	48

DRAFT

Collection & Non-Collection Scenarios

Non-Collection

400 Square Feet - Floating Constructed Wetlands

Collection

DEVELOPED RESIDENTIAL PARCELS IN WATERSHED

1

6 Residential Parcels in the watershed

RESIDENTIAL EQUIVALENTS NECESSARY TO MEET NITROGEN REDUCTION TARGET VIA COLLECTION

1

11 Residential Equivalents Necessary to Meet Nitrogen Reduction Target

= 50 Residential Parcels

11	1,635
Residential Equivalents Necessary to Meet Nitrogen Reduction Target	Flow Collected (gpd)

SCENARIO ASSUMPTIONS: Assumes treatment to 5 parts per million (ppm) nitrogen. Assumes disposal occurs inside the watershed. In this watershed, reduction targets may not be met with disposal inside the watershed. Assumes no natural attenuation; therefore, prioritizing parcels with a direct impact on the water body.

DRAFT

Town of Barnstable Local Progress

The Cape Cod Commission and the Town of Barnstable met and discussed the use of WatershedMVP to evaluate targeted watershed approaches for each of the watersheds in which they have jurisdiction. In 2015, the town reformulated its Citizen's Advisory Committee (CAC) for wastewater planning to better address local needs. In addition to local participation, the newly formed committee (the Water Resources Advisory Committee or WRAC) includes state and regional representatives. Town staff provided modifications to Commission-developed watershed scenarios and presented those scenarios to their WRAC for review and discussion. Those scenarios are included in this report.

The Town of Barnstable operates the Hyannis Water Pollution Control Facility (WPCF), located off Bearses Way in Hyannis, which is the primary wastewater treatment facility serving approximately 2,900 properties in Hyannis and Barnstable village. The treatment facility has been upgraded and permitted to treat additional flows up to a total of 4.2 million gallons per day (MGD), upon meeting requirements of an adaptive management plan approved by the Commission in 2007. Property along Route 132 was acquired by the town in 2002 to potentially accommodate future disposal needs. The site is approved under a 2006 Massachusetts Environmental Policy Act (MEPA) certificate to discharge up to 0.5 MGD. The site is not presently in use. However, a force main and sewer has been extended to the site from the WPCF.

The WPCF treats an average daily flow of 1.46 MGD and a maximum monthly average flow of 1.94 MGD. Treatment performance has averaged 5 milligrams per liter (mg/L) total nitrogen in the treated effluent and the facility has a discharge limit of 5 mg/L under the 2007 Development of Regional Impact (DRI) decision and a limit of 10 mg/L under a Groundwater Discharge Permit (GWDP). The facility is also equipped with sludge thickening, storage and dewatering facilities sized for the current process conditions.

The Town of Barnstable also operates two smaller facilities – the Marstons Mills Wastewater Treatment Facility (WWTF) and the Red Lily Pond Cluster System. The Marstons Mills WWTF is limited to a discharge flow of 42,900 gallons per day (GPD) and is intended to service the Barnstable United Elementary School and the Village at Marstons Mills affordable housing development. The Red Lily Pond Cluster System currently serves 17 homes. According to the comprehensive wastewater management plan (CWMP) approved in 2007, no performance sampling of the system occurs and the system is assumed to produce comparable effluent to any conventional single family septic system.

In addition to municipally-owned facilities, there are two privately-owned treatment facilities treating wastewater from the Cotuit Landing shopping plaza and the Cape Regency nursing and rehabilitation facility. These facilities provide high levels of wastewater treatment. The treatment facility at Cotuit Landing was designed with additional treatment capacity beyond the expected needs of the shopping plaza for potential treatment of flows from neighboring properties.

Barnstable is working on a town-wide nutrient management plan that will provide the basis of its CWMP. The plan will address nitrogen and other needs in watersheds draining to Three Bays, Centerville River, and Lewis Bay. A nitrogen total maximum daily load (TMDL) for Barnstable Harbor has not been approved by US EPA. The MEPA certificate scope for the Final Environmental Impact Report (FEIR) includes engagement in a targeted watershed approach, consistent with the 208 Plan Update.

In the fall of 2014, Barnstable adopted local nitrogen-oriented fertilizer management regulations consistent with the Cape-wide Fertilizer Managem ent District of Critical Planning Concern (DCPC).

In 2015, the Town submitted a Statement of Interest to the US EPA for a hydrogeologic site characterization as an initial step toward piloting a permeable reactive barrier in the town. One of three sites proposed by the Town was selected for characterization. The work was completed in 2016. The draft report is presently being reviewed by the Town.

In June 2016, Barnstable received $28,850 from the Commission to fund upgrades to three stormwater treatment BMPs. Funding was part of $142,149 in local grants made available to communities by the Commission in support of 208 Plan implementation.

DRAFT

Appendix H

Injection Well Pilot Testing Evaluation; March 2003

Report

Pilot Test for Using Injection Wells For Reclaiming Treated Municipal Wastewater Town of Barnstable, Massachusetts

March 2003 Revision

Stearns & Wheler
Companies

PILOT TEST FOR USING INJECTION WELLS FOR RECLAIMING TREATED MUNICIPAL WASTEWATER TOWN OF BARNSTABLE, MASSACHUSETTS

Prepared for

TOWN OF BARNSTABLE, MASSACHUSETTS

Prepared by

STEARNS & WHELER, LLC
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March 2003 Revision

Project No. 9019010

EXECUTIVE SUMMARY

The Town of Barnstable, through its consultant, Stearns & Wheler, conducted a pilot test to evaluate the feasibility of injecting treated wastewater into the subsurface using an injection well. This document provides a description of the technology, describes the pilot test operation, and presents results and conclusions to be considered as part of further evaluation of the technology.

The Town is in the process of completing a Wastewater Facilities Plan for their municipal Water Pollution Control Facility (WPCF). One issue facing Barnstable is finding a means to dispose of the treated effluent without creating significant adverse impacts on groundwater levels. In the course of completing the Wastewater Facilities Plan, Stearns & Wheler identified a number of alternatives for discharging effluent in a manner that would not adversely impact groundwater levels. The study concluded that the use of injection wells might be an appropriate method to meet the Town's goals for wastewater management. Subsurface injection may be a beneficial alternative to traditional effluent disposal methods due to smaller land requirements and an increased number of siting options. Injection wells do not have significant visual or public perception impact and may be less expensive. The viability of the technology was evaluated with an injection well pilot test.

Two areas of evaluation were identified for the pilot test. The first area of evaluation related to system operations. An objective of the pilot test was to evaluate operational aspects of the technology, including well design considerations, flow rates, injection pressure, and well plugging and its causes. The second area of evaluation related to environmental impacts of the application of the technology, including the impacts on the water table elevation (i.e., mounding) that would occur as a result of wastewater injection. Additionally, the study was designed to evaluate the fate and transport of nutrients and other wastewater constituents.

Prior to designing and conducting the pilot test, a review was completed of existing injection well projects. Wastewater injection facilities in California and Florida were studied, as well as potable water storage injection projects located in a number of regions of the country. To gain information regarding injection in this region, a groundwater treatment and reinjection program at the Massachusetts Military Reservation was studied. Through the review of these projects, a number of design criteria were identified. The greatest challenge in operating an injection well was determined to be plugging (reducing the injection rate). Plugging may result from bacterial

buildup, injection of suspended solids, injection of entrained air, or chemical reactions that cause precipitation of minerals in the injection zone.

A second challenge in introducing injection wells as an alternative technology is related to regulatory concerns. There was resistance by regulators regarding implementation of a new technology while remaining consistent with existing policies and regulations. An example of this relates to the disinfection of treated effluent. Through our case study review of existing effluent discharge facilities, it was identified that fouling due to biological buildup was probable without disinfection. The pilot test using treated effluent from the Hyannis WPCF demonstrated this to be true. However, because of concerns with the fate of chlorine and potential disinfection by-products, the Massachusetts Department of Environmental Protection (MADEP) would not allow the injected effluent to be disinfected with chlorine.

Based on information gathered from the case studies, on the goals of the pilot test, and the local site conditions, the pilot test was designed with the following specifications:

- Flow Rate - 350 gallons per minute (gpm). High enough to create measurable hydraulic and transport impacts for evaluation.

- Well Location - WPCF. A remote site was considered but not used because of the impacts to the project cost, schedule, and the ability to permit the project

- Disinfection - UV Radiation. The injected waste stream was disinfected using a UV system as required by MADEP, resulting from concerns about impacts of chlorination on groundwater quality (December 14, 1998 meeting minutes). The Town and Stearns & Wheler viewed disinfection with chlorine as a major factor in the success of the project.

- Filtration - Bag System. This was another limiting factor in the success of the test.

The pilot test was conducted in two phases. Phase I, using treated effluent, ended in 11 days as a result of well plugging of the injection zone. Phase II, using potable water, was sustained for approximately three months. The immediate plugging during Phase I was attributed to the build-up of bacteria at the formation face of the injection zone. This was determined after redevelopment failed to restore the well, but treatment with high concentrations of chlorine did

eliminate the plugging. Once the well was restored, approximately 7 million gallons of potable water were injected during Phase II.

Because of the many operational issues encountered during the test, the objectives of further investigation were modified by Stearns & Wheler, with approval from the Town of Barnstable Project Manager, to focus more on operational factors than environmental impacts. A number of conclusions were drawn from the results of the pilot test that should be used in considering the future testing of this technology:

- Injection wells can be a viable means of reclaiming treated wastewater by recharging utilized aquifers (as has been demonstrated in other regions of the United States through the case study review).

- Chlorine disinfection is necessary to maintain a residual disinfectant concentration in the subsurface, which will prohibit the growth of bacteria at the formation face of the injection zone and subsequently result in plugging.

- High level filtration (less than 10 microns) is required to minimize the impacts of injecting suspended solids.

- Injection pressure must be kept at a minimum so as not to disrupt the structure of the injection zone.

- Well design can be improved to increase and maintain efficiency.

- Additional pilot testing related to filtration and disinfection is needed to demonstrate viability before full-scale implementation is considered

Injection wells are used, primarily in Florida and California, for the disposal or reclamation of millions of gallons of treated wastewater each day, demonstrating the viability of the technology. This pilot test demonstrated that filtration and disinfection must be enhanced to levels greater than those used during the pilot test before it can be considered as a viable alterative for the Town of Barnstable. The recent thrust by regulatory agencies toward multiple centralized wastewater systems on Cape Cod, and the need to preserve the Cape's single source aquifer, will only intensify the need to develop sound, practical, environmentally sensitive, and economical

solutions to wastewater treatment and disposal needs. As more centralized systems are built or expanded, there will be a huge demand for valuable land for the purpose of discharging the treated water to groundwater. Injection wells present an ideal alternative that is less land intensive, has less environmental impact, and is more aesthetically acceptable than traditional effluent discharge practices. However, before the required additional pilot testing of this technology can be performed, resolution on MADEP's policy on prohibiting the chlorination of the treated effluent must be reached.

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Chapter 1
Introduction

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The Town of Barnstable, Massachusetts is in the process of completing a Wastewater Facilities Plan for their municipal Water Pollution Control Facility (WPCF). One issue facing the Town is disposing of the treated effluent from the WPCF without increasing the elevation of groundwater, which could subsequently flood basements and septic systems or cause surface flooding. Historically, ponding has occurred at the existing treatment facility, and groundwater levels have risen to potentially impact low lying areas in the immediate vicinity of the WPCF. The relative contribution of the natural rise in groundwater elevation and any increases in groundwater elevation by the plant have never been clearly determined. Groundwater modeling completed by the Town indicates that effluent discharge from the plant can theoretically result in mounding of the water table. The concern over adverse impacts related to local groundwater mounding in the vicinity of the WPCF is amplified by Town projections that wastewater quantities will increase from the current 2 million gallons per day (mgd) to 4 mgd as planned system improvements are constructed. Alternative technologies to traditional effluent discharge practices must be evaluated for a number of reasons, including:

- the need to reclaim treated wastewater at locations remote from the treatment plant
- the desire for reclamation with minimal impact on groundwater quality and elevation
- the desire for a cost-effective, easy to operate system
- the desire for minimal aesthetic impact and land use
- flexibility in siting discharge sites versus treatment plants
- offering economical discharge point distribution
- the ability to provide an odorless, closed system

While developing the Wastewater Facilities Plan, Stearns & Wheler identified a number of alternatives for discharging effluent in a manner that would not adversely impact groundwater levels. After evaluating the advantages and disadvantages of each alternative, the Town, together with Stearns & Wheler, determined that using injection wells had the potential to meet the Town's goals and objectives for managing treated effluent.

This document serves as a summary of a wastewater injection well pilot test conducted at the Hyannis WPCF for the Town of Barnstable. The purpose of the pilot test was to evaluate the viability of using injection wells as a means of recharging aquifers with reclaimed, treated municipal wastewater. Subsurface injection could be a beneficial alternative to traditional effluent disposal practices since smaller land requirements would allow a greater number of siting options while minimizing visual and public perception impacts. In addition, due to the rising cost of real estate, injection wells could be a less costly alternative to infiltration beds.

1.2 PROJECT SCOPE OF WORK

The pilot test was performed in accordance with Addendum No. 4 to the January 27, 1993 Agreement between the Town of Barnstable and Stearns & Wheler for the development of the Wastewater Facilities Plan. Amendment No. 4 authorized the following tasks. Because the scope of the project was revised as the project proceeded, the execution of each of the tasks is described.

A. **Task 1: Assist Town with SRF Funding.** Following project authorization, but prior to beginning the project, the Town decided to complete all SRF funding application tasks and requested no assistance from Stearns & Wheler. The funds for this task were moved to Task 5, Pilot Test Operation, when it became evident that additional funding would be needed when the testing was extended.

B. **Task 2: Characterization of Potential Injection Sites and Pilot Test Site.** This task had two components: (1) testing two remote discharge sites identified by the Town for use as potential future effluent discharge sites; and (2) completing a preliminary subsurface evaluation of the pilot test site. The first component was not completed; the Town elected not to investigate any candidate remote sites until the pilot test was completed. The characterization of the pilot test site was completed through the installation of a test boring and completion of sieve analysis on the soils recovered from the test boring.

C. **Task 3: Pilot Test Design.** This task was completed as scoped. A design was completed that specified the equipment and layout, including piping and pumps, flow and pressure metering, disinfection equipment, power supplies and controls, the injection well and observation well designs, and locations.

D. **Task 4: Equipment and Well Installation.** This task was completed as scoped. All equipment and wells were installed in accordance with the project design.

E. **Task 5: Pilot Test Operation.** This task was executed very differently than originally proposed. The original plan was to run the well continuously for six months. The well plugged after 11 days of operation. After reviewing potential causes, the well was serviced twice; the first servicing was not effective in restoring the well, and the second servicing restored the well. Prior to restarting the test, Stearns & Wheler recommended, and the Town agreed, continuing the test using potable water. The injection test resumed and was continued for three months. The longer duration of the test, two well servicing events, additional evaluations, and the installation of an additional observation well added to the scope and costs of this task.

F. **Task 6: Water Quality Testing.** Following project authorization, but prior to beginning the project, the Town decided to complete groundwater quality laboratory testing internally. The funding for this task was set aside and later allocated to Task 5 in accordance with Town direction. Because the focus of the project changed from potential environmental impacts to operational issues, the sampling and analysis program was not conducted.

G. **Task 7: Groundwater Modeling.** This task was originally proposed to model the mounding impacts of the injected effluent. Because the focus of the project changed from potential environmental impacts to operational issues, the modeling was not conducted. The funding for this task was set aside and later allocated to Task 5 in accordance with Town direction.

H. **Task 8: Final Report.** This report is being prepared in fulfillment of this task.

1.3 PROJECT GOALS

The ultimate goal of the pilot test was to evaluate the technical and environmental viability of the technology for application in Barnstable. The pilot test was designed to evaluate operational aspects of using injection well technology and the potential for environmental impacts. Specifically, the goals relating to operational aspects included:

- determining optimal flow rate
- evaluating injection pressure and its likely build-up over time

- determining the level of treatment needed to effectively operate the well
- evaluating plugging mechanisms that would limit the efficiency of the well

Goals related to environmental impacts included:

- determining degree of water table mounding caused by injection
- determining fate and migration of nutrients and other wastewater components in the receiving aquifer.

1.4 TECHNOLOGY SUMMARY

Prior to proceeding with design and execution of the injection well pilot test, a review of the existing application of the technology was completed. The purpose of the technology review was to determine how injection wells are being used, in what geologic environments injection is occurring, and to identify design considerations to be used in the pilot test. Other design considerations were site specific and would need to be based on existing operations. The technology review summary is included as Appendix A.

Chapter 2

Pilot Test Design and Construction

CHAPTER 2

PILOT TEST DESIGN AND CONSTRUCTION

2.1 PILOT TEST DESIGN CRITERIA

The issues identified in the technology review (Appendix A) provided a significant amount of information during the development of the basis of design for the pilot test. The pilot test was designed to evaluate:

- the operational and mechanical aspects of operating an injection well (in particular, evaluating plugging due to precipitation of solids and development of biofilms [biofouling])
- the hydraulic impacts of injection of wastewater
- concerns related to nutrient and bacteriological transport and exposure

The goal of the pilot test was to determine whether injection is a practical alternative for reclaiming wastewater, achieved by studying the following issues to make that judgment:

- Determine the nature of water table mounding associated with shallow well injection. What would the maximum water table elevation increase be at the well, and what would be the radial extent of the cone of influence? What would be the potential impacts to zones of contribution of production wells and to surface water bodies?

- Determine the extent to which bacteria, nutrients, and other wastewater constituents would be transported toward potential receptors, such as surface water or production wells.

- Evaluate biological and chemical activity at the well screen and in the injection formation that could affect the injection efficiency of the well.

- Determine the nature of the clogging, if any, so that remedial treatments can be included in final design.

- Gain information from the pilot test to develop design criteria for full-scale systems.

2.2 BASIS OF DESIGN

The basis of design for the pilot test was developed based on the goals of the test and operational and environmental considerations following a review of other injection well projects; meetings (telecons) with Massachusetts Department of Environmental Protection (MADEP) representatives; and input from Mr. Peter Doyle, Supervisor of the Barnstable Water Pollution Control Division, and other Town of Barnstable representatives. The basis of design for the pilot test is as follows:

A. **Flow Rate.** It was determined that a flow rate of 0.5 mgd, or 350 gpm, would be the target operational flow rate. The flow rate for the test had to be high enough to result in significant measurable effects to the water table. The effects had to be sufficient enough to make evaluations of mounding and the resultant groundwater flow rates and directions. However, the flow rate did have to be limited. The primary limiting factor was cost. As flow rate increased, so would the costs of the wells, pumps, piping, and treatment systems. It was determined that a pilot test facility capable of conveying 0.5 mgd could be constructed for $250,000, a cost determined to be manageable by the Town.

B. **Well Location.** It was determined that the pilot test well would be located in the southeast area of the Hyannis WPCF property. This location was selected primarily as a function of cost and schedule. A remote site location was considered first and was suggested by MADEP. A remote site would have been advantageous because impacts of recharge of the balance of the wastewater at the treatment plant's infiltration beds would be minimized, allowing a better assessment of the impacts of the well. However, costs and time associated with identifying a remote site, gaining access to the remote site, permitting a remote site facility and constructing a pipeline up to 2 miles long would have significantly impacted the schedule and cost of the project. The location near the existing plant facilities was selected because minimal piping and pumping would be required and power was readily available, and also because the balance of effluent flow could be diverted to the sand infiltration beds located on the opposite end of the property (far north end of the site and/or far west end of the site).

C. **Disinfection Requirements.** Based on past case studies (Florida and California; see Appendix A), Stearns & Wheler determined that the effluent liquid stream should be disinfected

prior to injection for the dual purpose of minimizing potential bacteriological transport into production well Zones of Contribution, as well as minimizing the potential for the development of biofilms causing plugging (biofouling) of the well. The MADEP was concerned that concentrations of heavy doses of chlorine (greater than 3 mg/L), the most common disinfectant, might be detrimental to the quality of groundwater; therefore, UV disinfection was specified for the effluent.

MADEP has repeatedly stated that it is their policy to encourage disinfection through UV systems. This policy is not written. Concerns related to disinfection were verbally expressed by MADEP representatives at a December 14, 1998 meeting, which was held to gain regulatory endorsement and define MADEP requirements for the project. At this meeting, Stearns & Wheler presented findings that indicated filtration and disinfection were routine treatment practices for wastewater effluent injected into groundwater. It was identified that the lack of chlorination residual added greater risk to the success of the project. The project proceeded using UV disinfection. The MADEP is currently reviewing its policy on chlorination of injected wastewater effluent into the groundwater.

D. **Filtering Requirements.** As indicated, injection wells are susceptible to plugging due to fine solids as well as biofouling. Filtering is a standard treatment practice for injection wells to remove fine particles. At the meeting with MADEP, it was determined that UV disinfection would be required but that filtration could be eliminated in the interest of keeping the project within the original budget. However, in the course of finalizing the design, Stearns & Wheler recommended that the test be modified to include a filtration device that would help sustain a constant injection rate. Because of the high cost of the sand filter that would be required to treat the pilot test flow of 350 gpm, and because of the presumably high level of quality of the wastewater regarding suspended solids (4 to 8 ppm TSS), it was determined that filtering could be accomplished using a bag filter system. The mesh size of the filters would be adjusted for optimal performance during the test. The filter selection and design was presented to the Town at a progress meeting held on October 14, 1999 and approved.

E. **General Well Construction.** The injection well was sized to be 10 inches in diameter. The well casing diameter is primarily a function of the diameter of the screen, which needs to have enough open space to convey 350 gpm to the aquifer with minimal headloss. The well would be completed in the uppermost aquifer, since a goal of the full-scale system is to replenish the water source aquifer. Discussions were held between the Town and Stearns & Wheler

regarding the possibility of completing the well above the saturated zone. Stated benefits included less injection pressure, filtering achieved by the naturally dry sands, and the potential for the well to rehabilitate itself of biological fouling if it is shut off and returns to a dry state. Because of the importance of being able to develop and redevelop the well if it became plugged, Stearns & Wheler and the Town agreed that the well would be completed below the water table.

F. **Monitoring Program.** The original monitoring program had three components:

1. **Operational Monitoring**. Injection flow rate and pressure (water level in injection well).

2. **Hydraulic Monitoring**. Monitoring mounding by periodically checking water levels in area wells.

3. **Water Quality Monitoring**. Groundwater quality, as determined by sampling area wells, was originally proposed. Six new monitoring wells were installed on the treatment plant property, and 10 of the existing wells on and near the treatment plant property were selected for the sampling program. Monitoring well locations are shown on Figure 1. Wells were to be sampled monthly for BOD, TSS, TS, nitrate, fecal coliform, DO, ammonia nitrogen, total phosphorus, and soluble reactive phosphorus.

As the pilot test proceeded, the performance of the well necessitated that the emphasis of the test be changed from evaluating environmental impacts to evaluating operational aspects of the well. As a result, the monitoring program was modified. Because the large quantities of water originally anticipated were not injected, the water quality monitoring program was eliminated. Also, the hydraulic (mounding) monitoring program was modified. Water levels were only recorded in the three monitoring wells closest to the injection well (Wells 2-SW, 10-SW, and 100-SW). Operational monitoring (injection rate and water level in the injection well) was continued as designed.

2.3 PILOT TEST FACILITIES CONSTRUCTION

A. **Pilot Boring and Observation Well Installation.** Prior to construction of the pilot test facilities, a pilot boring for the injection well was installed and completed as an observation well, and five additional observation wells were installed. The pilot boring was installed to a depth of

67 feet. The entire section penetrated down to 60 feet was comprised of medium to coarse sand. At 60 feet, the sand became finer. A number of samples were collected for the purpose of conducting sieve analyses to determine the most appropriate interval for setting the well screen and determining the slot size for the well screen. An monitoring well, designated as PT-10SW, was installed in the pilot boring. The observation well was completed with a 10-foot screen in the interval from 39 to 49 feet.

Upon completion of the pilot boring, and Well PT-10SW, the five additional observation wells described above were installed on the WPCF property to supplement existing monitoring wells.

B. **Well Installation and Development.** The injection well was installed from October 26 to October 28, 1999 by D.L. Maher Co. Maher was contracted to provide these services because of their experience in designing and installing injection wells related to remediation activities at the MMR. Maher assisted in the well design based on our specifications; in particular, the desired flow rate. The screen slot size was also specified by Maher based on sieve analysis of sand samples from the proximal observation well, Well PT-10SW, located 10 feet away.

A diagram of the well, as constructed, is shown in Figure 2. The well is 59 feet deep. It was installed by advancing a 16-inch boring and installing a 16-inch steel casing. The 10-inch well was then installed into the 16-inch steel casing. The 10-inch injection well was constructed of 10-inch Schedule 40 PVC pipe with a 10-inch diameter, 0.100-slot stainless steel screen. The well screen was set from 36 to 58 feet, providing 22 feet of screened interval. The annular space was filled with #4 sand to a depth of 28 feet. The temporary 16-inch steel casing was removed from the boring as the well completion material was placed. A 2-foot thick bentonite pellet seal was emplaced, and the remainder of the annulus was filled with cement-bentonite grout.

The well was completed with a 4-inch Schedule 40 PVC injection tubing that extended from the surface to a depth of 37 feet. A 15-foot 4-inch diffuser pipe was attached to the bottom of the injection tubing. The purpose of the diffuser was to evenly spread the discharge across the entire length of the screen. Just above the diffuser pipe, a pressure control valve was installed which required a certain amount of pressure (water column) above it to open. This was done to provide a constant column of water in the injection tubing, which was important to prevent water from cascading into the well. Cascading allows air to be entrained into the injected water, which in turn could lead to plugging of the injection zone. The injection tubing was held in place by three sets of centralizers. A 1-inch HDPE tube extended from the flange at the top of the well to a

depth of 44 feet to allow water level measuring instruments to be lowered into the well. With the exception of the access tube, the well is pressure tight. With the access tube plugged, the well was designed to operate under a positive pressure that would allow injection at greater flow rates. It was anticipated that the well would operate under gravity flow until plugging conditions developed.

The well was developed by pumping and surging from November 1 to November 9, 1999. At first, the well was pumped at a rate of 15 gpm. The development pump was positioned at increased depths in the screen as development continued. In addition to pumping, the well was periodically surged by moving the pump up and down within the well while the pump was off. Pumping rate increased to 125 gpm, to 200 gpm, to 214 gpm. An additional pump was installed on the discharge line to increase pumping capacity and on the last day of development, the pumping rate increased to 349 gpm. When pumping at 349 gpm, the water level in the well was drawn down from 26.2 feet below grade to 32.3 feet below grade, a total of 5.1 feet.

C. **Surface Equipment and Controls**. The surface facilities for the pilot test had the following components. A submersible pump was mounted in one of the plant's two chlorine contact tanks. The wastewater treatment facility controls allowed the effluent stream at the plant to be split to either one or both of the facility's two chlorine contact tanks. For the purpose of the pilot test, approximately 0.5 mgd was diverted to Chlorine Contact Tank 2. The balance of the plant flow was discharged to Chlorine Contact Tank 1 for chlorination and discharge to the plant sand beds.

The pump speed was controlled using a variable frequency drive (VFD). The VFD received a flow rate signal at the injection well. As flow rate declined at the well as a result of filter or well plugging, the VFD would increase the pump rate to sustain a constant and preset injection rate.

A four-chamber bag filter system was located at the well. The multiple chambers allowed flow to continue uninterrupted as the bags were changed. Both 10-micron and 25-micron bags were available for the test. A flow meter with a flow volume totalizer and a chart recorder was between the filters and the wellhead.

A schematic of the system is shown on Figure 3.

Chapter 3

Pilot Test Operation

CHAPTER 3

PILOT TEST OPERATION

3.1 PHASE I

The pilot test was designed to operate continuously for a six-month period. However, within two weeks of startup, the well rapidly plugged. As a result, the test was conducted in two phases: Phase I, which lasted for 11 days, was followed by well servicing; and Phase II, which lasted for approximately 3 months.

A. **Operation.** The injection well pilot test was initiated on February 15, 2000 at the design rate of 350 gpm with filtration accomplished through 10 micron (μ) bag filters. Within two hours, as a result of the filters becoming plugged, flow slowed considerably from 350 to 90 gpm. The 10μ filters were replaced with 25μ filters in an effort to increase the running time between filter changes. The well generally operated consistently through the first several days of the test. On the first day, the water level in the well increased from 30 feet below grade to 18 feet below grade, indicating either mounding or a loss of injection pressure across the screen or formation face. After four days, the water level in the well rose to the top flange and the well began to operate under positive pressure. Injection rate could only be sustained in the 100 to 125 gpm range. After water began seeping from the top of the well through the water level observation tube, it was shut off twice to let water levels recover. Both times, the well pressurized immediately upon being restarted, and sand surrounding the well at the surface began to cave in, with the resultant hole (2 to 3 feet across, 1 to 2 feet deep) filling with water.

It was not clear initially whether the increase in water level in the well was a result of hydraulic loading (mounding) or a result of plugging. To determine the cause, the well was shut down, the water level was allowed to recover, and the well was restarted at lower flow rates. However, even at lower flow rates, the well no longer accepted water. This indicated that the well had become plugged rather than simply filling up as a result of hydraulic loading.

After 11 days of operation, the injection well was shut down since the well or formation no longer accepted injected water. In that time period, 2.2 million gallons of water had been

injected. The water level within the injection well through the course of the first eleven days is shown on the graph on Figure 4.

B. **Evaluation of Phase I Performance.** It had become evident that the well screen or formation face had become plugged. Based on the literature review, there were four possible plugging mechanisms: (1) biological plugging; (2) plugging by total suspended solids in the water; (3) air entrainment; and (4) chemical precipitation in the injection zone. Each of these plugging mechanisms had been considered prior to startup, and in all likelihood, each was contributing to the plugging of the well to some degree. The goal was to determine which was causing the greatest impact and reduce those impacts. Each plugging mechanism was evaluated as follows:

1. **Biological**. Biological plugging, i.e., the growth of bacteria at the well screen or aquifer face, was considered to be the most likely source of the plugging. Literature reported that this is the most frequent source of plugging whether it be in effluent disposal wells, groundwater treatment system wells, or potable water storage wells. Bacteriological growth is common as oxygenated water is injected into formations where there are indigenous bacteria. In the case of treated effluent, elevated levels of nutrients can also serve to make the bacteria flourish. The most effective means of combating bacteriological growth is through the use of a chemical disinfectant such as chlorine. Due to concerns related to resultant groundwater quality, as expressed in the December 1998 meeting, MADEP would not allow chemical disinfectant to be used, since the effluent was being injected into a potable water supply aquifer. As a result, disinfection was accomplished through the use of a UV disinfection system. Although the UV system did serve to disinfect the effluent, the effluent still carried nutrients and oxygen to the aquifer where natural bacteria could thrive.

Iron-forming bacteria commonly thrive under these conditions; however, a sample of the slime on the screen was collected and tested and found not to be an iron-forming bacteria, but a common slime bacteria (*Klebsiella oxytoca*).

2. **Total Suspended Solids**. Suspended solids entrained in the effluent was a known plugging mechanism. Filtration was included in the system to eliminate as many of the solids as possible; however, the project budget limited filtration to the use of a bag filter system. When plugging first became evident, the TSS concentration in the injected water

was measured and found to be 6 mg/L after passing through 25μ filters. Case studies suggested that a target TSS load should be less than 2 mg/L with filtration down to 10μ. Although the test was started with 10μ filters, flow could only be sustained for a short period of time and larger mesh filters were used. Efforts were made to use 25μ filters, but 75μ and 100μ filters were also used during Phase I to evaluate performance under those conditions. Because the size and concentration of TSS was elevated compared to recommended levels, plugging as a result of TSS loading was considered likely.

3. **Air Entrainment.** The injection well design took into account the fact that entrained air can plug the pore space in sandy aquifers just as solid particles can plug pore space. To minimize the impacts of entrained air, the injection tubing was designed with a pressure control valve at the bottom that would only open with a specific head of water over it. This would result in creating a standing column of water in the injection tubing, minimizing cascading and the entrainment of air into the system. Although the performance of this device could not be verified, it was believed to be functioning as designed, with air entrainment being a minor cause of plugging, at the very least.

4. **Chemical Precipitation.** Chemical precipitation was also a potential cause of plugging. Prior to starting the pilot test, the chemistry of the natural groundwater, the treated effluent, and the aquifer matrix material was evaluated and results were compared. Analytical data is summarized in Table 1. Particular attention was paid to dissolved oxygen (DO), pH, and iron. Concerns lie in the fact that if the effluent contains high levels of DO or has a high pH, dissolved iron in the natural groundwater would come out of solution and precipitate on the well screen or on the formation pore space, plugging the passage of water. A review of the data indicates that the pH, iron content, and DO of the effluent and groundwater were generally consistent, and that no notable chemical reaction should have occurred that would significantly impact the performance of the well. As a result, it was concluded that although some chemical precipitation may be occurring, it is not the most likely cause of plugging.

C. **Well Chlorination/Restoration.** After review of the Phase I results, it was decided to service the well and resume a modified pilot test. The well servicing involved injecting chlorine into the well to treat the plugged screen and formation pore space and to redevelop the well to remove fines that might be plugging the screen or formation. The well servicing proceeded as described below.

When the well was opened, it was discovered that 20 feet of sand had accumulated in the well, virtually plugging off the entire screened interval. When the sand was removed, a TV camera survey was conducted to evaluate the condition of the screen. Because of the amount of sand that was present, it was initially believed the screen must have broken. The TV camera showed that not only was the screen fully intact, but it was clear, indicating that there was little buildup of biological material that would have plugged the screen. After the well was cleaned out, it was treated with a 1,000 ppm chlorine solution.

Following treatment, an attempt was made to redevelop the well. After pumping at 30 gpm for 2 minutes, the well went dry, yielding no more water and indicating that the formation was still plugged. The well was treated a second time with 8,000 gallons of 6,000 ppm chlorine solution. Following the second treatment, redevelopment was attempted again. This time, the well again yielded 350 gpm with 10 feet of drawdown, performance similar to the initial development of the well. The success of the chlorine treatment led to the conclusion that although multiple plugging mechanisms were probably contributing to the well's diminished performance, the biological plugging of the formation face was apparently the most significant factor.

With the well performance regained, a plan for continuing the pilot test was developed.

3.2 PHASE II

A second phase of testing included a step test, injecting potable water at steadily increasing rates. Injecting potable water would allow an assessment of the hydraulic impacts of injection alone, without disruption by water quality factors associated with injecting treated effluent. Following the potable water step test and depending on the results of that test, the pilot test with treated effluent would be resumed, preferably with improved filtration and disinfection implemented. Data gathering was enhanced by the addition of one additional monitoring well, 2 feet away from the injection well. The purpose of this well was to evaluate the change in head between the inside of the well and just outside the gravel pack to determine where the plugging may be occurring. The proximal observation well would provide data to suggest if the plugging was occurring at the formation face or deeper into the formation.

Evaluation of Phase I operations, the well servicing, and the planning for Phase II took place through the summer of 2000. On September 6, the pilot test was resumed. Potable water was obtained by piping water from a fire hydrant into Chlorine Contact Tank 2. The rest of the test

and equipment was used in the same way as Phase I. Filtration of the potable water was continued using 10μ filters throughout the test.

The well was operated for approximately one month at 50 gallons per minute. During that time period, water level in the well and the depth to the bottom of the well were recorded on a daily basis. The depth of well measurements was conducted to determine if there were any accumulations of sand in the well. During the first 30-day period, the depth to water in the well increased steadily from 29 feet below grade to 17 feet below grade. A plot of water levels in the injection well, as well as neighboring monitoring wells, is presented as Figure 5. There was no accumulation of sand in the bottom of the well. The buildup of injection pressure, as indicated by the rise in water level, was attributed to three possible factors:

1. The potable water has some TSS content as indicated by the fact that filters were still being used and accumulating solids out of the potable water supply.

2. The potable water may have had a DO level that would have caused the growth of bacteria, similar to the effluent.

3. For a short period of the test, in order to accommodate the needs of the plant, it was necessary to pipe water directly from the fire hydrant to the filters and well, bypassing the chlorine contact tank and submersible pump. The flow characteristics directly from the hydrant were different than from the submersible pump, presumably more turbulent and aerated. When it was discovered that flow directly from the hydrant may have been adversely impacting the well performance, the test was suspended until the chlorine contact tank could be used again.

When normal pumping could be resumed, the injection rate was increased to 100 gpm on October 9 for a period of 14 days, ending on October 24. During the 100 gpm period, the water level in the well steadily increased from 17 feet below grade to 7 feet below grade.

On October 24, the pumping rate was increased to 150 gpm. Until November 1, the water level in the well increased steadily until it reached the top of the well. At that point, the pumping rate was returned to 100 gpm and was continued at that rate until November 21. During that time period, the water level in the well fluctuated between 1.5 and 7 feet below grade, with water returning to a lower level in the well near the end of the test.

Following a presentation to MADEP on October 31 and subsequent conversations with MADEP on present agency policy prohibiting chlorine treatment of injected effluent, the pilot test was suspended on November 21, 2000. During Phase II, approximately 6.9 million gallons of water were injected.

Chapter 4
Evaluation of Results

CHAPTER 4

EVALUATION OF RESULTS

4.1 SUMMARY

The pilot test was originally designed to inject 350 gpm of effluent for a six-month period with operational and environmental factors being tested. As a result of the performance of the well, the pilot test scope was modified. The test operated for approximately 3-1/2 months, with operational factors being the entire focus of the test. Although the test was not completed as originally planned, a great deal of valuable information regarding the operation of an injection well in Barnstable's hydrogeologic environment was obtained. The results from the pilot test are both conclusive and non-conclusive and suggest additional pilot testing would be needed prior to any full-scale implementation.

4.2 PILOT TEST OBSERVATIONS AND RECOMMENDATIONS

A. Plugging by Biological Fouling (Biofouling).

1. **Observation.** The severe plugging of the injection well and its rehabilitation through high concentration chlorine treatment suggests that biological fouling was the most significant cause of plugging.

2. **Recommendation**. Injected wastewater needs to be disinfected prior to injection. Disinfection using chlorine is a standard practice in the underground storage of potable water (aquifer storage-recovery, or ASR) applications, as well as in wastewater injection facilities in Florida and California. The need for disinfection was recognized during the research and design phase of this project. Because of concerns related to the formation of disinfection by-products (DBPs) and their potential migration into water supplies, MADEP made the determination that chlorination at the levels needed (3 to 5 ppm) would not be acceptable (meeting with MADEP, December 1998). Treated wastewater at the treatment plant that is recharged via sand infiltration beds is treated to 1 ppm.

Prior to the pilot test (meeting with MADEP, December 1998), MADEP indicated that disinfection could be achieved through UV treatment. Although the UV treatment does disinfect the waste stream, the pilot test revealed that simply disinfecting the waste stream was not sufficient. It was learned through the pilot test that a disinfectant residual is needed in the injected waste stream, especially with injection into an aquifer with its own population of natural microbes. Although the injected waste stream itself is disinfected, it is still a nutrient- and oxygen-rich stream that may make the indigenous microbes flourish. With no disinfectant residual, the potential for biofouling increases.

Biofouling was not necessarily unexpected, as plugging through microbial growth is the most common cause of the loss of injectivity in injection wells. Future pilot testing and full-scale installations, if undertaken, will require disinfection through chlorination or a combination of chlorination and UV disinfection. A discussion on the management of disinfection by-products is provided below (paragraph E.1, Regulatory Concerns).

B. **Plugging by Buildup of Solids.**

1. **Observation.** Although the success of the chlorine treatment suggested the limiting factor affecting plugging was the result of microbial growth at the formation face, injection of fine-grained particulates was also a likely contributor. As stated previously in this report, the majority of the test was conducted using 25μ bag filters. This resulted in a solids loading of 6 ppm TSS. This is compared to the target level of 10μ filtration to 2 ppm TSS.

2. **Recommendation.** For future pilot testing and full-scale installations, enhanced filtration will be necessary. Sand or multimedia filters are most typically used in injection well installations. Multiple units are used to accommodate design flow rates and to allow cycling from one unit to another to permit continuous operation. An operational consideration with sand filters is the need to backwash the filters and manage the backwash water. At a wastewater treatment plant, returning the backwash water to the headworks is a reasonable method. Cartridge filters have also been used successfully, although cartridge replacement can be a significant O&M cost. Membrane filtration is the most effective treatment, becoming more frequently utilized as the number of water reclamation and recharge projects increases. Membrane filters can reduce particle size to .2 microns and can even filter out protozoa, bacteria, and some viruses.

C. **Plugging By Air Entrainment.**

1. **Observation.** It is possible that air entrainment contributed to plugging. Severe plugging occurred during Phase I, and to a lesser extent during Phase II of the pilot test. Although it is not possible to determine the degree to which each of the potential plugging mechanisms (biological, solids, chemical precipitation, or air entrainment) contributed to the plugging, each may have contributed to some extent. As stated previously, the well was designed to retain a standing column of water in the injection tubing to minimize cascading. Although it is not certain, it is possible that at the time hydrant water was discharged directly to the well in Phase II, excessive turbulence could have resulted in the entrainment of air.

2. **Recommendation.** Like the pilot test well, future wells must be designed to minimize cascading. Additionally, pumping or conveying wastewater to the well must be done in a manner that minimizes turbulence and aeration. The positive displacement pump used for the majority of the pumping test met that criteria.

D. **Disruption of Aquifer Materials and Injection Pressure.**

1. **Observation.** During Phase I, surface soils around the injection well began to cave in. A depression 2 to 3 feet in diameter and 1 to 2 feet in depth formed at the wellhead and filled with water. Initially, the cause of the depression was not known. When the well was opened for servicing, approximately 20 feet of sand was encountered in the screen. Based on the observations and the well performance, the following conclusions were developed. The formation face became plugged due to the buildup of microbial material. Because the plugging prevented the water from entering the formation, the injected water began circulating between the formation, the gravel pack, and the well screen. This circulation drew fine sand particles smaller than the screen slot size into the well, further reducing the injectivity and causing the collapse of the surface soils. Similar occurrences were identified in literature following the observation of this phenomenon during the pilot test. Based on the findings of prior cases, Demicco (1994) recommended that injection pressure be limited to 1/10 of a foot for every foot of saturated thickness within the aquifer above the well screen.

2. **Recommendations.** The injection pressure must be minimized to reduce the chances of fluidizing and mobilizing the sands in the screened interval of the well. The rule of thumb regarding injection pressure and saturated thickness should be regarded. Greater injection pressures can be used if the screened intervals of the injection well are installed as deep into the aquifer as feasible while meeting the other goals of the project; in this case, reclaiming water for future use. Minimizing turbulent flow and injection pressure at the formation face can also be achieved by maximizing the well diameter, well screen length, and screen slot size, as long as the purpose of the screen to hold out fines is not compromised.

E. Disinfection By-Product Fate and Migration.

1. **Regulatory Concerns.** MADEP has regulatory review and approval over the work that was completed as part of the pilot test operation. The subsurface discharge of treated effluent requires a groundwater discharge permit. The Hyannis WPCF site was chosen for the pilot test because administrative approval of the test could be obtained without filing an application for a new groundwater discharge permit.

As indicated previously, MADEP objected to the use of elevated levels of chlorine and required the use of UV disinfection. The plant presently treats recharged wastewater to approximately 1 ppm residual chlorine. Typical injection projects use a residual concentration of 3 to 5 ppm. Although MADEP does not specifically prohibit chlorination, and there is no regulation prohibiting chlorination, it is MADEP's policy to limit the concentration of chlorine in recharged groundwater due to concerns about the fate of the chlorine and associated DBPs. Using chlorine to treat water with organic content has the potential to form the DBPs haloacetic acids (HAAs) and trihalomethanes (THMs). Because these by-products have been identified as carcinogens, their presence in a potential drinking water source is of concern to the regulators. As of December 16, 2001, USEPA established MCLs of 80 μg/L and 60 μg/L for THMs and HAAs, respectively.

Based on the observations made during the test, the well lost its injection capacity due to excessive biological fouling. At the conclusion of the pilot test, the need for disinfection through chlorination was reported to MADEP.

2. **Response**. In 1993, a study was completed (Singer et al., 1993) that evaluated the fate of these DBPs upon injection into the subsurface. The investigation was conducted to evaluate the quality of drinking water injected into the ground for storage and future recovery for distribution. In this study, it was observed that THM concentrations, initially in the 70 to 90 μg/L range, decreased to nondetect levels within nine days of injection. HAA concentrations, initially in the 40 to 50 μg/L range, decreased to nondetect levels by the 56th day. No residual chlorine was detected in the recovered water after one day.

The study further evaluates the geochemical conditions in the aquifer that contribute to the degradation of the DBPs. Rather than having the disinfection of treated wastewater prohibited due to concerns related to the fate of DBPs in potential water sources, future pilot testing should be conducted which includes chlorination and monitoring for DBPs in groundwater at various distances from the injection well.

F. **Nitrosodimethylamine**.

1. **Regulatory Concerns.** Upon hearing of the pilot test results and recommendations for disinfecting treated wastewater, MADEP evaluated concerns related to the fate of DBPs, including discussions with operators of wastewater injection well facilities. That evaluation revealed newly identified concerns related to another disinfection by-product, nitrosodimethylamine (NDMA).

NDMA has only recently (1998) been identified as a contaminant and there is not yet a MCL or standard. California recently established an action level of 2 ng/L, but increased the action level to 20 ng/L (Bloetscher, 2001). NDMA is not a manufactured chemical in the United States; it is a by-product of some manufacturing processes and has entered the environment as a result of its formation in that manner. NDMA has been detected in raw water at southern California water production facilities. Investigations also found NDMA in chlorinated wastewater and in potable drinking water. Research has concluded that NDMA can form as a result of water or wastewater disinfection. In the case of wastewater, the formation of NDMA appears to be related to the presence of nitrate, nitrites, and ammonia. Detection of elevated levels of NDMA at Water Factory 21 in California, a water reclamation facility using injection, has resulted in the requirement of routine monitoring for NDMA.

2. **Response.** NDMA can be reduced or eliminated at two points in the treatment process. Either the precursors to NDMA formation, the nitrogen compounds, can be significantly reduced through high levels of filtration; or NDMA can be destroyed through UV disinfection. The high levels of treatment could also serve to minimize the formation of THMs and HAAs.

Chapter 5

Conclusions and Recommendation

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

The pilot test demonstrated that injection wells can not be operated for any extended period without high levels of filtration and disinfection using chlorine. To be considered a viable technology for the recharge of treated wastewater, the injection facility would require:

- high levels of filtration, that is filtration to less than 10 microns; and

- disinfection using chlorine that results in a residual concentration of chlorine entering the injection zone to minimize bacteriological growth that causes formation face plugging. Precedent projects indicate an operating range of 3 to 5 parts per million chlorine with periodic treatment with higher concentrations is likely to be needed.

Based on these requirements, the pilot test demonstrated that injection wells can not be considered a viable technology for this site at this time. MADEP does not presently allow chlorination of treated effluent with concentrations of chlorine needed to limit microbial growth to the extent that would make plugging impacts economically manageable.

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Tables

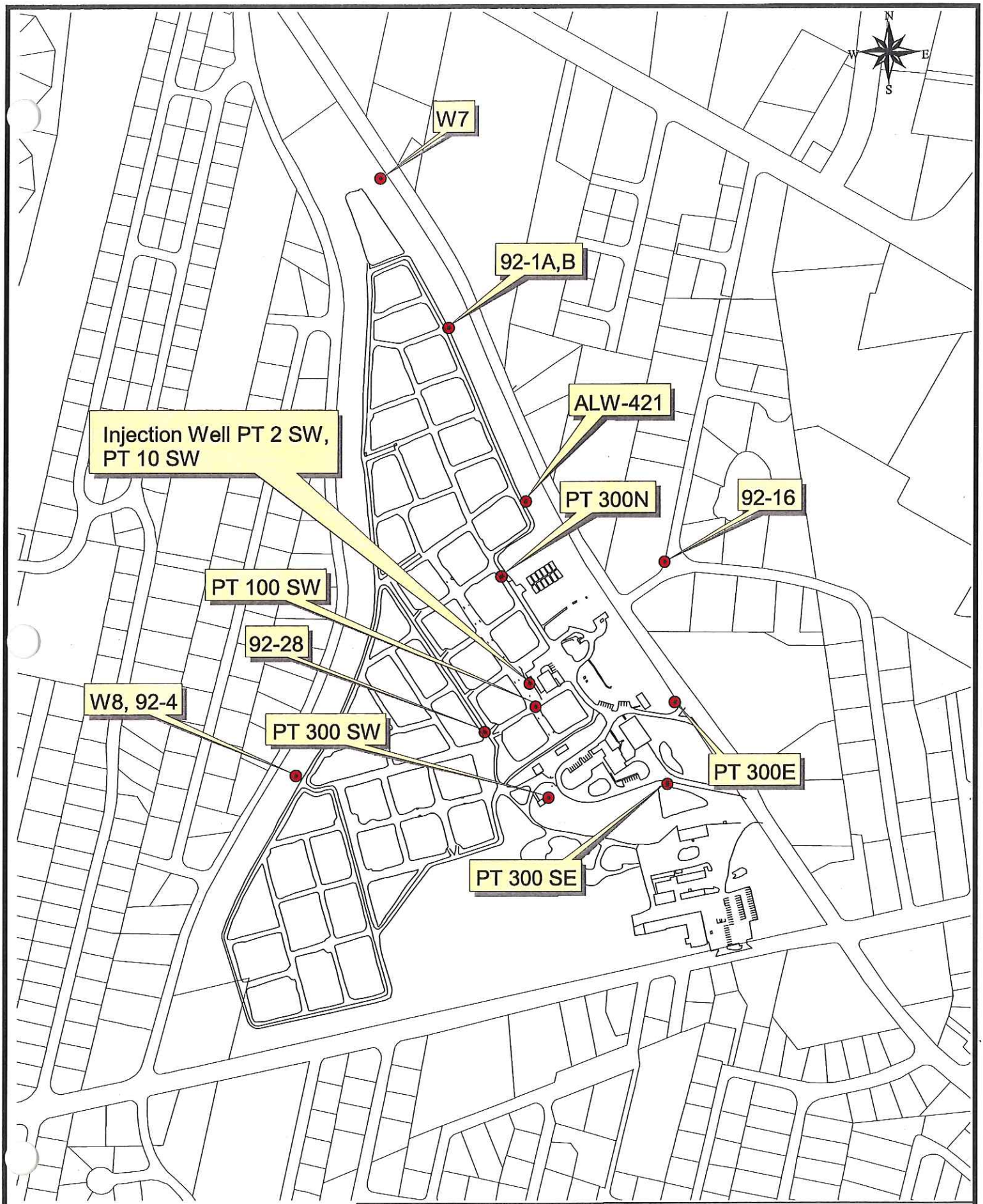
Table 1
Town of Barnstable
Injection Well Pilot Test
Water Quality Summary
(Including aquifer matrix analysis)

	Date	Sampling Location	DO*	pH*	BOD	TSS	TS	NH3	NO3	Coliform	Total PO4	Reactive PO4	Iron	Copper	Manganese	Sodium	SO4	Cl	Alk
Pilot Test Obs Wells (Background groundwater quality in area of injection pilot test)	12/14/99	10SW	5.70	6.32	0.00	7.00	392.00	0.04	6.10	<1	7.15	6.40	0.30						
		300SE	4.10	7.56	0.00	2.00	342.00	0.43	1.90	1.00	2.73	2.41	1.00						
		92-2B	6.50	7.34	0.00	<1	352.00	0.05	5.90	<1	6.00	5.10	0.50						
		92-1B	6.60	7.89	0.00	5.00	250.00	0.08	6.10	<1	0.34	0.26	<.1						
		C2	5.10	7.69	4.72	4.00	646.00	0.54	<1	<1	1.42	0.86	9.60						
		92-4	na	7.69	0.00	10.00	442.00	0.16	6.00	<1	1.31	0.50	0.40						
WPCD Monitoring Wells (Background groundwater quality farther away from injection pilot test)	12/16	BA1		6.70				0.98	0.10				0.20	<0.1	0.04	0.70	27.00	62.00	
		BA2		6.60				0.05	2.50				0.10	<0.1	0.65	0.66	30.00	69.00	
		BA3		6.50				0.04	1.90				0.10	0.10	0.70	0.75	28.00	70.00	
		BB1		6.10				0.35	2.90				0.20	0.10	0.10	0.43	20.00	59.50	
		BB2		5.27				0.06	5.40				0.20	0.10	0.29	0.14	9.00	20.50	
		BB3		5.95				0.04	<.1				0.40	0.10	0.09	0.12	13.00		
		BC		5.80				0.22	4.60				0.30	0.10	0.09	0.55	12.00	85.00	
		BD		6.40				7.13	0.30				0.20	0.10	0.01	0.61	20.00	62.50	
		BE		5.12				0.14	1.40				0.30	0.10	0.01	0.22	19.00	27.00	
Effluent (Quality of injected water)	4/3	Eff1	6.07	7.17	0.77			0.05	3.60										78.00
	4/12	Eff2	6.17	7.15	5.80			0.04	2.30										76.00
	4/28	Eff3	6.30	7.15	3.13			0.12	3.00										80.00
	5/12	Eff4	6.13	7.15	7.82			0.89	2.40										98.00
	3/15	Eff5				6.25 (1)													

* with respect to effluent, DO and pH are collected in Cl contact tank. All others collected before Cl contact tank. (note: BOD is prior to disinfection)
(1) TSS for effluent is after 25u bag filter, ahead of filter (from Cl tank) was 7.25u

		Depth	K	Ca	Fe	Mn	Mg	Al	Si
Aquifer Matrix (solid) Concentrations in ppm	8/18/99	15-17'	130.00	<100	2700.00	46.00	320.00	1000.00	680.00
		45-47'	140.00	<100	960.00	5.10	120.00	470.00	420.00

Figures

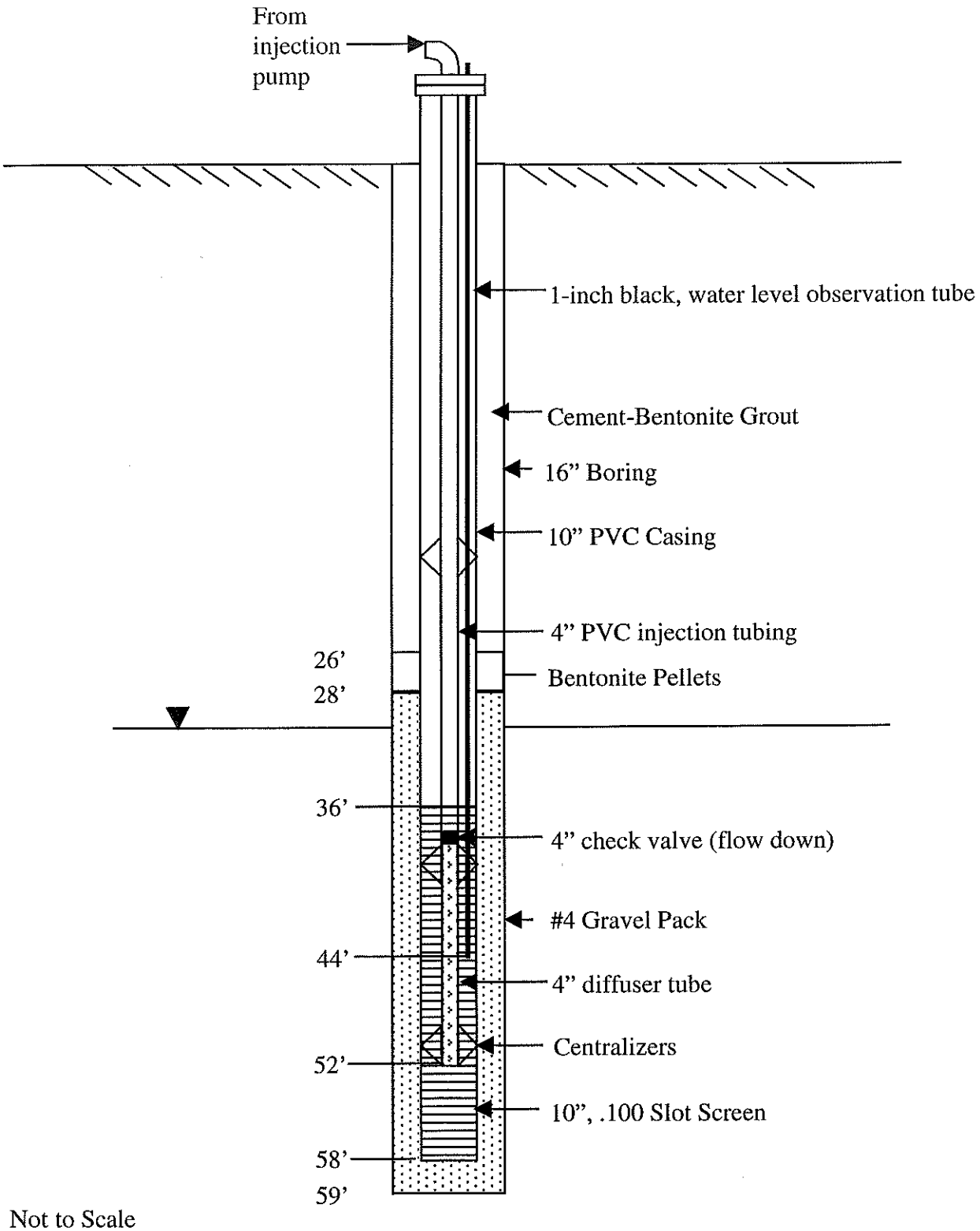


Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS

JOB NO.: 90190 DATE: 3/3/03

TOWN OF BARNSTABLE, MASSACHUSETTS
INJECTION WELL PILOT TEST

FIGURE 1
PROJECT MONITORING WELLS



Not to Scale

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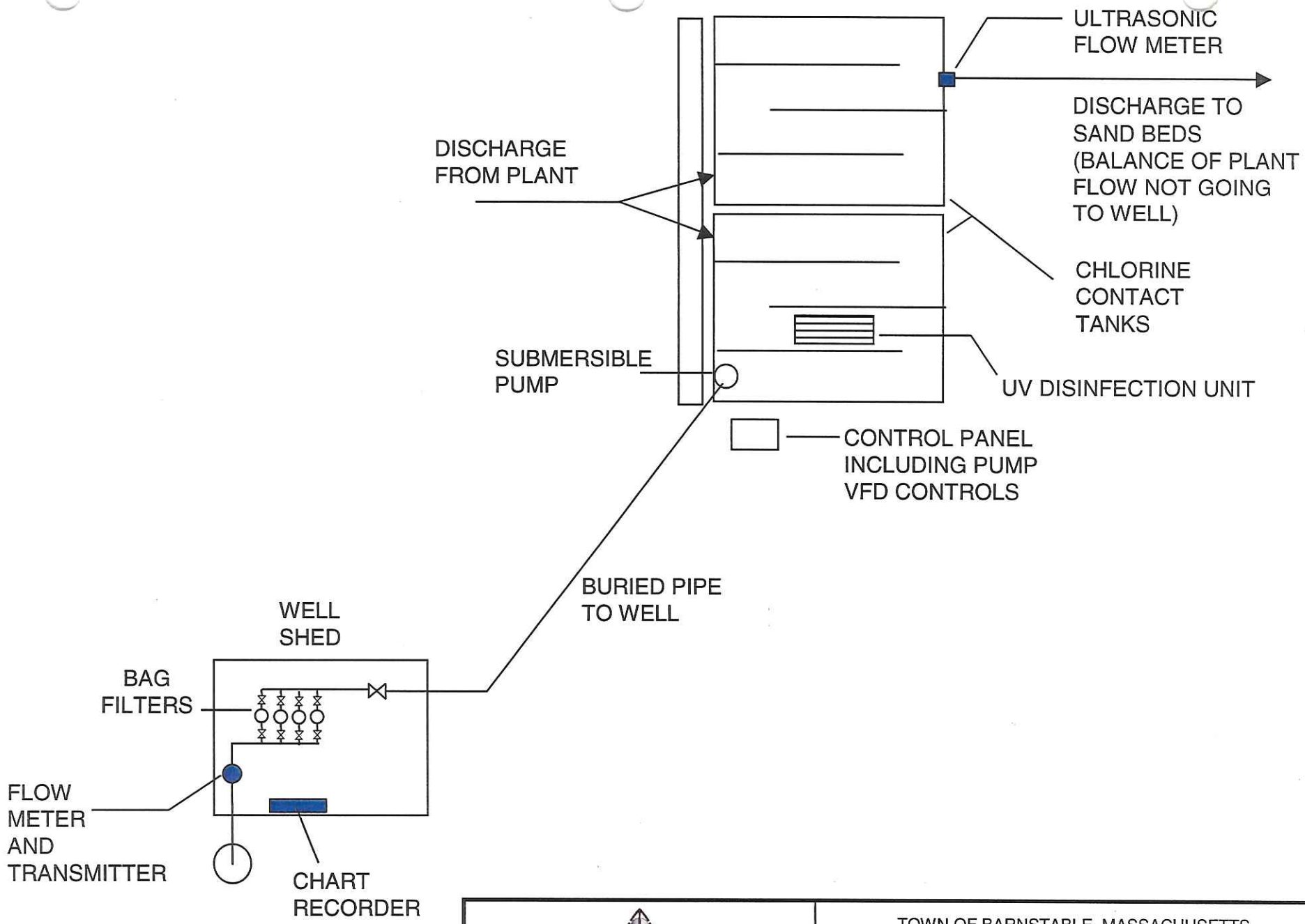
DATE: 9/02 JOB No: 90190

TOWN OF BARNSTABLE, MASSACHUSETTS
INJECTION WELL PILOT TEST

FIGURE 2
INJECTION WELL WELL SCHEMATIC



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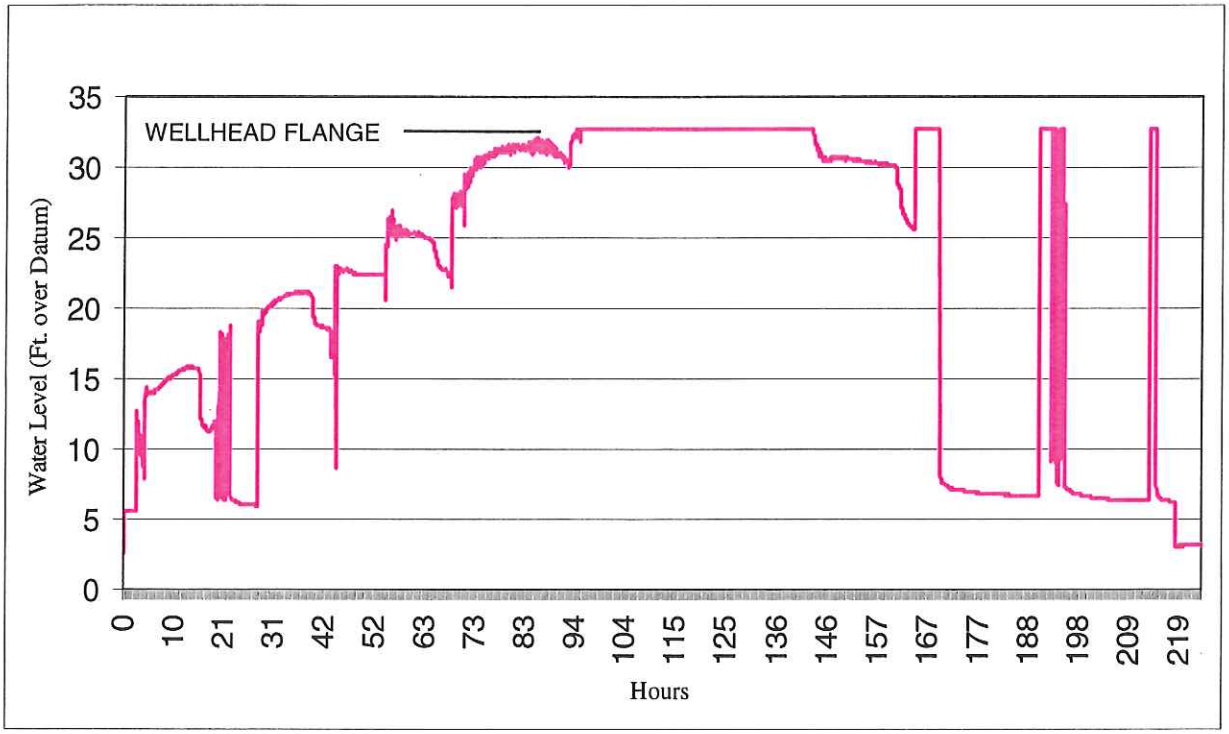
TOWN OF BARNSTABLE, MASSACHUSETTS
INJECTION WELL PILOT TEST

FIGURE 3
SYSTEM SCHEMATIC



WATER LEVEL IN INJECTION WELL

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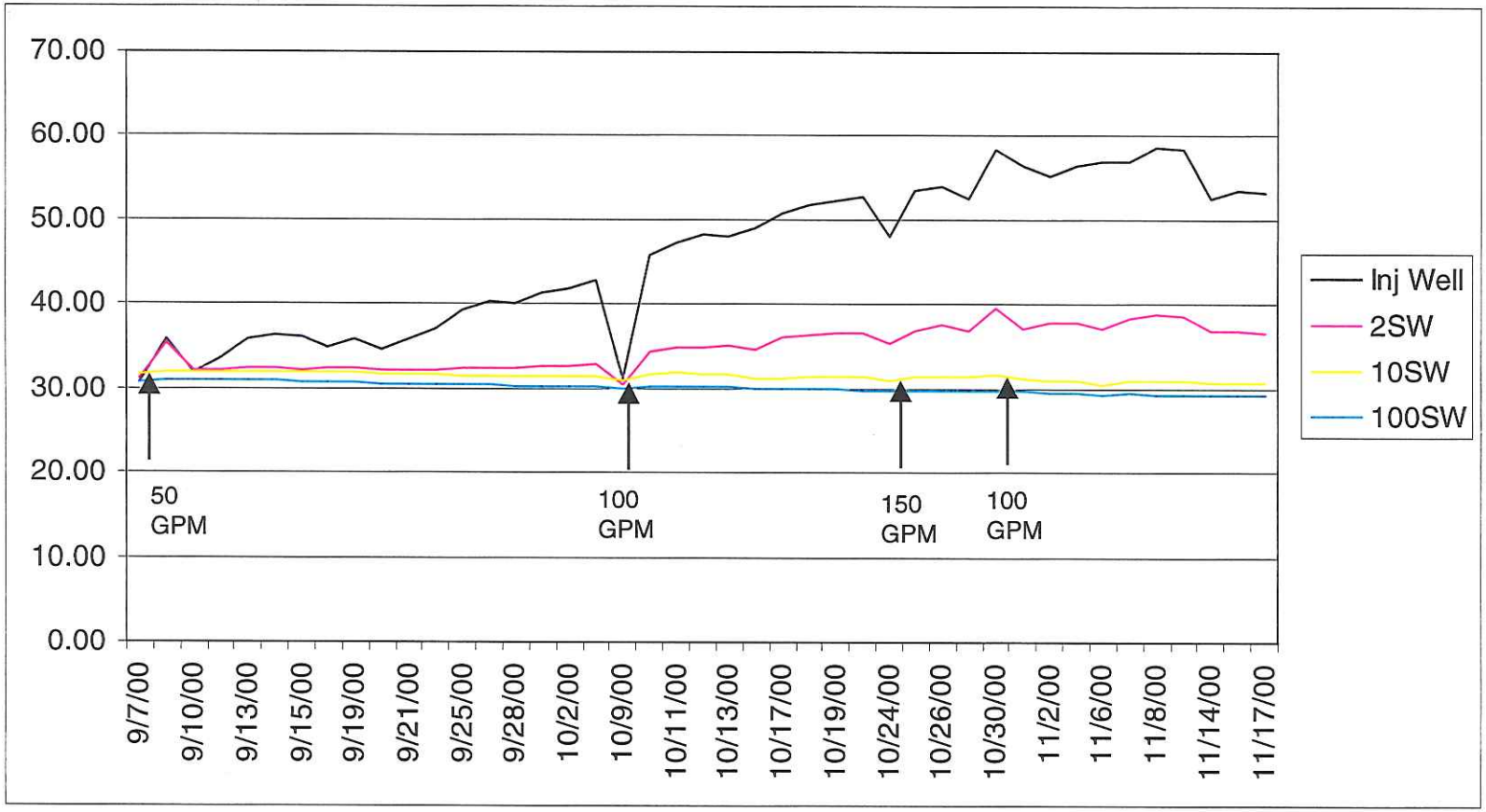
TOWN OF BARNSTABLE, MASSACHUSETTS
INJECTION WELL PILOT TEST

FIGURE 4
PHASE I RESULTS



Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS

DATE: 9/02 JOB No: 90190

TOWN OF BARNSTABLE, MASSACHUSETTS
INJECTION WELL PILOT TEST

FIGURE 5
WATER LEVELS IN INJECTION AND AREA WELLS

Appendix A
Injection Well Technology

APPENDIX A

INJECTION WELL TECHNOLOGY

GENERAL SUMMARY

Prior to proceeding with design and execution of the injection well pilot test, a review of the existing application of the technology was completed. The purpose of the technology review was to review how injection wells are being used, in what geologic environments injection is occurring, and which design considerations have to be included in the test based on existing operations.

Subsurface injection of water is generally practiced for a number of reasons, including groundwater control, solution mining, waste disposal, and recovering geothermal energy. Subsurface injection of municipal wastewater is a common practice in Florida and California but the application of this technology has little precedent in the northeast. Industrial hazardous wastes are disposed of using injection wells in the Gulf Coast region and in the Great Lakes area. Oil field brines are disposed of via injection wells in most of the oil-producing regions of the country, including the Gulf Coast region, the mid-Atlantic region, Ohio, and Michigan. These practices are different from the wastewater reinjection that Barnstable is considering because the wastes are disposed of in consolidated rock layers several hundred or several thousand feet deep, into aquifers that have been demonstrated to be geologically isolated from aquifers used for water supply (underground sources of drinking water [USDWs]). Injection in these situations is into groundwater with greater than 10,000 ppm total dissolved solids (TDS) that is not suitable for use as a water supply.

In Florida, municipal wastewater is disposed of via injection wells into consolidated rock. Some disposal occurs in the Floridan Aquifer, which is a potential water supply aquifer; in the Biscayne Aquifer which, remote from injection sites, is a utilized water source; and into the Boulder Zone, a saline aquifer with no use potential. Municipal wastewater injection has been pilot tested on Long Island and utilized for decades in California to mitigate salt water intrusion. Locally, reinjection of treated groundwater is taking place at Otis Air Force base on Cape Cod.

Although none of these situations match the Barnstable project in all aspects (injecting municipal wastewater into a shallow, unconsolidated, utilized aquifer at rates up to 1,000 gallons per minute [gpm]), each situation did offer information, which helped evaluate the feasibility of injection at Barnstable. Four different injection scenarios that were considered prior to proceeding with and designing the Barnstable pilot test are discussed below.

MUNICIPAL WASTEWATER INJECTION – FLORIDA

Deep well injection of treated wastewater has been practiced in Florida for over 25 years. Currently, there are approximately 47 injection wells in southern Florida. Injected water must either meet primary drinking water standards at the point of discharge or be into an aquifer with groundwater containing a TDS concentration of 10,000 ppm or more. In Broward County, 18 injection wells dispose of 110 mgd of treated wastewater (an average of 6 mgd, or 4,200 gpm per well). In Florida, these wells are regulated as Class I wells, a designation typically assigned to hazardous waste disposal wells. Literature describing the use of this technology claims a disposal cost of approximately $0.23/1,000 gallons. This was compared to $0.38/1,000 gallons for an ocean outfall. In Florida, tertiary treatment (advanced wastewater treatment) is required for surface discharge. This can bring the cost of surface discharge to $1.50/1,000 gallons.

The North Regional Facility of Broward County injects about 60 mgd through four 24-inch injection wells spaced about 300 feet apart. Wastewater is injected into the Boulder Zone at a depth of about 3,000 feet. The Boulder Zone is a saline aquifer approximately 2,500 feet deeper than the Biscayne Aquifer, the source of water in the area. Prior to injection, the wastewater undergoes secondary treatment. BOD is reduced to approximately 5 ppm, and TSS is reduced to less than 5 ppm.

There are currently two hurdles to the operation of wells in Broward County. Despite injection into extremely fractured rock, the facility has experienced formation plugging and a buildup of injection pressure, which reduces the injection capacity of the system. Various treatments are applied to maintain the injectivity of the system. Batch superchlorination aids in cleaning up biological slimes that collect on the well casing and injection face. Backflushing is used to clear up the vugs and fractures into which the wastewater is being injected. Because of the pressure in the injection zone, the wells will backflush themselves. Physical treatment (i.e., scraping the casing) has proven to be somewhat effective. Physical and chemical treatment of the injection zone (acidizing or scraping) has not been particularly effective.

Greater levels of treatment are not considered economically feasible. Filtering and high-level disinfection, currently not part of the process, could amount to a plant upgrade that would cost between $100 and $150 million at the North Regional Facility. Currently, there is no nutrient removal, but that is not considered to be an operational issue.

The second hurdle relates to regulatory and public acceptance of the technology. Although wastewater injection wells have been used for nearly 25 years and are permitted by the state, recent negative public opinion has resulted in enhanced scrutiny by USEPA and FDEP. USEPA has been sued by the Legal Environmental Assistance Foundation (LEAF) because of the potential environmental and health effects of deep well injection. USEPA is responding to the suit and FDEP is also evaluating the suitability of the technology. The concern of LEAF is that it cannot be demonstrated that the Biscayne Aquifer and the Floridan Aquifer (still defined as a USDW although not used as a source of potable water in this area) are hydraulically isolated from the injection zone.

The City of Hollywood, Florida is currently investigating the potential use of treated effluent to mitigate salt water intrusion by injection into the Biscayne Aquifer. Because of the increased use of groundwater in coastal Florida, groundwater levels near the coast have dropped about 4 feet, resulting in salt water intrusion inland. There is some concern about the Hollywood plan. A pilot test using treated effluent was being considered, but was deferred until a pilot test using potable water was first completed. Hollywood is proposing injection at a sufficient depth (135 to 165 feet) so that injection will be into an aquifer with groundwater having a TDS concentration greater than 10,000 ppm, the regulatory threshold defining a USDW. Twelve injection wells are planned to be located 1/4 mile apart and each is designed to handle 1 to 1.5 million gallons per day. The aquifer is highly transmissive (between 5 and 10 million ft^2/day), thus allowing such high injection rates. The Biscayne Aquifer is a highly fractured and vugular limestone. In the opinion of the operator, the greatest hurdle to maintaining an effective injection system is the buildup of biological slimes and plugging. Avoiding iron-based tubulars was recommended to mitigate buildup of iron bacteria. Physical plugging is not considered to be as significant an issue.

Wastewater injection in Florida differs from wastewater injection on Cape Cod in that:

- Injection in Florida is to a depth of approximately 3,000 feet, below any USDWs and most likely separated from the USDWs by confining layers, as compared to the injection depth of 60 feet for the pilot test.

- Injection is into consolidated fractured rock rather than unconsolidated sands.

- Injection is through open hole completions rather than through well screens, as would be required in Barnstable.

- Water table mounding is not an issue because the water table is isolated from the injection zone.

Similarities include the like chemistry of the two wastewaters; both undergo secondary treatment; TSS loading and plugging of the receiving zone are concerns that have to be managed; and regulatory and public acceptance may be an issue.

TREATED GROUNDWATER REINJECTION – MASSACHUSETTS MILITARY RESERVATION (MMR)

Since August 1997, MMR has been operating a groundwater pump-and-treat system that reinjects treated groundwater back into the subsurface using injection wells. At the time of the review, the system operated at a flow rate of approximately 350 gpm (.5 mgd). Groundwater extraction was accomplished with ten 8-inch withdrawal wells. Eight operated at 30 gpm and two operated at 57 gpm. Injection was through eight 6-inch wells operated at approximately 44 gpm. The injection wells are spaced in two lines with four wells in each line. Wells in each line are separated by 50 to 100 feet and the two lines are separated by a space of about 500 feet. The two lines of injection wells are located at either end of the line of extraction wells and are approximately 200 feet downgradient. The depth to water at the injection site is approximately 40 feet. Mounding of approximately .5 feet was observed despite the proximity of the injection wells to the withdrawal wells. The wells are 45 to 95 feet deep and are screened over the bottom 40 feet of the well. The well screens have slot sizes of .050 or .030 inch. The injection interval has a hydraulic conductivity of approximately 300 feet per day. The injection wells are constructed of PVC with gravel packed stainless steel screens. Extracted water was treated for

VOCs using activated carbon. Water is treated with potassium permanganate to raise the pH in order to precipitate iron and manganese. Prior to precipitation, there was approximately 1.7 ppm total iron and manganese. Following precipitation, that concentration was reduced to approximately .02 ppm. The water is filtered through a green sand filter before injection. Precipitation is performed ahead of all treatment systems to minimize plugging in the carbon. Biodegradation of petroleum products in the treated plume resulted in higher than background levels of metals in the influent groundwater coming into the treatment system.

Despite the precipitation of metals and filtering, some plugging of the injection wells had been observed. The reduction in injectivity was attributed to encrustation of the well screens and plugging of the aquifer matrix. The plugging was attributed to possible additional precipitation as a result of a higher oxygen content in the injected water. No analyses had been performed to characterize the plugging. As the wells inject by gravity flow, the plugging was indicated by an increase in the water level in the wells rather than a buildup of injection pressure.

Injection at MMR differs from potential injection at Barnstable because:

- The quantities are so much less -- 350 gpm as compared to 700 to 1000 gpm ultimately planned for Barnstable.

- Injection is in very close proximity to the extraction wells at MMR, minimizing the hydraulic impacts (mounding).

- Nutrient loading and migration are not an issue at MMR because treated groundwater, not wastewater, is being injected.

- Process impacts of municipal wastewater treatment (pH and O level adjustments) are not the same at MMR as they would be at Barnstable.

- MMR precipitates metals out of the water prior to any other treatment or process to minimize impacts on process equipment. This has the secondary benefit of minimizing TDS in the effluent stream.

The MMR situation is similar to Barnstable in that it occurs in the same aquifer with presumably similar hydraulic properties. Prior to design and construction of the MMR treatment system,

injection tests of up to 500 gpm in a single well were conducted. Results of this testing, as well as associated hydraulic modeling, provided insights related to the Barnstable pilot test design such as potential injection rate, well design and operational parameters

RECYCLED WATER REINJECTION - ORANGE COUNTY, CALIFORNIA

Excessive pumping of groundwater resources in Orange County has resulted in a lowering of the water table in coastal areas and subsequent salt water intrusion. As early as the 1950s, salt water had migrated as far as 5 miles inland. A primary area where this has occurred is the Talbot Gap, the buried mouth of an alluvial fan between Newport Beach and Huntington Beach. In a project referred to as Water Factory 21, approximately 22.6 mgd are injected into 23 multipoint injection wells located about 600 feet apart. The 22.6 mgd injected is derived from approximately 14 mgd of treated effluent from the OCSD and 8.6 mgd derived from deep well water. Five mgd from the OCSD undergoes reverse osmosis, and the other 9 mgd undergo carbon adsorption. The resulting product water meets California Department of Health Services' primary and secondary drinking water standards. The total treatment process includes chemical clarification, recarbonation, multimedia filtration, granular activated carbon, reverse osmosis, chlorination, and blending. Total treatment cost is approximately $6 per 1,000 gallons. Injection is through 150 wells that range in depth from 280 to 700 feet. Some of the injected water flows oceanward, creating a salt water intrusion barrier, and most of the injected water flows inland, replenishing well fields.

The California project differs from Barnstable in that much greater quantities of water are being injected and the water is treated to an extremely high level. The California project is similar in that injection is into a utilized aquifer. Orange County is currently developing a $350 to $400 million project to more fully utilize treated water, referred to as the Groundwater Replenishment System.

WASTEWATER REINJECTION TO MITIGATE SALT WATER INTRUSION -- PILOT TEST ON LONG ISLAND

Between the 1960s and 1980s, the Nassau County Department of Environmental Protection and the United States Geologic Survey conducted pilot tests on the southern side of Long Island to study the feasibility of injecting treated wastewater to mitigate salt water intrusion. The tests took place in two phases. In both cases, the water underwent tertiary treatment. During the first

set of tests in Bay Park, treated water was injected into the Magothy Formation, comprised of unconsolidated silts and fine sands at a depth of approximately 480 feet. Between 200 and 400 gpm were injected into a single 8-inch fiberglass injection well with a stainless steel screen. Injectivity began to decline after about a month, but injection continued for about six months before the well needed to be treated. Plugging was attributed to a high suspended solids load in the effluent. Injectivity was restored by letting the well backflow for approximately one hour, which served to clear out the pore space adjacent to the well. In the 1980s, similar testing was performed at East Meadow. At that location, treated effluent was injected into the Upper Glacial aquifer at a depth of 200 feet and was also recharged via recharge basins. The pilot tests were completed, but a full-scale system was never implemented because it was determined that salt water intrusion had not become a significant enough issue to warrant the expense.

AQUIFER STORAGE-RECOVERY (ASR)

In some regions of the country, potable water is processed and is then injected back into the ground for storage for use during dry periods when the usual surface water or groundwater supplies become diminished. A great deal of research has been conducted into the operation of these ASR wells. Although the ASR wells are injecting potable water, not treated wastewater, a number of operational issues are similar, including well mechanics, injection rate and pressure, plugging, and water quality impacts. Much of the research related to ASR wells is applicable to design considerations for a wastewater injection well.

SUMMARY OF TECHNOLOGY REVIEW

Four cases of injection of treated water were reviewed to assist in evaluating the feasibility of injecting treated effluent at Barnstable. There are no precedent projects that are identical to the situation at Barnstable, so it was necessary to gain available information from the similar projects and apply that information to the Barnstable project.

A. **Regulatory Issues.** All of the reviewed programs were being completed in compliance with local and federal regulations. MADEP was aware of all aspects of this project, both in terms of the Bureau of Resource Protection and the State UIC (Underground Injection Control) programs. Also, MADEP informed USEPA of the project. All involved regulatory groups have been supportive of the project.

B. **Public Concern.** Public concern was not identified as an issue at any site except Florida. Barnstable residents can take comfort in the fact that wastewater has historically been recharged to groundwater and that the wells are only another mechanism to achieve the same goal.

C. **Operations.** The common operational concern that affects or potentially affects all systems and will be a factor with Barnstable is the decline in injectivity as a result of plugging. In the Long Island pilot tests, it was apparently precipitation of mineral solids that caused plugging. In all other cases, biological fouling was cited as the likely cause for loss of injectivity. Florida manages this through superchlorination and mechanical cleaning of the wells. Stearns & Wheler knew that plugging was going to be a potential problem during the test. The objectives of the test included identifying and addressing plugging mechanisms that could impact operation. Filtration, disinfection, and well design were all based on this knowledge. Responses to plugging were not included in the work plan because it was not certain that plugging would occur (every geologic setting and wastestream is a unique situation) and the plan was to see what problems arose and then address them specifically and appropriately.

D. **Hydraulic Issues.** is the Town of Barnstable was concerned that the treatment plant could elevate the water table to a point that impacts the surface, either through flooding basements, causing ponding or impacting water levels at ponds or lakes. This was not an issue at any of the other sites with the exception of MMR. At MMR, there was enough concern to monitor water levels, but because of the relatively low quantities being reinjected and because reinjection is occurring near withdrawal wells, mounding was not a significant issue. Water table levels had increased by about .5 feet at the MMR injection site. At Barnstable, impacts to the level of the water table are a primary concern.

E. **Health and Environmental Issues.** As a rule, injection in Florida is into zones that underlie, and that are likely separate from, USDWs. In the instance of the Hollywood pumping test, regulators suggested that the pilot test first be conducted with potable water. In California, injection is into a USDW, but the water is highly treated. At MMR, the effluent is not treated municipal wastewater with the associated concerns regarding bacteriological pathogens and nutrients. If Barnstable wishes to inject wastewater that has undergone secondary treatment into USDWs, either inside or outside of Zones of Contribution of municipal supply wells, sufficient demonstration of no significant health or environmental impacts will have to be made by the Town during a permitting process. Specifically, compliance with MADEP's and EOEA's Interim Guidelines on Reclaimed Water will have to be demonstrated

F. **Summary.** Based on the information summarized above, subsurface injection may be a viable alternative for disposal of treated municipal wastewater in Barnstable. There are three primary motivators for considering subsurface injection:

1. Replenishing the groundwater resources of Cape Cod (as does rapid bed infiltration). This goal eliminates deep well injection below a USDW as an alternative because it would not meet the Barnstable and MADEP shared objective.

2. A significantly reduced acreage requirement or aesthetic disruption.

3. Considerably less cost.

Hurdles to overcome are:

1. Operational difficulties in terms of plugging, which can be caused by injection solids, air entrainment or biological plugging, and maintaining injectivity.

2. Demonstrating that the technology is as protective of human health and the environment as rapid bed infiltration.

3. Demonstrating that a more concentrated source area will not result in unacceptable hydraulic impacts.

Considering the motivators and hurdles to overcome, and in view of the information gathered related to other injection scenarios, pilot testing to evaluate the applicability of the technology was determined to be warranted, and design and execution of the pilot test proceeded.

Appendix B
Well Design Considerations

APPENDIX B

WELL DESIGN CONSIDERATIONS

The design of the well was based on logs from existing wells at the site, design specifications of production wells in the area, literature available on the design of injection wells, and information gained from a comparable injection well test at MMR. A pilot boring was installed at the location of the injection well to allow the collection of sediment samples so that screen length, depth, and slot size could be determined.

There were three limiters to the rate that water could be injected, including:

1. A high water table that limits mounding to an elevation that would not impact surface water bodies or subsurface structures and would not cause ponding.

2. The rate at which the receiving formation could accept water

3. The mechanics of the well, including its diameter, screen length, and screen slot size.

Due to its high transmissivity, the aquifer was able to receive a significant quantity of water and the well could be designed to transmit a significant quantity of water. Mounding impacts would probably be the first limiting factor. Therefore, the well design (the only one of the three limiters that can be engineered) should be able to convey enough water to meet but not exceed the amount permitted by the mounding limitation. At the time of design, it was not known what discharge rate would correspond to an acceptable level of mounding. Although modeling could serve as a guide, only the pilot test would be able to accurately define the maximum allowable injection rate.

Injection wells must be carefully designed because they are much more likely to fail than are pumping wells. As previously discussed, water chemistry, air entrainment, and mechanical plugging are common problems with injection wells. Solids concentrations as low as 1 mg/L can clog injection wells in a short time. A 6-inch test well in California pumping 32 gpm with 3.3 mg/L solids showed a 30 percent increase in injection pressure in 9 days. In one of the case

histories reviewed, an injection well operated for six months, and the head in the well rose by 6 feet even though the water contained only .004 mg/L solids.

The design of injection wells is similar to pumping wells with the exception of entrance velocity and screen length. Because of concerns with plugging, optimizing screen opening area (slot size and screen length) is critical. Production wells are typically designed to have an entrance velocity of 0.1 ft/sec. The entrance velocity for an injection well should not exceed 0.05 ft/.sec. Therefore, everything else being equal, the open area of a screen for an injection well needs to be twice that of a production well. Minimizing pressure buildup in an injection well is the primary objective of design and construction. Reducing pressure buildup decreases the number of wells required and increases the recharge rate per well.

The basis of design for determining the diameter and screen length was derived from investigating production wells in the area. A rule of thumb is that an injection well to convey X gpm would be comparable to a production well designed to convey 2X gpm. The smallest municipal well (West Barnstable Fire District) in the area has an 8-inch screen that is 10 feet long. That well can convey approximately 700 gpm (just over 1 mgd). Most other production wells in the district have 24-inch screens that are 5 to 20 feet long. Production rates range from 300 to 1000 gpm. The assumption that 350 to 500 gpm can be injected into a 10-inch by 30-foot screen seemed reasonable based on the capacities of the production wells in the area.

Appendix I

Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension Preliminary Design Report; September 2003

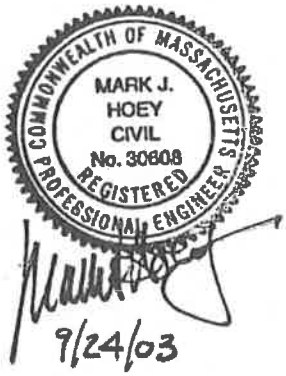
Final

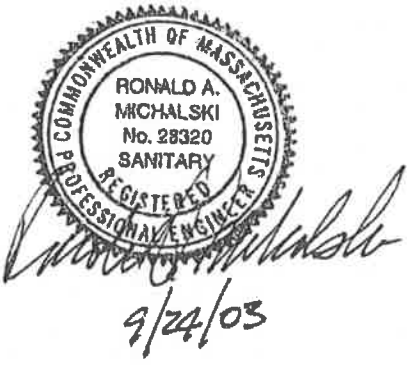
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension

Preliminary Design Report

Town of Barnstable
Department of
Public Works







September, 2003

Submitted by

Tighe&Bond

Barnstable is a Cape Cod community with a wealth of water resources in the form of lakes, harbors, embayments and an extensive coastline along Nantucket Sound. For a number of years, Barnstable has been studying the water pollution control needs of the community because a majority of the Town is served by septic tanks with leach fields that discharge treated sewage to the ground. The exception is Hyannis, where the developed, downtown area is served by a municipal sewerage system with a modern wastewater treatment facility.

The most recent, ongoing sewer study or Comprehensive Wastewater Management Plan has identified a number of community areas where on-site septic systems are contributing to elevated nitrogen levels in local water resources. The term "Area of Concern" (AOC) was developed in the recent sewer study and is used to identify specific areas of the community where water pollution control needs are most obvious and can only be mitigated by extending the municipal sewerage system so that septic systems can be abandoned, sewage collected and eventually treated at an appropriate wastewater treatment facility.

The ongoing Comprehensive Wastewater Management Plan (CWMP) has identified the Lake Wequaquet/Long Pond area of the community as an AOC and has confirmed the need for sewer extensions to serve the area. The CWMP process reviewed a variety of sewer extension options for the Lake Wequaquet/Long Pond area but concluded that a more detailed analysis was needed to develop a cost-effective and environmentally sensitive sewer extension program. As a point of interest, the Barnstable CWMP process identified a number of AOC's and acknowledged that a detailed layout of sewer extensions to each area was beyond the limits of the general planning effort.

The Preliminary Design Report that follows focuses on the Lake Wequaquet/Long Pond area and has one primary purpose: to determine the most economical and environmentally sensitive sewer extension program to serve the area. The Preliminary Design Report includes an analysis of the sewerage extension needs of Cape Cod Community College, which is located just outside of the AOC but is a State facility that needs to mitigate concerns associated with its existing on-site septic systems.

Barnstable has authorized $1,200,000 for the preliminary and final design for the Lake Wequaquet/Long Pond sewer extension program and retained Tighe & Bond Consulting Engineers in the summer of 2002 to work on the evaluation. Over the last eight months, the engineer has reviewed the topography of the AOC, existing development patterns, the number of homes within the AOC, the location of potential connection points to the existing Barnstable sewerage system, the sewerage needs of areas directly adjacent to the AOC, the street and private way layouts that serve the area, and the existing utilities that may impact the construction of municipal sewer extensions.

Using available data, the engineer evaluated four different comprehensive sewer layouts to serve the AOC and eventually recommended Alternative 3 (or 3A if the grinder pumps are purchased and maintained by the residents), a sewer layout that consists of a combination of gravity sewers, five pumping stations, low pressure sewers and 598 grinder pumps to provide sewer service to the AOC. This alternative includes the installation of 120,200 feet of sewer pipe consisting of 36,200 feet of gravity sewer and 62,800 feet of low pressure sewer to be constructed in existing streets and public ways. A complete description of all alternatives that were evaluated, including additional information on the recommended alternative, can be found in Section 12, Summary and Recommendations.

The total estimated construction cost of the recommended alternative is $17,797,000 (engineering costs are not included) and will serve 1,315 properties. Excluding grinder pump costs, the total estimated construction cost of the recommended alternative is $13,312,000. In addition, the alternative provides design flexibility to serve additional Barnstable areas that are adjacent to the AOC and recommends improvements to the existing municipal sewerage system so that sewage flows from the AOC can be transported to and treated at the existing Hyannis wastewater treatment facility.

As part of the extensive review work associated with the evaluation of all sewer alternatives during this study, the following additional criteria were incorporated into the final recommendation:

- Environmental impacts (water quality, wetlands, rare species, etc.),
- Neighborhood impacts (aesthetics, traffic, noise, air quality, land acquisition needs, etc.),
- Sewerage system operating costs,
- Private home information regarding plumbing features and septic tank locations,
- Sewer system reliability, and
- Sewer system expandability.

The Preliminary Design Report also includes extensive discussions about various sewer extension technologies, reviews a variety of municipal sewerage pumping station construction options, provides information on grinder pumps that are an integral part of a low pressure sewerage system, and provides preliminary siting information for the five pumping stations that are included in the recommended alternative. Finally, the engineering effort also includes the development of a project-specific website that is

located at http://projects.tighebond.com and contains project information that can be accessed by the public.

Finally, the Preliminary Design Report recommends that Barnstable proceed with the Final Design of the recommended project with a goal of having complete design plans and specifications for the project ready in the summer of 2004 so that Barnstable can initiate the construction phase of the project in a timely manner.

Tighe & Bond would like to take this opportunity to thank a number of municipal officials who assisted during the preliminary design engineering effort including Bob Burgmann, P. E., Town Engineer; Mark Giordano, P. E. Senior Project Manager in the Department of Public Works; Peter Doyle, Water Pollution Control Facility Supervisor; Jack Harris, Project Manager; and Dr. Paul Canniff, a representative of the Lake Wequaquet Association. The municipal officials provided valuable assistance, guidance and input during the preparation of this preliminary engineering report.

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1.1 PURPOSE

This report presents a sewer extension evaluation performed for the neighborhoods surrounding Lake Wequaquet, Long Pond, Bearse Pond and Shallow Pond in the Town of Barnstable as well as for the Cape Cod Community College. The purpose of this report is to determine the most economical preliminary sewer extension design, which can be used as the basis for the development of detailed construction contract documents.

Previous facilities planning efforts identified several areas of environmental concern in Barnstable, including the Lake Wequaquet and Long Pond areas. Lake Wequaquet, Bearse Pond, Shallow Pond, and Long Pond are important natural resources in the area, as described below:

1. The Lake Wequaquet/Long Pond area is within the state approved Zone II groundwater protection area.

2. There are several wetland resources in the Lake Wequaquet/Long Pond area.

3. There are priority habitats of rare species and estimated habitats of rare wildlife throughout the Lake Wequaquet/Long Pond area.

4. These fresh water bodies are used for recreational purposes, including swimming, fishing, and boating.

5. The scenic nature of these water bodies has a positive impact on the quality of life of the nearby residents and draws both residents and non-residents to their shores. In fact, the scenic and recreational qualities of the Town are the foundation of the economy, which include tourism, vacation, and retirement homes.

A reduction in water quality has been observed in Lake Wequaquet and Long Pond, primarily due to high nutrient loadings, as is documented through prior planning efforts. Septic system discharges were determined to be a major source of these nutrient loadings. The nutrient loadings can affect surface water quality, natural resources, and human use of these resources. High nutrient loadings to surface water bodies can result in excessive growths of algae and aquatic plants that deteriorate the water environment (eutrophication). Secondary effects can include a change in biota, a buildup of organic material, low dissolved oxygen levels, fish and shellfish mortality, and increased bacteria levels.

The proposed project will implement facilities planning recommendations to provide sewer service to the neighborhoods surrounding Lake Wequaquet, Long Pond, Bearse Pond and Shallow Pond, eliminating the septic systems within this area of concern.

As noted above, this report also includes a sewer extension evaluation for the Cape Cod Community College, which is currently served by several septic systems. The college is currently designing a pump station to collect and then discharge its wastewater flow into the Town's collection system. The pump station force main route and Town sewerage system connection point has been investigated as part of this evaluation.

1.2 SCOPE

The following tasks were performed as part of this evaluation and are described in this report:

1. Reviewed existing background information
2. Developed mapping of the study area
3. Reviewed prior planning efforts
4. Reviewed sewer service layout questionnaires sent to each property owner within the AOC
5. Determined current wastewater flows in the study area
6. Projected future wastewater flows in the study area
7. Evaluated potential connection points to the existing sewerage system
8. Developed and evaluated sewer layout alternatives
9. Provided the Town with sewer extension recommendations
10. Assisted the Town with a Public Participation Program
11. Performed an assessment of the environmental and neighborhood impacts of the sewer extension alternatives and determined the permits expected to be required
12. Performed an assessment of traffic impacts
13. Collected information on existing utilities within the project area

2.1 DESCRIPTION OF PROJECT AREA

2.1.1 General

The project area has been divided into three parts in this evaluation:

1. The Area of Concern
2. The "Bowl"
3. Cape Cod Community College

Each of these areas is described below. A general street map of the project area is presented in Figure 2-1.

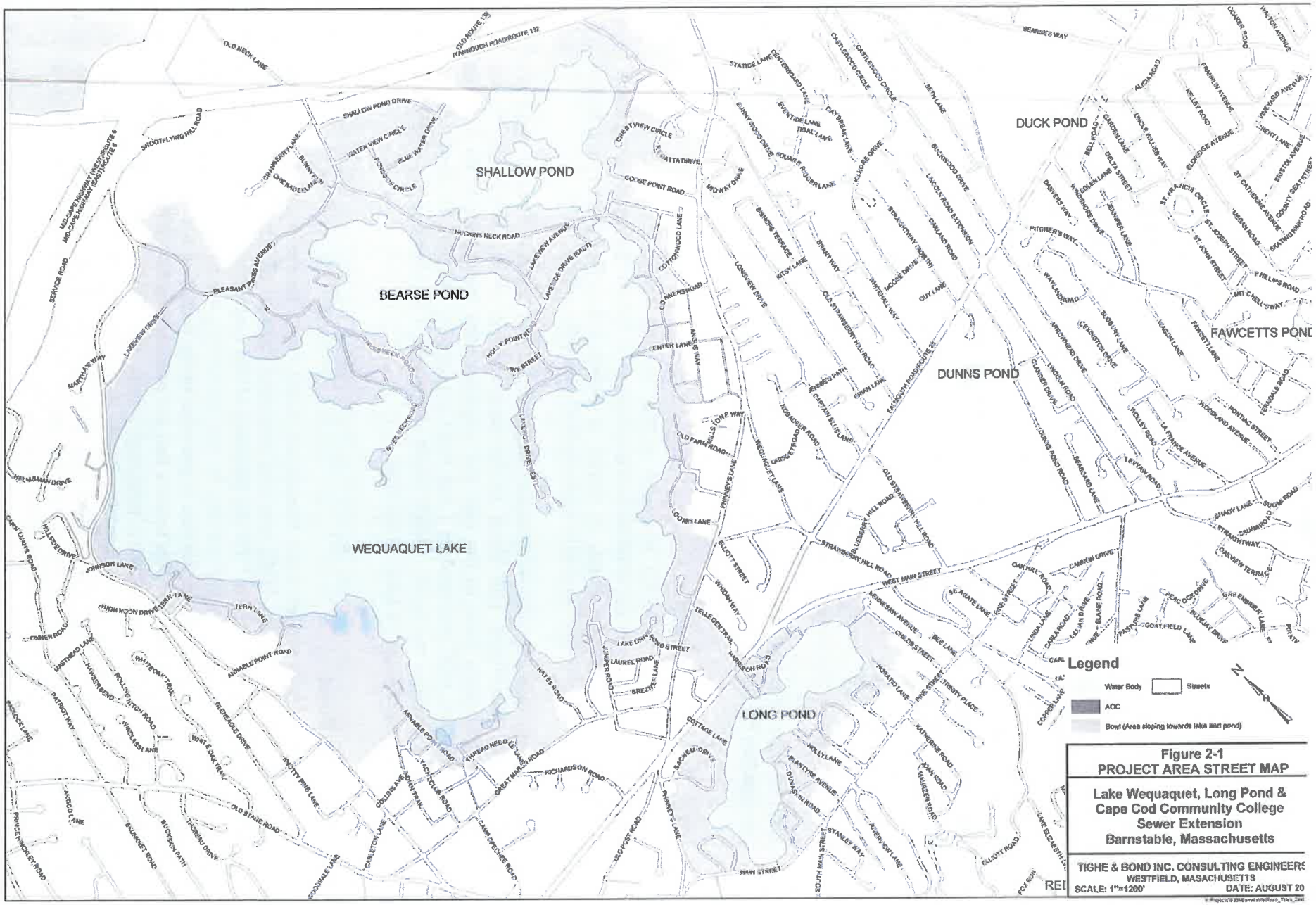
2.1.2 Area of Concern

The Area of Concern (AOC) has been defined by the Town, based on previous evaluations, and includes the neighborhoods surrounding Lake Wequaquet, Long Pond, Bearse Pond and Shallow Pond, as shown in Figure 2-2. The preliminary design developed provides sewer service to each resident within the AOC.

The AOC surrounding Lake Wequaquet, Bearse Pond and Shallow Pond is generally bounded by Shootflying Hill Road to the west and northwest, Route 132 to the northeast, Phinney's Lane to the east and southeast, and Great Marsh Road to the southwest. The AOC surrounding Long Pond is generally bounded by Route 28 and West Main Street to the north, Childs Street to the east, Pine Street to the south, and Main Street and Phinney's Lane to the west.

2.1.3 The Bowl

The area that drains toward Lake Wequaquet, Long Pond, Bearse Pond, and Shallow Pond, but is outside of the AOC, was also determined as part of this evaluation. This area is described as the "Bowl" for the purposes of this evaluation and is also shown in Figure 2-2. Although sewer service is not currently planned for this area, it is anticipated that if future sewer service is provided to the Bowl that the wastewater from this area would flow into the new sewers that are proposed in the AOC. As such, the new gravity and vacuum sewers proposed within the AOC have been sized to accommodate wastewater flow from the Bowl. Because low pressure sewers are not readily expanded, the low pressure sewers proposed have been sized to serve only properties within the AOC and properties adjacent to proposed sewers. This is discussed in greater detail in subsequent report sections.


SHALLOW POND
BEARSE POND
WEQUAQUET LAKE
DUCK POND
DUNNS POND
FAWCETTS POND
LONG POND
OLD NECK LANE
SHALLOW POND DRIVE
SMOOTH LYNG HILL ROAD
SERVICE ROAD
PLEASANT TIMES AVENUE
LAKEVIEW CIRCLE
MATTAKEESE WAY
HELM SHAW DRIVE
CAPE LUNA ROAD
HILLSIDE DRIVE
JOHNSON LANE
HIGH NOON DRIVE
TERN LANE
CONNER ROAD
EASTHEAD LANE
HAWKEWOOD
WHITEOAK TRAIL
ROLLING HITCH ROAD
WHIPPLEASE LANE
WHITE OAK TRAIL
EAGLEDALE DRIVE
PATRIOT WAY
PEACOCK LANE
PRINCE HICKLEY ROAD
ANTICO LANE
SUMMERSET ROAD
BUCKSKIN PATH
TIOBEAU DRIVE
OLD STAGE ROAD
WOODVALE LANE
CARLETON LANE
COLLINS AVENUE
INDIAN TRAIL
ANNABLE POINT ROAD
CRANBERRY LANE
BUNNY LYN
CHICKADEE LANE
WATER VIEW CIRCLE
PONGEE CIRCLE
BLUE WATER DRIVE
CHESTVIEW CIRCLE
GOOSE POINT ROAD
HIGGINS NECK ROAD
LAKEVIEW AVENUE
LAKESIDE DRIVE EAST
LAKESIDE DRIVE SOUTH
HOLLY POINT ROAD
WE STREET
CENTER LANE
ANGIE'S WAY
OLD FARM ROAD
LOUMIS LANE
PINNEY'S LANE
ELLIOTT STREET
WHOWAY
TELLGEN TRAIL
HARRISON ROAD
LAKE DRIVE
POND STREET
LAUREL ROAD
BREZEE LANE
HAYES ROAD
COTTAGE LANE
RACHEL DRIVE
THREAD NEEDLE LANE
GREAT MARSH ROAD
RICHARDSON ROAD
OLD POST ROAD
PINNEY'S LANE
CAMP OPECHEE ROAD
MAIN STREET
SOUTH MAIN STREET
STANLEY WAY
RIVERVIEW LANE
ELLIOTT ROAD
FOX RUN
STATICE LANE
COVERBOARD LANE
CASTLEWOOD CIRCLE
SUNNYWOOD DRIVE
EVENTIDE LANE
SQUARE RIGGER LANE
PLAY BREAK LANE
KALMORE DRIVE
SETH LANE
BEARSE'S WAY
DUNKER ROAD
WALTON AVENUE
ALICIA ROAD
FRANKLIN AVENUE
ACKLEY ROAD
ORCHARD AVENUE
KENT LANE
BRISTOL AVENUE
BELL ROAD
GARDEN LANE
UNCLE FULLER'S WAY
DELTA STREET
GLADIOLA AVENUE
COUNTY SEAT STREET
SKATING RINK ROAD
ST. CATHERINE AVENUE
ST. FRANCIS CIRCLE
ST. JOSEPH STREET
ST. JOHN STREET
MEGAN ROAD
PHILLIPS ROAD
MT. CAELL WAY
EDEN LANE
WINDEMERE DRIVE
JENNIFER LANE
DANYERS WAY
PITCHER'S WAY
WAYLANDIUM D
BRONWYN LANE
FAWCETT LANE
WOODLAND AVENUE
PONTIAC STREET
LA FRANCE AVENUE
LEVYAN ROAD
SHADY LANE
SUNSET ROAD
CRAIG ROAD
STRAIGHTWAY
CRAIGVIEW TERRACE
CAMERON DRIVE
OAK HILL ROAD
SE AGATE LANE
PEACEDALE DRIVE
GREENMEER LANE
PINEWAY DRIVE
LINDA LANE
CORELA ROAD
LILIAN DRIVE
BLAKE ROAD
PASTURE LANE
GOAT FIELD LANE
CARL
BANNISTERS TERRACE
KITSY LANE
BRANT WAY
OLD STRAWBERRY HILL ROAD
IMPERIAL WAY
HOSSE DRIVE
GUY LANE
LAGOON ROAD EXTENSION
DALLAS ROAD
STRAIGHTWAY NORTH
BUCKWOOD DRIVE
LAGOON ROAD
BLOSSOM LANE
CEDARCLIFF DRIVE
ARROWHEAD DRIVE
CANDLER DRIVE
LOUNS FORD ROAD
BEARSEARD LANE
FALMOUTH ROAD ROUTE 28
ERWIN LANE
JEREMY'S PATH
CAPTAIN ELLIS LANE
NOBSKEER ROAD
DUSSET ROAD
NEQUAQUE LANE
OLD STRAWBERRY HILL ROAD
BLUEBERRY HILL ROAD
STRAWBERRY HILL ROAD
WEST MAIN STREET
KINNESAW AVENUE
CHILDS STREET
BEE LANE
TRINITY PLACE
PINE STREET
HOWARD LANE
KATHERINE ROAD
JOAN ROAD
MAUREEN ROAD
POLLY LANE
PLANTYRE AVENUE
DUNLISON ROAD
COPPER LANE
Legend
Water Body
Streets
AOC
Bowl (Area sloping towards lake and pond)
N
Figure 2-1
PROJECT AREA STREET MAP
Lake Wequaquet, Long Pond &
Cape Cod Community College
Sewer Extension
Barnstable, Massachusetts
TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASACHUSETTS
SCALE: 1"=1200'
DATE: AUGUST 20

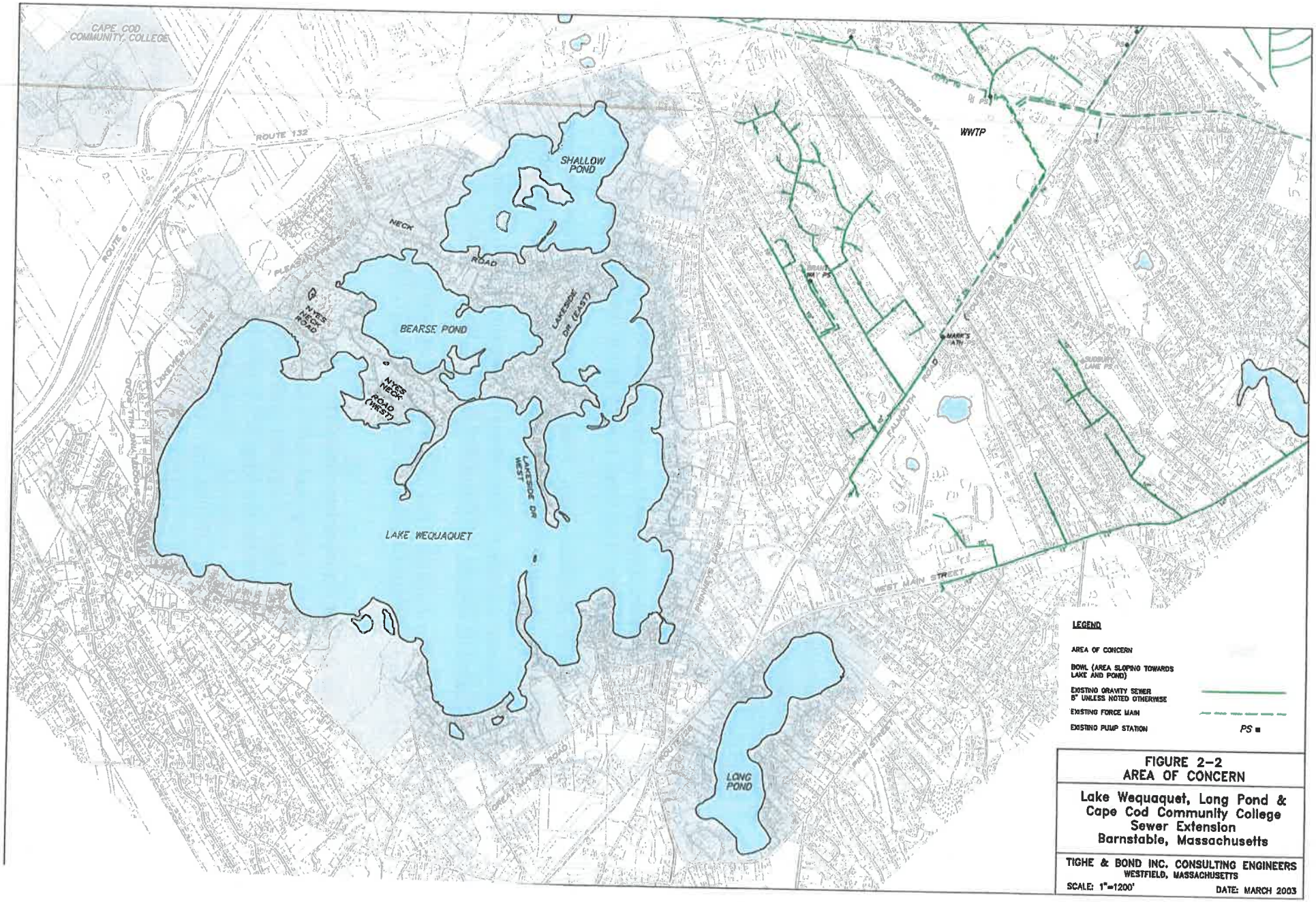


FIGURE 2-2
AREA OF CONCERN

Lake Wequaquet, Long Pond & Cape Cod Community College Sewer Extension Barnstable, Massachusetts

TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASSACHUSETTS

SCALE: 1"=1200'

DATE: MARCH 2003

The Bowl surrounding Lake Wequaquet, Bearse Pond and Shallow Pond is generally bounded by Oak Street to the northwest, Route 6 and Route 132 to the north, Phinney's Lane to the east, Wequaquet Lane to the southeast, Route 28 to the south, Old Stage Road to the southwest, and Shootflying Hill Road to the west. The Bowl surrounding Long Pond is generally bounded by Route 28 and West Main Street to the north, Old Strawberry Hill Road and Strawberry Hill Road to the east, Pine Street to the south, and Main Street and Phinney's Lane to the west.

2.1.4 The Cape Cod Community College

The Cape Cod Community College is located off of Route 132, just north of the Route 132/Route 6 intersection. The college is currently designing improvements to its existing wastewater collection system and a new wastewater pump station, which will allow it to abandon its existing septic systems once a connection can be made to the Town sewerage system. Layouts that convey the pumped flow via a new force main from the college to the Town sewerage system were evaluated as part of this evaluation.

2.2 PREVIOUS STUDY WORK

A wastewater facilities plan was developed for the Town of Barnstable and was performed in three phases. This work is described in the following documents:

1. *Wastewater Facilities Plan Phase I, Needs Assessment Report, Town of Barnstable, MA*, prepared by Stearns & Wheler and dated December 1993.

2. *Wastewater Facilities Plan Phase II Interim Report, Town of Barnstable,* prepared by Stearns & Wheler and dated December 15, 1994.

3. *Wastewater Facilities Plan, Town of Barnstable, Draft Phase III Sections,* prepared by Stearns & Wheler and dated June 21, 1996.

2.2.1 Phase I Facilities Plan Report

In the Phase I report, existing and future land use and demographics were used to determine existing wastewater flows and project future wastewater flows and loadings in the Town of Barnstable for the Year 2014. Wastewater issues and specific problem areas were identified and evaluated. In addition, the existing sewerage system was reviewed. The Town was divided into several sub-areas in the Phase I report. Area CE4, established in the Phase I report, matches the AOC defined by the Town for the Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension Project.

Regulatory issues related to wastewater disposal were identified in the Phase I report, including especially the nitrogen removal requirement included in the Water Pollution Control Facility's (WPCF's) draft groundwater discharge permit. Several areas of environmental concern were identified, including:

- Groundwater zones of contribution to public water supply wells (Zone II areas)
- Freshwater bodies and their recharge areas
- Coastal resources
- Wetland buffers
- Rare and endangered wildlife and plant habitat

Many of the Town's natural resources and environmentally sensitive areas were reported to have had problems attributable to the disposal of wastewater, boat waste and stormwater, resulting in the eutrophication of several water bodies. In particular, Area CE4 was identified as an area of environmental concern. Area CE4 is within a Zone II wellhead protection area, includes wetlands and wetland buffer areas, is in a FEMA flood area, is a coastal resource (shellfish, finfish), is a critical recharge area (area contributing groundwater to a sensitive receptor), and is a wildlife and plant habitat.

Failing on-site wastewater disposal systems (cesspools or septic tanks and leaching fields) were identified throughout Barnstable, including in Area CE4, and the causes identified included small lot size, poor soils, high groundwater, and substandard treatment (cesspools). It was reported that greater than 65% of the houses in Area CE4 were built prior to the establishment of the Massachusetts Title 5 Regulations and/or Barnstable Board of Health Regulations. The Phase I report indicated that many of these lots would not meet current State and/or Town septic system regulations.

Current and projected future wastewater flows were determined for the Town, and for Area CE4 in particular, using water use data and population estimates. The population estimates and wastewater flows for Area CE4 are summarized in Table 2-1:

Table 2-1

Area CE4 Population and Wastewater Flow Estimates

Current Conditions		Future Conditions (Year 2014)	
Max. Month Population	Max. Month Wastewater Flow (gpd) [1]	Max. Month Population	Max. Month Wastewater Flow (gpd) [1]
1,717	152,000	2,070	178,000

Notes:

(1) Includes commercial and industrial wastewater flows, which were also determined using water use data.

Based upon a review of the existing collection system, the 10-inch sewers on South Street, the 10-inch sewers on Pleasant Street, the 10-inch sewers on Center Street, and the 8-inch sewers on Sea Street were determined to be hydraulically overloaded under summer flow conditions. The trunk line on West Main Street was determined to be adequately sized for current conditions but to have little excess capacity for future expansion.

2.2.2 Phase II Facilities Plan Report

The Phase II report presented alternatives to address wastewater problems identified in the Phase I report. Sewerage system improvements considered included:

1. Decentralized wastewater treatment and disposal, ranging from upgrading existing septic systems to constructing neighborhood treatment and disposal systems

2. Centralized wastewater treatment and disposal at the existing Hyannis Water Pollution Control Facility (WPCF)

3. Wastewater collection system improvements, including alternatives to sewer areas that are currently unsewered and upgrading the existing collection system

4. Residuals management improvements, including treatment and disposal of residuals within the Town and treatment and disposal of residuals at a regional facility

5. Improvements to the Hyannis WPCF treated effluent groundwater discharge

Alternatives were screened in the Phase II report using a standard set of criteria in order to determine the most feasible alternatives. The alternatives selected were evaluated in greater detail in the Phase III report.

Several additional areas of concern were identified in the Phase II report, based on nitrogen loading modeling performed by the Cape Cod Commission, which was used to predict nitrate-nitrogen concentrations in the public water supply wells. Note in particular that Areas CO7 and BWST1, which were identified as areas of concern using the nitrogen loading model, overlap with Area CE4, which is the focus of this Preliminary Design Report.

Of most interest to this current evaluation was the screening of collection system alternatives for Area CE4. Four types of collection systems were considered, including gravity sewers, pressure sewers, septic tank effluent sewers (septic tank effluent pump systems and small diameter gravity sewers), and vacuum sewers. Vacuum sewers were

dropped from consideration in the Phase II report because of concerns regarding high capital costs, high maintenance, the need for significant staff training, limited expandability, and the need for greater accuracy in estimating initial flows. In addition, it was noted that the technology is not established or well proven.

An alternative consisting entirely of gravity sewers was considered economically impractical due to the topography around Lake Wequaquet and the other water bodies in Area CE4. An alternative consisting entirely of pressure sewers was considered for Area CE4 as well as two combination gravity sewer/pressure sewer alternatives. The first combination alternative included eight pump stations and would provide gravity service to many of the residents in Area CE4. The second combination alternative included more pressure sewers in order to reduce the number of pump stations needed to four. Connection points to the existing sewerage system on Old Strawberry Hill Road, West Main Street, and Route 28 were considered. The Phase II report recommended that only the entirely low pressure sewer alternative and the combination alternative with four pump stations be evaluated in the Phase III report for Area CE4. The eight pump station combination alternative was dropped from consideration because of the perceived high operation and maintenance costs.

The Phase II report indicated that improvements to the existing sewerage system were recommended in a 1987 Wastewater Management Report to improve existing conditions and allow for new sewer extensions. Some of the major recommendations in that report included:

1. A 16-inch relief sewer on Pleasant Street, Center Street and South Streets to relieve the overloaded lines

2. Diverting the discharge from the West Main Street pump station from South Street directly to the wastewater treatment facility

3. Reconstruction of the West Main Street pump station

The 1987 report also recommended sewering all of the areas within the zones of contribution of the public water supply wells.

The Phase II report confirmed that there are existing sewer segments with restricted capacity on South Street (10-inch, 12-inch, and 15-inch), Center Street (10-inch), Pleasant Street (10-inch), and West Main Street (12-inch). In addition, the impact of infilling and new sewer connections on the existing sewerage system were evaluated. In particular, the Phase II report indicated that if CE4 were connected to the existing sewerage system that the 10-inch, 12-inch, and 15-inch sewers on South Street would not have adequate hydraulic capacity, under current and future flow conditions.

2.2.3 Phase III Facilities Plan Report

The Phase III report provided cost estimates for the feasible alternatives developed in the Phase II report. The Phase III report also provided information on the cost evaluation approaches and criteria used for the various improvement alternatives.

The areas of concern identified in the Phase I and Phase II reports were prioritized in the Phase III report based on the number of failed septic systems, location in a Zone II of a public water supply well, potential impact on freshwater and coastal water habitat, and conformance with Title 5 Regulations. Area CE4 was ranked second out of twelve areas. The Cape Cod Community College force main was ranked last out of the twelve areas.

The Area CE4 wastewater disposal improvements alternative with the lowest present worth cost was determined to be conveying the wastewater flow from CE4 to the existing sewerage system. The construction of decentralized treatment facilities was also considered but was determined to be more expensive. Single unit Title 5 septic systems were considered but were determined to not be feasible for many lots without significant variances from the Board of Health.

The capital cost to sewer Area CE4 and convey the wastewater flow to the existing sewerage system was estimated as $10,200,000 and the total present worth cost was estimated as $12,600,000. Note that grinder pump costs were not specifically identified in the facilities plan estimate. The maximum month wastewater flow from Area CE4 was estimated as 190,000 gpd. Note that the maximum month flow presented in the Phase I report is 178,000 gpd. No explanation was provided for the difference between the maximum month flow presented in the Phase I report and the maximum month flow presented in the Phase III report. Extending the West Main Street sewer around Long Pond was proposed to serve the southern portion of Area CE4 while a new gravity sewer on Route 132 was proposed to tie in parcels on the north side of Lake Wequaquet.

The following non-monetary considerations were identified:

- Connection to the Hyannis WPCF or a small treatment plant provides the highest level of treatment of the alternatives considered
- Sewering north of CE4 along Route 132 would potentially serve other commercial areas along Route 132 and the sewer could be used to tie in Cape Cod Community College
- Area CE4 overlaps Areas CO7 and BWST1, which were identified as areas with potential future groundwater nitrogen levels greater than 5 mg/l

- Sewering and treating at the Hyannis WPCF would remove some groundwater recharge

The Phase III report also included a needs assessment and alternatives evaluation for the Cape Cod Community College. The sanitary flows from the college were projected using water usage data from January 1991 to June 1996. Water usage was assumed to equal sanitary flow at the college because the college did not water athletic fields and had minimal non-sanitary water use.

The average annual water usage was reported as 2.92 million gallons per year from 1991 to 1995, which is approximately 8,000 gpd. Monthly water usage varied depending on the semester, with values exceeding 350,000 gallons (12,000 gpd) in the spring and fall, when the student population is greater, and much lower values in the summer. In addition, daily usage was reported to have exceeded 15,000 gpd seven times in 1996 during the months of January and February. Note that the implementation of water conservation measures was underway during the evaluation at the college and these measures were expected to reduce daily flows by approximately 4,000 gpd.

Daily water usage in 1996 was reported to range from 10,000 gpd to 13,000 gpd in the spring semester and from 4,000 gpd to 5,000 gpd in the summer semester. In comparison, tabular data presented in the Phase III report shows that the daily water usage ranged from 6,000 gpd to 16,600 gpd in the spring semester (12,100 gpd average) and from 2,000 gpd to 10,500 gpd in the summer semester (5,100 gpd average). Note that maximum daily summer usage typically did not exceed 6,000 gpd.

The then current college population was estimated in the Phase III report, based on enrollment information provided by the college for 1996, and is presented in Table 2-2 below:

Table 2-2
1996 Population Estimates – Cape Cod Community College

Season	Student Population	Staff Population	Total Population
Spring	3,500	450	3,950
Summer	1,200	350	1,550

Based on population and the projected daily flow ranges, a per capita flow rate range was established in the report of 2.5 to 3.3 gpcd (13,000 gpd/3,950 people) for the spring semester and 2.6 to 3.2 gpcd (5,000 gpd/1,550 people) for the summer semester.

Future growth at the college was projected in the 1996 Phase III report, based on the following:

- A student population growth of 5%/year over the planning period
- A staff population growth of 10% over the planning period
- The construction of a Technology Center, which would increase support staff by 2% and faculty by one person

The future maximum day spring sanitary flow is reported as 35,000 gpd in the 1996 Draft Phase III Facilities Plan. No peak hourly flow values are provided in the Phase III report.

Four alternatives for managing the wastewater needs of the college were developed and are described below:

Alternative No. 1	Continued use of the existing on-site systems
Alternative No. 2	Construction of a small wastewater treatment facility
Alternative No. 3	Connection to the Hyannis WPCF with a force main sewer
Alternative No. 4	Connection to the Hyannis WPCF with a force main and gravity sewer

Present worth costs were developed for each of the alternatives and are shown in Table 2-3 below:

Table 2-3
Present Worth Costs of Cape Cod Community College
Wastewater Management Alternatives

Alternative No.	Capital Cost	Annual O&M Cost	Total Present Worth Cost
1	$0	$4,200	$42,000
2	$1,840,000	$47,300	$2,310,000
3	$1,140,000	$35,000	$1,490,000
4	$1,530,000	$42,000	$1,950,000

Continued use of the existing on-site systems was determined to be the lowest cost alternative. However, this alternative requires that wastewater flows stay below

15,000 gpd in order to comply with Title 5 regulations and, as such, does not allow for future expansion. Construction of a new small wastewater treatment facility would have the highest cost of the four alternatives.

The following recommendations were made in the Phase III report for the college evaluation:

1. The college and the Town should meet to discuss the report results and the college's decision on wastewater management implementation

2. If the college and the Town decide that the college could connect to the Hyannis WPCF, the discussions should address the following questions:

   - Should a force main be constructed to the WPCF, or would the Town best be served if a combination force main and gravity sewer is built?

   - How much of the proposed force main and/or gravity sewer would the college be responsible to construct and maintain?

   - Can a long-term arrangement be negotiated between the Town and the college for wastewater treatment and disposal?

3. Continue with water conservation efforts

4. Continue to record water meter totalizer readings to establish long-term daily water consumption data

5. Consider adding an automatic recorder to obtain daily weekend and holiday water consumption

SECTION 3 SEWER SERVICE LAYOUT QUESTIONNAIRE

3.1 DESCRIPTION

A sewer service questionnaire was prepared and mailed to each homeowner in the Area of Concern (AOC) in order to obtain information on their septic systems and sewer pipes. The questionnaire package included a transmittal letter explaining the project and the purpose for the questionnaire, the questionnaire itself, and a map of the homeowner's property. The questionnaire and transmittal letter are included in Appendix A. The following information was requested in the questionnaire:

- Location of sewer discharge pipe, septic tank, and leachfield (to be marked on the attached map)
- Type of home (cape/standard, ranch, or raised ranch)
- Whether there is a cellar and the type (full cellar, finished cellar, or crawl space)
- Whether there are plumbing facilities in the basement and the type (sink, toilet, bath/shower, or other)
- How the sewer pipe exits the basement (through the wall or through the floor)
- The basement wall height and the height to the sewer if it exits through the wall

The information provided by these questionnaires has been used to determine whether the property owner can be served by a gravity sewer service or whether sewage pumping is required. In addition, the survey information will be used to guide the location of house service connections during design.

3.2 RESULTS

The questionnaire responses are summarized in Table 3-1. A total of 793 questionnaires were distributed within the AOC and 490 were returned, representing a 62% response rate. This is considered a good level of response for this type of survey effort. The homes that returned the questionnaire are shown on Figure 3-1.

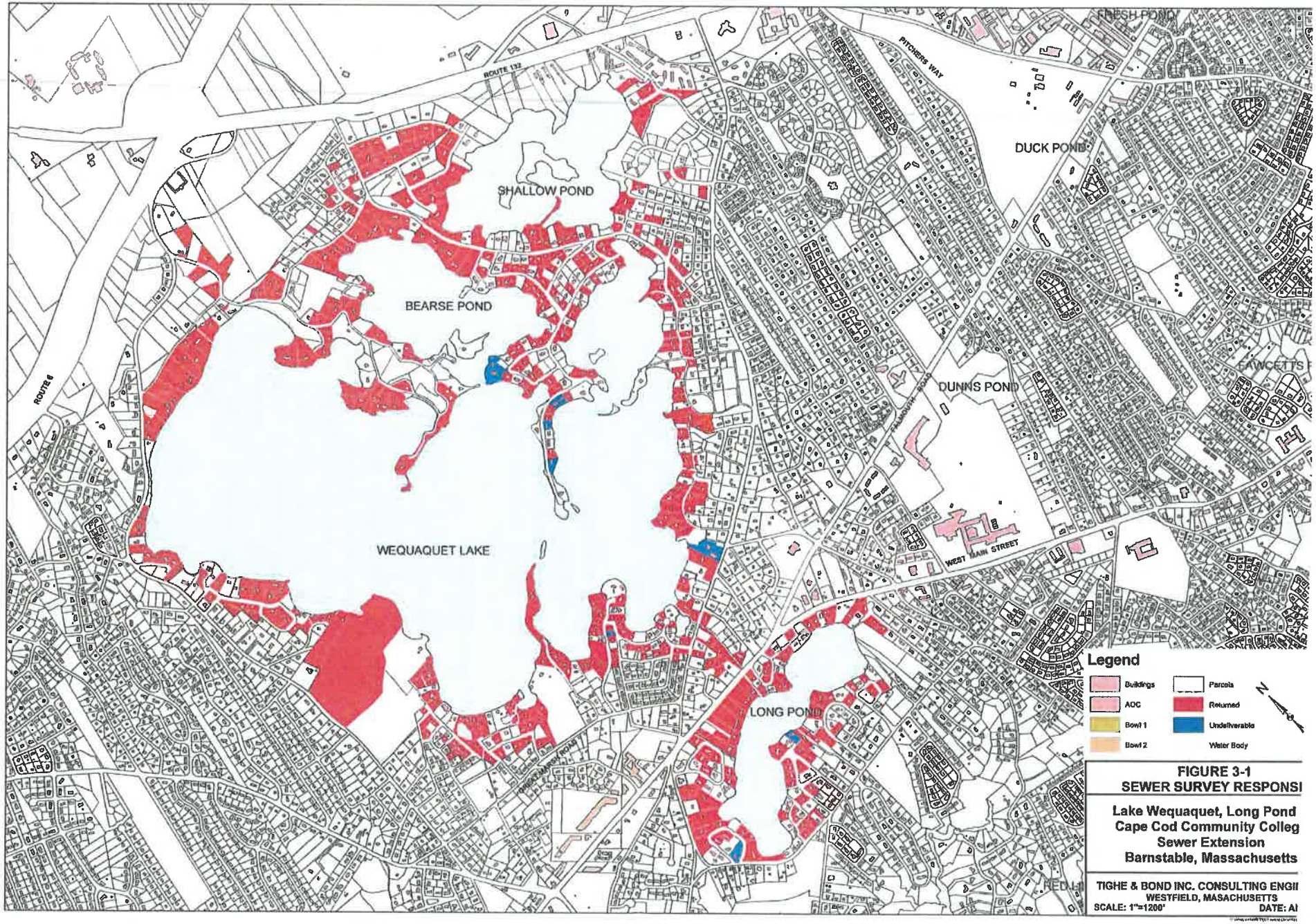
A large percentage of the buildings in the AOC have full basements (73%), while only a small percentage have no basement (4%). The remainder of the building basements were crawl spaces. Information on basement heights, which averaged approximately 7 feet, provided an indication of minimum sewer depth where the sewer pipes exit the basement through the floor. However, at the vast majority of the homes (81%) the

sewer pipes exit the house through the basement wall rather than the floor. The location where the sewer exits the basement wall, which averaged approximately 3 feet below the first floor level, was also requested and was used to help determine if gravity service is possible.

Approximately 38% of the buildings had plumbing facilities in their basements. It may be necessary to pump the wastewater from these facilities to the collector sewer on the street, depending on collector sewer depth.

Table 3-1
Sewer Service layout Questionnaire Summary
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension

No. of Questionnaires Distributed	No. of Questionnaires Returned	Percent of Questionnaires Returned	Basement Type			Plumbing Facilities in Basement	How Does Sewer Pipe Exit Basement		Avg. Height of Basement Wall (ft)	Avg. Height of Pipe Through Wall (ft)
			Full	Crawl	None		Thru Wall	Thru Floor		
793	513	65%	73%	23%	4%	39%	81%	19%	6.78	2.96


ROUTE 132
FRESH POND
PITCHERS WAY
DUCK POND
SHALLOW POND
BEARSE POND
ROUTE 6
DUNNS POND
FALMOUTH ROAD
WEST MAIN STREET
WEQUAQUET LAKE
LONG POND
Legend
Buildings
AOC
Bowl 1
Bowl 2
Parcels
Returned
Undeliverable
Water Body
N
FIGURE 3-1
SEWER SURVEY RESPONSI
Lake Wequaquet, Long Pond
Cape Cod Community Colleg
Sewer Extension
Barnstable, Massachusetts
TIGHE & BOND INC. CONSULTING ENGI
WESTFIELD, MASACHUSETTS
SCALE: 1"=1200'
DATE: Al

4.1 GENERAL

Current and projected future wastewater flow estimates for the AOC were developed in this report section. The wastewater flow projections were used to determine the appropriate size of new sewers needed to serve the AOC, which are shown in Section 6.

In addition, current and projected future wastewater flow estimates were developed for Cape Cod Community College, which currently utilizes septic systems for wastewater disposal. A wastewater pump station is currently being designed by another consultant that will allow the college to abandon its septic systems and pump all of its wastewater flow to the Town collection system for subsequent treatment at the municipal wastewater treatment facility. The piping size and layout from the college pump station to the Town collection system has been evaluated in this preliminary design report.

4.2 AOC

4.2.1 General

For the purposes of this evaluation, the AOC has been divided into 9 sub-areas, as shown on Figure 4-1. Current and projected future residential wastewater flows within the AOC were calculated for each sub-area using population estimates and per capita flow rates established during previous planning efforts and confirmed during this evaluation. Current commercial wastewater flows were estimated for each sub-area using recent water usage data.

Note that in some areas new sewers outside of the AOC have been proposed in order to convey wastewater from portions of the AOC to the existing sewerage system, as is detailed in Section 6. For example, in order to serve the southern portion of Long Pond, a sewer along Pine Street is proposed to convey wastewater from this portion of the AOC to the existing sewer system to the east. Barnstable officials have indicated that the homeowners along the street where this sewer is proposed may also be required (or if not required, allowed) to connect to the sewerage system, if there is available downstream hydraulic capacity. As such, homes outside of the AOC but adjacent to proposed sewers have been included in the development of current and future wastewater flows.

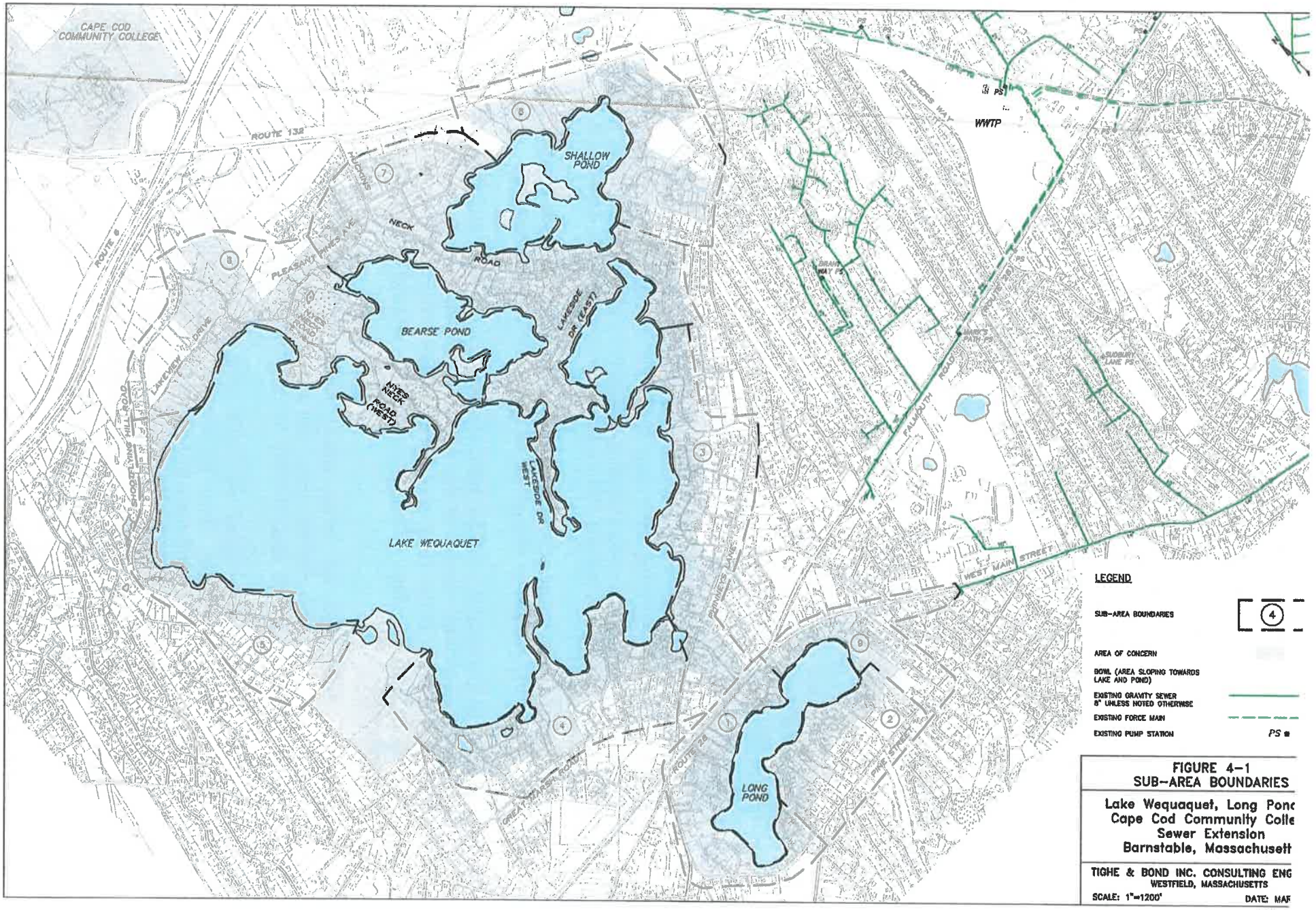


FIGURE 4-1
SUB-AREA BOUNDARIES

Lake Wequaquet, Long Pond
Cape Cod Community Colle
Sewer Extension
Barnstable, Massachusett

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WESTFIELD, MASSACHUSETTS

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4.2.2 Current Conditions

The current maximum month residential population in the AOC has been estimated as 2,141 people, based on a count of the number of single-family homes (850) plus two multi-family homes (bed & breakfast inns) in the study area. We have assumed that there are, on average, 2.5 residents in each single-family household and 2 people per room in the bed & breakfast inns. Note that an average household size of 2.5 people was determined during the 1993 Phase 1 Facilities Planning. In addition, a total of 743 people (297 homes) are outside of the AOC but adjacent to the proposed sewers. As noted above, these residents may be required (or if not required, allowed) to connect to the proposed sewer, and, as such, have been included in the determination of current wastewater flows. In total, the current residential population to be served by the project is estimated as 2,884 people. A breakdown of the number of homes in each of the nine sub-areas is presented in Table B-1 in Appendix B.

The average daily residential sanitary flow was estimated by multiplying the estimated current population by an average per capita sanitary flow rate. The average per capita residential sanitary flow rate was determined in the Phase 1 Facilities Plan as 72 gallons per capita per day (gpcd) using water usage data. The average wastewater flow value was confirmed using recent pump operating data provide by the Town for the Marks' Path and Main Street pump stations. This comparison is presented in Appendix B.

The current maximum month average daily residential sanitary flow rate is calculated as approximately 207,700 gpd by multiplying 72 gpd/person by 2,884 people.

A total of 10 commercial facilities were identified in the AOC and 8 commercial facilities were identified outside of the AOC but adjacent to the proposed sewers. Commercial facilities in the Town have been classified using the criteria presented in the Phase I Facilities Plan. The three applicable commercial classifications are described below:

Type I — Designated for office space, banks, medical offices, and other commercial establishments that are expected to produce wastewater BOD_5 and TSS concentrations of less than 200 mg/l.

Type II — Designated for motels and hotels without restaurants, auto repair shops, service stations, bus facilities, marinas, and other commercial establishments expected to produce a wastewater with BOD_5 and TSS concentrations of 200 to 400 mg/l.

Type III — Designated for restaurants, bars, cafeterias, supermarkets, and other establishments expected to produce wastewater with BOD_5 and TSS concentrations of greater than 400 mg/l.

Average daily sanitary flows were estimated for the commercial facilities identified within the AOC and outside the AOC but adjacent to the proposed sewers using water usage data collected by the Town water districts in 2001 and 2002. For the purposes of this evaluation, we have assumed that 90% of the water usage is sanitary flow. Seasonal peaking factors were determined in the Phase I Facilities Plan report for the different types of commercial facilities, based on a review of seasonal population (for Type I facilities) and flow variations at the Barnstable Wastewater Treatment Facility (for Type II and Type III facilities). The maximum month average daily commercial sanitary flows are presented below in Table 4-1.

Table 4-1

Maximum Month Average Daily Commercial Sanitary Flows

Facility Type	Average Daily Flow (gpd)	Seasonal Peaking Factor	Maximum Month Average Daily Flow (gpd)
I	3,000	1.32	4,000
II	12,000	2.16	26,000
III	5,100	2.16	11,000
Total	**20,200**	---	**41,000**

As noted above, two bed & breakfast inns were identified during the evaluation, one in Sub-Area 1 and one in Sub-Area 7. These "commercial" facilities were treated as multi-family residential homes for the purpose of estimating wastewater flow with average daily flows of 720 gpd and 432 gpd for the Sub-Area 1 and 7 inns, respectively.

In total, the current maximum month average daily sanitary flow was calculated as 248,700 gpd by summing the residential and commercial flow components. The peak sanitary flow was calculated as approximately 994,800 gpd by multiplying the average daily sanitary flow by a peaking factor of 4.0. This peaking factor was determined based on the following:

- Tighe & Bond's experience estimating peak residential wastewater flows.
- *Technical Report No. 16, Guides for the Design of Wastewater Treatment Works*, 1998 edition, prepared by the New England Interstate Water Pollution Control Commission (commonly referred to as TR-16), which is often used as a guide for this type of work. A peaking factor of approximately 4.8 was graphically determined using Figure 2-1 in TR-16, based on the current average daily flow. We believe that the TR-16 peaking factor is more conservative than is necessary for most residential wastewater flows.

- *Recommended Standards for Wastewater Facilities*, 1997 edition, prepared by the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers (commonly referred to as 10-State Standards), which is also often used as a guide for this type of work. A peaking factor of approximately 3.5 was graphically determined using Figure 1 in the 10-State Standards, based on the current population of 2,884 people.

If new sewers are constructed to serve the AOC, some infiltration of groundwater into the sewers can be expected and is normally considered in estimating flow quantities. For this evaluation, we have estimated infiltration rates by multiplying the typical infiltration value for new PVC sewers of 350 gpd per inch diameter per mile length of sewer (350 gpd/im), published in TR-16, by the estimated length of new gravity sewers and the predominant sewer size that would be constructed of 8 inches. We project the sewer infiltration rate within the AOC to be approximately 36,300 gpd, based on a gravity sewer length of approximately 68,300 linear feet. This length of new sewer is the greatest amount of gravity sewers anticipated of the four sewer layout alternatives.

The AOC average and peak wastewater flows were estimated as approximately 285,000 gpd and 1,031,100 gpd, respectively, by adding the projected sewer infiltration rate to the average and peak sanitary flows.

The average and peak wastewater flows estimated for each sub-area are summarized in Table 4-2.

4.2.3 Future Conditions

The projected future residential population at full build-out conditions was determined as part of this evaluation in order to size sewerage system components that will meet the long-term needs of Barnstable. The projected future residential population includes three components:

- Current residential population in AOC and outside of the AOC but adjacent to the proposed sewers (described in the previous report section)
- Future population in the AOC
- Current and future population in the Bowl

There are some open lots within the AOC where future development could occur. We have assumed that large lots would be sub-divided in the future to accommodate more homes and that construction would not occur in wetland areas. The sub-divided lots were sized to meet current zoning regulations for this area, which require a minimum lot size of 1 acre.

Table 4-2
Summary of Current Wastewater Flows to Proposed Sewers
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension

Sub-Area	Gravity Pipe Length (lf) [1]	Infiltration (gpd) [2]	Average Wastewater Flow (gpd) [3]			Peak Wastewater Flow (gpd) [4]		
			AOC	Outside of AOC but Adjacent to Proposed Sewer	Total	AOC	Outside of AOC but Adjacent to Proposed Sewer	Total
1	6,800	3,600	18,200	4,100	22,300	62,000	16,400	78,400
2	7,300	3,900	11,800	7,000	18,800	35,500	28,000	63,500
3	10,900	5,800	21,100	7,400	28,500	67,000	29,600	96,600
4	7,500	4,000	25,100	5,800	30,900	88,400	23,200	111,600
5	5,200	2,800	11,100	8,300	19,400	36,000	33,200	69,200
6	6,100	3,200	15,300	500	15,800	51,600	2,000	53,600
7	16,900	9,000	53,200	4,000	57,200	185,800	16,000	201,800
8	3,800	2,000	50,200	21,500	71,700	194,800	86,000	280,800
9	3,800	2,000	5,400	15,000	20,400	15,600	60,000	75,600
Total	**68,300**	**36,300**	**211,400**	**73,600**	**285,000**	**736,700**	**294,400**	**1,031,100**

Notes:

(1) Based on the gravity sewer lengths for Sewer Layout Alternative 1, presented in Section 6.

(2) Calculated as pipe length (in miles) x pipe diameter (in inches) x 350 gpd/im.

(3) Maximum month value, including residential and commerical flows and infiltration.

(4) Calculated as 4 times the average daily sanitary flow plus infiltration.

The "Bowl", which is defined as the surface area that drains towards Lake Wequaquet, Long Pond, Bearse Pond, and Shallow Pond, and extends beyond the AOC, was considered in the determination of projected future wastewater flows. Although sewer service is not currently planned for the Bowl, it is anticipated that if future sewer service is provided to the Bowl that the wastewater from this area would flow into the new sewers that are proposed in the AOC. As such, the new sewers proposed within the AOC have been sized to accommodate wastewater flow from the Bowl and the AOC, where possible. Low pressure sewers are designed to accommodate a specific flow range and, in some cases, can not be sized to accommodate both current and future flow conditions.

The population estimates are based on house counts and an average of 2.5 people per house, similar to the methodology used to determine the current wastewater flows. House counts for the three categories listed above are presented in table 4-3.

Table 4-3
Future Residential House Counts & Population

Category	House Count	Population
Current – AOC & Adjacent to Proposed Sewers	1,149	2,884
Future - AOC	166	415
Bowl (current and future)	671	1,678
Total	**1,986**	**4,977**

The projected future study area population at full build-out has been estimated as 4,977 people by adding the current population estimate of 2,884 people to the population projected in the areas of potential future development in the AOC of 415 people and the Bowl of 1,678 people, as shown in Table 4-3.

The projected future study area population was used to project the future maximum month average daily sanitary flow that would be generated in the study area. The future average daily residential sanitary flow was estimated as approximately 358,300 gallons per day (gpd) by multiplying the projected future population by 72 gallons per person per day.

Although no new businesses or industries are projected for the study area, there are 19 existing commercial buildings within the Bowl, which have been included in the future flow projection. A summary of the maximum month commercial wastewater flows is presented in Table 4-4.

Table 4-4
Maximum Month Average Daily Commercial Sanitary Flows

Facility Type	Current Wastewater Flows (gpd)	Future Wastewater Flows (gpd)	Total Wastewater Flows (gpd)
I	4,000	16,300	20,300
II	26,000	4,500	30,500
III	11,000	0	11,000
Total	**41,000**	**20,800**	**61,800**

In total, the projected future maximum month average daily sanitary flow was calculated as 420,100 gpd by summing the residential and commercial flow components. The projected future peak sanitary flow was estimated as approximately 1,680,400 gpd by multiplying the average daily sanitary flow by the peaking factor of 4.0, similar to the approach used to calculate current peak sanitary flow.

If new sewers are constructed to serve the study area, some infiltration of groundwater into the sewers can be expected, as discussed under the description of current conditions. The study area average and peak projected future wastewater flows were estimated as 480,600 gpd and 1,740,900 gpd, respectively, by adding the projected sewer infiltration of 60,500 gpd to the sanitary flow projections noted above. This infiltration rate is based on a projected future total length of gravity sewers of 114,400 linear feet.

The average and peak projected future wastewater flows were determined for each of the study sub-areas using the approach described above. These flow rates are presented in Table 4-5.

4.3 CAPE COD COMMUNITY COLLEGE

4.3.1 Current Conditions

An evaluation of wastewater flows at Cape Cod Community College (CCCC) was performed in the 1996 Draft Phase III Facilities Plan, as is discussed in Section 2. In the Phase III report, the sanitary flows from the college were projected using water usage data from January 1991 to June 1996. Water usage was assumed to equal sanitary flow at the college because the college was not watering athletic fields and had minimal non-sanitary water use.

The Phase III report shows that the daily water usage ranged from 6,000 gpd to 16,600 gpd in the spring semester (12,100 gpd average) and from 2,000 gpd to 10,500 gpd in

Table 4-5
Summary of Projected Future Wastewater Flows at Full Build-Out (AOC and Bowl)
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension

Sub-Area	Gravity Pipe Length (lf) [1]	Infiltration (gpd) [2]	Average Wastewater Flow (gpd) [3]			Peak Wastewater Flow (gpd) [4]		
			Current	Future [5]	Total	Current	Future [5]	Total
1	11,200	5,900	22,300	25,000	47,300	78,400	93,100	171,500
2	9,500	5,000	18,800	5,400	24,200	63,500	18,300	81,800
3	16,300	8,600	28,500	19,000	47,500	96,600	67,600	164,200
4	14,500	7,700	30,900	35,700	66,600	111,600	131,700	243,300
5	18,500	9,800	19,400	46,400	65,800	69,200	164,600	233,800
6	10,000	5,300	15,800	23,500	39,300	53,600	87,700	141,300
7	18,900	10,000	57,200	12,000	69,200	201,800	45,000	246,800
8	4,400	2,300	71,700	11,500	83,200	280,800	45,100	325,900
9	11,100	5,900	20,400	17,100	37,500	75,600	56,700	132,300
Total	**114,400**	**60,500**	**285,000**	**195,600**	**480,600**	**1,031,100**	**709,800**	**1,740,900**

Notes:

(1) Based on the gravity sewer lengths projected for full-build-out and Sewer Layout Alternative 1, presented in Section 6.

(2) Calculated as pipe length (in miles) x pipe diameter (in inches) x 350 gpd/im.

(3) Maximum month value, including residential and commerical flows and infiltration.

(4) Calculated as 4 times the average daily sanitary flow plus infiltration.

(5) Future wastewater flows consider infilling within the AOC and current and new houses within the Bowl.

the summer semester (5,100 gpd average). However, the implementation of water conservation measures was underway during the CCCC evaluation and these measures were expected to reduce daily flows by approximately 4,000 gpd.

Recent discussions with officials from the college and limited flow data provided in a 1999 study of sewage disposal at the college indicate that water conservation measures have been effective in reducing water use at the school. Current spring semester average daily water usage was reported to be in the range of 7,000 to 10,000 gpd and 1999 summer semester water usage was reported to be in the range of 3,000 to 5,000 gpd. As such, we have used average daily spring and summer semester wastewater flows of 10,000 gpd and 4,000 gpd, respectively, for the purposes of this evaluation.

The 1996 college population was presented in the Phase III report based on enrollment information provided by the college. Approximately 3,500 students were enrolled during the spring semester and 1,200 students were enrolled in the summer semester in 1996. In addition, there were approximately 450 spring staff and 350 summer staff at the college. The spring 1999 student enrollment was reported to have increased approximately 9% from the 1996 values while the summer 1999 student enrollment was reported to have increased approximately 17% from the 1996 values, as shown in Table 4-6. The 1999 staff levels were unchanged from those presented in the Phase III report.

Table 4-6
Cape Cod Community College 1999 Population

Season	Student Population	Staff Population	Total Population
Spring	3,800	450	4,250
Summer	1,400	350	1,750

We estimate 1999 average per capita spring and summer sanitary flow rates of 2.4 gpd (10,000 gpd/4,250 people) and 2.3 gpd (4,000 gpd/1,750 people), respectively. These values reflect the water conservation measures performed since the 1996 report was prepared.

We calculate the current peak sanitary flow as 56,000 gpd by multiplying the average daily sanitary flow of 10,000 gpd by the more conservative peaking factor determined from TR-16 of 5.6. Based on a estimated collection system length of 2,000 linear feet, a pipe diameter of 8 inches, and an infiltration rate of 350 gpd/im, the college collection system infiltration is estimated as approximately 1,100 gpd. The average wastewater flow is calculated as approximately 11,100 gpd and the peak wastewater flow is calculated as approximately 57,100 gpd by adding the estimated infiltration rate to the average and peak sanitary flows.

4.3.2 Future Conditions

Future growth at the college was projected in the 1996 Phase III report, based on the following:

- A student population growth of 5%/year over the 20-year planning period
- A staff population growth of 10% over the 20-year planning period
- The construction of a Technology Center, which would increase support staff by 2% and faculty by one person

Note that the annual student population growth from 1996 to 1999 is approximately 3% for the spring semester and 5-1/2% for the summer semester. For the purposes of this evaluation, we have used the population growth rate of 5% presented in the 1996 Phase III report to estimate future student population, based on the 1999 population data. In addition, we have considered a 20-year planning period from the date of this evaluation (2003). The projected Year 2023 college population is presented in Table 4-7.

Table 4-7
Cape Cod Community College Year 2023 Population

Season	Future Student Population	Future Staff Population	Future Total Population
Spring	12,255	505	12,760
Summer	4,515	393	4,908

Using the projected future spring semester population of 12,760 people and the average per capita flow rate of 2.4 gpd determined from 1999 flow data, the future average daily sanitary flow is calculated as approximately 30,600 gpd (2.4 x 12,760). We calculate the peak sanitary flow as 171,400 gpd by multiplying the average daily sanitary flow of 30,600 gpd by the more conservative peaking factor determined from TR-16 of 5.6, similar to the calculation for determining current peak flows.

As was noted in the previous report section, the college collection system infiltration rate is estimated as approximately 1,100 gpd. The future average wastewater flow is calculated as approximately 31,700 gpd and the future peak wastewater flow is calculated as approximately 172,500 gpd by adding the infiltration rate to the average and peak sanitary flows.

The college's engineering consultant for the design of their wastewater pumping facility has indicated that the pumps have been sized for a flow rate of 120 gpm (172,800 gpd), which closely matches the peak flow estimate developed in this evaluation.

5.1 GENERAL

A total of five connection points to the existing sewerage system were evaluated to determine the feasibility of sending wastewater flow to them from the Area of Concern (AOC) and the Cape Cod Community College. The surplus hydraulic capacity downstream of each connection point was reviewed by comparing full-pipe capacities and pump station design capacities to the estimated wastewater flows currently conveyed by these sewers and pump stations.

Full-pipe capacities were estimated using the Manning Equation, which is commonly used to calculate gravity pipe flow from pipe diameter, slope and internal surface roughness. Record plans provided by the Town were used to obtain information on pipe diameter and slope. The pipe roughness was assumed to be 0.013, which is a conservative value commonly used for this type of evaluation.

Current wastewater flows to the existing sewers downstream of the potential connection points were estimated using the approach described in Section 4. Residential flow rates were determined based on house counts and the average wastewater flow/house of 180 gpd (72 gpcd x 2.5 people/house) established in Section 4 while commercial flow rates were estimated using water usage data and a seasonal peaking factor was applied. Peak sanitary flows were estimated as 4 times the average daily sanitary flow estimates, similar to the approach used to estimate peak wastewater flow within the AOC. Infiltration was estimated based on sewer diameter and length and an assumed infiltration rate of 1,000 gpd/im. This infiltration rate is higher than that projected for new sewers of 350 gpd/im and reflects that the older pipes in the system, especially the AC pipes, typically experience more infiltration than new PVC sewers. The infiltration estimates were added to the peak sanitary flow values in order to calculate the peak wastewater flows.

The five connection points considered are listed below and are shown in Figure 5-1:

1. Old Strawberry Hill Road
2. Route 28
3. West Main Street
4. Route 132
5. Freezer Road pump station force main

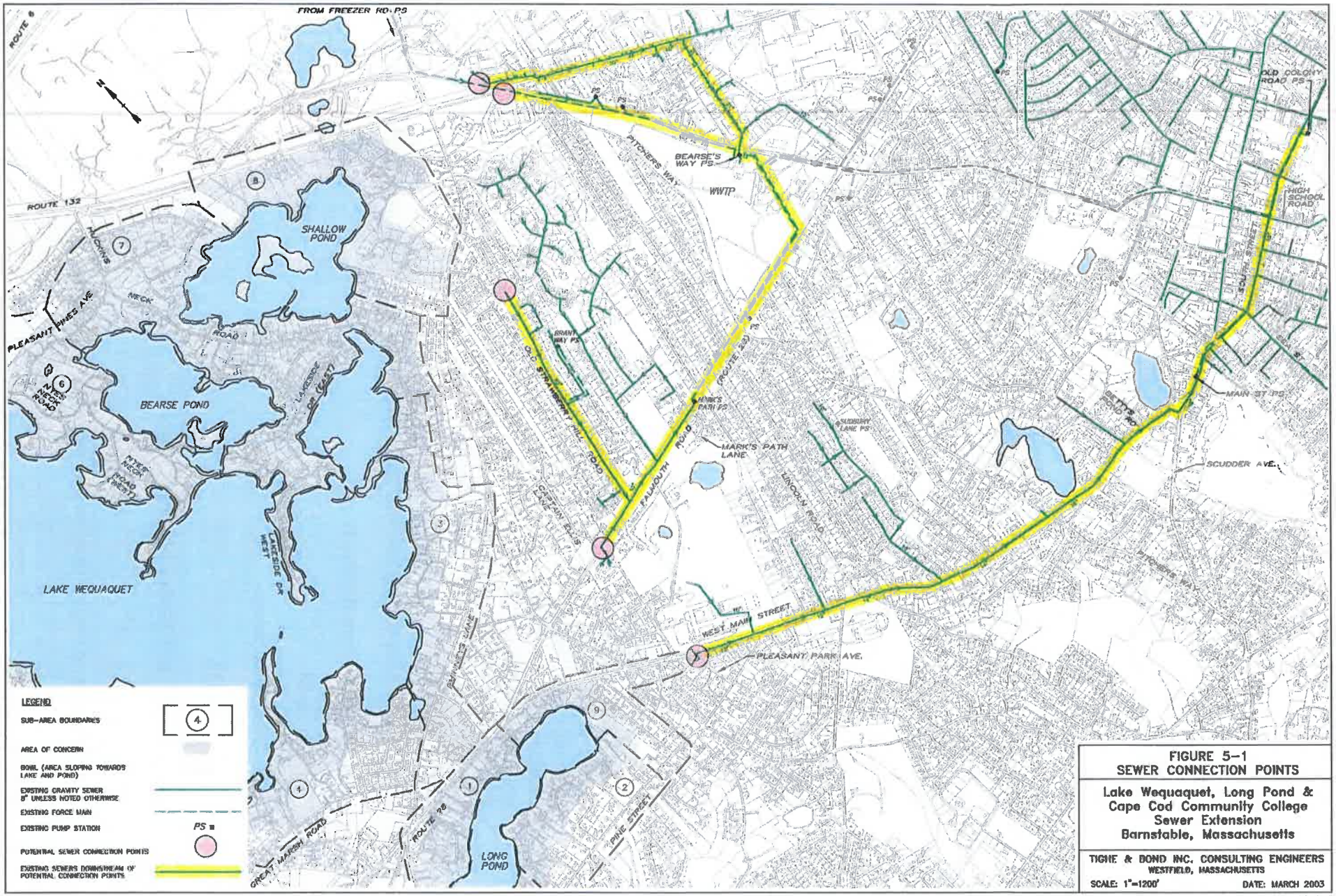

FIGURE 5-1
SEWER CONNECTION POINTS

Lake Wequaquet, Long Pond & Cape Cod Community College Sewer Extension
Barnstable, Massachusetts

TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASSACHUSETTS

SCALE: 1"=1200' DATE: MARCH 2003

5.2 OLD STRAWBERRY HILL ROAD

Connection to the Old Strawberry Hill Road sewer was considered in this evaluation because it is only 900 feet east of the northeastern section of the AOC, near Phinney's Lane. This sewer was also identified as a potential connection point in the 1987 Phase II facilities plan report.

The Old Strawberry Hill Road gravity sewer consists of 10-inch diameter PVC pipe and extends from Centerboard Lane to Route 28. The hydraulic capacity of this sewer was calculated as 0.75 mgd. In comparison, the estimated current peak wastewater flow was calculated as 0.06 mgd. As such, the surplus hydraulic capacity was calculated as 0.69 mgd (0.75 mgd - 0.06 mgd). However, it is important to note that wastewater flow from the Old Strawberry Hill Road sewer is conveyed to the Route 28 sewer. As such, the surplus capacity of the Route 28 sewer must also be considered in evaluating this potential wastewater connection point.

5.3 ROUTE 28

Connection to the Route 28 sewer was considered in this evaluation because it is only 2,000 feet east of the AOC. This sewer is in the vicinity of the southeastern section of Lake Wequaquet and the northeastern section of Long Pond. The Route 28 sewer was also identified as a potential connection point in the 1987 Phase II facilities plan report.

The Route 28 gravity sewer extends from Captain Ellis Lane to Mark's Path Lane. Wastewater flow collected by this gravity sewer is conveyed to the Marks' Path pump station, where it is subsequently pumped through a 6-inch force main on Route 28 to the wastewater treatment plant (WWTP). The gravity sewer is 8-inch diameter from Captain Ellis Lane to Old Strawberry Hill Road and is 10-inch diameter from Old Strawberry Hill Road to the Marks' Path pump station.

The hydraulic capacity of the Route 28 gravity sewer ranges from 0.50 mgd to 2.10 mgd and the Mark's Path pump station has a design capacity of 0.43 mgd. In comparison, the estimated current peak wastewater flow entering the Mark's Path pump station is 0.30 mgd. The Route 28 sewer has been divided into several sections for the purposes of comparing sewer capacity to estimated peak wastewater flow and calculating surplus hydraulic capacity, as shown in Table 5-1.

Table 5-1
Existing Wastewater Flows vs. Sewer Capacity – Route 28

Sewer Section/Pump Station	Sewer Diameter (inches)	Min. Pipe Slope (%)	Peak Wastewater Flow (mgd) (1)	Sewer Capacity (mgd) (2)	Surplus Capacity (mgd) (3)
End to Old Strawberry Hill Rd.	8	0.40	0.07	0.50	0.46
Old Strawberry Hill Rd. to Whitehall Way	10	0.28	0.14	0.75	0.61
Whitehall Way to pump station	10	0.14	0.30	0.53	0.23
Mark's Path pump station	---	---	0.30	0.43	0.13

Notes:
(1) Estimated based on residential house counts and commercial water use data.
(2) Based on lowest capacity reach within sewer section under review.
(3) Calculated by subtracting peak wastewater flow from sewer capacity.

The capacity of the Mark's Path pump station currently limits the capacity available to accept wastewater flow from the AOC to 0.13 mgd. Note that the Mark's Path pump station also limits the amount of wastewater flow that can be accepted from the upstream Old Strawberry Hill Road connection point.

AOC Sub-Areas 1, 2, 3, 4 and 9, shown in Figure 5-1, are closest to the Route 28 sewer and, as such, the projected flows from these sub-areas were compared in Table 5-2 to the surplus capacities described above in Table 5-1.

Table 5-2
AOC Peak Wastewater Flows vs. Route 28 Sewer Surplus Capacity

AOC Sub-Area	Estimated Current Peak Wastewater Flow (mgd)	Surplus Capacity (mgd)	Projected Future Peak Wastewater Flow (mgd)	Surplus Capacity (mgd)
1	0.08	0.13	0.17	0.13
2	0.06	0.13	0.08	0.13
9	0.08	0.13	0.13	0.13
Subtotal	**0.22**	**0.13**	**0.38**	**0.13**
3	0.10	0.13	0.16	0.13
4	0.11	0.13	0.24	0.13
Subtotal	**0.21**	**0.13**	**0.40**	**0.13**
Total	**0.43**	**0.13**	**0.78**	**0.13**

This connection point would be most effectively utilized by:

1. accepting the wastewater flow from the Long Pond area and the southern portion of Lake Wequaquet (Sub-Areas 1, 2, 3, 4 and 9);

2. accepting the wastewater flow from the Long Pond area only (Sub-Areas 1, 2 and 9); or

3. accepting the wastewater flow from the southern portion of Lake Wequaquet only (Sub-Areas 3 and 4)

Table 5-2 shows that this connection point does not have sufficient surplus capacity to serve any of the AOC sections described above. In fact, this connection point only has surplus capacity to accommodate the projected peak wastewater flow from Sub-Area 2 alone. In order to accommodate the current or future wastewater flows from either the Long Pond area or the southern portion of Lake Wequaquet, improvements to the Mark's Path pump station would be required. In addition, sewer improvements from Whitehall Way to the pump station would also be required in order to accommodate the projected peak future wastewater flows from these areas.

5.4 WEST MAIN STREET

Connection to the West Main Street sewer was considered in this evaluation because it is approximately 1,500 feet east of the AOC surrounding Long Pond. This sewer was also identified as a potential connection point in the 1987 Phase II facilities plan report.

The West Main Street gravity sewer extends from Pleasant Park Avenue to Scudder Avenue, and then continues on Main Street, discharging wastewater flow into the Main Street pump station. Wastewater flow is then discharged from the Main Street pump station into a gravity sewer on South Street, which conveys the wastewater flow to the Old Colony Road pump station. The West Main Street sewer is 12-inch diameter from its upstream end to Lincoln Road, 14-inch diameter from Lincoln Road to Pitcher's Way, 16-inch diameter from Pitcher's Way to Bettys Pond Road, and 18-inch diameter from Bettys Pond Road to the Main Street pump station. Wastewater flow from the Main Street pump station is discharged through an 8-inch force main to an 8-inch gravity sewer on South Street at Sea Street. The South Street gravity sewer is 8-inch diameter for approximately 8 feet, then changes to a 10-inch diameter sewer. The South Street gravity sewer is 10-inch diameter from Sea Street to High School Road, 12-inch diameter from High School Road to Ocean Street, 15-inch diameter from Ocean Street to approximately 250 feet east of Ocean Street, and 21-inch diameter from approximately 250 feet east of Ocean Street to the Old Colony Road pump station.

The hydraulic capacity of the West Main Street, Main Street and South Street gravity sewers range from 0.78 mgd to 12.57 mgd and the Main Street pump station has a design capacity of 0.70 mgd. The hydraulic capacity of the gravity sewers was calculated in this evaluation as the largest quantity of flow that the pipe can convey (full pipe flow) without flowing under pressure. In comparison, the estimated current peak wastewater flow at the downstream end is 1.33 mgd. The West Main Street/Main Street/South Street sewer has been divided into several sections for the purposes of comparing sewer capacity to estimated peak wastewater flow and calculating surplus hydraulic capacity, as shown in Table 5-3.

The Main Street pump station and the downstream sewer sections on South Street, from the pump station to Ocean Street, do not have any surplus hydraulic capacity. As such, sewerage system improvements would be necessary in order to use this potential connection point from the AOC to the existing sewerage system. The 1987 Phase II facilities plan report noted that there are currently hydraulic restrictions on South Street within the 10-inch and 12-inch sewer sections, as is confirmed by this evaluation.

However, note that there does appear to be sufficient surplus capacity within the sewers upstream of the Main Street pump station to accommodate the estimated current peak wastewater flows from Sub-Areas 1, 2 and 9, as shown in Table 5-4. The surplus hydraulic capacity value shown in Table 5-4 is the lowest surplus capacity value calculated within the pipe sections upstream of the pump station developed in Table 5-3. In addition, there may be sufficient surplus capacity within the sewers upstream of the Main Street pump station to accommodate the projected future peak wastewater flow from these sub-areas. The word "may" is emphasized because the projected future peak wastewater flow value is only slightly higher than the estimated surplus capacity. Because significant growth has been estimated in Sub-Areas 1 and 9, which may or may not occur, and there are expected to be opportunities to convey wastewater flow from these potential growth areas to other connection points, we recommend that this connection point be considered.

Table 5-4

AOC Peak Wastewater Flows vs. West Main Street Sewer Surplus Capacity

AOC Sub-Area	Estimated Current Peak Wastewater Flow (mgd)	Surplus Capacity (mgd)	Projected Future Peak Wastewater Flow (mgd)	Surplus Capacity (mgd)
1	0.08	0.34	0.17	0.34
2	0.06	0.34	0.08	0.34
9	0.08	0.34	0.13	0.34
Total	**0.22**	**0.34**	**0.38**	**0.34**

Table 5-3
Existing Wastewater Flows vs. Sewer Capacity - West Main St./Main St./South St.
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension

Sewer Section/Pump Station	Sewer Diameter (inches)	Min. Pipe Slope (%)	Peak Wastewater Flow (mgd) [1]	Sewer Capacity (mgd) [2]	Surplus Capacity (mgd) [3]
West Main St. (end to Seaboard Ln.)	12	0.19	0.19	1.01	0.82
West Main St. (Seaboard-Lafrance)	12/14	0.22	0.48	1.08	0.60
West Main St. (LaFrance-Pitcher's way)	14	0.10	0.76	1.10	0.34
West Main St. (Pitcher's way-Pine Grove Ave.)	16	0.11	0.88	1.65	0.77
West Main St. (Pine Grove-North St.)	16/18	0.14 (18 inch)	0.96	2.55	1.59
Main St. (North St.- Pump Station)	18	0.05	1.08	1.52	0.44
Main St. Pump Station	---	---	1.37	0.70	None
South St. (Sea St.-Chase St.)	8/10	0.30 (10 inch)	1.11 [4]	0.78	None
South St.(Chase St.-Pine Ave.)	10	0.30	1.15 [4]	0.78	None
South St.(Pine Ave-High School Rd.)	10	0.30	1.18 [4]	0.78	None
South St. (High School Road-Pearl St.)	12	0.21	1.58 [4]	1.06	None
South St. (Pearl St.-Ocean St.)	12	0.21	1.66 [4]	1.06	None
South St. (Ocean St. to Old Colony Rd. Pump Station)	15/21	0.15 (15 inch)	1.69 [4]	1.62	None

Notes:

(1) Estimated based on residential house counts and commercial water use data.

(2) Based on lowest capacity reach within sewer section under review.

(3) Calculated by subtracting peak wastewater flow from sewer capacity.

(4) Includes a pumped flow of 0.70 mgd from the Main Street pump station and a pumped flow of 0.29 mgd from the Sea Street pump station.

No surplus capacity available

Upgrading the pump station and redirecting the pump station force main to the nearby Old Colony Road pump station force main was considered in this evaluation in order to utilize the surplus capacity upstream of the Main Street pump station. These upgrades are discussed in greater detail in Section 6.

5.5 ROUTE 132

Connection to the Route 132 sewer was considered in this evaluation because it is approximately 1,800 feet east of the AOC. This sewer extends from Old Route 132 to Enterprise Road along Route 132 and then from Route 132 to the WWTP on Enterprise Road. The Route 132 sewer is 8-inch and 10-inch in diameter and the Enterprise Road sewer is 21-inch in diameter. The 21-inch Enterprise Road sewer discharges into the Bearses Way pump station, which is located at the WWTP. The Bearses Way pump station pumps the wastewater flow to the plant headworks for subsequent treatment.

The hydraulic capacity of the Route 132 and Enterprise Road gravity sewers range from 0.54 mgd to 5.71 mgd. In comparison, the estimated current peak wastewater flow at the downstream end is 1.38 mgd. The Route 132 and Enterprise Road sewer capacities, as well as the capacity of the Bearses Way pump station, have been compared to the estimated peak wastewater flows in Table 5-5.

Table 5-5

Existing Wastewater Flows vs. Sewer Capacity – Route 132

Sewer Section/Pump Station	Sewer Diameter (inches)	Min. Pipe Slope (%)	Peak Wastewater Flow (mgd) [1]	Sewer Capacity (mgd) [2]	Surplus Capacity (mgd) [3]
Route 132	8/10	0.48 (8 inch)	0.71	0.54	None
Enterprise Road	21	0.12	1.38	3.56	2.18
Bearses Way Pump Station	---	---	1.38	1.06	None

Notes:

(1) Estimated based on residential house counts and commercial water use data.

(2) Based on lowest capacity reach within sewer section under review.

(3) Calculated by subtracting peak wastewater flow from sewer capacity.

The Route 132 gravity sewers and the Bearses Way pump station do not have any surplus hydraulic capacity. As such, sewerage system improvements would be necessary in order to use this potential connection point from the AOC to the existing sewerage system.

5.6 FREEZER ROAD PUMP STATION FORCE MAIN

Connection to the Freezer Road pump station force main was considered in this evaluation because it is approximately 1,800 feet east of the AOC. There are two 12-inch force mains that extend from the Freezer Road pump station located in North Barnstable, along Phinney's Lane, Old Route 132, and Bearses Way, to the WWTP. Currently, only one of the two force mains is utilized. However, Town officials have indicated that the unused force main may be used in the future to convey treated wastewater to a new groundwater recharge site in North Barnstable.

We estimate that each Freezer Road pump station 12-inch force main has a maximum capacity of approximately 4.0 mgd, based on a peak pipe velocity of 8.0 feet per second. This approach provides an upper-end value that can be compared to projected pipe flows. However, the determination of force main capacity is typically more complex since the quantity of flow that the force main conveys has a direct impact on the operation of the upstream pumps. In comparison, the design flow of the Freezer Road pump station is 1.08 mgd and the current velocity through one main is 2.13 fps.

The Freezer Road pump station force mains appear to have a significant amount of surplus hydraulic capacity and connection to it has been considered in developing sewer layout alternatives, as is detailed in Section 6.

5.7 CONCLUSIONS

The Freezer Road pump station force mains appear to have the greatest amount of surplus hydraulic capacity of the connection points considered. The sewer layouts developed in Section 6 have utilized this connection point. In addition, the West Main Street connection point has been considered in Section 6 because there appears to be sufficient surplus capacity upstream of the Main Street pump station to accommodate wastewater flows from the Long Pond area. As noted previously, this connection point will require improvements to the Main Street pump station and the existing sewer system in this area.

The remaining potential connection points considered on Old Strawberry Hill Road, Route 28, and Route 132 would require significant pipe and pump station upgrades to the existing sewerage system and, as such, are not recommended.

6.1 GENERAL

Sewer layout alternatives to serve the Area of Concern (AOC) and the Cape Cod Community College (CCCC) were developed as part of this evaluation with the goals of minimizing construction costs, life cycle costs, environmental impacts, and neighborhood impacts, while providing a flexible and reliable sewer collection system. In order to accomplish the above goals, three sewer collection system technologies were considered:

- Conventional gravity sewers and pump stations
- Low pressure sewers and grinder pumps
- Vacuum sewers and vacuum stations

Both current and projected future conditions were considered in developing each of the sewer alternatives so that both the short-term and long-term sewage collection needs of the area can be accommodated, to the extent possible, with the new sewers proposed. Future conditions are based on full build-out within the AOC and potential expansion of the AOC collection system to provide sewer service to the surrounding areas (the Bowl).

Four sewer layout alternatives were determined to be most appropriate for conveying wastewater flow from the AOC and the Cape Cod Community College to the existing sewerage system and consist of various combinations of the technologies listed above. Other alternatives were eliminated from consideration during a preliminary screening process.

For each of the four sewer extension alternatives, detailed construction cost estimates have been developed and are presented in Section 9. In addition, an evaluation of non-monetary criteria, such as neighborhood impacts and environmental impacts, has been performed for each alternative and is also presented in Section 9.

The three sewer collection system technologies are generally described in the paragraphs below followed by a detailed description of each of the four sewer extension alternatives.

6.1.1 Gravity Sewers and Pump Stations

Gravity sewer systems are the most prevalent of the collection system technologies considered and modern gravity sewer construction has been implemented for well over 100 years. Gravity sewers are installed at a constant downward gradient, with a sufficient slope to prevent solids from settling in the pipe.

For the gravity sewers, the following preliminary design criteria were used in this evaluation:

- A minimum pipe diameter of 8 inches, as required by the MADEP for public sewers and in accordance with TR-16 guidelines.
- A minimum installation depth of 8 feet, to serve the building first floor levels within the project area (it may be possible to reduce this depth during design in some areas).
- A maximum installation depth of 25 feet below grade.
- A minimum slope of 4 feet per 1,000 feet (this is the minimum slope to maintain sufficient velocity prevent solids deposition in an 8-inch diameter sewer).
- A maximum flow depth of 80% of the pipe diameter at peak flow (under full build-out conditions).

In most cases, homes along a gravity collector sewer connect into it using gravity house service pipes. However, houses below the street elevation may need grinder pumps to convey the flow from the house to the collector sewer. The houses along gravity collector sewers that would require grinder pumps were identified for each of the four alternatives, based on the difference in grades between the house and the street, the distance from the house to the street, the proposed collector sewer depth, and a minimum house service slope of 1/4-inch/foot. The need for grinder pumps along gravity sewers will be confirmed during design based on more detailed topographic data, the finalized sewer layout, and data provided by the homeowners.

The construction costs associated with the installation of gravity sewers depend upon local topography. In areas where the topography is constantly increasing or decreasing, the sewer can be installed at the minimum depth required to serve the houses along the sewer. However, where there is rolling, hilly terrain, deep excavation and/or pump stations may be needed, which can significantly increase construction costs. This is especially true in areas where ledge will be encountered or where there are high groundwater levels.

Gravity sewer construction is most cost-effective in densely developed areas since the cost of the main line pipe is relatively high while the cost of the service connections is relatively low.

Gravity sewer advantages include:

- Little maintenance, although maintenance needs increase if pump stations are proposed.
- Can be easily designed to accommodate future growth and system expansion.
- Low potential for odors, although odor potential increases if pump stations are proposed.
- Reliable, since there is no reliance on mechanical equipment or power. If pump stations are needed, standby generators would be provided to supply power in the event of power loss and standby pumps would be provided to ensure continuous, uninterrupted operation in the event of a pump failure.

Gravity sewer disadvantages include:

- Can require deep excavations or pump stations, depending on topography, which increase construction cost.
- Susceptible to groundwater infiltration.

Because pump stations are proposed in some areas within the AOC, under each of the alternatives, to reduce the amount of deep sewer trench excavations that would otherwise be required, four pump station types were considered for this evaluation:

- Grinder pump stations
- Submersible pump stations
- Suction lift (self-priming) pump stations
- Wetwell/drywell pump stations

The grinder pump stations are prefabricated, package units while the submersible, suction lift, and wetwell/drywell pumping facilities can either be prefabricated, package facilities or built-in-place facilities, depending on community preference and service area size. Built-in-place facilities are often more appropriate and cost-effective for large service areas.

Duplex grinder pump stations were considered for this evaluation and are considered appropriate where the anticipated wastewater flows are relatively small (up to an average daily flow of 6,000 gpd). These facilities consist of two grinder pumps (semi-positive displacement or submersible) in a below-grade prefabricated polyethylene or fiberglass

reinforced plastic wetwell, high water level instrumentation, and pump controls housed in an above-grade panel. The grinder pump facilities are package pump stations, similar to the single-home grinder pump units described in the next report section. Normally, facilities of this size do not require standby power but can be provided with a connection for a portable generator. For this evaluation, we have assumed that a portable generator connection would be provided. The prefabricated grinder pump facilities provide a low cost pump station option but are only appropriate for relatively small service areas.

Submersible pump stations were also considered for this evaluation. These facilities offer the advantage of being relatively low in cost and typically have a less significant aesthetic impact than suction lift or wetwell/drywell pump stations since most of the facility components, with the exception of the control panel and a generator, if needed, would be located below grade. A submersible pump station typically consists of two or more submersible pumps, a concrete wetwell, water level monitoring instrumentation, and pump controls. The pumps at these facilities must be removed and disassembled for inspection and maintenance, requiring a hoist or crane. The submersible pumping facilities, which can accommodate a wide range of flows, are often package facilities where the pumps, instrumentation, and controls are provided as an integrated system. The submersible pump stations can be provided with or without a building, depending on owner preferences, and, for the larger facilities, are typically provided with standby power. If standby power is needed and a building is planned, the generator can be housed within the building, along with the pumps, instrumentation, and controls. Otherwise, the standby generator would be provided within a weather-proof enclosure. A separate valve chamber is often constructed just downstream of the submersible pump station to facilitate maintenance of the valves on the discharge side of the pump. A typical submersible pump station is shown in Figure 6-1.

Suction lift pump stations, which can accommodate a similar flow range to the submersible pumping facilities, were also considered. The suction lift pump station components are similar to the submersible pump station components with the exception that the pumps would be located above the wetwell and at grade, if possible, to facilitate pump maintenance. Typical suction lift pumps have the capability to lift wastewater approximately 20 feet. If the wetwell operating levels are greater than 20 feet below grade, then either a different type of pump would be needed or the suction lift pumps would need to be installed below grade. The suction lift pump stations are often package-type facilities, similar to the submersible pumping facilities. A building or above-grade enclosure can be provided, similar to the submersible pumping facilities, to house pump controls, instrumentation, and a standby generator, if needed. Otherwise, the pumps can be located in a below-grade drywell with the controls located in an above-grade panel. However, under this arrangement the drywell would be considered a confined space and appropriate safety precautions would need to be taken by Town personnel when working on the pumps. Suction lift pump stations are generally preferred by the Town over

submersible pumping facilities. A typical suction lift pump station is shown in Figure 6-2.

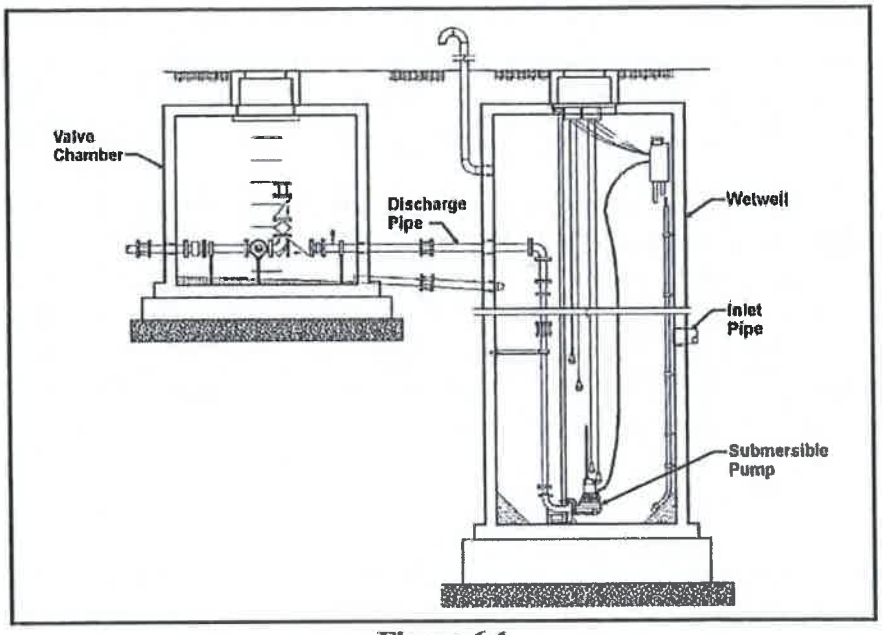

Figure 6-1
Typical Submersible Pump Station

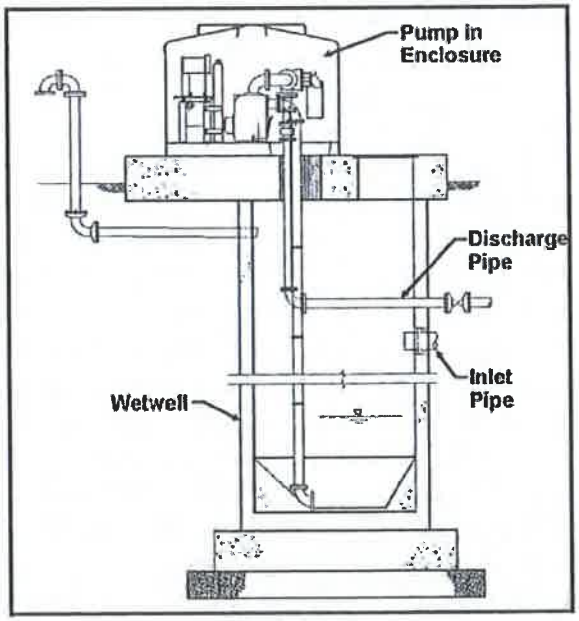

Figure 6-2
Typical Suction Lift Pump Station

Wetwell/drywell pumping stations were considered in this evaluation and consist of a wetwell, a drywell where the pumps are located, solids-handling pumps and pump controls/instrumentation. These facilities are typically more expensive than the submersible or suction lift facilities because of the added cost to construct the below-grade drywell. In a typical wetwell/drywell pump station arrangement, there are two levels. The pumps and piping would be located in the drywell, which would be located adjacent to the wetwell and at the bottom level of the facility. The station controls, instrumentation, and standby generator would be located at the top level of the facility. The drywell would be provided with appropriate lighting and ventilation to avoid confined space safety concerns. Pumps are more easily maintained at these facilities. A typical wetwell/drywell pump station is shown in Figure 6-3.

A summary of the advantages and disadvantages of the pump stations types considered is presented in Table 6-1.

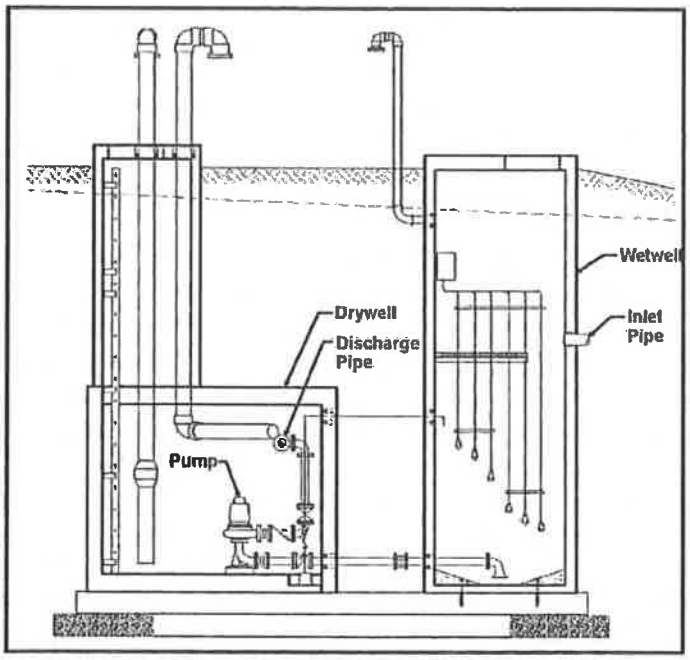

Figure 6-3
Typical Wetwell/Drywell Pump Station

Table 6-1

Advantages and Disadvantages of the Pump Station Types Considered

Pump Station Type	Advantages	Disadvantages
Duplex grinder	• Lowest cost • Smallest aesthetic impact	• Can only accommodate small service areas
Submersible	• Relatively low cost • Small aesthetic impact • Small land area needed • Drywell is not needed	• More difficult to maintain pumps • Separate vault typically provided for discharge valves
Suction lift	• Relatively low cost • Relatively easy to access and maintain pumps • Drywell is not needed	• Less reliable than other pumps due to need for priming • Distance from the low wetwell level to the pumps is limited to approximately 20 feet
Wetwell/drywell	• Easiest to maintain pumps • Can accommodate the widest range of flows • Flooded suction pumps are more reliable	• Highest cost • Largest aesthetic impact • Largest land area needed

6.1.2 Low Pressure Sewers

Low pressure sewer systems have been constructed in the United States since the early 1970s and the use of this collection system technology has increased significantly over the past 10 years. In a low pressure sewer system, wastewater flows by gravity from the building(s) being served into a sump, where the wastewater is subsequently shredded and then pumped through a pressure pipe to a low pressure collector sewer. The low pressure collector sewer then discharges into a downstream gravity sewer or force main. Because the collector sewers are pressure pipes, they may be installed to more closely follow the existing topography, allowing excavation depths to be minimized. Typical operating pressures are less than 60 psi within the collector sewers.

Low pressure sewers are well-suited for areas with hilly, rolling terrain because the deep excavation and/or pump stations that would be required for gravity sewer systems can be avoided. In addition, low pressure sewers are generally more cost-effective in areas that are less densely developed since the cost of the main line pipe is relatively low while the cost of the service connections (which include grinder pumps) is relatively high.

Low pressure sewer piping is sized small enough to provide a velocity sufficient to assure that the pipe will be self-cleansing while large enough to avoid excessive headlosses that

would impact grinder pump operation. Because pipe velocity and headloss must be balanced, a low pressure system is sized for a specific flow range and can not as readily accommodate significant future expansion as can gravity sewer systems.

A typical residential home grinder pump would operate over a short duration (5± minutes) once or twice per day. As such, only a percentage of the total number of grinder pumps in a service area would be operating at the same time. A common approach used to determine the size of the low pressure sewers needed to serve the area is to assume that a certain percentage of the grinder pumps would be active. For example, E/One indicates that if there are 19-30 upstream grinder pumps, typically no more than 5 of these grinder pumps will be active at the same time.

One grinder pump unit would typically be installed at each home or business/commercial property. The grinder pump unit typically consists of a semi-positive displacement or centrifugal pump, a below-grade prefabricated wetwell (constructed of polyethylene or fiberglass reinforced plastic) to store wastewater flow from the house, high water level alarm instrumentation, and pump controls housed in an above-grade panel, as shown in Figure 6-4.

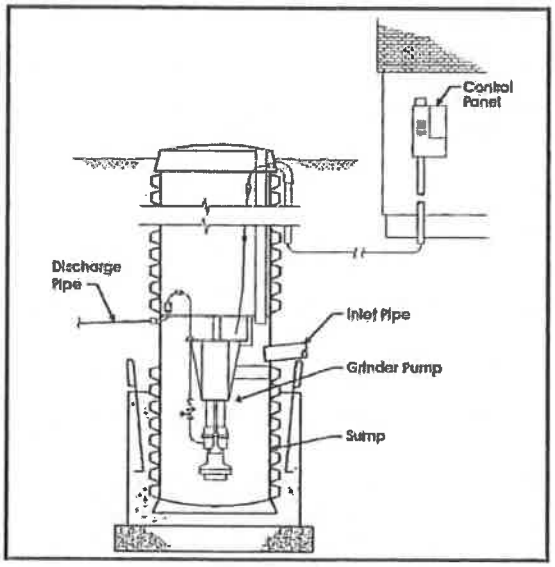

Figure 6-4
Typical Grinder Pump Unit (E/One Unit Shown)

Pump operation is normally initiated by a water level in the sump and a visual local high water alarm is normally provided. An audible alarm is also available and can be provided at each control panel. Remote monitoring of the grinder pumps can also be provided. Grinder pump monitoring information that can be collected locally and transmitted to a remote location include:

- Wastewater level in the sump
- Pump run time
- Number of pump activations
- Alarm status

In some communities that have installed low pressure sewers, the grinder pumps are owned, operated, and maintained by the individual homeowners, while in others, the community owns, operates, and maintains the grinder pumps. For the purposes of this evaluation, we have included the grinder pump costs in the alternatives cost estimates.

For the purposes of this evaluation, we have assumed that there will be one grinder pump for every home connected to a low pressure sewer. However, in some cases it may be possible and appropriate to serve two or more residential homes with a duplex grinder pump station. The feasibility and cost-effectiveness of serving multiple single-family homes with duplex grinder pump stations is a function of housing density in the neighborhood where this is being considered, land availability, and public acceptance. The feasibility and appropriateness of constructing duplex grinder pump stations will be evaluated during the design phase of the project. We have also assumed that each grinder pump will be provided with a connection for a portable generator that can be connected and engaged in the event of a power failure.

Low pressure sewer advantages include:

- Excavation depths can be shallow since the low pressure sewer can follow the existing topography.
- Collector sewer construction can proceed more quickly and with less disruption than gravity sewers as a result of the more shallow excavation depths.
- Smaller piping (typically ranging from 1-1/2-inch to 6-inch) can be used than is needed for gravity sewers because the grinder pumps shred the wastewater solids.
- Infiltration is not a concern since the wastewater is conveyed in a pressure pipe.

Low pressure sewer disadvantages include:

- Operation and maintenance costs are typically higher than for gravity systems since each building would have its own pump.
- Normally backup power is not provided in the event of a power failure. Sewage backups into house service lines could occur during a prolonged power outage.

This concern can be mitigated, to some extent, by providing portable generator connections on the grinder pumps.

- The wastewater retention time is marginally longer than is typically experienced in a well-designed gravity sewer system, which could lead to the formation of blockages and/or odors. Communities with seasonal flow variations are more susceptible to this problem.
- Exfiltration could occur if there are leaks or breaks in the pipe.
- Can accommodate less future growth.

6.1.3 Vacuum Sewers

Vacuum sewer systems have been constructed in the United States since the early 1970s, similar to the low pressure sewer systems, and there are over 200 vacuum sewer systems in place in 28 states. However, there is only one completed vacuum sewer system in New England, located in Barnstable, although a second system in Provincetown is expected to be completed this December. As such, we consider vacuum sewers to be a relatively new technology in this area.

In a vacuum sewer system, wastewater flows by gravity from the building(s) being served into a sump. When the wastewater reaches a preset level in the sump then a pneumatically actuated control valve opens, allowing the wastewater to be drawn out of the sump and into the vacuum collector sewer because of the pressure difference between the collector sewer and the atmospheric pressure in the sump. The wastewater in the vacuum collector sewer is conveyed further downstream each time a control valve is opened, until the wastewater flow eventually reaches the vacuum station. From the vacuum station, the wastewater is pumped into a gravity sewer or force main.

Similar to the low pressure sewers, the vacuum sewers may be installed to more closely follow the existing topography, allowing excavation depths to be minimized. However, for level or uphill pipe runs the vacuum sewers must be installed in a specific, saw-tooth configuration in order for the system to function as intended. Similar to the low pressure sewers, the vacuum sewers are generally more cost-effective in areas that are less densely developed since the cost of the main line pipe is relatively low while the cost of the service connections (which include the valve pits) is relatively high.

For the vacuum sewer system, a valve pit package would typically be installed at each home or business, although up to 4 homes can be served by one package. The valve pit package includes a control valve, a valve pit, and a control panel, as shown in Figure 6-5. The valve pit is split into two chambers: the lower chamber where wastewater from the home is stored and the upper section, which is completely sealed from the

lower section, where the valve is housed. The control valve requires no power and activates pneumatically based on pressure differential in the lower chamber caused by rising sewage level. This allows wastewater collected within the lower chamber to be drawn into the vacuum sewer in the street and subsequently to the downstream vacuum station.

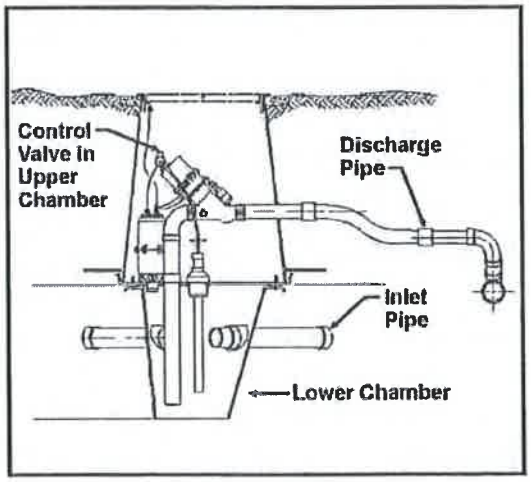

Figure 6-5
Typical Vacuum Valve Pit Package (AIRVAC unit shown)

Vacuum sewer advantages include:

- Excavation depths can be shallow since the vacuum sewers can generally follow the existing topography.
- Construction can proceed more quickly and with less disruption than gravity sewers as a result of the more shallow excavation depths.
- Smaller piping (typically ranging from 3-inch to 10-inch) can be used than is needed for gravity sewers.
- Infiltration is not a significant concern since the piping needs to be "tight" in order for the vacuum system to operate properly.
- Exfiltration is less of a concern.
- Low potential for odors within the piping system, although odors can occur and are a concern within the vacuum stations.

- The mechanical valve provided at each home would not be affected by a power outage. At the vacuum stations, standby generators would be provided to supply power in the event of power loss and standby pumps would be provided to ensure continuous, uninterrupted operation in the event of a power failure.

Vacuum sewer disadvantages include:

- Because a vacuum must be maintained in the system for it to operate properly, a pipe break will impact the entire system.
- Leaks in the system may be difficult to locate.
- Operation and maintenance costs are typically higher than for gravity systems since each building would have its own control valve.
- Vacuum sewer technology is relatively new in the New England area, which could result in higher construction costs than would be experienced in other areas where contractors are more familiar with the installation of these systems.

6.1.4 Odor Control

Because some long low pressure sewers and force mains will be constructed as part of this project, for each of the alternatives under consideration, hydrogen sulfide generation, which is a source of sewage odors, is a concern. Hydrogen sulfide odor is commonly characterized as smelling like rotten eggs. Hydrogen sulfide can form where anaerobic conditions exist, as is often found in long pressure pipes which flow full because of the long detention times. The release of hydrogen sulfide gas is also a concern because it could lead to the formation of sulfuric acid, which can deteriorate concrete manholes and wetwells. Significant hydrogen sulfide generation (and subsequently sulfuric acid) can also occur in gravity sewers with long wastewater detention times, although this is less common.

For the Barnstable project, facilities to provide hydrogen sulfide control are recommended. Hydrogen sulfide control is most often provided through chemical addition to oxidize the hydrogen sulfide or to inhibit its formation. Oxidizing chemical feed options include:

- Chlorine,
- hydrogen peroxide, and
- potassium permanganate.

Although oxidizing the hydrogen sulfide can be effective, oxidizing chemicals are not recommended because:

- They are more difficult and dangerous to handle because of their corrosive nature
- Storage of these corrosive chemicals near to the nearby surface water bodies is a concern
- They are generally more expensive than the inhibitors on the market

A commonly used inhibitor, calcium nitrate (commonly known as Bioxide), can be supplied in liquid form, is easily handled, does not freeze at the low temperatures experienced in the project area, an does not readily degrade. For the purposes of this evaluation, calcium nitrate has been selected as the preferred odor control chemical. However, other odor control chemicals will be reviewed in greater detail during design. Specific locations where odor control may be appropriate will be discussed under the description of each alternative.

A calcium nitrate feed system is typically provided as a package unit and consists of a chemical storage tank, a chemical feed pump, and chemical feed controls.

6.2 DESCRIPTION OF ALTERNATIVES

6.2.1 Alternative 1 – Gravity & LP Sewers, 8 Pump Stations

Alternative 1, shown in Figure 6-6, was developed to maximize the amount of gravity sewers while minimizing the number of conventional pump stations and low pressure sewers/grinder pumps within the AOC. Vacuum sewers were not considered as part of this alternative. This alternative is described in detail in the paragraphs that follow and is summarized in Table 6-2.

Alternative 1 includes:

- 125,500 feet (24± miles) of proposed sewers;
- 68,250 feet of gravity sewers (54% of total);
- 8 proposed pump stations and replacement of the Main Street pump station; and
- 361 grinder pumps.

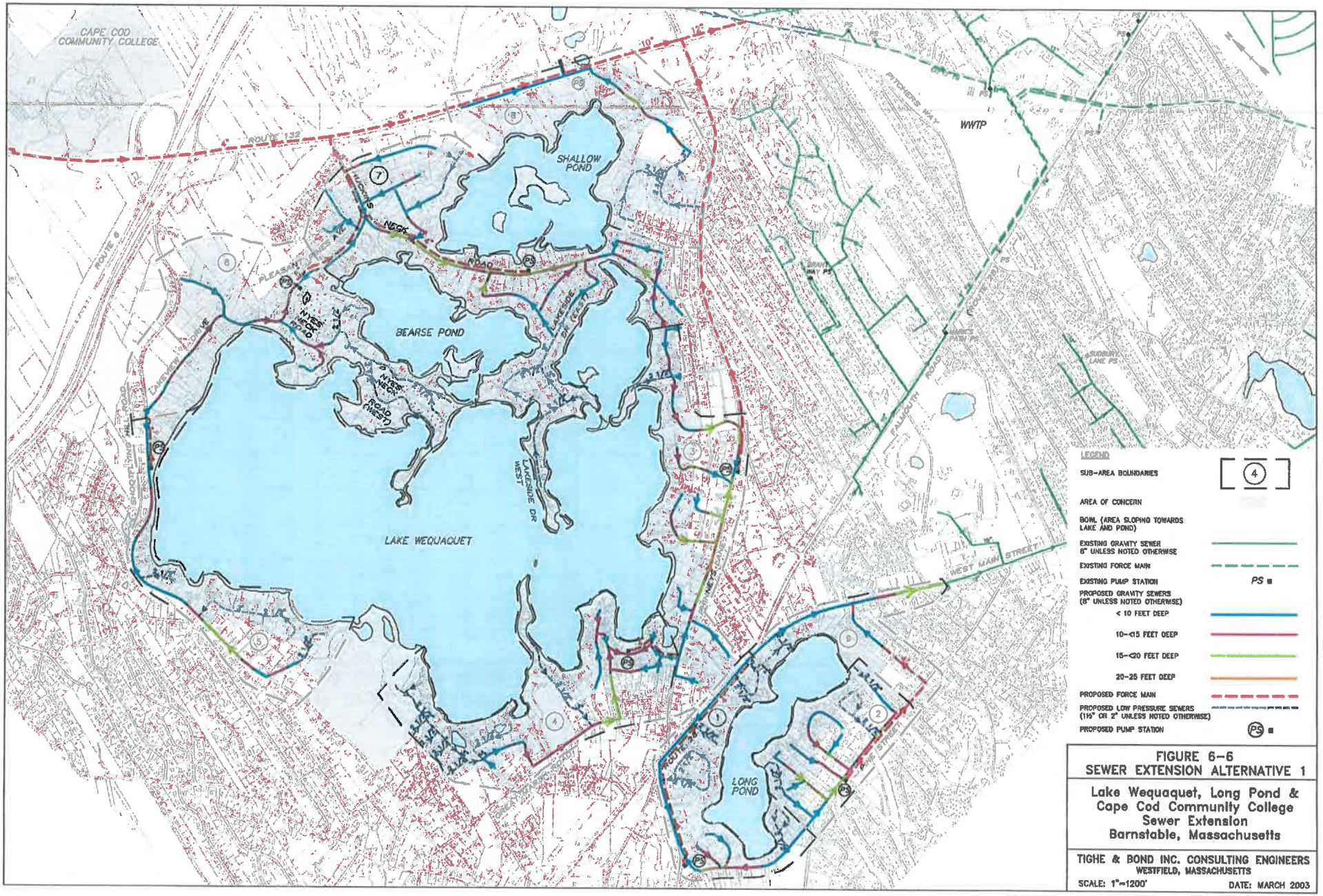

FIGURE 6-6
SEWER EXTENSION ALTERNATIVE 1

Lake Wequaquet, Long Pond & Cape Cod Community College Sewer Extension Barnstable, Massachusetts

TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASSACHUSETTS

SCALE: 1"=1200' DATE: MARCH 2003

Table 6-2
Alternative 1 Sewer layout Summary

Sub-Area	Gravity Sewer Length (ft)	Low Pressure Sewer Length (ft)	Force Main Length (ft)	Total Pipe Length (ft)	No. of Pump Stations	No. of Grinder Pumps
1	6,760	4,240	3,400	14,400	1	51
2	7,340	2,420	2,600	12,360	1	14
3	10,860	650	6,500	18,010	1	25
4	7,460	5,620	850	13,930	1	63
5	5,170	3,160	700	9,030	1	44
6	6,110	5,030	2,650	13,790	1	42
7	16,880	5,700	2,500	25,080	1	69
8	3,850	2,960	100	6,910	1	45
9	3,820	470	0	4,290	0	8
CCCC	0	0	6,300	6,300	0	0
Improvements to Existing Sewerage System (1)	0	0	1,400	1,400	1	0
Total	**68,250**	**30,250**	**27,000**	**125,500**	**9**	**361**

Notes:

(1) Includes replacement of the Main Street pump station and diverting flow from the pump station to the Old Colony Road pump station force main.

6.2.1.1 Long Pond (Sub-Areas 1, 2 & 9)

Under Alternative 1, the wastewater flow from the Long Pond area would be conveyed easterly to the existing gravity sewer on West Main Street. The current peak wastewater flow from this area is approximately 0.22 mgd and the projected future peak wastewater flow, at full build-out and including sewer expansion into the Bowl, is 0.38 mgd. In comparison, the surplus capacity of the West Main Street and Main Street gravity sewers is estimated as approximately 0.34 mgd without any surcharging. As such, the existing West Main Street and Main Street gravity sewer sections have sufficient surplus capacity to accommodate current peak flows and may have sufficient capacity to accommodate the projected future peak flows, as discussed in Section 5. The word "may" is emphasized because the projected future peak flow is slightly higher than the surplus capacity available. Because significant growth has been estimated in Sub-Areas 1 and 9, which may or may not occur, and there are expected to be opportunities to convey wastewater flow from these potential growth areas to other connection points, we recommend that this nearby connection point, which is the most cost-effective, be used for Sub-Areas 1, 2 and 9. Additionally due to the depths of the existing sewers, minor surcharging (pressure flow) could be accommodated without negative impact. This would increase the carrying capacity of the sewers above the gravity flow limit noted above. Improvements to the Main Street pump station and its force main would be required in order to utilize this connection point.

Conveying the wastewater flow from the Long Pond area to the nearby Route 28 sewer was also considered. However, this connection point is not recommended because it has less surplus hydraulic capacity than the West Main Street connection (0.22 mgd) and would require the replacement of 1,000± feet of gravity sewer and the Mark's Path pump station. Another alternative considered was to convey the wastewater flow from the Long Pond area northerly to the Freezer Road pump station force main. This connection point is not recommended because it would result in a higher life cycle cost.

Sub-Area 1

Sub-Area 1 includes the portions of the AOC north, west, and southwest of Long Pond. Under Alternative 1, wastewater from the northern section of Long Pond would be conveyed by an 8-inch gravity trunk sewer on Route 28 westerly to a gravity trunk sewer on Phinney's Lane. The Phinney's Lane sewer would convey the wastewater flow to a proposed pump station off of Phinney's Lane, in Mother's Park. Wastewater from the southwestern section of Long Pond would be conveyed by an 8-inch gravity trunk sewer on Pine Street westerly to the Mother's Park pump station. The Mother's Park pump station site is shown in Figure 6-7. Wastewater flow from the Mother's Park pump station would discharge to the gravity sewer on Route 28, just east of Harrison Road, through a 4-inch force main.

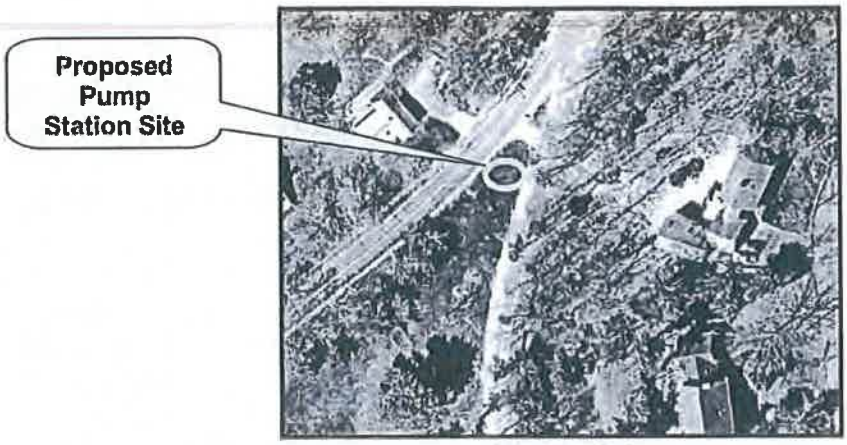

Figure 6-7
Sub-Area 1 Pump Station Site

The collector sewers tributary to the trunk sewers described above would be low pressure, except on Long Pond Circle, in order to avoid deep collector sewer trench excavations and to minimize trunk sewer excavation depths. Gravity collector sewers are proposed on Long Pond Circle. The Sub-Area 1 trunk sewers would generally be constructed less than 10 feet deep, with the exception of the Long Pond Circle area, where approximately 350 feet of sewer on Pine Street would be constructed greater than 15 feet deep and approximately 250 feet of sewer on Pine Street would be constructed greater than 20 feet deep.

Sub-Area 2

Sub-Area 2 includes the portions of the AOC south of Long Pond, between Dunaskin Road and Horatio Lane. Under Alternative 1, an 8-inch gravity trunk sewer would convey wastewater from Dunaskin Road easterly along Pine Street to a proposed pump station between Riverview Lane and the St. Francis Xavier's Cemetery. In addition, an 8-inch gravity trunk sewer would convey wastewater from Horatio Lane westerly along Pine Street to the Pine Street pump station described above. The Pine Street pump station site is shown in Figure 6-8. Wastewater flow from the Pine Street pump station would discharge to the gravity sewer on Childs Street through a 4-inch force main.

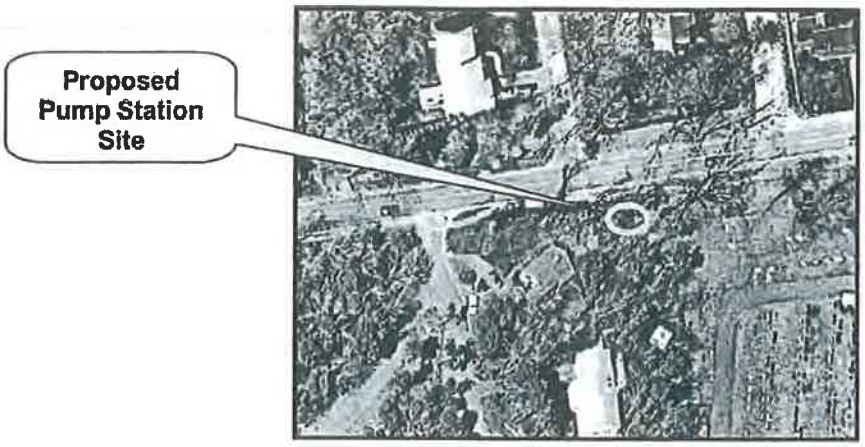

Figure 6-8
Sub-Area 2 Pump Station Site

Low pressure sewers are proposed on Herring Run Drive and on the northern ends of Dunaskin Road and Horatio Lane. Gravity collector sewers are proposed for the remaining streets in this sub-area. The Sub-Area 2 trunk and collector sewers would range in depth from less than 10 feet to greater than 20 feet for some sewer sections. Approximately 700 feet of the 2,100-foot Pine Street trunk sewer would be constructed greater than 15 feet deep and a 200-foot section of sewer on Blantyre Avenue would be constructed greater than 20 feet deep.

Sub-Area 9

Sub-Area 9 includes the portion of the AOC east of Long Pond, from the West Main Street/Route 28 intersection to Pleasant Park Avenue. Under Alternative 1, an 8-inch gravity trunk sewer would convey wastewater flow along West Main Street easterly to the existing sewerage system. The wastewater flow from Sub-Area 1 would be pumped into this trunk sewer while the wastewater flow from Sub-Area 2 would be pumped into an 8-inch gravity sewer on Childs Street, which is tributary to the West Main Street trunk sewer described above.

Under this alternative, deep trench excavation (greater than 15 feet deep) would be required for approximately 800 feet of sewer at the easterly end of the West Main Street trunk sewer. Sewer trench excavations would not exceed 20 feet in this sub-area under this alternative. Low pressure sewers are only proposed on Scottsdale Road in this sub-area.

6.2.1.2 Southern Portion of Lake Wequaquet (Sub-Areas 3 & 4)

Under Alternative 1, the wastewater flow from the southern portion of Lake Wequaquet would be conveyed northerly to the existing force main from the Freezer Road pump

station. The current peak flow from this area is approximately 0.21 mgd and the projected future peak flow, at full build-out and including sewer expansion into the Bowl, is 0.41 mgd. In comparison, the surplus capacity of the 12-inch Freezer Road pump station force main is estimated to be as much as 4.0 mgd (based on a velocity of 8 feet/second), as discussed in section 5. With the addition of the peak flow of 0.41 mgd, the force main velocity would increase from 2.13 feet/second (fps) to 2.94 fps. The operation of the Freezer Road pump station and the force main hydraulics would need to be reviewed if this alternative is pursued to determine the impact on pump operation of increasing the force main flow. Improvements to the pumps may be necessary to accommodate the higher pressure losses that would result from increasing the force main flow, although these improvements would likely be minor for this relatively small velocity change.

As an alternative, wastewater flow from the southern portion of Lake Wequaquet could be conveyed to the nearby Route 28 connection point. However, this connection point is not recommended because it has less surplus hydraulic capacity than the Freezer Road pump station force main connection (0.22 mgd) and would require the replacement of 1,000± feet of gravity sewer and the Mark's Path pump station. Connection to the existing sewerage system on West Main Street was not considered for this area because the Long Pond area would already be directed to this connection point and would utilize all of the remaining surplus capacity. Another alternative considered was to convey the wastewater flow from the southern portion of Lake Wequaquet northerly to the Route 132 gravity sewer. This connection point is not recommended because there is no surplus capacity available in the Route 132 gravity sewer or the Bearses Way pump station.

Sub-Area 3

Sub-Area 3 includes the portion of the AOC southeast of Lake Wequaquet and extends from Conners Road to the north to Crosby Road to the south and is bounded by Phinney's Lane to the east and the lake to the west. Under Alternative 1, wastewater from the northern section of Sub-Area 3 would be conveyed by an 8-inch gravity trunk sewer on Phinney's Lane southerly to a proposed pump station near the intersection of Phinney's Lane and Old Farm Road. Wastewater from the southern section of Sub-Area 3 would be conveyed by an 8-inch gravity trunk sewer on Phinney's Lane northerly to the Old Farm Road pump station described above. The Old Farm Road pump station site is shown in Figure 6-9. Wastewater flow from the Old Farm Road pump station would discharge to the proposed Cape Cod Community College pump station force main on Route 132 through a 6-inch force main.

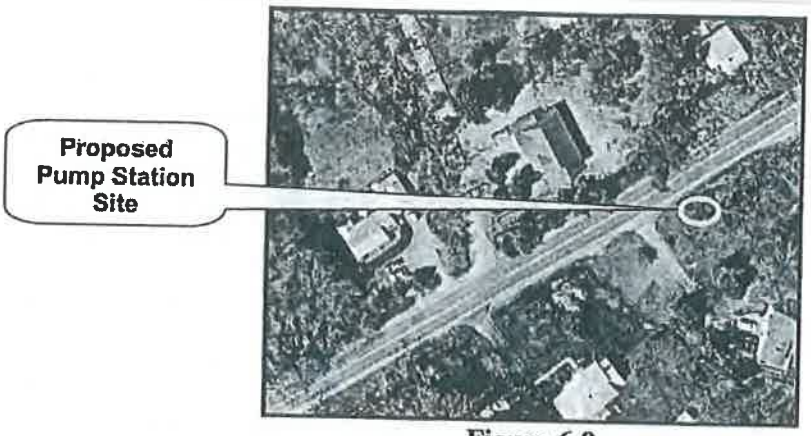

Figure 6-9
Sub-Area 3 Pump Station Site

A significant portion of the Phinney's Lane trunk sewer would be constructed greater than 15 feet deep under this alternative in order to accommodate gravity collector sewers on the side streets tributary to Phinney's Lane. In fact, approximately 2,200 feet of the 3,700-foot Phinney's Lane trunk sewer (59%) would be constructed greater than 15 feet deep and approximately 800 feet of the trunk sewer would be constructed greater than 20 feet deep. Low pressure sewers are proposed only on Center Lane in this sub-area, under Alternative 1.

Sub-Area 4

Sub-Area 4 includes the portion of the AOC southwest of Lake Wequaquet and extends from Annable Point Road to the west to Phinney's Lane to the east and is bounded by Great Marsh Road to the south and the lake to the north. Under Alternative 1, wastewater from the western portion of Sub-Area 4 would be conveyed by an 8-inch gravity trunk sewer on Great Marsh Road easterly to Juniper Road and then northerly along Juniper Road to Lake Drive. The 8-inch trunk sewer on Lake Drive would subsequently convey the wastewater flow into a proposed pump station in the vicinity of the Wequaquet Estates beach on Lake Drive. Wastewater flow from Brezner Road and Pond Street would be conveyed through 8-inch gravity sewers westerly to the Lake Drive pump station. The Lake Drive pump station would discharge into the Sub-Area 3 gravity trunk sewer on Phinney's Lane through a 4-inch force main. The Lake Drive pump station site is shown in Figure 6-10.

In order to avoid excessively deep trench excavations, low pressure sewers would be constructed in the Annable Point Road area and on Hayes Road. Gravity collector sewers are proposed for the remaining streets in this sub-area. Deep trench excavations (greater than 15 feet deep) would be required along Juniper Road and a short section of

Great Marsh Road. Sewer trench excavations would not exceed 20 feet in this sub-area under this alternative.

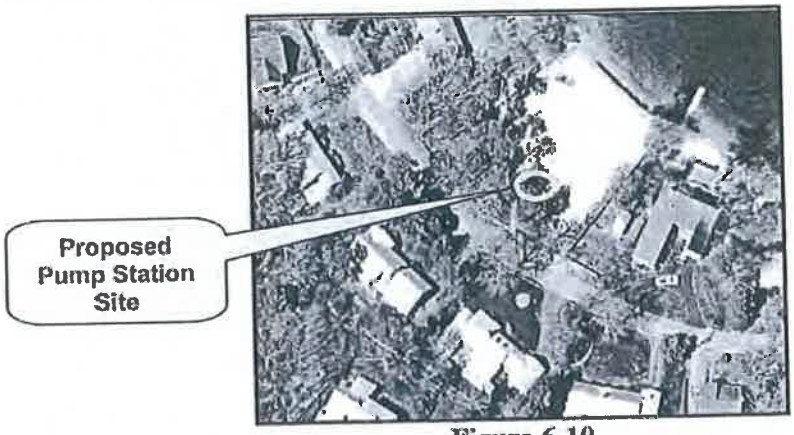

Figure 6-10
Sub-Area 4 Pump Station Site

6.2.1.3 Northern Portion of Lake Wequaquet (Sub-Areas 5, 6, 7 & 8)

Under Alternative 1, the wastewater flow from the northern portion of Lake Wequaquet would be conveyed to the existing force main from the Freezer Road pump station, similar to the southern portion of Lake Wequaquet. As discussed in Section 5, we have assumed that only one of the two force mains will be available to accept wastewater flow from the AOC. The current peak flow from the northern portion of Lake Wequaquet is approximately 0.61 mgd and the projected future peak flow, at full build-out and including sewer expansion into the Bowl, is 0.95 mgd. When the flow from the southern portion of Lake Wequaquet is also considered, the current peak flow from the northern and southern portions of Lake Wequaquet is approximately 0.82 mgd and the projected future peak flow, at full build-out and including sewer expansion into the Bowl, is 1.36 mgd. In comparison, the surplus capacity of the 12-inch Freezer Road pump station force main is estimated to be as much as 4.0 mgd (based on a velocity of 8 fps), as noted previously. With the addition of the peak flow of 1.36 mgd, the wastewater flow through the force main would increase from 1.08 mgd to 2.44 mgd and the velocity would increase from 2.13 fps to 4.79 fps. This pipe velocity is well within what is considered an acceptable range. The operation of the Freezer Road pump station and the force main hydraulics would need to be reviewed if this alternative is pursued to determine the impact on pump operation of increasing the force main flow. Improvements to the pumps may be necessary to accommodate the higher pressure losses that would result from increasing the force main flow.

As an alternative, wastewater flow from the northern portion of Lake Wequaquet could be conveyed to the Route 28 connection. However, this connection point is not recommended because it has less surplus hydraulic capacity than the Freezer Road

pump station force main connection and would require the replacement of 2,500± feet of gravity sewer, the Mark's Path pump station, and the Mark's Path pump station force main. Another alternative considered was to convey the wastewater flow from the northern portion of Lake Wequaquet northerly to the Route 132 gravity sewer. This connection point is not recommended because there is no surplus capacity in the Route 132 gravity sewer.

Sub-Area 5

Sub-Area 5 includes the portion of the AOC northwest of Lake Wequaquet and is bounded by Lakewood Drive to the south, Shootflying Hill Road to the west, Lakeview Drive to the north, and the lake to the east. Under Alternative 1, wastewater from the southern portion of Sub-Area 5 would be conveyed by an 8-inch gravity trunk sewer on Shootflying Hill Road northerly to a proposed pump station at the Town beach on Shootflying Hill Road. Wastewater flow from the northern portion of Sub-Area 5 would be conveyed by an 8-inch gravity trunk sewer on Shootflying Hill Road southerly to the Shootflying Hill Road pump station described above. The Shootflying Hill Road pump station site is shown in Figure 6-11. Wastewater flow from the Shootflying Hill Road pump station would discharge to the gravity sewer on Shootflying Hill Road, just south of the Lakeview Drive, through a 4-inch force main.

Low pressure sewers are proposed on Lakewood Drive, Tern Lane, and Johnson Lane in this sub-area. The majority of the proposed gravity sewers would be less than 15 feet deep, with the exception of 800 feet of sewer at the southern end of this drainage area on Shootflying Hill Road. None of the sewer depths would exceed 20 feet.

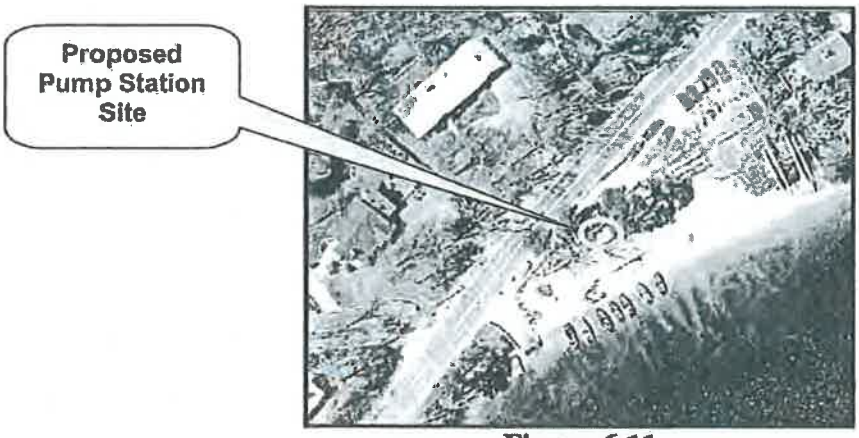

Figure 6-11
Sub-Area 5 Pump Station Site

Sub-Area 6

Sub-Area 6 includes the portion of the AOC north of Lake Wequaquet and is bounded by Shootflying Hill Road to the east, a point 750 feet west of Bunny Run to the west,

Route 132 to the north and Lake Wequaquet to the south. This sub-area includes the Nyes Neck peninsula. Under Alternative 1, wastewater from the eastern portion of Sub-Area 6 would be conveyed by an 8-inch gravity trunk sewer on Lakeview Drive and Pleasant Pines Avenue easterly to a proposed pump station on Pleasant Pines Avenue. An 8-inch gravity sewer would also convey wastewater flow to the Pleasant Pines Avenue pump station from a few homes west of the proposed pump station. The Pleasant Pines Avenue pump station site is shown in Figure 6-12. Wastewater flow from the Pleasant Pines Avenue pump station would discharge to the proposed Cape Cod Community College pump station force main on Route 132 through 6-inch and 8-inch force mains.

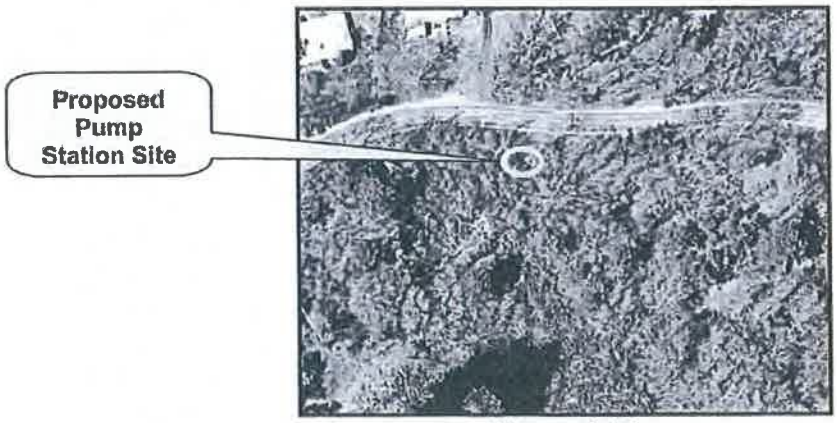

Figure 6-12
Sub-Area 6 Pump Station Site

The excavation depths of the proposed gravity sewers in this sub-area would not exceed 15 feet.

The Nyes Neck peninsula would be served primarily by low pressure sewers under this alternative. Gravity sewers and conventional pump stations were considered for this area and preliminary layouts were prepared. However, due to the anticipated difficulties in constructing pump stations in this wet, low-lying area, gravity sewers and conventional pump stations were eliminated from consideration for the peninsula.

Sub-Area 7

Sub-Area 7 includes the portion of the AOC north of Lake Wequaquet and is bounded by a point 750 feet west of Bunny Run to the west, Conners Road to the east, Route 132 and Shallow Pond to the north, and Bearse Pond and Lake Wequaquet to the south. This sub-area includes the Lakeside Drive peninsula. Under Alternative 1, wastewater from the northern portion of Sub-Area 7 would be conveyed by an 8-inch gravity trunk sewer southeasterly on Huckins Neck Road to a proposed pump station on Huckins

Neck Road, between Holly Point Road and Lakeview Avenue. Wastewater flow from the southeastern portion of Sub-Area 7 would be conveyed by an 8-inch gravity trunk sewer on Huckins Neck Road northwesterly to the Huckins Neck Road pump station described above. The Huckins Neck Road pump station site is shown in Figure 6-13. Wastewater flow from the Huckins Neck Road pump station would discharge to the proposed Cape Cod Community College pump station force main on Route 132 through 4-inch and 8-inch force mains.

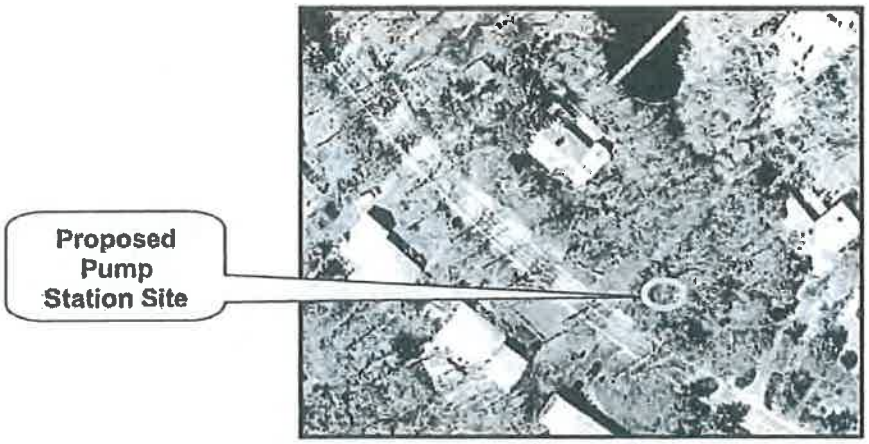

Figure 6-13
Sub-Area 7 Pump Station Site

Because of the rolling, hilly terrain on Huckins Neck Road, deep trench excavation would be required for several sewer sections along this street. In fact, approximately 2,900 feet of sewer would require trench excavation greater than 15 feet deep and approximately 700 feet of sewer would require trench excavation greater than 20 feet deep. Construction is expected to be especially difficult along these deep sewer sections on Huckins Neck Road because of the proximity of the adjacent ponds and high groundwater conditions.

The Lakeside Drive peninsula would be served primarily by low pressure sewers under this alternative. Gravity sewers and conventional pump stations were considered for this area and preliminary layouts were prepared. However, due to the anticipated difficulties in constructing pump stations in this wet, low-lying area, gravity sewers were eliminated from consideration for the peninsula.

Sub-Area 8

Sub-Area 8 includes the portion of the AOC northeast of Shallow Pond and is bounded by Shallow Pond Drive to the west, Phinney's Lane to the east, Route 132 to the north and Shallow Pond to the south. Under Alternative 1, wastewater from the western portion of Sub-Area 8 would be conveyed by an 8-inch gravity trunk sewer easterly on

Route 132 to a proposed pump station on Route 132, near Old Strawberry Hill Road. Wastewater flow from the southeastern portion of Sub-Area 8 would be conveyed by an 8-inch gravity trunk sewer on Old Strawberry Hill Road northerly to the Route 132 pump station described above. The Route 132 pump station site is shown in Figure 6-14. Note that this pump station site may need to be changed to accommodate the Route 132 improvements currently being designed. Wastewater flow from the Route 132 pump station would discharge to the proposed Cape Cod Community College pump station force main on Route 132 through a 4-inch force main.

The majority of the sewers would be less than 15 feet depth, with the exception of a 350-foot sewer section on Old Strawberry Hill Road, which would be 15 to 20 feet deep. Sewer depths would not exceed 20 feet.

Low pressure sewers would be constructed on Crestview Circle, Regatta Drive and Dacey Drive as part of this alternative.

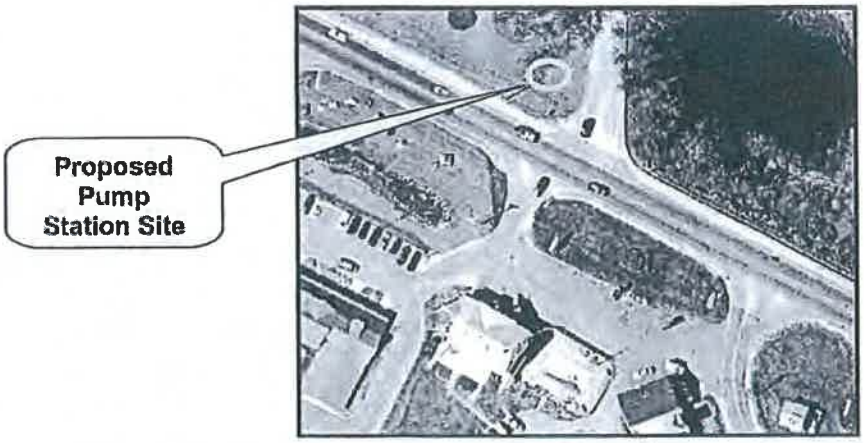

Figure 6-14
Sub-Area 8 Pump Station Site

6.2.1.4 Cape Cod Community College

The Cape Cod Community College (CCCC) is currently designing a wastewater pump station that would allow it to send its wastewater flow to the Town sewerage system and subsequently abandon the existing college septic systems. The design of the piping from the college to the Town sewerage system is a component of this project and has been considered as part of this evaluation.

Under Alternative 1, a force main would be constructed from the Cape Cod Community College pump station, along Route 132, to the existing Freezer Road pump station force main. As discussed previously, the sub-areas around Lake Wequaquet would also be conveyed to the Freezer Road pump station force main.

The current peak flow from the CCC is estimated as approximately 0.06 mgd and the projected future peak flow, based on growth over a 20-year period, is 0.17 mgd. When the flows from the AOC around Lake Wequaquet are also considered, the current peak flow from the AOC around Lake Wequaquet and the CCCC is approximately 0.88 mgd and the projected future peak flow is 1.53 mgd. In comparison, the surplus capacity of the 12-inch Freezer Road pump station force main is estimated to be as much as 4.0 mgd (based on a velocity of 8 fps), as noted previously. With the addition of the peak flow of 1.53 mgd, the wastewater flow through the force main would increase from 1.08 mgd to 2.61 mgd and the velocity would increase from 2.13 fps to 5.12 fps. The operation of the Freezer Road pump station and the force main hydraulics would need to be reviewed if this alternative is pursued to determine the impact on pump operation of increasing the force main flow. Improvements to the pumps may be necessary to accommodate the higher pressure losses that would result from increasing the force main flow.

6.2.2 Alternative 2 - Gravity & LP Sewers, 11 Pump Stations

Alternative 2, shown in Figure 6-15, was developed to reduce the deep excavation that would be required under Alternative 1 on Huckins Neck Road (Sub-Area 7), Phinney's Lane (Sub-Area 3), and Pine Street (Sub-Area 2). Excavation depths exceeding 20 feet would be required in these areas under Alternative 1. With the changes provided by Alternative 2, the excavation depths have been limited to no more that 20 feet. In order to reduce excavation depths, additional pump stations have been proposed on Huckins Neck Road and Phinney's Lane and additional low pressure sewers have been proposed for collector sewers tributary to Phinney's Lane and Pine Street.

Vacuum sewers were not considered as part of this alternative, similar to Alternative 1. This alternative is described in detail in the paragraphs that follow and is summarized in Table 6-3.

Alternative 2 includes:

- 129,550 feet (25± miles) of proposed sewer
- 60,980 feet of gravity sewers (47% of total)
- 11 proposed pump stations and replacement of the Main Street pump station
- 401 grinder pumps

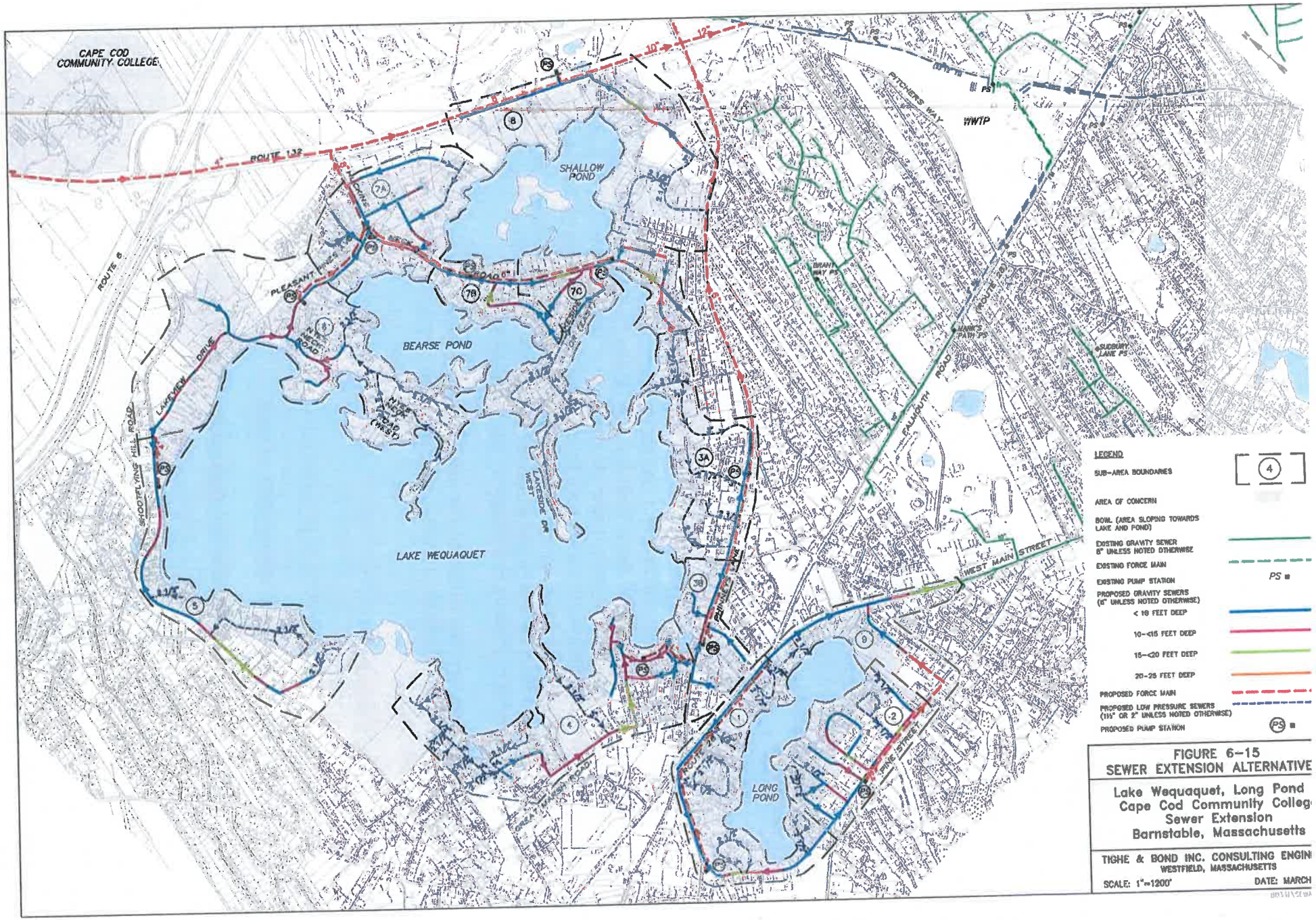

FIGURE 6-15
SEWER EXTENSION ALTERNATIVE

Lake Wequaquet, Long Pond
Cape Cod Community Colleg
Sewer Extension
Barnstable, Massachusetts

TIGHE & BOND INC. CONSULTING ENGIN
WESTFIELD, MASSACHUSETTS

SCALE: 1"=1200' DATE: MARCH

Table 6-3

Alternative 2 Sewer Layout Summary

Sub-Area	Gravity Sewer Length (ft)	Low Pressure Sewer Length (ft)	Force Main Length (ft)	Total Pipe Length (ft)	No. of Pump Stations	No. of Grinder Pumps
1	5,500	5,500	3,400	14,400	1	63
2	6,890	2,870	2,600	12,360	1	18
3	5,300	6,210	9,000	20,510	2	49
4	7,460	5,620	850	13,930	1	63
5	5,170	3,160	700	9,030	1	44
6	6,110	5,030	2,650	13,790	1	42
7	16,880	5,700	4,050	26,630	3	69
8	3,850	2,960	100	6,910	1	45
9	3,820	470	0	4,290	0	8
CCCC	0	0	6,300	6,300	0	0
Improvements to Existing Sewerage System [1]	0	0	1,400	1,400	1	0
Total	**60,980**	**37,520**	**31,050**	**129,550**	**12**	**401**

Notes:

(1) Includes replacement of the Main Street pump station and diverting flow from the pump station to the Old Colony Road pump station force main.

6.2.2.1 Long Pond (Sub-Areas 1, 2 & 9)

The Long Pond area wastewater flows would be conveyed to the existing sewerage system on West Main Street, similar to Alternative 1. Minor layout changes have been proposed in the Long Pond Area as part of Alternative 2 to reduce excavation depths on Pine Street and are describe below.

Sub-Area 1

Under Alternative 2, Sub-Area 1 would be served as described for Alternative 1, except that the collector sewers on Long Pond Circle would be low pressure sewers rather than gravity sewers. As a result of this change, the maximum excavation depth on Pine Street is reduced from approximately 22 feet under Alternative 1 to approximately 16 feet in the area of Long Pond Circle.

Sub-Area 2

Under Alternative 2, Sub-Area 2 would be served as described for Alternative 1, except that low pressure sewers are proposed at the north end of Blantyre Avenue rather than gravity sewers. As a result of this change, the maximum excavation depth on Blantyre Avenue is reduced from approximately 21 feet to approximately 12 feet. In addition, the maximum excavation depth on Pine Street, in the area of Blantyre Avenue, is reduced from approximately 19 feet under Alternative 1 to approximately 10 feet.

Sub-Area 9

The proposed Alternative 2 layout is the same as the proposed Alternative 1 layout for this Sub-Area.

6.2.2.2 Southern Portion of Lake Wequaquet (Sub-Areas 3 & 4)

Similar to Alternative 1, the wastewater flow from the southern portion of Lake Wequaquet would be conveyed northerly to the existing force main from the Freezer Road pump station under this alternative. Layout changes have been proposed in the southern portion of Lake Wequaquet as part of Alternative 2 to reduce excavation depths on Phinney's Lane.

Sub-Area 3

The differences between the Alternative 1 and Alternative 2 layouts for this sub-area are summarized below:

1. Under Alternative 2, Sub-Area 3 would be served by two pump stations rather than one.

2. Under Alternative 2, the collector sewers on Loomis Lane, Richards Lane, Old Farm Road, and Conners Road would be low pressure sewers rather than gravity sewers.

The changes described above would reduce the maximum excavation depth along Phinney's Lane from 25 feet to 14 feet and the majority of the piping on this street would be less than 10 feet deep.

Sub-Area 3 was divided into two parts, reflecting the two pump station service areas: Sub-Area 3A and Sub-Area 3B, as shown in Figure 6-15. Sub-Area 3A includes the northern portion of Sub-Area 3, north of Strawberry Hill Road while Sub-Area 3B includes the southern portion of Sub-Area 3, south of Strawberry Hill Road. The Sub-Area 3A pump station would be located near the intersection of Phinney's Lane and Old Farm Road, similar to the Alternative 1 Sub-Area 3 pump station location. The Sub-Area 3B pump station would be located between Crosby Road and Tellegen Trail on Phinney's Lane, near the culvert/drainage channel between Lake Wequaquet and Long Pond. The Sub-Area 3B pump station site is shown in Figure 6-16.

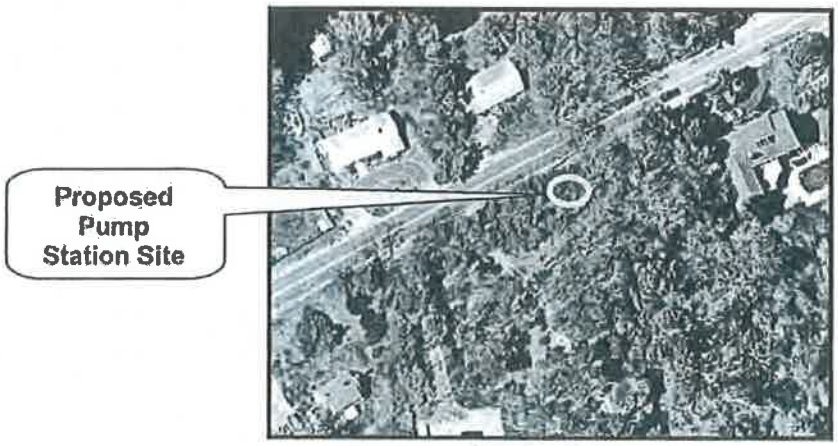

Figure 6-16
Sub-Area 3B Pump Station Site

Sub-Area 4

The proposed Alternative 2 layout is the same as the proposed Alternative 1 layout for this Sub-Area.

6.2.2.3 Northern Portion of Lake Wequaquet (Sub-Areas 5, 6, 7 & 8)

Similar to Alternative 1, the wastewater flow from the northern portion of Lake Wequaquet would be conveyed northerly to the existing force main from the Freezer Road pump station under this alternative. Layout changes have been proposed in the

northern portion of Lake Wequaquet as part of Alternative 2 to reduce excavation depths on Huckins Neck Road.

Sub-Area 5

The proposed Alternative 2 layout is the same as the proposed Alternative 1 layout for this Sub-Area.

Sub-Area 6

The proposed Alternative 2 layout is the same as the proposed Alternative 1 layout for this Sub-Area.

Sub-Area 7

Under Alternative 2, Sub-Area 7 would be served by three pump stations on Huckins Neck Road in order to reduce the deep excavations that would be required under Alternative 1, which would be served by one pump station. Under Alternative 1, especially difficult construction was identified along Huckins Neck Road. Sub-Area 7 is divided into three parts as part of this alternative, reflecting the three pump station service areas: Sub-Areas 7A, 7B, and 7C, as shown in Figure 6-15. The pump stations serving Sub-Areas 7A, 7B, and 7C are shown in Figures 6-17, 6-18, and 6-19, respectively.

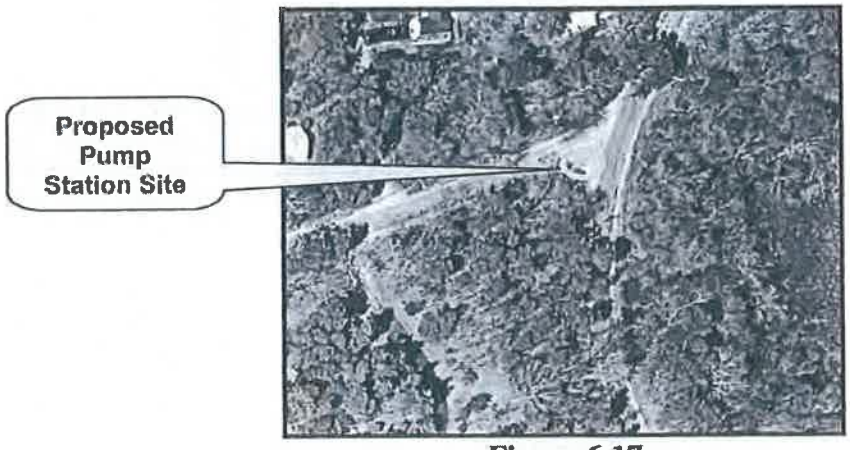

Figure 6-17
Sub-Area 7A Pump Station Site

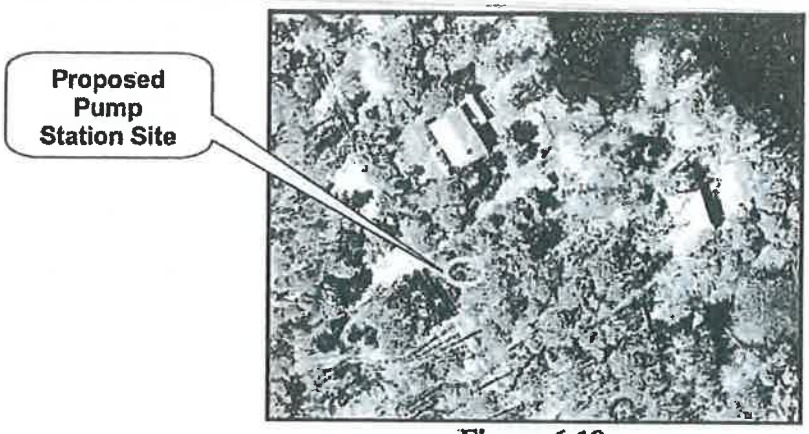

Figure 6-18
Sub-Area 7B Pump Station Site

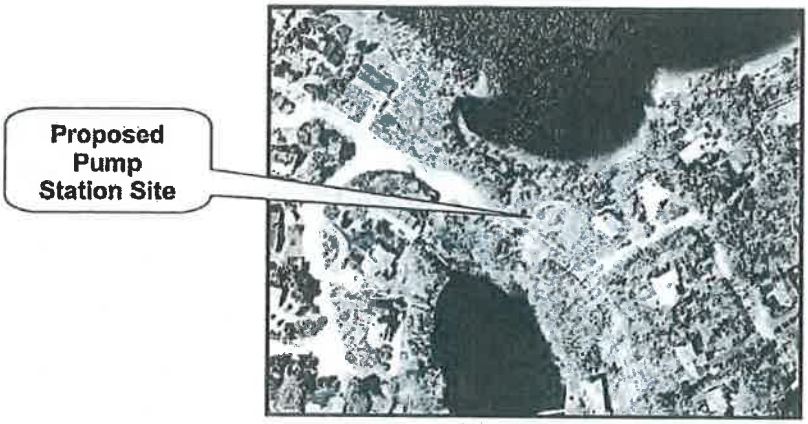

Figure 6-19
Sub-Area 7C Pump Station Site

The Sub-Area 7A pump station would be located at the intersection of Pleasant Pines Avenue and Huckins Neck Road, the Sub-Area 7B pump station would be located on Huckins Neck Road, approximately 300 feet northwest of Holly Point Road, and the Sub-Area 7C pump station would be located on Huckins Neck Road, near Cottonwood Lane.

By constructing three pump stations on Huckins Neck Road, the maximum excavation depth is reduced from approximately 25 feet to approximately 19 feet and the quantity of deep sewers is reduced from approximately 2,900 feet to approximately 800 feet. Although deep sewer construction is reduced significantly by this alternative, the construction of the three pump stations is still a concern because they are expected to be approximately 10 feet deeper than the invert of the sewer inlet pipe.

Sub-Area 8

The proposed Alternative 2 layout is the same as the proposed Alternative 1 layout for this sub-area.

6.2.2.4 Cape Cod Community College

The proposed Alternative 2 layout for the college is the same as the proposed Alternative 1 layout.

6.2.3 Alternative 3 - Gravity & LP Sewers, 5 Pump Stations

Alternative 3, shown in Figure 6-20, was developed to further reduce excavation depths in the northern portion of Lake Wequaquet from that shown for Alternatives 1 and 2 by installing low pressure sewers throughout this area. Vacuum sewers were not considered as part of this alternative, similar to Alternatives 1 and 2. This alternative is described in detail in the paragraphs that follow and is summarized in Table 6-4.

Alternative 3 includes:

- 120,210 feet (23± miles) of proposed sewer
- 36,240 feet of gravity sewers (30% of total)
- 5 proposed pump stations and replacement of the Main Street pump station
- 598 grinder pumps

6.2.3.1 Long Pond (Sub-Areas 1, 2 & 9)

The proposed Alternative 3 layout is the same as the proposed Alternative 1 layout for these sub-areas. The Alternative 1 layout is preferred over the Alternative 2 layout for Sub-areas 1, 2, and 9 because Alternative 1 provides more gravity sewers and, correspondingly, less low pressure sewers and fewer grinder pumps at essentially the same construction cost as the Alternative 2 layout. There is only a 1% difference between the Alternative 1 costs and Alternative 2 costs for Sub-Areas 1 and 2 and no cost difference for Sub-Area 9.

6.2.3.2 Southern Portion of Lake Wequaquet (Sub-Areas 3 & 4)

The proposed Alternative 3 layout is the same as the proposed Alternative 1 layout for these sub-areas. The Alternative 1 layout is preferred over the Alternative 2 layout for

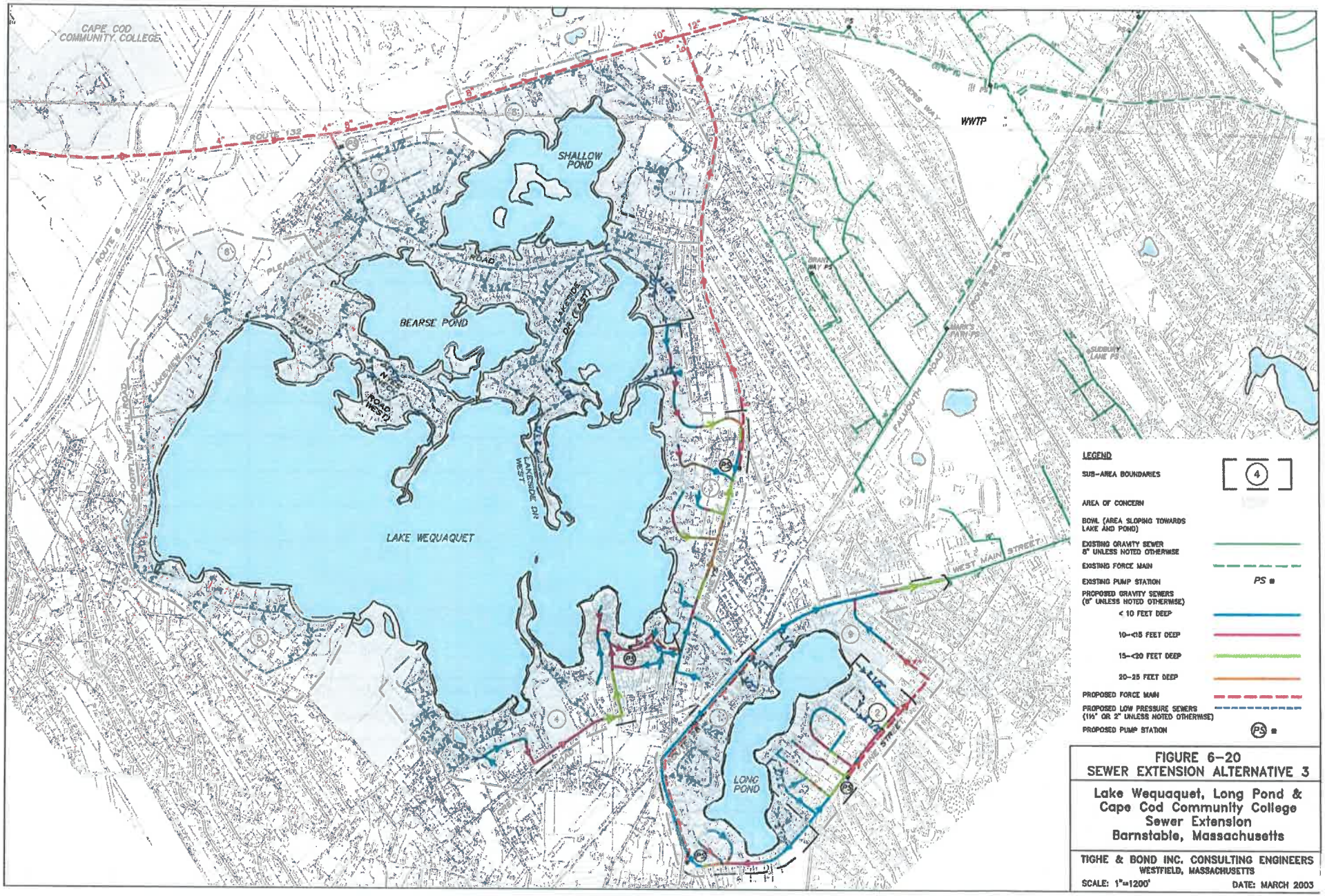

FIGURE 6-20
SEWER EXTENSION ALTERNATIVE 3

Lake Wequaquet, Long Pond & Cape Cod Community College Sewer Extension
Barnstable, Massachusetts

TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASSACHUSETTS

SCALE: 1"=1200'

DATE: MARCH 2003

Table 6-4
Alternative 3 Sewer Layout Summary

Sub-Area	Gravity Sewer Length (ft)	Low Pressure Sewer Length (ft)	Force Main Length (ft)	Total Pipe Length (ft)	No. of Pump Stations	No. of Grinder Pumps
1	6,760	4,240	3,400	14,400	1	51
2	7,340	2,420	2,600	12,360	1	14
3	10,860	650	6,500	18,010	1	25
4	7,460	5,620	850	13,930	1	63
5	0	8,330	0	8,330	0	46
6	0	11,140	0	11,140	0	67
7	0	23,140	100	23,240	1	244
8	0	6,810	0	6,810	0	80
9	3,820	470	0	4,290	0	8
CCCC	0	0	6,300	6,300	0	0
Improvements to Existing Sewerage System (1)	0	0	1,400	1,400	1	0
Total	**36,240**	**62,820**	**21,150**	**120,210**	**6**	**598**

Notes:

(1) Includes replacement of the Main Street pump station and diverting flow from the pump station to the Old Colony Road pump station force main.

Sub-area 3 because it is projected to be significantly less expensive and requires fewer pump stations. The sewer layout in Sub-Area 4 is the same for Alternatives 1 and 2.

6.2.3.3 Northern Portion of Lake Wequaquet (Sub-Areas 5, 6, 7 & 8)

Under Alternative 3, the northern portion of Lake Wequaquet would be served by low pressure sewers and grinder pumps. This alternative would eliminate deep sewer construction in this area and minimize pump station construction. However, because pipe velocity and headloss must be balanced in a low pressure sewer system, the low pressure sewers in this area would be sized for a specific flow range and would not be able to accommodate significant future expansion. In particular, the low pressure sewers proposed within the AOC along Shootflying Hill Road would not be able to accommodate the full build-out flows projected within the relatively large Bowl area to the west.

One pump station is expected to be needed for this area to pump flow from Sub-Areas 5, 6, and 7 into the CCCC pump station force main. This pump station is expected to be necessary because the pressure in the low pressure sewer at the downstream end of these sub-areas would be too low to overcome the pressure in the Cape Cod Community College pump station force main. The low pressures that are projected at the downstream end of the system are expected to occur because of the long length of piping from the upstream end to the downstream end of this large sub-system, which results in high pipe friction losses.

This pump station would be located near the intersection of Route 132 and Huckins neck Road, as shown in Figure 6-21. Note that this pump station site may need to be changed to accommodate the Route 132 improvements currently being designed.

The wastewater flow from Sub-Area 8 would discharge directly into the CCCC pump station force main on Route 132, near Old Strawberry Hill Road. The pressure available at the downstream end of the proposed low pressure sewer system in this relatively small sub-area is expected to be great enough to overcome the pressure in the Cape Cod Community College pump station force main and a pump station to serve this area is not expected to be necessary.

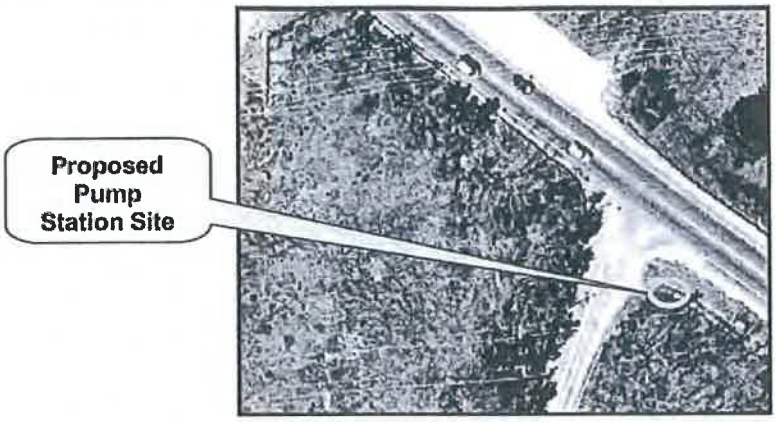

Figure 6-21
Sub-Areas 5, 6 & 7 Pump Station Site

6.2.3.4 Cape Cod Community College

The proposed Alternative 3 layout for the college is the same as the proposed Alternative 1 layout.

6.2.4 Alternative 4 – Gravity, LP and Vacuum Sewers, 4 Pump Stations, and 2 Vacuum Stations

Alternative 4, shown in Figure 6-22, is similar to Alternative 3 except that Sub-Areas 6 and 7 would be served by vacuum sewers rather than low pressure sewers. This alternative is described in detail in the paragraphs that follow and is summarized in Table 6-5.

Alternative 4 includes:

- 125,400 feet (24± miles) of proposed sewer
- 36,240 feet of gravity sewers (29% of total)
- 4 proposed pump stations, 2 proposed vacuum stations, and replacement of the Main Street pump station
- 287 grinder pumps
- 311 valve pits

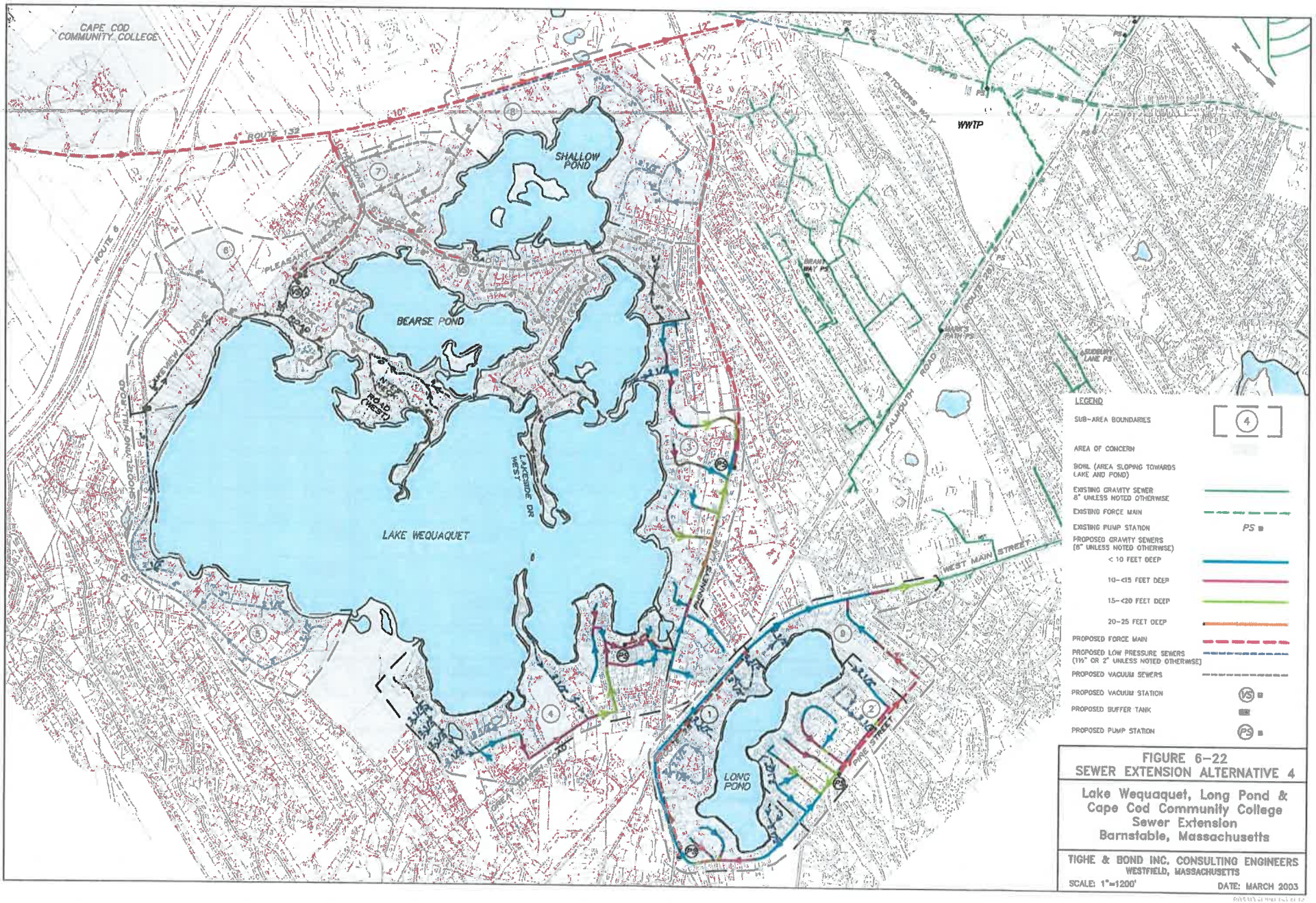

FIGURE 6-22
SEWER EXTENSION ALTERNATIVE 4

Lake Wequaquet, Long Pond & Cape Cod Community College Sewer Extension
Barnstable, Massachusetts

TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASSACHUSETTS

SCALE: 1"=1200'

DATE: MARCH 2003

Table 6-5
Alternative 4 Sewer Layout Summary

Sub-Area	Gravity Sewer Length (ft)	Low Pressure Sewer Length (ft)	Vacuum Sewer Length (ft)	Force Main Length (ft)	Total Pipe Length (ft)	No. of Pump/Vacuum Stations	No. of Grinder Pumps	No. of Valve Pits
1	6,760	4,240	0	3,400	14,400	1	51	0
2	7,340	2,420	0	2,600	12,360	1	14	0
3	10,860	650	0	6,500	18,010	1	25	0
4	7,460	5,620	0	850	13,930	1	63	0
5	0	8,330	0	0	8,330	0	46	0
6	0	0	11,140	2,700	13,840	1	0	67
7	0	0	23,230	2,500	25,730	1	0	244
8	0	6,810	0	0	6,810	0	80	0
9	3,820	470	0	0	4,290	0	8	0
CCCC	0	0	0	6,300	6,300	0	0	0
Improvements to Existing Sewerage System (1)	0	0	0	1,400	1,400	1	0	0
Total	**36,240**	**28,540**	**34,370**	**26,250**	**125,400**	**7**	**287**	**311**

Notes:

(1) Includes replacement of the Main Street pump station and diverting flow from the pump station to the Old Colony Road pump station force main.

6.2.4.1 Long Pond (Sub-Areas 1, 2 & 9)

The proposed Alternative 4 layout is the same as the proposed Alternative 1 layout for these sub-areas. Vacuum sewers were considered for these sub-areas but were not expected to be cost-effective because either the vacuum sewers would need to be installed at depths similar to those needed for gravity sewers or vacuum stations would be needed to serve relatively small areas.

Alternatively, a hybrid system was considered, which would consist of vacuum sewers and low pressure sewers. This alternative was also not expected to be cost-effective since it would require that low pressure sewers be constructed in a large portion of this area and that, correspondingly, a vacuum station be constructed to serve a relatively small area.

6.2.4.2 Southern Portion of Lake Wequaquet (Sub-Areas 3 & 4)

The proposed Alternative 4 layout is the same as the proposed Alternative 1 layout for these sub-areas. The majority of these sub-areas would be served by gravity sewers, which was considered appropriate for these areas.

6.2.4.3 Northern Portion of Lake Wequaquet (Sub-Areas 5, 6, 7 & 8)

Sub-Areas 5 & 8

The proposed Alternative 4 layout is the same as the proposed Alternative 3 layout for these sub-areas; low pressure sewers are proposed. Vacuum sewers were considered for Sub-Area 5 but because of the significant grade changes in this area (ranging from 38± feet to 76± feet), vacuum sewers are not expected to be cost-effective. The two vacuum sewer vendors contacted (AIRVAC and Roediger) provided vacuum sewer layout information that confirmed this. Similarly, vacuum sewers were considered for Sub-Area 8 but because of the significant grade changes in this sub-area (ranging from 48± feet to 84± feet), vacuum sewers are not expected to be cost-effective for much of this sub-area. This was also confirmed by the two vacuum sewer vendors, based on the vacuum sewer layout information provided.

Sub-Areas 6 & 7

Under Alternative 4, Sub-Areas 6 and 7 would be served by vacuum sewers. These two sub-areas were determined to be appropriate for vacuum sewers because of the smaller changes in grade throughout these areas. A vacuum station would be constructed to serve each sub-area under this alternative. The Sub-Area 6 vacuum station would be located on Pleasant Pines Avenue, at the same site as the Sub-Area 6 pump stations under Alternatives 1 and 2. The Sub-Area 7 vacuum station would be

located on Huckins Neck Road, at the same site as the Sub-Area 7B pump station under Alternative 2.

7.1 GENERAL

This section outlines the anticipated permitting requirements of the various federal, state, regional, and local agencies and authorities that have jurisdiction over the construction of the proposed project. Although the four alternatives will require, in many cases, the same permits, the permitting effort is expected to vary among the four alternatives.

7.2 FEDERAL PERMIT PROGRAMS

7.2.1 NPDES General Stormwater Permit

The proposed project will be under the jurisdiction of the EPA Phase I Stormwater Program - Large Construction Activities, because greater than 5 acres will be disturbed. Under the Phase I Program, owners/operators of construction activities that disturb greater than 5 acres are required to obtain a General Permit, which is typically re-issued every 5 years. The General Permit requirements include:

1. The preparation of a Storm Water Pollution Prevention Plan (SWPPP). This document is not submitted to the EPA but must be on-site during construction activities and is subject to review by regulatory authorities inspecting the work.

2. The preparation of weekly inspection reports and periodic progress reports documenting that the SWPPP is being followed. These reports are required by the SWPPP.

3. The preparation and submittal to the EPA of a stormwater Notice of Intent (NOI) two days prior to the start of construction.

4. The preparation of a Notice of Termination at the end of the project.

Note that the stormwater pollution prevention requirements are expected to also be subject to local stormwater ordinances that are required by the Municipal Separate Storm Sewer System (MS4) program. The DEP/EPA have determined that Barnstable is under the jurisdiction of this program and regulated communities are required to apply for permit coverage 90 days from when the EPA issues the General Stormwater Permit, which is expected in May, 2003.

7.2.2 Section 404 of the Clean Water Act

Section 404 of the Clean Water Act (CWA) regulates the discharge of dredged material into "Waters of the United States", which includes wetlands. The U.S. Army Corps of

Engineers has regulatory authority of this program through 33 CFR parts 320-330. Within the limits of the project, any filling, excavation, or soil compaction from the movement of vehicles within wetlands in excess of 5,000 square feet will require Programmatic General Permit review by the U.S. Army Corps of Engineers.

Wetland disturbances greater than 5,000 square feet are not anticipated, based on the layout of the four alternatives developed. A more detailed evaluation of the need for this permit will be performed during design, once the preferred alternative is selected and pump station locations are finalized.

7.2.3 Federal Endangered Species Act of 1973 (16 U.S.C. 1531)

In the event that a permit is required from a federal agency (such as the U.S. Army Corps of Engineers or U.S. EPA), the permit will not be valid unless the U.S. Fish and Wildlife Service issues a letter stating that the project is not likely to jeopardize the continued existence of any federally listed endangered species or threatened species or result in the destruction or adverse modification of habitat of such species. Federal Endangered Species Act (FESA) review is not triggered if no federal permits are required by another agency.

Because a federal permit will be needed for the project (the General Stormwater Permit), the U.S. Fish and Wildlife has been contacted to obtain their input on whether there are any federally listed endangered species in the project area. No federally listed or proposed, threatened or endangered species are known to occur in the project area, with the exception of the occasional transient bald eagles.

7.2.4 National Historic Preservation Act of 1966 (16 U.S.C. 470)

In the same fashion as above, the need for a federal permit requires the need for project review under this statute. If the project is likely to occur within the proximity of historic, cultural or archaeological features listed in the *National Register of Historic Places*, letters from the Massachusetts Historical Commission (MHC) and local Native American tribal council will be needed stating no adverse effects to these resources will occur as a result of the project.

As noted above, because a federal permit will be needed for this project (the General Stormwater Permit), the MHC and the local Native American tribal council have been contacted to determine if any historic, cultural or archaeological features will be impacted by the proposed work. The MHC has indicated that there are three recorded historical archaeological sites and one recorded ancient Native American site within the project area. In addition, the MHC has indicated that the project area is archaeologically sensitive and likely to contain additional archaeological sites and historic resources, although the project area has not been systematically surveyed by

professional archaeologists. The MHC will be provided with another opportunity to review project impacts through the ENF and EIR. The Wampanoag Tribal Historic Preservation Officer has not responded to our request for information.

7.3 STATE PERMIT PROGRAMS

7.3.1 Massachusetts Wetlands Protection Act (M.G.L. Chapter 131, Section 40)

Wetland resource areas, consisting primarily of Bordering Land Subject to Flooding (BLSF), Isolated Land Subject to Flooding (ILSF), Bordering Vegetated Wetlands (BVWs), and Land Under Waterbodies and Waterways (LUWBW) exist in the Area of Concern (AOC), especially in the Nyes Neck Road area, as shown in Figure 7-1. The majority of the proposed sewers will be constructed within existing roadways and will not impact nearby wetland areas, assuming that standard good construction practices are employed, including proper placement of haybales and siltation fences, and appropriate dewatering methodologies.

However, because new sewers in the study area will be constructed within the 100-foot wetlands buffer zone under each alternative, the sewer construction work will be regulated by the Massachusetts Wetlands Protection Act (WPA) and a wetlands permit (Order of Conditions) will be required. As part of the permitting process, the Barnstable Department of Public Works will need to file a Notice of Intent with the local Conservation Commission and the MADEP. The local Conservation Commission is responsible for determining whether construction will be allowed in areas under the jurisdiction of the WPA and whether the construction is subject to conditions/restrictions to protect these areas.

The Town Conservation Administrator (Mr. Rob Gatewood) indicated during a meeting regarding this project on February 4, 2003 that wetlands along the streets where new sewers are proposed can be delineated based on current state and local GIS mapping and a more detailed delineation, by flagging wetlands and subsequent field verification, is not required. However, where construction activity is proposed outside of the existing roadways, and it encroaches on wetland areas, a more detailed delineation of wetland areas, through flagging and field verification, is required in order to quantify impacts in detail.

Wetlands delineation will be performed in accordance with guidelines established by the MADEP and 310 CMR 10.00, and the appropriate resource area designations assigned.

It is important to note that this project may proceed under the Limited Project provisions of the WPA, as outlined in 310 CMR 10.53(3)(d):

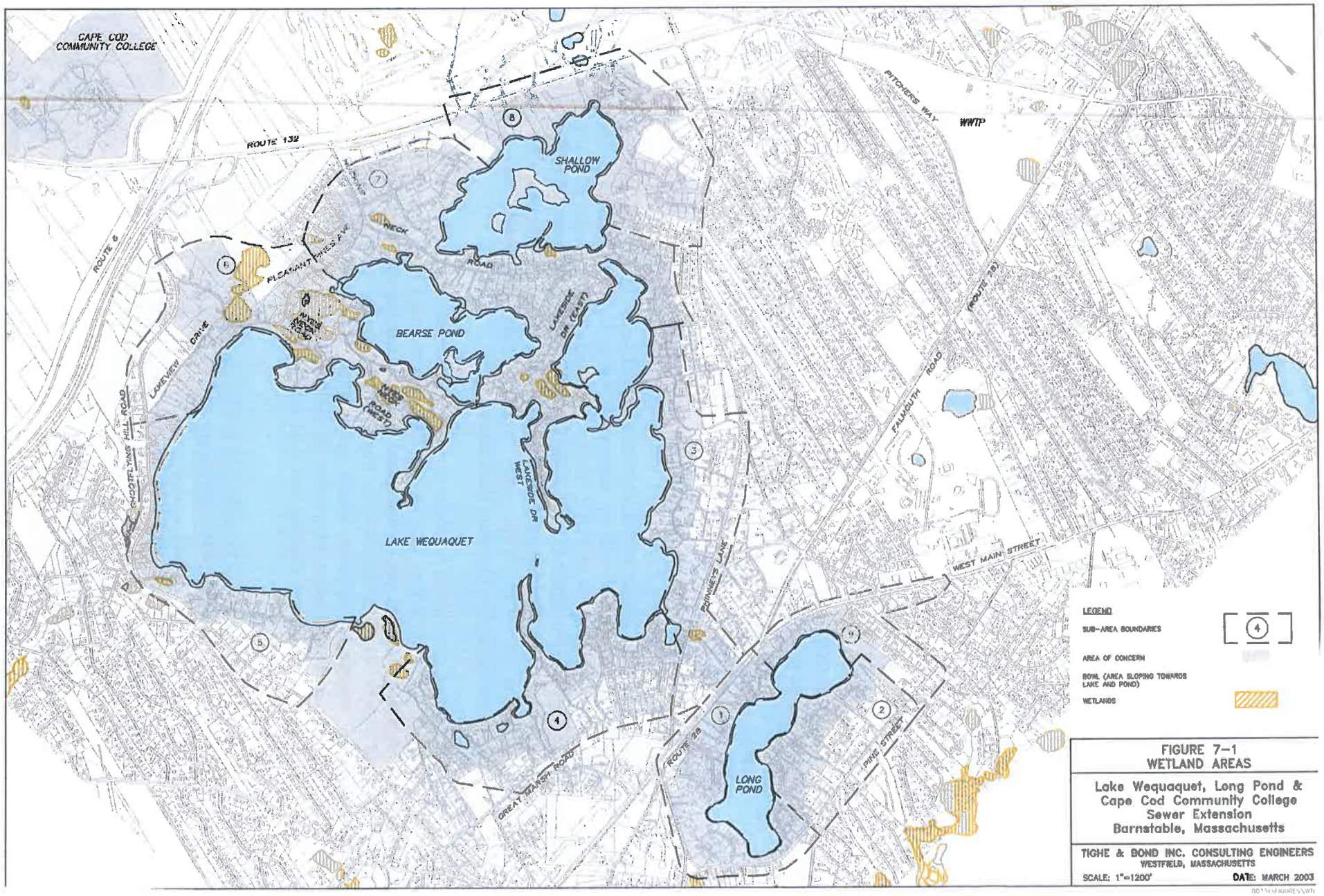

FIGURE 7-1
WETLAND AREAS

Lake Wequaquet, Long Pond & Cape Cod Community College Sewer Extension
Barnstable, Massachusetts

TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASSACHUSETTS

SCALE: 1"=1200' DATE: MARCH 2003

". . . The construction, reconstruction, operation and maintenance of underground and overhead public utilities, such as electrical distribution or transmission lines, or communication, sewer, water, and natural gas lines, may be permitted, in accordance with the following general conditions and any additional conditions deemed necessary by the reserving authority.

1. *the reserving authority may require a reasonable alternative route with fewer adverse effects for a local distribution or connecting line not reviewed by the Energy Facilities Siting Council;*
2. *best available measures shall be used to minimize adverse effects during construction;*
3. *the surface vegetation and contours of the area shall be substantially restored; and*
4. *all sewer lines shall be constructed to minimize inflow and leakage . . ."*

Activities that proceed under the Limited Project provisions of the WPA are recognized as generally being beneficial to public welfare, or those that otherwise may not be able to meet the general performance standards of resource areas due to temporary impacts.

Under the WPA, a general wildlife habitat evaluation will need to be conducted in the event the following impact thresholds are exceeded:

- Bank: greater than 50 linear feet.
- BLSF: greater than 5,000 square feet.
- LUWBW: great than 5,000 square feet.
- Riverfront Area: greater than 5,000 square feet.

The need for a wildlife habitat evaluation will be determined during design once the areas that will be disturbed are better defined.

7.3.2 Water Quality Certification

Under Section 401 of the federal Clean Water Act, a Water Quality Certification (WQC) is required for certain activities proposing discharges to water bodies or wetlands. This regulatory program is implemented by the individual states – in this case the MADEP. The program gives states the authority to review projects that must

obtain federal permits and that result in a discharge to state waters, including excavating and placement of fill in wetlands. The purpose of the State 401 review is to ensure that a project will comply with state water quality standards and other appropriate requirements of state law. Regulatory authority for the certification is found in 314 CMR 9.00.

The impact thresholds of the 401 WQC program have largely been coordinated with the WPA regulations. As a result, smaller projects approved by municipal conservation commissions under the WPA generally do not need further state review under the 401 program. These projects are automatically certified when they obtain an Order of Conditions. However, some types of projects with potentially large wetland impacts require an individual certification by MADEP.

A 401 Certification must be obtained for any project that results in filling or excavating in bordering vegetated wetlands, and that is also subject to regulation by the U.S. Army Corps or Engineers, Federal Energy Regulatory Commission, or other federal agency.

There are two categories of water quality certification which concern discharge, fill, and excavation projects: Major Fill and Excavation Project Certification (BRP WW 10) and Minor Fill and Excavation Project Certification (BRP WW 11). A Major Fill/Excavation Project Certification (BRP WW 10) is required for projects involving excavation or filling of more than 5,000 square feet of bordering and isolated vegetated wetland and land under water, while a Minor Fill/Excavation Project Certification (BRP WW 11) is required for projects involving excavation or filling of up to 5,000 square feet of bordering and isolated vegetated wetlands and land under water. For projects involving less than 5,000 square feet of impacts to Bordering Vegetated Wetlands, the Order of Conditions received from the local Conservation Commission serves as the WQC, and a separate WQC submittal to MADEP is not required. Exceptions to this rule include but are not limited to work in rare species habitat or Outstanding Resource Waters. The BRP WW 10 permit application (for a Major Fill/Excavation Project Certification) has a State review period of up to 150 days from the date of submission while the BRP WW 11 permit application (for a Minor Fill and Excavation Project Certification) has a review period of up to 120 days from the date of submission.

The wetland impacts are not expected to exceed 5,000 square feet, based on the sewer extension alternatives developed.

7.3.3 Sewer Extension Permit

In accordance with 314 CMR 7:00, Sewer System Extension and Connection Program, any modification to an existing sewer system requires a permit from MADEP. This permit application must be filed at least 150 days prior to the date of when the sewer

construction is to commence. In general, the application must describe the location of the extension, type of piping system to be used, the design capacity of the proposed extension, the estimated flow to be collected by the proposed extension, the type of wastewater to be collected, and the ultimate treatment point for the wastewater and the availability of capacity at that facility. A Sewer Extension Permit will be required for the preferred alternative, regardless of which alternative is selected.

7.3.4 Massachusetts Environmental Policy Act (MEPA)

The Massachusetts Environmental Policy Act (MEPA – M.G.L. Chapter 30, Section 61-62H) requires applicants of proposed projects to study the potential environmental consequences of their proposed project, and take measures to avoid, minimize and mitigate damage to the environment.

MEPA applies to projects that exceed certain thresholds outlined in their regulations and that also require a permit from a state agency. The MEPA review process is not a permitting process, but rather a public review process intended to act as a "clearing house" for public agencies. The MEPA process is administered through the Executive Office of Environmental Affairs (EOEA) and regulatory authority for the MEPA process is under 301 CMR 11.00.

MEPA review is required for a project if impact thresholds are triggered for a number of separate categories:

- Land;
- Rare Species;
- Wetlands, Waterways and Tidelands;
- Water;
- Wastewater;
- Transportation;
- Energy;
- Air;
- Solid and Hazardous Waste;
- Historical and Archaeological Resources;

- Areas of Critical Environmental Concern; and
- Regulations.

Under the category of wastewater, the review threshold for an ENF and an EIR is the construction of 10 miles or more of new sewers for the collection of wastewater. Because this Project includes the construction of 24± miles of sewers, both an ENF and an EIR will be required.

Further, the MEPA regulations do not allow for construction of a wastewater project without the project first receiving approval of a Comprehensive Wastewater Management Plan (CWMP) by MADEP. Since the Town of Barnstable's CWMP has not yet been approved, a request for a waiver to construct this Project must be filed with the EOEA, if the project is to proceed to construction prior to completion of the CWMP.

7.3.5 Massachusetts Department of the State Secretary (M.G.L. Chapter 9, Sections 26-27D)

No state permit from any other agency will be valid before the Massachusetts Historical Commission (MHC) is consulted to determine potential impacts on any historical or archaeological resources. Notification of the project impacts will be sent to MHC during the MEPA review process. MHC will review the project and make a determination as to whether it may or may not have any impacts on significant State cultural, historic, or archaeological assets.

As was noted previously, the MHC has been contacted to determine if any historic, cultural, or archaeological features will be impacted by the proposed work. The MHC has indicated that there are three recorded historical archaeological sites and one recorded ancient Native American site within the project area. In addition, the MHC has indicated that the project area is archaeologically sensitive and likely to contain additional archaeological sites and historic resources, although the project area has not been systematically surveyed by professional archaeologists.

7.3.6 Massachusetts Endangered Species Act (M.G.L. Chapter 131A)

No state permit from any other agency will be valid before the Massachusetts Division of Fisheries and Wildlife, Natural Heritage and Endangered Species Program (NHESP) is consulted to determine potential impacts on state-listed rare species. Notification will be sent to the NHESP describing the potential project impacts during the MEPA review process. The 2000-2001 Massachusetts Natural Heritage Atlas indicates that Priority Habitats of Rare Species are located across the entire area surrounding Lake Wequaquet, Bearse Pond and Shallow Pond. In addition, Estimated Habitats of Rare

Wildlife and Certified Vernal Pools are located north of Bearse Pond and east of Lake Wequaquet. All construction-related activities for the project will be included as part of the ENF and, as such, will be subject to NHESP review.

The Massachusetts Division of Fisheries and Wildlife, Natural Heritage and Endangered Species Program has been contacted to determine the species of concern in order to better understand if the rare species or priority habitats will be impacted by the proposed work. The NHESP has indicated that the following species in the project area are of concern:

Table 7-1
Species of Concern

Common Name	Taxon	Status
Comet Darter	Dragonfly	Special Concern
Wright's Panic-Grass	Plant	Special Concern
Bushy Rockrose	Plant	Special Concern
Redroot	Plant	Special Concern
Sandplain Flax	Plant	Special Concern
Pondshore Knotweed	Plant	Special Concern
Papillose Nut-Sedge	Plant	Endangered
Torrey's Beak-Sedge	Plant	Endangered
Plymouth Gentian	Plant	Special Concern
Terete Arrowhead	Plant	Special Concern
Water-Willow Stem Borer	Butterfly	Threatened
Plymouth Gentian	Plant	Special Concern

7.3.7 Massachusetts Highway Department

The Massachusetts Highway Department (MHD) requires that a permit be obtained for any work performed in the right-of-ways under their jurisdiction. This permit is to ensure that any work performed in the right-of way does not have any negative effects on the integrity and therefore the safety, presently provided by the Highway in question.

A force main, which would serve the Lake Wequaquet area and the Cape Cod Community College, is proposed on Route 132, which is a state highway. In addition, new sewers are proposed on Route 28, which is also a state highway. Therefore, a MHD permit must be obtained for the construction of this project. Once the

preliminary design of the sewers on Route 28 and Route 132 is complete, it will be presented to the MHD to obtain their early input. This will help reduce the overall review time for the Project by the Department.

7.4 REGIONAL REVIEW PROGRAMS

The Cape Cod Commission (CCC) is a regional planning agency that reviews and provides input on the design, construction and operation of new development/construction projects on Cape Cod. The purpose of the Cape Cod Commission is to further:

1. the conservation and preservation of natural, undeveloped areas, wildlife, flora and habitats for endangered species;
2. the preservation of coastal resources including aquaculture;
3. the protection of groundwater, surface water and ocean water quality, as well as the other natural resources of Cape Cod;
4. balanced economic growth;
5. the provision of adequate capital facilities, including transportation, water supply, and solid, sanitary and hazardous waste disposal facilities;
6. the coordination of the provision of adequate capital facilities with the achievement of other goals;
7. the development of an adequate supply of fair affordable housing; and
8. the preservation of historical, cultural, archaeological, architectural, and recreational values.

The CCC requires that a project proponent develop and submit a report that describes the environmental impacts that the project may have on the Region. This report and subsequent permit application, which is referred to as a Development of Regional Impact (DRI), will also detail the possible measures that will be taken to mitigate the environmental impacts identified. The CCC permitting process and the MEPA Process are usually undertaken in a joint process referred to as a "Major and Complicated Project" review. As in the MEPA process, this process will involve several public hearings and meetings with the Commission and a public information process.

7.5 LOCAL TOWN PERMITS

7.5.1 Street Opening Permits

The Town of Barnstable requires that a permit be obtained for any work performed in Town Streets - this is known as a Street Opening Permit. This permit is issued by the Engineering Division of the Barnstable Department of Public Works. A Street Opening Permit will be required for this project since the majority of the new sewers will be constructed within roadways.

7.5.2 Barnstable Conservation Commission

In conjunction with the MADEP WPA, described above, the Town of Barnstable also has its own Wetlands Protection Bylaw (Chapter III, Article XXVII). Application for a permit under this ordinance will be made in conjunction with the application for the MADEP NOI. The municipal wetlands bylaw is more stringent than the WPA in two noteworthy areas:

1. Abutter notification is required to residents within 300 feet of the lot where the wetlands have been disturbed instead of 100 feet.

2. A 50-foot "no disturb" zone is established within the WPA 100-foot Buffer Zone. In cases where the slope of the Buffer Zone exceeds 18%, the Commission has the discretion to increase the width of the "no disturb" zone beyond 50 feet.

7.6 SUMMARY OF PERMITS

Table 7-2 provides a summary of the permits discussed previously in this report section.

Table 7-2
Summary of Project Permits Anticipated

Reviewing Authority	Agency	Permit or Review Required	Threshold
Federal	U.S. EPA	NPDES General Stormwater Permit	Construction Project greater than 5 Acres
	Wampanoagan Tribal Historic Preservation Officer	Tribal Resources review and comment	Any work within areas that may contain historic or archaeological resources
	U.S. Army Corps of Engineers	Programmatic General Permit [1]	>5,000 sq. feet of wetland impacts

Table 7-2

Summary of Project Permits Anticipated

Reviewing Authority	Agency	Permit or Review Required	Threshold
	U.S. Fish & Wildlife Service	Rare species review and consultation	Any work within the vicinity of federally-listed rare species habitat
State	Massachusetts Department of Environmental Protection	Sewer Extension Permit	Any modification to an existing sewer system
	Massachusetts Department of Environmental Protection	401 Water Quality Certification	5,000 sf to 1 acre wetland impact, discharges of fill to rare species habitat, Outstanding Resource Waters, etc.
	Massachusetts Highway Department	Construction Permit	Any work within Mass Highway right of way
	MA Division of Fisheries and Wildlife, NHESP	Rare Species review and consultation	Work within estimated habitat of State-listed rare species
	MA Historical Commission	Historic and archaeological features review and consultation	Any work within areas that may contain historic or archaeological resources
	Massachusetts Environmental Policy Act Unit (EOEA)	Environmental Impact Report Certifications (Draft and Final)	Construction of 10 or more miles of new sewers
	Massachusetts Environmental Policy Act Unit (EOEA)	Waiver for Construction	Construction of a MEPA project without an approved EIR
Regional	Cape Cod Commission	Development of Regional Impact	Same as that for a EIR
Local	Barnstable Conservation Commission	Order of Conditions	Construction within a Resource Area or within 100 feet of a Resource Area
	Barnstable Department of Public works	Street opening permit	Construction within a Town roadway

Notes: (1) Only if wetland resource areas are determined to meet the jurisdictional criteria of "Waters of the United States" per 33 CFR 328.

8.1 TRAFFIC IMPACT ROUTE ASSESSMENT

As described previously, the proposed project is located in central Barnstable and encompasses the properties surrounding Wequaquet Lake and Long Pond, generally south of Route 6 and Route 132, north of Pine Street, West of Phinney's Lane and Wequaquet Lane and east of Shootflying Hill Road. The project also includes the installation of a force main in the Route 132 Right-of Way (ROW), under Route 6, from Cape Cod Community College to the Route 132/Bearses Way intersection.

In order to provide sewer service to this diverse area, construction will be required within roadway ROW's of all different classifications. The construction will include the installation of sewer lines along the roadways for the most part. However, there are also numerous ROW crossings (including the Route 6 on-ramps and off-ramps), the installation of individual property lateral connections, and pump stations.

The roadways affected by the construction can be classified in the following categories:

1. Major Arterials (State Routes)
   - Route 132 – 30,000-40,000 Average Daily Traffic (ADT), south of Rte 6
   - Route 28 (Falmouth Road) - 30,000 ADT
2. Minor Arterials (Town Roads)
   - Phinney's Lane - 15,000 ADT
   - West Main Street - 15,000 ADT
3. Collectors
   - Shootflying Hill Road - 6,000 ADT
   - Great Marsh Road - 6,000 ADT
4. Local Residential
   - Thru Roads
   - Dead Ends

5. Driveways
    - Single
    - Shared

Each roadway, whether it is to have a sewer installed along it or across it, will be classified and appropriate maintenance and protection of traffic procedures will be assigned to it. Access to all adjoining properties, commercial and residential, will be maintained during construction. A comprehensive traffic plan will be outlined during the Final Design phase.

8.2 TRAFFIC OPERATIONS

With the objective of maintaining acceptable traffic operations on all affected roadways, each street will be inventoried for:

1. Roadway width
2. ROW width
3. Location of proposed sewer lines within those widths
4. Roadway operation
    - one-way versus two-way
    - number of lanes
5. Intersection control
6. Traffic volumes
7. Traffic speeds
8. Ownership (State, Town, or private)

Once each street is inventoried, it will be assigned the appropriate classification associated with the proper maintenance and protection of traffic procedures.

8.3 TRAFFIC SAFETY

8.3.1 Traffic Control During Construction

The guidelines described in the paragraphs that follow will be used to determine where and what type of traffic control patterns to use for various situations. These guidelines will provide for the safe and efficient movement of traffic though work zones and enhance the safety of work forces in the work area.

8.3.2 Traffic Control Patterns

Typical Massachusetts Highway Department traffic control patterns will be used where a work operation requires that all or part of any vehicle or work area protrudes onto any part of a travel lane or shoulder. For each situation, the installation of traffic control devices will be based on the following:

1. Speed and volume of traffic
2. Duration of operation
3. Exposure to hazards

In the case of horizontal or vertical sight restriction in advance of the work area, the traffic control pattern will be extended to provide adequate sight distance for approaching traffic. If a lane reduction taper is required to shift traffic, the entire length of the taper will be installed on a tangent section of roadway so that the motorist can see the entire taper area. Any existing signs that are in conflict with the traffic control patterns will be removed, covered, or turned so that they are not readable by oncoming traffic. When installing a control pattern, a buffer area will be provided. This area will be free of equipment, workers, materials and parked vehicles.

Although the traffic control pattern for each street will be considered individually, conformity with the typical traffic control plans develop during design and generally described here will be provided.

8.3.3 Placement of Signs

Signs will be placed to allow motorists the opportunity to reduce their speed prior to the work area. Signs will be installed on the same side of the roadway as the work area. On multi-lane divided highways, advance warning signs may be installed on both sides of the highway. On directional roadways (on-ramps, off-ramps, one-way roads), where the sight distance to signs is restricted, signs will be installed on both sides of the roadway.

8.4 TRAFFIC SAFETY DISCUSSION

8.4.1 Coordination Meetings

A meeting with local and state department representatives, including fire, police, public works, utility companies, transit operators and transportation departments, will be held to review the pending project. The project scope, layout, schedule and Maintenance and Protection of Traffic (MPT) plans and specifications will be reviewed. Based on questions and concerns expressed at this meeting, a Memorandum of Understanding will be prepared to document items discussed at the meeting and concerns to be addressed during the development of the final MPT Plan.

8.4.2 Work Zone Safety Meetings

Prior to commencement of construction, a work zone safety meeting will be conducted with Representatives of the Massachusetts Highway Department (MHD), the Massachusetts State Police (Local Barracks), the Barnstable Police, the contractor and the Traffic Control subcontractor (if different than the prime contractor) to review the contract requirements and discuss the contract procedures. Other work zone safety meetings during the course of the project will be scheduled as needed.

9.1 GENERAL

The four alternatives developed in detail as part of this evaluation, and described in Section 6, have been compared in this section. These alternatives have been compared with respect to (1) construction costs, operation & maintenance costs, and 50-year life-cycle costs and (2) non-monetary criteria, such as environmental impacts and short-term and long-term neighborhood impacts. This comparison provides the basis for selecting a recommended alternative.

9.2 COSTS

Estimated sewer system expansion costs have been developed for each of the four alternatives developed in detail in this report. These costs are based on the November 2002 Engineering News Record Construction Cost Index (ENR CCI) of 6578. The cost estimates include:

- Construction costs
- Land acquisition costs
- Operation and maintenance (O&M) costs
- Equipment replacement costs

It is important to note that although land acquisition costs have been included in this estimate, land acquisition costs can vary significantly, depending on the value of the property under consideration, and are subject to negotiation with the individual property owners. The land acquisition costs include the purchase of land, legal fees, survey, and the preparation of easement/land taking drawings

The cost components described above were used to develop 50-year life cycle costs for each alternative in order to determine the most cost-effective alternative.

The following cost sources were utilized in this evaluation:

1. Bid prices from recent projects with similar sewerage system components, especially those obtained in the eastern portion of Massachusetts. Note in particular that bid prices from the recent vacuum sewer projects in Barnstable and Provincetown were used for this evaluation. A complete list of bid references is included in Section 14.

2. Estimated costs provided by manufacturer's representatives were used to supplement the bid prices. In particular, AIRVAC and Roediger provided cost

estimates for vacuum sewer system components and E/One and Meyers provided cost estimates for low pressure sewer system components.

3. RSMeans construction cost data, which is a commonly used source of cost information, was used to check bid prices and to determine costs for special construction activity, such as sheeting and dewatering.

9.2.1 Construction Costs

The construction costs include the following general components, which are listed in the detailed construction cost summaries included in Appendix C:

Gravity Sewers

- Gravity sewer piping (main line pipe and service laterals to property line)
- Manholes
- Pump stations
- Force Mains
- Odor control equipment

Low Pressure Sewers

- Low pressure sewer piping (main line pipe and service laterals to property line)
- Grinder pumps
- Air release manholes
- Cleanout manholes
- Odor control equipment and related facilities

Vacuum Sewers

- Vacuum sewer piping (main line pipe and service laterals to property line)
- Valve pit
- Vacuum stations
- Force mains
- Buffer tanks

Each item includes the cost of materials, installation, testing, mobilzation/demobilization, and the contractor's overhead and profit. The piping unit costs vary depending on the depth of construction anticipated. Where low pressure sewers are proposed, we have assumed that there would be a grinder pump for each house, rather than a grinder pump station serving two or more houses. Similarly, where vacuum sewers are proposed, we have assumed that there would be a valve pit for each house, rather than a valve pit serving two or more houses.

The construction costs include the cost of the new sewerage system components proposed within the AOC, infrastructure costs from the AOC to the existing system connection point, and the cost of improvements needed to the existing sewerage system. Each alternative includes the cost to replace the Main Street pump station with a new pumping facility and the cost to redirect the pump station force main to the nearby Old Colony Road pump station force main.

The cost of odor control equipment, a building, if needed, and odor control chemicals (calcium nitrate) have been included in the cost estimates. Odor control equipment is recommended at the Sub-Area 3 pump station, under Alternatives 1, 3, and 4, and the Sub-Area 3A pump station, under Alternative 2, in order to prevent odors generation within the 6,500-foot long force main from these pump stations.

Odor control equipment is also recommended in the pump station proposed under Alternative 3 to serve the low pressure sewers in Sub-Areas 5, 6, and 7. Similarly, a chemical feed facility is recommended under Alternative 4 to provide odor control for the low pressure sewers in Sub-Area 5. This odor control facility would be a small, unheated building constructed near the upstream end of Sub-Area 5 to house the chemical storage and feed equipment.

In addition to the sewerage system components listed above, where special construction conditions exist, they were also considered in evaluating the construction costs for each alternative. For example, the deep sewers proposed on Huckins Neck Road for Alternative 1 are expected to be difficult to construct because of the high groundwater conditions in this area. In order to account for these difficult construction conditions, an additional cost for sheeting and dewatering the deep sewers in this area was included in the cost estimate. Similarly, many of the pump stations proposed are expected to require deep construction and the cost of constructing a cofferdam and dewatering the building site was included in the construction cost for these pumping facilities.

The construction costs developed for Alternatives 1 through 4 include the cost of the grinder pumps. However, because there is the potential that the homeowners will purchase, own, and maintain the grinder pumps, construction costs have also been developed for alternatives that exclude grinder pump costs. These alternatives are referred to in this report as Alternatives 1A, 2A, 3A and 4A.

The construction costs for Alternatives 1, 2, 3 and 4 range from $17.8 million to $21.4 million and the construction costs for Alternatives 1A, 2A, 3A and 4A range from $13.3 million to $18.7 million, as shown in Table 9-1. Note that the construction costs for Alternatives 1, 2 and 4 were similar and only varied by approximately 4%. Similarly, the construction costs for Alternatives 1A, 2A, and 4A also varied by only 4%. For each alternative, a 20% construction contingency has been added to the cost of the new infrastructure and to the cost of upgrading the existing sewer system on West Main Street to accommodate the wastewater flow from the Long Pond area, as is described in Section 6. However, a construction contingency was not added to the grinder pump construction costs since there is less potential for variability in these costs or unforeseen conditions that could impact these costs.

Note that the construction costs developed do not include:

1. house service connections between the building and the street line, other than the cost of the grinder pump unit or vacuum valve pit, where required;
2. police for traffic control;
3. engineering design services, or
4. engineering services to monitor construction activity.

Several enhancements to a typical grinder pump unit can be provided and are listed below in Table 9-2. These enhancement costs have not been included in the construction cost estimates developed.

Table 9-2

Grinder Pump Unit Enhancements

Enhancement	Estimated Cost
Larger sump storage volume	$200-$400 (1) (2)
Generator connection at control panel	$200-$300 (1)
Dialer to send standard high water alarm signal to a remote location (3)	$300
Monitoring of wastewater level, pump run time, number of pump activations and alarm status, which can be sent to a remote location via a modem (3)	$1,000

Notes:

(1) Cost varies, depending on manufacturer.

(2) Sump storage volume would increase to 1.5 to 2 times standard volume.

(3) If remote monitoring is pursued, the grinder pump signals would likely be relayed to the WWTP for review and action, as appropriate.

Table 9-1
Engineer's Opinion of Probable Sewer System Extension Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension Project

Alternative	Total Length of Sewers (lf)	No. of Pump/ Vacuum Stations	No. of Grinder Pumps	Construction Cost				
				New Infrastructure	Upgrades to Existing Sewers	20% Contingency	New Grinder Pumps	Total
Grinder Pumps Purchased by Town								
1	125,500	8 PS's	361	$15,102,000	$512,000	$3,123,000	$2,708,000	$21,445,000
2	129,550	11 PS's	401	$14,555,000	$512,000	$3,013,000	$3,008,000	$21,088,000
3	120,210	5 PS's	598	$10,581,000	$512,000	$2,219,000	$4,485,000	$17,797,000
4	125,400	4 PS's/2 VS's	287	$14,788,000	$512,000	$3,060,000	$2,153,000	$20,513,000
Grinder Pumps Purchased by Residents								
1A	125,500	8 PS's	0	$15,102,000	$512,000	$3,123,000	$0	$18,737,000
2A	129,550	11 PS's	0	$14,555,000	$512,000	$3,013,000	$0	$18,080,000
3A	120,210	5 PS's	0	$10,581,000	$512,000	$2,219,000	$0	$13,312,000
4A	125,400	4 PS's/2 VS's	0	$14,788,000	$512,000	$3,060,000	$0	$18,360,000

9.2.2 Operation and Maintenance Costs

The annual operation and maintenance (O&M) costs that would be incurred have been estimated for each of the alternatives and include the following components:

- Labor costs to maintain the sewer system and operate and maintain the pump/vacuum stations (including grinder pumps and vacuum valves)
- Pump/vacuum station and grinder pump electricity costs
- Chemical addition costs for odor control
- General O&M costs for the pump stations, vacuum stations, grinder pumps, and odor control equipment
- Sewer maintenance costs

For the purposes of this evaluation, we have assumed that it would require a two-person, full-time maintenance crew complete with generator-equipped service truck to operate and maintain the new sewers and pumping facilities proposed under Alternatives 3 and 4. A labor cost of $50,000/year/person was assumed, which includes typical benefit add-ons. The labor costs under Alternatives 1 and 2 were estimated to be less than those for Alternatives 3 and 4, primarily because there are fewer grinder pumps/vacuum valves. For Alternative 1, only one additional full-time person is expected to be necessary while for Alternative 2, one full-time person and one person working 8 hours per week to maintain the proposed sewerage system are expected to be needed. For Alternatives 1A, 2A, 3A, and 4A, which assume that the grinder pumps will be maintained by the residents, the additional labor that would be required by the Town has been reduced to one person working 20 hours per week.

Annual electricity costs were estimated for each alternative based on estimated power consumption for the pump stations, vacuum stations, and grinder pumps. Power consumption was estimated for the pump/vacuum stations by calculating pump sizes and estimating pump run times, based on average daily flow projections. An electricity use unit cost of $0.11/kilowatt-hour, which is currently being charged to the Town wastewater treatment facility, was used to calculate annual electricity costs for each pump/vacuum station.

Annual grinder pump electricity costs were also calculated for Alternatives 1, 2, 3 and 4. Grinder pump electricity costs were based on a flow rate of 11 gpm, an average annual run time of approximately 100 hours per pump, and a electricity use unit cost of $0.11/kilowatt-hour. The average annual estimated electricity cost to operate a grinder pump is $10-$20/year.

Odor control is expected to be needed in some areas, as discussed previously. Chemical addition to control odors, using calcium nitrate, has been proposed in this evaluation, although a more detailed review of available odor control chemicals will be

performed during design. The annual cost to purchase the amount of calcium nitrate that is projected to be needed for each alternative has been calculated by multiplying the annual quantity needed by the unit cost for this chemical, which has been provided by a calcium nitrate supplier.

General equipment O&M costs were also considered for the pump stations, vacuum stations, grinder pumps and chemical feed facilities and were estimated as 3% of the equipment construction costs. General O&M includes the periodic replacement of parts and lubrication over the life of the facilities.

Sewer maintenance costs were included in the O&M costs for each alternative and include:

- Periodic inspection and cleaning of the sewer lines
- Repair/rehabilitation of pipe sections

The estimated annual O&M costs for each of the categories described above are summarized in Table 9-3. Note that the O&M costs did not vary significantly among alternatives for each of the categories, with the exception of chemical addition. Chemical addition is estimated to be more expensive for Alternative 3 because of the need to control odors within the more extensive low pressure system proposed under this alternative.

Table 9-3

Summary of Annual O&M Costs

Alternative No.	Labor [1]	Electricity	Chemical Addition	General Equipment O&M	Sewer Maintenance	Total
Grinder Pumps Maintained by Town						
1	$ 55,000	$5,800	$12,600	$46,400	$62,700	$ 182,500
2	$ 65,000	$7,400	$12,600	$55,400	$64,800	$ 205,200
3	$ 105,000	$6,400	$55,400	$54,100	$60,100	$ 281,000
4	$ 105,000	$5,800	$21,800	$39,700	$62,700	$ 235,000
Grinder Pumps Maintained by Residents						
1A	$25,000	$2,800	$12,600	$24,800	$62,800	$128,000
2A	$25,000	$4,100	$12,600	$31,500	$64,800	$138,000
3A	$25,000	$1,100	$55,400	$18,500	$60,100	$160,100
4A	$25,000	$3,100	$21,800	$22,600	$62,700	$135,200

Notes:

(1) Includes cost of generator-equipped service truck - $5,000/year.

9.2.3 Life Cycle Costs

Once the construction costs and annual O&M costs were determined, they were used to determine life cycle costs for each alternative. The life cycle costs provide a comprehensive summary of the total costs anticipated over the life of the new sewers. We consider the life cycle cost comparison to be the most appropriate method of determining which alternative is most cost-effective. A 50-year period was determined to be the most appropriate life cycle period for this analysis since several components of the proposed work have 50-year design lives, including the proposed piping, pump station structures, and vacuum station structures.

As part of the life cycle cost comparison, all future capital and O&M costs have been converted to present worth costs so that all costs are on an equal time basis, for each alternative. The total present worth cost is commonly referred to as the Net Present Value (NPV). In this evaluation, the NPVs have been categorized as construction NPVs or O&M NPVs. The construction NPVs include the installed construction costs and the equipment replacement costs over the 50-year period. For the pump stations, vacuum stations, and chemical feed facilities, the major equipment is expected to require replacement every 25 years, or twice over the 50-year life cycle period. In comparison, the grinder pump equipment is expected to require replacement every 10 years or five times over the 50-year life cycle period and the vacuum system control valves are expected to require replacement every 15 years or 3 times over the 50-year life cycle period. The current EPA discount rate of 5.88% and an inflation rate of 2.33% were used to determine the Net Present Values of the projected capital costs for each alternative. The capital cost inflation rate was determined by calculating the annual average change in the Engineering News Record Construction Cost Index (ENR CCI) over the past 5 years. The ENR CCI reflects the current cost of construction and is typically used to determine the change in construction costs over time. The O&M NPVs were calculated using the same current EPA discount rate of 5.88% and an inflation rate of 2.42%. The O&M cost inflation rate was determined by calculating the change in the Consumer price Index (CPI) in the northeast over the past 5 years. The CPI reflects the price of goods and services and is typically used to determine the change in the price of these goods and services over time, similar to the ENR CCI.

The total NPV cost for each alternative is calculated as the sum of the NPV capital cost and the NPV O&M cost. The NPV costs are summarized in Table 9-4.

Table 9-4
Summary of Net Present Value (NPV) Costs

Alternative No.	NPV Construction Costs	NPV O&M Costs	Total NPV Costs
Grinder Pumps Purchased and Maintained by Town			
1	$22,274,000	$4,380,000	$26,654,000
2	$22,222,000	$4,924,000	$27,146,000
3	$19,602,000	$6,744,000	$26,346,000
4	$21,731,000	$5,639,000	$27,370,000
Grinder Pumps Purchased and Maintained by Residents			
1A	$18,299,000	$3,072,000	$21,371,000
2A	$17,807,000	$3,311,000	$21,118,000
3A	$13,017,000	$3,841,000	$16,858,000
4A	$18,570,000	$3,243,000	$22,813,000

The life-cycle analysis illustrates that the NPV construction cost, which ranges from $13.0 million to $22.3 million, is a much more significant component than the NPV O&M cost, which ranges from $3.2 to $6.7 million. Alternative 3A provides the lowest total NPV cost, at $16.9 million.

9.3 NON-MONETARY EVALUATION CRITERIA

In addition to the cost of the sewer system expansion alternatives, other criteria are also important in evaluating and comparing alternatives and were considered in this evaluation. The non-monetary evaluation criteria considered include:

- environmental impacts,
- neighborhood impacts,
- reliability, and
- expandability.

Each of these non-monetary factors is discussed in the paragraphs that follow. The four alternatives have been assigned a ranking value from 1 to 5 in each of these categories with lower values indicating that the alternative is less favorable in the category of concern and higher numbers indicating that the alternative is more favorable in the category of concern. At the end of this section, an average non-monetary rank is presented for each alternative, for comparison purposes.

9.3.1 Environmental Impacts

The following categories were considered in evaluating the potential environmental impacts of the proposed project and anticipated mitigation measures:

- water quality,
- wetlands,
- rare species and wildlife, and
- historic and archaeological resources.

The environmental impacts within each category were compared and ranked in the paragraphs that follow for the four sewer extension alternatives considered in order to determine an overall environmental impact ranking for each alternative. The ranking approach is described at the beginning of Section 9.3.

9.3.1.1 Water Quality

Previous evaluations identified high nutrient loadings to Lake Wequaquet and Long Pond from septic systems within the AOC, which can negatively impact water quality. Each of the sewer extension alternatives would improve water quality within Lake Wequaquet, Bearse Pond, Shallow Pond, and Long Pond by eliminating septic systems within the AOC. Similarly, each of the sewer extension alternatives would improve groundwater quality by eliminating the septic systems within the AOC. Note that the northern and eastern portions of the AOC are of special concern because they have been delineated as State approved Zone II groundwater protection areas, as shown in Figure 9-1. These areas are within the recharge area of the Town's sole source aquifer.

There is the potential for short-term negative water quality impacts during construction, primarily related to soil erosion. These water quality impacts will be minimized under each alternative through the use of haybales, siltation fencing, and soil stabilization, where determined to be necessary. The Storm Water Management Plan (SWMP), which is required as part of the Stormwater Phase I permitting process, will require that the construction contractor provide adequate controls to prevent soil erosion and other pollutants from reaching the surface water bodies. In addition, appropriate dewatering procedures will be established in the SWMP to prevent the uncontrolled discharge of groundwater during dewatering operations to a nearby surface water body.

The potential for short-term negative water quality impacts during construction due to erosion are greater for those alternatives that require deeper excavation, since there will be larger disturbed areas (a wider trench is normally needed), a greater amount of trench dewatering, and a greater amount of excavated material stockpiled during the

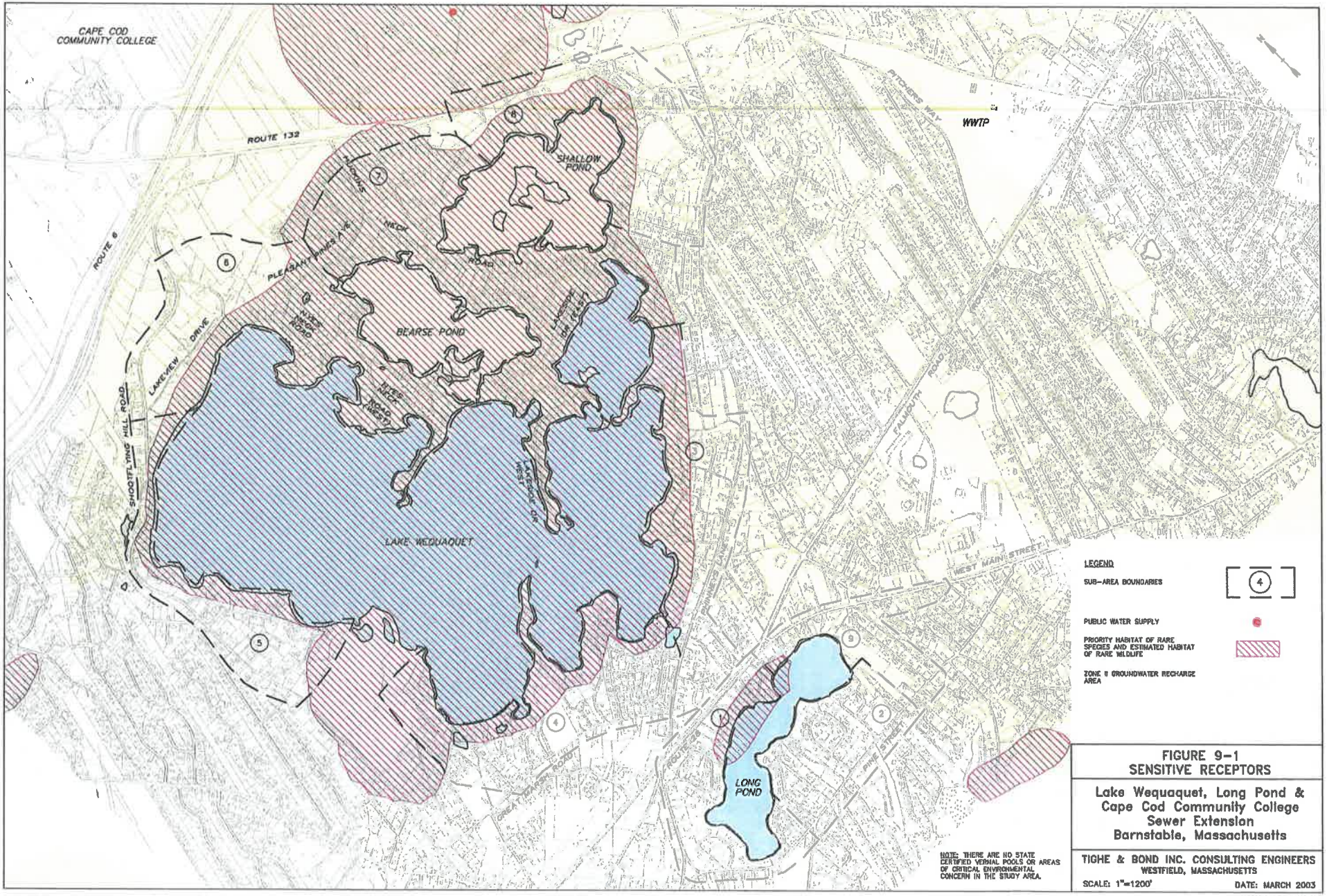

FIGURE 9-1
SENSITIVE RECEPTORS

Lake Wequaquet, Long Pond & Cape Cod Community College Sewer Extension
Barnstable, Massachusetts

TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASSACHUSETTS

SCALE: 1"=1200'

DATE: MARCH 2003

course of construction activity. A summary of the sewer lengths by depth for each alternative is presented in Table 9-5. Alternative 1 requires the greatest amount of deep excavation and, as such, would have a larger potential for short-term negative water quality impacts during construction.

Table 9-5
Sewer Lengths Summary

Sewer Type	Alternative 1 Lengths (ft)	Alternative 2 Lengths (ft)	Alternative 3 Lengths (ft)	Alternative 4 Lengths (ft)
Gravity				
<10 ft. deep	37,530	38,790	18,890	18,890
10-<15 ft. deep	18,720	17,810	9,470	9,470
15-<20 ft. deep	9,240	4,380	5,770	5,770
20-25 ft. deep	2,760	0	2,110	2,110
Subtotal	**68,250**	**60,980**	**36,240**	**36,240**
Low Pressure	30,250	37,520	62,820	28,540
Vacuum	0	0	0	34,370
Force Main	27,000	31,050	21,150	26,250
Total	**125,500**	**129,550**	**120,210**	**125,400**

The potential for short-term negative water quality impacts are also greater for the alternatives with more pump stations since, in most cases, deep excavation is required and the disturbed area is relatively large, in comparison to a pipe trench. In addition, in many cases significant groundwater control will be necessary for the pumping facilities. Table 9-6 presents the number of pumps stations proposed for each of the alternatives and the anticipated excavation depths and structure depths below average groundwater levels. Pump station excavation depths range from 16 feet to 34 feet and were generally deeper under Alternative 1. More pump stations are provided under Alternative 2 in order to reduce the pipe and pump station excavation that would be required under Alternative 1, as is shown in Table 9-6. As a result, less groundwater control would be necessary under Alternative 2 at several pump station sites, in comparison to Alternative 1, although groundwater control would be necessary at more sites. Alternative 3, which requires the fewest pump stations (5), has the lowest potential for water quality impacts related to pump station construction.

As noted previously, each of the sewer extension alternatives would improve water quality within Lake Wequaquet, Bearse Pond, Shallow Pond, and Long Pond. Temporary negative water quality impacts, primarily related to soil erosion, will be minimized during construction for each of the four alternatives considered through

Table 9-6
Pump/Vacuum Station Groundwater Impacts Summary
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension

Pump/ Vacuum Station	Alternative 1 (8 PS's)		Alternative 2 (11 PS's)		Alternative 3 (5 PS's)		Alternative 4 (4 PS's/2 VS's)	
	Excavation Depth (ft)	Structure Depth Below Groundwater (ft)	Excavation Depth (ft)	Structure Depth Below Groundwater (ft)	Excavation Depth (ft)	Structure Depth Below Groundwater (ft)	Excavation Depth (ft)	Structure Depth Below Groundwater (ft)
1	18	13	18	13	18	13	18	13
2	26	14	26	14	26	14	26	14
3/3A	30	22	18	10	30	22	30	22
3B	---	---	22	16	---	---	---	---
4	25	19	25	19	25	19	25	19
5	21	11	21	11	---	---	---	---
6	23	17	23	17	---	---	16	10
7	34	17	---	---	16	Above GW level	16	Above GW level
7A	---	---	18	8	---	---	---	---
7B	---	---	18	10	---	---	---	---
7C	---	---	19	12	---	---	---	---
8	18	3	18	3	---	---	---	---
Average	24	15	21	12	23	17	22	16

Notes:

(1) Groundwater levels were determined using 1986 USGS groundwater resources mapping, based on the average elevation of the groundwater table from 1963 to 1976. This data was confirmed using more recent, but less comrehensive groundwater contour information developed in June, 1992 by Gehrety & Miller through modeling.

appropriate erosion control measures, although Alternatives 1 and 2 have the greatest potential for negative water quality impacts during construction. Conversely, Alternative 3 is least likely to negatively impact water quality because of its shallower pipe installation depths and fewer pump stations. Each alternative is ranked in this sub-category in Table 9-7, included at the end of Section 9.3.1.

9.3.1.2 Wetlands

Wetland resource areas are present throughout the AOC, including especially the Nyes Neck area, as shown in Figure 7-1. The majority of the proposed sewers will be constructed within existing roadways and will not impact nearby wetland areas, assuming that standard good construction practices are employed, including proper placement of haybales and siltation fences, and appropriate dewatering methodologies.

However, the proposed sewers and pump stations will be constructed within the 100-foot wetlands buffer zone under each alternative. Five areas were identified as being of particular concern and are listed below:

- On the south side of Phinney's Lane, just west of Tellegen Trail, in Sub-Area 3. A pump station is proposed near this wetland area as part of sewer extension Alternative 2, detailed in Section 6.

- At the northerly corner of the intersection of Huckins Neck Road and Cottonwood Lane, in Sub-Area 7. A pump station is proposed at this location under Alternative 2, near a drainage channel between Shallow Pond and Lake Wequaquet and within the 100-foot Buffer Zone of the Banks of Shallow Pond and Lake Wequaquet.

- On the south side of Pleasant Pines Avenue, just east of Nyes Neck Road, in Sub-Area 6. A pump station or vacuum station is proposed in this area under Alternatives 1, 2 and 4, and is within 100 feet of a Bordering Vegetated Wetland just south of the pump station site.

- On the south side of Shoot Flying Hill Road, just south of Lakeview Drive and on the Town beach in Sub-Area 5. A pump station is proposed at this location under Alternatives 1 and 2. The pump station is within the 100-foot Buffer Zone of the Bank of Lake Wequaquet.

- On the north side of Lake Drive, on the Wequaquet Lake Association beach in Sub-Area 4. A pump station is proposed at this location under each of the four alternatives. The pump station will likely be within the 100-foot Buffer Zone of the Bank of Lake Wequaquet.

Alternative 2 has the greatest potential for wetland impacts since pump stations would be constructed near the five wetland sites listed above as being of concern. In comparison, Alternative 1 would require construction at three of the sites identified above as being of concern, Alternative 4 would require construction at two of the sites identified above as being of concern, and Alternative 3 would require construction at one of the sites listed above as being of concern.

As noted previously, wetland impacts will be minimized during construction for each of the four alternatives considered through appropriate erosion control measures, although Alternative 2 has the greatest potential to impact wetlands during construction. Alternative 3 has the lowest potential to impact wetlands during construction and is ranked highest in this sub-category. Each alternative is ranked in this sub-category in Table 9-7, included at the end of Section 9.3.1.

9.3.1.3 Rare Species and Wildlife Habitats

The Massachusetts Division of Fisheries and Wildlife has determined Priority Habitats of Rare Species and Estimated Habitats of Rare Wildlife in Massachusetts through the Natural Heritage and Endangered Species Program (NHESP). These areas have been mapped in the most recently published (2000-2001) Massachusetts Natural Heritage Atlas. Priority habitats of rare species have been identified within and along the banks of Lake Wequaquet, Bearse Pond and Shallow Pond, and along the northern banks of Long Pond, as shown in Figure 9-1. In addition, estimated habitats of rare wildlife were identified just north of Bearse Pond and west of Lake Wequaquet, in the area of Lewis Point. The NHESP has indicated that several rare species are present in the AOC.These species are listed in Table 7-1.

Because the majority of the proposed work will be in existing roadways, significant impacts to these habitats are not anticipated. However, because the pump/vacuum stations proposed for each of the alternatives will be located off of the roadways, they are of greater concern. The following pump/vacuum stations are near the Priority Habitats of Rare Species and Estimated Habitats of Rare Wildlife identified and have the greatest potential for impacting these habitats:

- Alternative 1 – Pump Stations 4, 5, 6 and 7
- Alternative 2 – Pump Stations 4, 5, 6, 7A, 7B, and 7C
- Alternative 3 – Pump Station 4
- Alternative 4 – Pump Station 4 and Vacuum Stations 6 and 7

Alternative 2 has the greatest potential to impact rare species and wildlife habitats and is ranked lowest in this sub-category, while Alternative 3 has the least potential to impact rare species and wildlife habitats and is ranked highest in this sub-category.

Each alternative is ranked in this sub-category in Table 9-7, included at the end of Section 9.3.1.

9.3.1.4 Historic and Archaeological Resources

The Massachusetts Historical Commission (MHC) has been contacted to identify locations within the AOC of historic or archaeological significance. The MHC has indicated that there are three recorded historical archaeological sites and one recorded ancient Native American site within the project area. In addition, the MHC has indicated that the project area is archaeologically sensitive and likely to contain additional archaeological sites and historic resources, although the project area has not been systematically surveyed by professional archaeologists.

Since the majority of work will be in existing roadways, the historical/archaeological impacts are expected to be minimal under each of the proposed alternatives. However, because the pump/vacuum stations proposed for each of the alternatives will be located off of the roadways, they are more likely to have impacts on historic/archaeological resources. As such, alternatives that require a greater number of pump/vacuum stations are expected to have a greater potential for impacts to historic/archaeological resources.

9.3.1.5 Summary

The alternatives developed have been ranked with respect to each environmental category and then averaged in order to develop an overall ranking for environmental impacts, as shown below in Table 9-7.

Alternative 3 is ranked highest in the category of environmental impacts because it has the smallest impact on water quality, wetlands, and rare species and wildlife habitats, and the lowest potential for impacts to historic/archaeological resources. The environmental impacts rankings, along with the rankings for the other non-monetary criteria reviewed, are summarized in Table 9-13, included at the end of Section 9.3.

Table 9-7
Environmental Impacts Overall Ranking

Sub-Category	Ranking			
	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Water Quality	1	2	4	3
Wetlands	2	1	4	3
Rare Species and Wildlife	3	1	5	4
Historic and Archaeological Resources	3	2	5	4
Average	**2.3**	**1.5**	**4.5**	**3.5**

9.3.2 Neighborhood Impacts

The following categories were considered in evaluating the potential neighborhood impacts of the proposed project and anticipated mitigation measures:

- aesthetics,
- traffic,
- noise,
- air quality, and
- land acquisition.

9.3.2.1 Aesthetics

The majority of the components of the proposed sewer extension alternatives (piping, valves, manholes, grinder pump packages, air valves pits, etc.) would be below grade and are not expected to have a significant aesthetic impact on the residents within the AOC. However, above-grade pumping/vacuum facilities will be needed under each sewer extension alternative and are expected to have an aesthetic impact on the residents within the AOC. Although below-grade submersible pump stations could be provided, we anticipate that a standby generator to provide emergency power in the event of a power failure will be required at each of the pump stations and vacuum stations. As such, an above-grade enclosure would be provided or a building would be constructed at each facility to house the generator and pump station controls. The extent to which the pumping/vacuum stations will have an impact on residents within the AOC depends on the proximity of these facilities to residences, the degree to which these facilities can be hidden from view, and the appearance of these facilities. In addition, note that a chemical feed facility to control odors is proposed in Sub-Area 5. This facility would be a small, unheated building to house a chemical storage tank, chemical feed pumps, and pump controls. This facility will be sited during design.

Based on input provided by Town officials, we have assumed, for the purposes of this evaluation, that a building will be provided for each pump station to house the standby generator, pump controls, instrumentation, and pump station equipment. In addition, we anticipate that the pump station/vacuum station buildings will be designed with architectural features similar to the buildings in the surrounding area in order to blend in with the neighborhood appearance, to the extent practical. Architectural features that will be considered during design include roofing material and type (flat vs. pitched) and building façade (brick, cedar clapboard, vinyl-sided, concrete, etc.).

The pump/vacuum station sites have been described in Section 6 and each facility's potential aesthetic impact on residences within the AOC is categorized in Table 9-8 as minor, moderate, or high, depending on its location with respect to nearby residents. Subsequently, this information was used to establish a ranking for each alternative. Each alternative is ranked in this sub-category in Table 9-10, included at the end of Section 9.3.2.

Table 9-8
Aesthetic Impacts Summary

Pump/Vacuum Station	Alternative 1	Alternative 2	Alternative 3	Alternative 4
1	high	high	high	high
2	moderate	moderate	moderate	moderate
3/3A	moderate	moderate	moderate	moderate
3B	---	minor	---	---
4	high	high	high	high
5	high	high	---	---
6	minor	minor	---	minor
7	moderate	---	---	moderate
7A	---	minor	---	---
7B	---	minor	---	---
7C	---	moderate	---	---
5-7			minor	
8	minor	minor	---	---
Total High	3	3	2	2
Total Moderate	3	3	2	3
Total Minor	2	5	1	1

Pump/vacuum stations that would be constructed in public areas, such as parks and beaches, were considered to have a "high" impact on area residents. The Sub-Area 1 pump station, which would be constructed in Mother's Park for each of the alternatives, falls into this category. Similarly, the Sub-Area 4 pump station would be constructed on the Wequaquet Lake Association beach located off of Lake Drive for each of the alternatives and is expected to have a "high" aesthetic impact. In addition, a pump station is proposed under Alternatives 1 and 2 on the Town beach off of Shootflying Hill Road in Sub-Area 5 and would also have a "high" aesthetic impact.

The pump/vacuum stations that are proposed on private property but that are either a significant distance away from the nearby homes or buffered from view were considered to have a "minor" aesthetic impact. The pump/vacuum stations that are proposed on private property but that are relatively close to nearby houses and are not buffered from view were considered to have a "moderate" aesthetic impact.

Alternative 2, which has the greatest number of pump stations, is ranked lowest in this sub-category, while Alternative 3, which has the fewest number of pump stations, is ranked highest in this category.

9.3.2.2 Traffic

The proposed project will not generate any new traffic except during construction. Therefore, the traffic impacts will be temporary and traffic control concerns will be reviewed during the public information process with Town residents that might be impacted. Traffic impacts should be limited to short and temporary detours around construction for short periods of time.

The alternatives that require longer construction durations within the existing roadways will have greater traffic impacts. Construction will be slower where deeper sewers or more pump stations are proposed. A summary of the sewer lengths by depth is shown in Table 9-4 and the number of pump stations for each alternative is shown in Table 9-5. Alternatives 1 and 2 are expected to require a longer period to construct because of the deeper sewer construction required and the greater number of pump stations, in comparison to Alternatives 3 and 4. Alternative 4 would require one more pump station than alternative 3 and, as such, is ranked slightly lower. In addition, Alternative 3 is ranked highest because it requires the least total quantity of new piping, which would also contribute to a shorter construction duration.

Each alternative is ranked in this sub-category in Table 9-10, included at the end of Section 9.3.2.

9.3.2.3 Noise

Heavy machinery, such as trucks, loaders, backhoes, etc., will be needed during construction to excavate pipe trenches, grade work areas, and replace disturbed pavement. In addition, pumps will be needed periodically to dewater trenches. The operation of this equipment will generate noise greater than is typically experienced in the residential areas within the AOC. However, these noise impacts will be short-term, lasting only as long as the construction activity within a particular area. In order to minimize noise impacts during construction, the contractor will be limited to specific hours of the day established prior to construction and with the input of Town officials and neighborhood residents.

Similar to traffic impacts, the alternatives that require longer construction durations will have greater noise impacts. Construction will be slower where deeper sewers or more pump stations are proposed, as noted above. Alternatives 1 and 2 are expected to require a longer period to construct because of the deeper sewer construction required and the greater number of pump stations, in comparison to Alternatives 3 and 4, as discussed under traffic impacts.

Each alternative is ranked in this sub-category in Table 9-10, included at the end of Section 9.3.2, and is similar to the ranking for traffic impacts.

9.3.2.4 Air Quality

Short-term air quality impacts may be experienced due to dust generation during construction. Construction-related dust can typically be effectively controlled using calcium chloride or water, as appropriate.

Similar to traffic and noise impacts, the alternatives that require longer construction durations will have greater air quality impacts related to dust generation. Construction will be slower where deeper sewers or more pump stations are proposed, as noted above. Alternatives 1 and 2 are expected to require a longer period to construct because of the deeper sewer construction required and the greater number of pump stations, in comparison to Alternatives 3 and 4.

The generation of sewage odors is a concern when constructing sewage collection systems, especially in the following areas:

1. In vacuum stations, where odors are of particular concern since substantial quantities of air are drawn from the collection system into the station. Air removal equipment, such as carbon filters or biofilters, is typically recommended.

2. In pump station wetwells, where substantial quantities of wastewater are stored.

3. In pipelines with long detention times, such as long force mains or low pressure sewers.

For the purposes of this preliminary design evaluation, odor control equipment has been proposed for the Sub-Area 3 pump station under Alternatives 1, 3 and 4 and for the Sub-Area 3A pump station under Alternative 2, since these pump stations would have a relatively long force main. In addition, this pump station receives wastewater flow from an upstream pump station in Sub-Area 4, increasing the potential for septic conditions to occur, which can lead to odors.

As noted above, sewage odors are also concern where there are long low pressure sewers, resulting in long sewage detention times in the piping. This is even more of a concern in areas such as Barnstable that have seasonal fluctuations in population, which can result in even longer sewage detention times when the summer population leaves the area for the winter. Odor control equipment is proposed in the pump station serving Sub-Areas 5, 6, and 7 under Alternative 3 since long lengths of low pressure sewer will be installed in these sub-areas under this alternative. Similarly, an odor control facility is proposed in Sub-Area 5 under Alternative 4 since long lengths of low pressure sewers will be installed in this sub-area under this alternative.

Appropriate measures will be taken to control dust during construction and sewage odors after the sewer extension construction has been completed. However, for the purposes of this evaluation, the alternatives have been ranked with respect to their potential to impact air quality. The potential for sewage odors is considered to be a more significant air quality concern than the potential for dust during construction. As such, the alternatives with a greater potential for sewage odors were ranked lower than alternatives with a greater potential for dust generation.

Alternative 4 is ranked lowest in this sub-category because it requires odor control equipment at one pump station, two vacuum stations and at a separate odor control facility in Sub-Area 5. Alternative 3, which requires odor control equipment at two pumping facilities, is also ranked relatively low in this sub-category. Alternatives 1 and 2 only require odor control equipment at one pump station and are ranked highest in this sub-category.

Each alternative is ranked in this sub-category in Table 9-10, included at the end of Section 9.3.2.

9.3.2.5 Land Acquisition

Each of the alternatives considered requires the purchase of land for the construction of pump/vacuum stations on private property or the purchase of land rights for sewer easements on private property. In addition, Alternative 4 will likely require the purchase of land for an odor control facility in Sub-Area 5. Although most of the sewers will be constructed within the existing roadways under each alternative, many of the streets within the AOC are privately owned. The Town will need to obtain easements on these streets to construct the proposed sewers and then, once installed, to maintain them. The sewer locations are essentially the same under each alternative and will require that the same easements be obtained, regardless of the alternative pursued.

There are locations off of the existing roadways and on private property where pump/vacuum stations are proposed under each alternative. In each case, a small plot of land (on the order of 2,500 square feet) would need to be purchased to construct the

proposed facilities, with sufficient space to park a maintenance vehicle and remove equipment. A summary of the pump/vacuum stations required under each alternative and whether they are proposed on private property is presented in Table 9-9.

Table 9-9
Pump/Vacuum Station Site Property Information

Pump/Vacuum Station	Property Owner			
	Alternative 1	Alternative 2	Alternative 3	Alternative 4
1	Town of Barnstable (1)	Town of Barnstable (1)	Town of Barnstable (1)	Town of Barnstable (1)
2	Privately Owned (2)	Privately Owned (2)	Privately Owned (2)	Privately Owned (2)
3/3A	Privately Owned	Privately Owned	Privately Owned	Privately Owned
3B	---	Privately Owned (2)	---	---
4	Wequaquet Estates Beach Association (3)	Wequaquet Estates Beach Association (3)	Wequaquet Estates Beach Association (3)	Wequaquet Estates Beach Association (3)
5	Town of Barnstable (4)	Town of Barnstable (4)	---	(5)
6	MA Division of Fisheries & Wildlife (2)	MA Division of Fisheries & Wildlife (2)	---	MA Division of Fisheries & Wildlife (2)
7	Privately Owned	---	---	Privately Owned
7A	---	Privately Owned	---	---
7B	---	Privately Owned	---	---
7C	---	Privately Owned	---	---
5-7	---	---	Nstar Electric Company (2)	---
8	Privately Owned	Privately Owned	---	---
No. of Land Acquisitions Required	6	9	4	6

Notes:

(1) Mother's Park

(2) Open lot

(3) Wequaquet Beach Association beach

(4) Town beach

(5) A chemical feed facility for odor control is expected to be needed in this Sub-Area but has not yet been sited.

Land acquisitions are important since they increase the cost of sewer system expansion; can impact the sewer system expansion schedule, depending on the length of time

required to negotiate an agreement; and can result in the Town pursuing the purchase of land on other properties if an agreement with a homeowner can not be reached.

Alternative 3 would require the fewest number of land acquisitions and is most favored in this sub-category. Alternative 2 would require the greatest number of land acquisitions and is least favored in this sub-category. The alternatives developed have been ranked with respect to land acquisition in Table 9-10, included at the end of Section 9.3.2.

9.3.2.6 Summary

The alternatives developed have been ranked with respect to each of the neighborhood impact categories described above. These individual rankings have been averaged in order to develop an overall ranking for neighborhood impacts, as shown below in Table 9-10.

Table 9-10
Neighborhood Impacts Overall Ranking

Sub-Category	Ranking			
	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Aesthetics	2	1	4	3
Traffic	2	2	4	3
Noise	2	2	4	3
Air Quality	4	4	3	1
Land Acquisition	3	1	5	3
Average	2.6	2.0	4.0	2.6

Alternative 3 is ranked highest in the category of neighborhood impacts because it has the smallest impact on aesthetics, noise, and traffic and requires the acquisition of the fewest properties for the construction of new sewerage system facilities. The neighborhood impacts rankings, along with the rankings for the other non-monetary criteria reviewed, are summarized in Table 9-13 included at the end of Section 9.3.

9.3.3 Reliability

An important consideration in evaluating alternatives is the expected reliability of the proposed sewer system. Generally, alternatives that require more mechanical equipment, such as pumps, for their operation are considered less reliable since mechanical equipment can more readily fail than pipes, especially if not properly operated and maintained. This is not expected to be a significant concern for the proposed pump/vacuum stations in Barnstable since each facility will be equipped with

a standby pump that can be used in the event of a pump failure and a standby generator that can be used in the event of a power failure.

Individual homeowner grinder pumps are not typically provided with standby power and, although there is some storage provided within the grinder pump pits, during a prolonged power outage there is the potential for sewage backups into house service lines. In addition, individual homeowner grinder pump units are typically not provided with standby pumps. As such, if a grinder pump fails, there will not be service to that house until the pump is repaired or replaced. Downtime can be minimized with early detection of problems (visual and audible alarms) and proper stocking of spare parts. However, because of these concerns, alternatives that include a greater number of grinder pumps are considered less reliable.

Reliability is also a concern for the vacuum sewers because a significant leak in the collection system, caused by a pipe break, will impact the operation of the entire vacuum sewer system tributary to the vacuum station. A system leak could result in sewage backups if not quickly identified and corrected. Because a leak can affect a relatively large area, it may be difficult to locate. Because of this concern, alternatives that include a greater amount of vacuum sewers are also considered less reliable.

The alternatives developed have been ranked with respect to reliability below in Table 9-11.

Table 9-11
Reliability Ranking

Alternative No.	Ranking
1	5
2	4
3	3
4	3

9.3.4 Expandability

With proper planning, gravity sewers and pumping stations can be designed to accommodate both current wastewater flows and projected future wastewater flows in the AOC. Similarly, vacuum sewers and vacuum stations can be designed to accommodate both current wastewater flows and projected future wastewater flows in the AOC. In comparison, low pressure sewers are sized based on a specific range of flows and cannot accommodate substantial flow increases, as discussed in Section 6. If there is a substantial increase in flows in an area where low pressure sewers are installed, a second pipe may be necessary. As such, low pressure sewer systems can not readily accommodate significant sewer system expansion.

Alternative 3, which includes the construction of the greatest amount of low pressure sewers, is least favored under this category. Note in particular that the low pressure sewers proposed within the AOC along Shootflying Hill Road under Alternative 3 would not be able to accommodate the full build-out flows projected within the relatively large Bowl area to the west.

The alternatives developed have been ranked with respect to expandability below in Table 9-12.

Table 9-12
Expandability Ranking

Alternative No.	Ranking
1	4
2	4
3	3
4	4

9.3.5 Summary of Non-Monetary Criteria

The four sewer extension alternatives developed have been ranked in each of the categories described previously in this report section and listed below:

- environmental impacts,
- neighborhood impacts,
- reliability, and
- expandability.

The rankings in each category for each alternative are presented in Table 9-13. The alternatives were ranked from 1 to 5 for the non-monetary criteria with 1 being the least favorable and 5 being the most favorable, as described previously.

Table 9-13

Non-Monetary Criteria Ranking Summary

Sub-Category	Ranking			
	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Environmental Impacts	2.3	1.5	4.5	3.5
Neighborhood Impacts	2.6	2.0	4.0	2.6
Reliability	5.0	4.0	3.0	3.0
expandability	4.0	4.0	3.0	4.0
Average	**3.5**	**2.9**	**3.9**	**3.3**

Alternative 3 provides the highest overall ranking, primarily because it has the lowest potential for environmental and neighborhood impacts. However, it is important to note that there is only a small variation in overall ranking among the four alternatives.

Generally, the alternatives with a greater amount of gravity sewers (Alternatives 1 and 2) had greater environmental and neighborhood impacts, primarily as a result of the need for more pump stations and the longer construction duration anticipated. However, Alternatives 1 and 2 are considered more reliable and can readily accommodate future expansion.

The opposite is true for Alternative 3, which includes the greatest amount of low pressure sewers. The environmental and neighborhood impacts are expected to be least significant but the low pressure sewers are considered less reliable and can not readily accommodate future expansion.

Alternative 4, which includes a significant amount of vacuum sewers, is expected to have a lower environmental impact than Alternatives 1 and 2 but a higher neighborhood impact than Alternative 3. Similar to Alternative 3, there are some reliability concerns associated with Alternative 4, although it can readily accommodate future growth, if properly designed.

SECTION 10 FIELD AND UTILITY SURVEY AND MAPPING

10.1 GENERAL

Information on existing underground utilities within the areas to be sewered was collected as part of this evaluation. This information will be used during design to adjust the layout of the preferred sewer layout, as necessary, to minimize conflicts during construction. The following utility companies were contacted and provided information on their utilities in the AOC:

Utility Company	Buried Utility
Barnstable Dept. of Public Works	Drainage
Massachusetts Highway Department	Drainage
Centerville-Osterville-Marstons Mills Water Department	Water
Barnstable Water Company	Water
Barnstable Fire District	Water
Keyspan Energy Delivery	Gas
NSTAR Electric	Electric
Verizon	Telephone
Comcast	Cable

Information on the utilities listed above and their potential impact on the recommended sewer extension alternative are described in the paragraphs that follow.

10.2 DRAINAGE

Plans and GIS mapping of existing drainage systems within portions of the AOC were obtained from the Town. In addition, the Massachusetts Highway Department (MHD) provided plans showing the location of drainage piping and structures on Route 132 and Route 28 as well as older plans for Phinney's Lane and Shootflying Hill Road. The plans and GIS mapping were supplemented by field investigations of the existing drainage system within the AOC. More detailed information on the drainage system within the AOC, including pipe depths, will be obtained during the field verification phase scheduled during design, as part of the overall field survey that will be performed.

Two specific drainage conduits were identified as being of concern during a review of the drainage system. The first is a 72± inch diameter corrugated metal pipe (CMP) drain that conveys flow from the cranberry bogs north of Pleasant Pines Avenue, across Pleasant Pines Avenue, to Lake Wequaquet. The drain invert is 8 to 9 feet below road

grade with 2 to 3 feet of cover over the pipe. As such, the proposed piping on Pleasant Pines Avenue would need to have an invert elevation that is about 11 feet below grade at the location of this drainage pipe. In comparison, the current gravity sewer layouts for Alternatives 1 and 2 show a sewer invert elevation between 8 and 10 feet below grade at this location. The preferred sewer extension alternative will be adjusted as necessary during design to avoid conflicts with this drainage pipe, once the drain pipe size and depth has been confirmed through field survey.

In addition, there are two 48± inch diameter culverts crossing Pine Street that convey water away from Long Pond, which were identified as being of concern. The drain inverts are approximately 8 feet below road grade with about 4 feet of cover over the pipe. As such, the proposed piping on Pine Street would need to have an invert elevation that is about 10 feet below grade at the location of these drainage pipes. In comparison, for the four alternatives described in Section 6, the gravity sewers at this location have invert elevations between 8 and 10 feet below grade. The preferred sewer extension alternative will be adjusted as necessary during design to avoid conflicts with these drainage pipes, once the drain pipe sizes and depths has been confirmed through field survey.

10.3 WATER

The AOC is served by three separate and independent water companies: the Centerville-Osterville-Marstons Mills (C-O-M-M) Water Department, the Barnstable Water Company, and the Barnstable Fire District. The C-O-M-M Water Department services the majority of the AOC except the Nyes Neck Peninsula on Lake Wequaquet, Route 132 south of Route 6, and the Crestview Circle/Regatta Drive development. Route 132, south of Route 6, is served by the Barnstable Fire District while the Crestview Circle/Regatta Drive development is served by the Barnstable Water Company. There is no water service to the Nyes Neck peninsula.

Each of the water companies has provided approximate information on the location of their water mains, valves and hydrants within the AOC, as well as on pipe sizes. However, water main depth information was not provided. Based on common water main construction practices, the majority of the water mains are expected to be about 5 feet below grade. No conflicts with the existing water mains in the AOC that would significantly impact the comparison of alternatives were identified.

10.4 GAS

The AOC is served by Keyspan Energy Delivery, who provided plans of the gas distribution system within the AOC. There is gas service throughout this area, with the exception of the Nyes Neck peninsula.

The records plans provide approximate information on the location of the gas mains within the AOC. Although gas main depth information was not provided, the majority of the gas mains are expected to be less than 5 feet below grade. No conflicts with the existing gas mains in the AOC that would significantly impact the comparison of alternatives were identified.

10.5 ELECTRIC

The AOC is served by NSTAR Electric, who provided schematics of the underground primary electric lines within the AOC. The streets where underground primary electric lines were identified include:

- Route 132, in the area of Phinney's Lane
- Shallow Pond Village
- Crosby Lane
- Phinney's Lane at Crosby Lane
- Hayes Road
- Route 28, near West Main Street
- West Main Street, between Strawberry Hill Road and Old Strawberry Hill Road
- Shootflying Hill Road at High Noon Drive and near Knotty Pines Lane

The schematics provide approximate information on the location of the underground electric conduits within the AOC. Although conduit depth information was not provided, the majority of the underground electrical conduits are expected to be less than 5 feet below grade. No conflicts with the existing electrical conduits in the AOC that would significantly impact the comparison of alternatives were identified.

10.6 TELEPHONE

The AOC is served by Verizon, who provided some plans of the underground telephone lines within the AOC. The plans provided by Verizon show underground telephone on the following streets:

- Shootflying Hill Road, from Lakeview Drive to Route 132
- Route 132, in the area of Phinney's Lane

- Phinney's Lane, near Route 132

The records plans provide approximate information on the location of the underground telephone conduits within the AOC. Although conduit depth information was not provided, the majority of the underground telephone conduits are expected to be less than 5 feet below grade. No conflicts with the existing electrical conduits in the AOC that would significantly impact the comparison of alternatives were identified.

10.7 CABLE

The AOC is served by Comcast, who provided some plans of the underground cable lines within the AOC. The plans provided by Comcast show underground cable on the following streets:

- Route 28, near Phinney's Lane
- Crosby Road
- Indian Trail
- Hayes Road
- Loomis Lane
- Waterview Circle
- Pondside Circle
- Blue Water Drive
- Cottonwood Lane
- Goose Point Road
- Regatta Drive
- Crestview Circle
- Dacey Drive
- Old Strawberry Hill Road, near Route 132
- Shootflying Hill Road, near Lakeview Drive
- Shallow Pond Drive

The records plans provide approximate information on the location, size and material of the underground cable conduits within the AOC. Although conduit depth information was not provided in most cases, the majority of the underground cable conduits are expected to be less than 5 feet below grade. No conflicts with the existing cable conduits in the AOC that would significantly impact the comparison of alternatives were identified.

The geotechnical program for the project, which was originally scheduled for the preliminary design phase, has been deferred until a preferred sewer extension alternative has been selected. This approach allows the Town to tailor the geotechnical program to a specific sewer extension layout and correspondingly to minimize the cost to perform this work.

The geotechnical program consists of the advancement of soil borings and test pits in order to determine:

- soil conditions;
- the presence of ledge; and
- groundwater level.

In order to maintain eligibility for state funding, the geotechnical program must comply with specific criteria established by the MADEP. These criteria include:

1. The advancement of soil borings every 300 feet where new sewers are proposed.
2. The advancement of soil borings a minimum of 50% deeper than the sewer invert.
3. The collection of information on change in soil stratum, soil classification, groundwater level, and blow counts at 5-foot intervals.

12.1 SUMMARY

The Town initiated facilities planning activities in the early 1990s, which are still on-going. The facilities planning effort identified high nutrient loadings to Lake Wequaquet, Bearse Pond, Shallow Pond, and Long Pond, which were negatively impacting water quality. One of the major sources of this high nutrient loading was determined to be septic system discharges. In order to reduce these high nutrient loadings, the Town has implemented this sewer extension project, which will allow the existing septic tanks within the Area of Concern (AOC) established by the Town around Lake Wequaquet and Long Pond to be abandoned.

In addition, this project includes a sewer extension evaluation for Cape Cod Community College, which is currently served by several septic systems. The college is currently designing a pump station to collect and then discharge its wastewater flow into the Town's collection system. The pump station force main route and Town sewerage system connection point has been investigated as part of this evaluation.

Current and projected future wastewater flow estimates for the AOC and the Cape Cod Community College were developed in this report. The wastewater flow projections were used to determine the appropriate size of new sewers needed to serve these areas. For this evaluation, the AOC has been divided into 9 sub-areas and wastewater flows were determined for each sub-area.

Four sewer extension alternatives were developed in detail in this evaluation in order to determine the most economical preliminary sewer extension design, which can be used as the basis for the development of detailed construction contract documents. The alternatives were developed to accommodate full build-out conditions within the AOC, to the extent possible. These alternatives consist of various combinations of three sewer collection system technologies:

- Gravity sewers and pump stations
- Low pressure sewers and grinder pumps
- Vacuum sewers and vacuum stations

The four alternatives were compared with respect to costs and other non-monetary criteria. These alternatives are generally described below and are summarized in Table 12-1.

Alternative 1, shown in Figure 6-6, was developed to maximize the amount of gravity sewers while minimizing the number of conventional pump stations and low pressure

sewers/grinder pumps within the AOC. Alternative 1 consists of a combination of gravity and low pressure sewers.

Alternative 2, shown in Figure 6-15, consists of a combination of gravity and low pressure sewers, similar to Alternative 1. This alternative was developed to reduce the deep excavation that would be required under Alternative 1 on Huckins Neck Road (Sub-Area 7), Phinney's Lane (Sub-Area 3), and Pine Street (Sub-Area 2). Excavation depths exceeding 20 feet would be required in these areas under Alternative 1. With the changes provided by Alternative 2, the excavation depths have been limited to no more that 20 feet. In order to reduce excavation depths, additional pump stations have been proposed on Huckins Neck Road and Phinney's Lane and additional low pressure sewers have been proposed for collector sewers tributary to Phinney's Lane and Pine Street.

Alternative 3, shown in Figure 6-20, was developed to further reduce excavation depths in the northern portion of Lake Wequaquet from that shown for Alternatives 1 and 2 by installing low pressure sewers throughout this area. The southern portion of Lake Wequaquet and the Long Pond area would be served by a combination of gravity and low pressure sewers, similar to Alternative 1.

Alternative 4, shown in Figure 6-22, is similar to Alternative 3 except that Sub-Areas 6 and 7 would be served by vacuum sewers rather than low pressure sewers. These two sub-areas were determined to be the most appropriate for the installation of vacuum sewers because they are relatively flat and there are no large grade changes, which can present problems for vacuum sewers due to vacuum lift limitations.

Table 12-1

Alternatives Summary

Alternative	Total Sewer Length (ft)	Total Gravity Sewer Length (ft)	No. of Pump/Vacuum Stations	No. of Grinder Pumps	No. of Air Valve Pits
1	125,500	68,300	8 PSs	361	---
2	129,500	61,100	11 PSs	401	---
3	120,100	36,300	5 PSs	598	---
4	125,300	36,300	4PSs/2VSs	287	311

Five connection points to the existing sewerage system were considered during this evaluation:

1. Old Strawberry Hill Road sewer
2. Route 28 sewer

3. West Main Street sewer
4. Route 132 sewer
5. Freezer Road pump station force main on Route 132

The freezer Road pump station force main connection has been recommended to serve the areas around Lake Wequaquet while the West Main Street sewer connection has been recommended to serve the areas around Long Pond. Note that in order for the West Main Street sewer connection to serve the project area, improvements to the Main Street pump station and the existing sewer system in this area will be required, at an estimated cost of approximately $512,000. This cost is included in the construction costs presented in Table 12-2 for each alternative.

A detailed cost evaluation was performed, including a comparison of construction costs, operation and maintenance costs, and 50-year life cycle costs for the four alternatives. These costs are presented in Table 12-2.

Table 12-2
Alternative Costs and Non-Monetary Rank

Alternative	Construction Costs [1]	Annual O&M Costs [2]	Life Cycle Costs [3]	Non-Monetary Rank [4]
Grinder Pumps Purchased and Maintained by Town				
1	$21,445,000	$182,500	$26,654,000	3.4
2	$21,088,000	$205,200	$27,146,000	2.8
3	$17,797,000	$281,000	$26,346,000	3.6
4	$20,513,000	$235,000	$27,370,000	3.2
Grinder Pumps Purchased and Maintained by Residents				
1A	$18,737,000	$128,000	$21,371,000	3.4
2A	$18,080,000	$138,000	$21,118,000	2.8
3A	$13,312,000	$160,100	$16,858,000	3.6
4A	$18,360,000	$135,200	$22,813,000	3.2

Notes:

(1) Includes the cost of materials, installation, testing, and the Contractor's overhead and profit. In addition, a 20% contingency has been added to the cost of new infrastructure and the cost to upgrade the existing sewerage system. Refer to Table 9-1 for the development of these costs.

(2) Includes labor costs, electricity costs, chemical costs, general O&M costs, and sewer maintenance costs. Refer to Table 9-3 for the development of these costs.

(3) Includes construction costs, equipment replacement costs, and O&M costs. Refer to Table 9-4 for the development of these costs.

(4) Environmental impacts, neighborhood impacts, reliability, and expandability were considered.

In addition, non-monetary criteria were considered, including environmental impacts (water quality, wetlands, rare species and wildlife, and historic and archaeological resources), neighborhood impacts (aesthetics, traffic, noise, air quality, and land acquisition), reliability, and expandability. The alternatives were ranked from 1 to 5 for each of the non-monetary criteria, with 1 being the least favorable and 5 being the most favorable, and then an average non-monetary rank was calculated. The average non-monetary ranks for the four alternatives are also presented in Table 12-2.

12.2 RECOMMENDATIONS

Alternative 3 (or 3A if the grinder pumps are purchased and maintained by the residents) is recommended. This alternative provides the lowest construction cost and lowest 50-year life cycle cost. In addition, this alternative is the highest ranked in the non-monetary category because it is expected to have the least significant impact on the environment and on the neighborhoods surrounding Lake Wequaquet and Long Pond. However, due to the greater quantity of grinder pumps and associated low pressure sewers, Alternative 3/3A was rated lower in reliability and expandability (outside the AOC) than other alternatives. Reliability concerns were related primarily to the impact on sewer service in the unlikely event of a prolonged power outage. These apparent disadvantages can be mitigated through proper staffing, stocking of spare parts, and the use of portable generators. Expansion outside of the AOC, if and when required, can be achieved with additional infrastructure.

A larger version of the Alternative 3 layout (Figure 6-20) is included in Appendix D.

We recommend that the Town take the following actions in order to proceed with implementation of the proposed sewer extension project:

1. Authorize final design of the project to proceed in order to meet the schedule established for the project to complete design by the summer of 2004.

2. Establish a phased construction approach to the project.

3. Prepare a State Revolving Fund (SRF) Project Evaluation Form (PEF) in order to be placed on the State's priority list for loan funding.

1. Aerospace Systems, Inc., *Massachusetts State Project DCP 98/2 HD1 Task 02, Final Study of Sewage Treatment/Disposal at Cape Cod Community College, 2240 Iyanough Road, West Barnstable, MA 02668*, July 23, 1999.

2. Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, *Recommended Standards for Wastewater Facilities*, 1997 Edition.

3. New England Interstate Water Pollution Control Commission, *Guides for the Design of Wastewater Treatment Works, Technical Report #16*, 1998 Edition.

4. Stearns & Wheler, *Wastewater Facilities Plan Phase I, Needs Assessment Report, Town of Barnstable, MA*, December 1993.

5. Stearns & Wheler, *Wastewater Facilities Plan Phase II Interim Report, Town of Barnstable*, December 15, 1994 (draft).

6. Stearns & Wheler, *Wastewater Facilities Plan, Town of Barnstable, Draft Phase III Sections*, June 21, 1996.

Bid References		
Community	**Project Name**	**Bid Information**
Agawam, MA	Campbell Drive Pump Station	• Submersible pump station
Agawam, MA	Combined Sewer Overflow Elimination Project	• Gravity sewers
Barnstable, MA	Bearses Way and Route 28 Vacuum Sewer	• Vacuum sewers
Hinsdale, MA	Sanitary Sewer System Improvements, Ashmere Lake Area	• Low pressure sewers • Submersible pump stations
Hinsdale, MA	Sanitary Sewer System Improvements, Plunkett Reservoir Area	• Low pressure sewers • Submersible pump stations
Hull, MA	Straits Pond Sewer Extension	• Gravity sewers • Low pressure sewers
Hull, MA	Rockaway and Rockaway Annex Sewer Project	• Low pressure sewers
Hull, MA	Penberton Area and Rockland House Road Sewer Improvements	• Gravity sewers
Leicester, MA	Hillcrest Sewer District	• Gravity sewers • Low pressure sewers
Mattapoisett, MA	Mattapoisett River Basin Protection Project	• Gravity sewers • Suction lift pump station
Mattapoisett, MA	Buzzards Bay Water Preservation Project	• Gravity sewers • Wetwell/drywell pump station
Mattapoisett, MA	Ned's Point Sewer Extension Project	• Gravity sewers • Low pressure sewers • Submersible pump station
Provincetown		• Vacuum sewers
Raynham, MA	Phase IV Sewer System Expansion	• Gravity sewers • Suction lift pump stations
Raynham, MA	Phase V Sewer System Expansion	• Gravity sewers • Suction lift pump stations
Russell, MA	Blandford Stage Road Sewer Replacement Project	• Gravity sewers

Bid References		
Community	**Project Name**	**Bid Information**
Sturbridge, MA	Cedar Lake Sewers	• Low pressure sewers
Sturbridge, MA	Phase III Sewer Extension Project	• Gravity sewers • Low pressure sewers • Submersible pump stations
Sturbridge, MA	Big Alum Sewer Project	• Gravity sewers • Low pressure sewers

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Appendix A

Questionnaire Survey

Town of Barnstable
Department of Public Works
Engineering Division
367 Main Street, Hyannis MA 02601

Office: 508-862-4088
Fax: 508-862-4711

Thomas J. Mullen, Director
Robert A. Burgmann, P.E.
Town Engineer

November 18, 2002

RESIDENT
Lake Wequaquet and Long Pond Area
Town of Barnstable

Re: Sewer Service Layout Questionnaire

Dear Resident:

The Town of Barnstable is currently conducting preliminary engineering studies to provide new sewers in the Lake Wequaquet and Long Pond areas to serve your property. The proposed sewers will be able to serve toilets, sinks and other plumbing fixtures above the street level and may be able to serve basement fixtures at some locations.

Please provide information on your existing septic system and sewer pipe. This information will assist us in providing sewer service to your house and will help us minimize sewer costs and construction impacts.

Your input is important. The information you provide will help us to design sewer service to meet your needs. As such, we request that you fill out the attached questionnaire as completely as possible and return it to:

David Popielarczyk, P.E., Tighe & Bond, Inc., 53 Southampton Road, Westfield, MA 01085

Please complete and return this questionnaire by December 1, 2002, so that we can incorporate your responses into the preliminary engineering report. A self addressed, stamped envelop is included, for your convenience. For more information on this project, visit our website at htt://projects.tighebond.com or call David Popielarczyk at (508) 563-5643.

Very truly yours,

Robert A. Burgmann, P.E.
Town Engineer

Enclosure

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TOWN OF BARNSTABLE
SEWER SERVICE LAYOUT QUESTIONNAIRE

NAME _____ ADDRESS _____

1. Please indicate on the attached drawing of your property the location of your current sewer discharge pipe, septic tank, and leachfield.

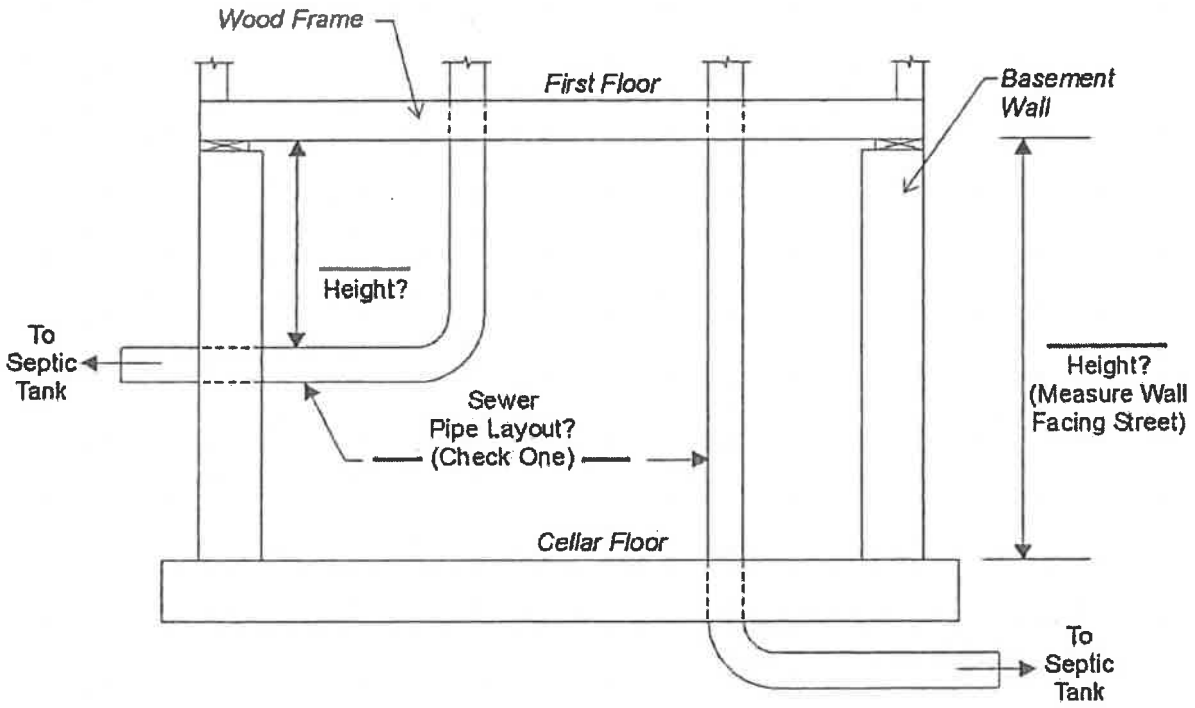
2. Type of home: Cape/Standard _____ Ranch _____ Raised Ranch _____

3. Full Cellar _____ Finished Cellar _____ Crawl Space _____ No Cellar _____

4. Please indicate any plumbing facilities you have in your basement:
   Sink _____ Toilet _____ Bath/Shower _____ Other _____ None _____

5. How does your sewer pipe exit your basement? Through the Wall ____ or Through the Floor ____

6. Please provide the measurements/dimensions requested below:



7. Comments _____

PLEASE COMPLETE AND RETURN THIS FORM TODAY SO THAT WE MAY BETTER SERVE YOU!

Appendix B

House Counts and Wastewater Flows

Table B-1

Summary of Current Wastewater Flows to Proposed Sewers

Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension

Sub-Area	Gravity Pipe Length (lf) [1]	Infiltration (gpd) [2]	No. of Residential Buildings			Avg. Daily Residential Sanitary Flow (gpd) [3]			No. of Commercial Buildings			Avg. Daily Commercial Sanitary Flow (gpd) [4]			Total Avg. Wastewater Flow (gpd) [5]			Peak Wastewater Flow (gpd) [6]		
			AOC	Outside of AOC but Adjacent to Proposed Sewer	Total	AOC	Outside of AOC but Adjacent to Proposed Sewer	Total	AOC	Outside of AOC but Adjacent to Proposed Sewer	Total	AOC	Outside of AOC but Adjacent to Proposed Sewer	Total	AOC	Outside of AOC but Adjacent to Proposed Sewer	Total	AOC	Outside of AOC but Adjacent to Proposed Sewer	Total
1	6,800	3,600	74	23	97	13,900	4,100	18,000	1	0	1	700	0	700	18,200	4,100	22,300	62,000	16,400	78,400
2	7,300	3,900	44	39	83	7,900	7,000	14,900	0	0	0	0	0	0	11,800	7,000	18,800	35,500	28,000	63,500
3	10,900	5,800	85	41	126	15,300	7,400	22,700	0	0	0	0	0	0	21,100	7,400	28,500	67,000	29,600	96,600
4	7,500	4,000	116	32	148	20,900	5,800	26,700	1	0	1	200	0	200	25,100	5,800	30,900	88,400	23,200	111,600
5	5,200	2,800	46	46	92	8,300	8,300	16,600	0	0	0	0	0	0	11,100	8,300	19,400	36,000	33,200	69,200
6	5,100	3,200	67	3	70	12,100	500	12,600	0	0	0	0	0	0	15,300	500	15,800	51,600	2,000	53,600
7	16,900	9,000	244	22	266	44,200	4,000	48,200	0	0	0	0	0	0	53,200	4,000	57,200	185,800	16,000	201,800
8	3,800	2,000	157	13	170	28,300	2,300	30,600	8	4	12	19,900	19,200	39,100	50,200	21,500	71,700	194,800	86,000	280,800
9	3,800	2,000	19	78	97	3,400	14,000	17,400	0	4	4	0	1,000	1,000	5,400	15,000	20,400	15,600	60,000	75,600
Total	68,300	36,300	852	297	1,149	154,300	53,400	207,700	10	8	18	20,800	20,200	41,000	211,400	73,600	285,000	736,700	294,400	1,031,100

Notes:

(1) Based on the gravity sewer lengths for Sewer Layout Alternative 1, presented in Section 6.

(2) Calculated as pipe length (in miles) x pipe diameter (in inches) x 350 gpd/in.

(3) Calculated as 2.5 people/house x 72 gpd/person x the number of houses. Both Sub-areas 1 and 7 include a bed & breakfast, which were treated as multi-family homes.

(4) Avg. daily flow calculated as 90% of water usage data and then adjusted to max. month flow based on the peaking factors included in the 1993 Facilities Planning report.

(5) Calculated as the sum of the avg. daily residential sanitary flow rate, the avg. daily commercial sanitary flow rate and the infiltration rate (max. month values).

(6) Calculated as 4 times the average daily sanitary flow plus infiltration.

Table B-2
Summary of Projected Future Wastewater Flows at Full Build-Out (AOC and Bowl)
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension

Sub-Area	Gravity Pipe Length (lf) [1]	Infiltration (gpd) [2]	No. of Residential Buildings				Avg. Daily Residential Sanitary Flow (gpd) [3]			No. of Commercial Buildings			Avg. Daily Commercial Sanitary Flow (gpd) [4]			Total Avg. Wastewater Flow (gpd) [5]			Peak Wastewater Flow (gpd) [6]		
			Current	Future AOC	Future Bowl	Total	Current	Future	Total	Current	Future	Total	Current	Future	Total	Current	Future	Total	Current	Future	Total
1	11,200	5,900	97	5	45	147	18,000	9,000	27,000	1	13	14	700	13,700	14,400	22,300	25,000	47,300	78,400	93,100	171,500
2	9,500	5,000	83	10	14	107	14,900	4,300	19,200	0	0	0	0	0	0	18,800	5,400	24,200	63,500	18,300	81,800
3	16,300	8,600	126	9	81	216	22,700	16,200	38,900	0	0	0	0	0	0	28,500	19,000	47,500	96,600	67,600	164,200
4	14,500	7,700	148	41	137	326	26,700	32,000	58,700	1	0	1	200	0	200	30,900	35,700	66,600	111,600	131,700	243,300
5	18,500	9,800	92	29	190	311	16,600	39,400	56,000	0	0	0	0	0	0	19,400	46,400	65,800	69,200	164,600	233,800
6	10,000	5,300	70	34	60	164	12,600	16,900	29,500	0	1	1	0	4,500	4,500	15,800	23,500	39,300	53,600	87,700	141,300
7	18,900	10,000	266	20	41	327	48,200	11,000	59,200	0	0	0	0	0	0	57,200	12,000	69,200	201,800	45,000	246,800
8	4,400	2,300	170	17	45	232	30,600	11,200	41,800	12	0	12	39,100	0	39,100	71,700	11,500	83,200	280,800	45,100	325,900
9	11,100	5,900	97	1	58	156	17,400	10,600	28,000	4	5	9	1,000	2,600	3,600	20,400	17,100	37,500	75,600	56,700	132,300
Total	114,400	60,500	1,149	166	671	1,986	207,700	150,600	358,300	18	19	37	41,000	20,800	61,800	285,000	195,600	480,600	1,031,100	709,800	1,740,900

Notes:

(1) Based on the gravity sewer lengths projected for full-build-out and Sewer Layout Alternative 1, presented in Section 6.

(2) Calculated as pipe length (in miles) x pipe diameter (in inches) x 350 gpd/in.

(3) Calculated as 2.5 people/house x 72 gpd/person x the number of houses. Both Sub-areas 1 and 7 include a bed & breakfast, which were treated as multi-family homes.

(4) Avg. daily flow calculated as 90% of water usage data and then adjusted to max. month flow based on the peaking factors included in the 1993 Facilities Planning report. No future commercial facilities were projected.

(5) Calculated as the sum of the avg. daily residential sanitary flow rate, the avg. daily commercial sanitary flow rate and the infiltration rate (max. month values).

(6) Calculated as 4 times the average daily sanitary flow plus infiltration.

Appendix C

Cost Estimates

Alternative 1

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
1	Harrison Rd.	1.5	325	LP	$40		$13,000
		2	325	LP	$40		$13,000
		2.5	270	LP	$45		$12,150
	Cottage Lane	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	200	LP	$45		$9,000
	Route 28 (Harrison to Phinney's)	8	1,900	< 10	$90		$171,000
	Route 28 (W. Main St. to Harrison)	8	140	< 10	$90		$12,600
	Sachem Drive	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	830	LP	$45		$37,350
		3	230	LP	$45		$10,350
	Phinney's Lane (Rt. 28 to PS)	8	1,380	< 10	$90		$124,200
	Piney Point Drive	1.5	295	LP	$40		$11,800
		2	295	LP	$40		$11,800
		2.5	420	LP	$45		$18,900
	Pine Street (High Point to Long Pond Cir.)	8	850	< 10	$90		$76,500
		8	520	10 - < 15	$100		$52,000
		8	20	15-<20	$115		$2,300
	Long Pond Circle	8	770	< 10	$90		$69,300
		8	410	10 - < 15	$100		$41,000
		8	80	15 - < 20	$115		$9,200
	Pine Street (Long Pond Circle to PS)	8	290	< 10	$90		$26,100
		8	120	15 - < 20	$115		$13,800
		8	280	20 - 25	$140		$39,200
	Gravity sewer manholes				$2,000	26	$52,960
	Grinder pumps				$7,500	45	$337,500
	Air release/cleanout manholes				$5,000	9	$45,000
	Force main	4	3,400		$50		$170,000
	cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pumping Station (119 gpm)						$260,000
Subtotal			**14,400**				**$1,832,010**
2	Dunaskin Rd.	8	520	< 10	$90		$46,800
		1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	350	LP	$45		$15,750
	Pine Street (High Point to Blantyre Ave.)	8	500	< 10	$90		$45,000
	Blantyre Avenue	8	260	< 10	$90		$23,400
		8	200	10 - < 15	$100		$20,000
		8	410	15 - < 20	$115		$47,150
		8	180	20 - 25	$140		$25,200
	Argyle Ave.	8	320	<10	$90		$28,800

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Pine Street (Blantyre Ave. to PS) from west	8	380	15 - < 20	$115		$43,700
	Horatio Lane	8	410	< 10	$90		$36,900
		8	80	10 - < 15	$100		$8,000
		1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	250	LP	$45		$11,250
	Pine Street (Horatio to Herring Run Dr.)	8	300	10 - < 15	$100		$30,000
		8	150	15 - < 20	$115		$17,250
	Herring Run Drive	1.5	445	LP	$40		$17,800
		2	445	LP	$40		$17,800
		2.5	450	LP	$45		$20,250
	Pine Street (Herring Run to Pondview Dr.)	8	70	< 10	$90		$6,300
		8	520	10 - < 15	$100		$52,000
	Pondview Drive	8	1,070	< 10	$90		$96,300
		8	700	10 - < 15	$100		$70,000
		8	190	15 - < 20	$115		$21,850
	Holly Lane	8	30	< 10	$90		$2,700
		8	580	10 - < 15	$100		$58,000
		8	310	15 - < 20	$115		$35,650
	Pine Street (Pondview to PS)	8	90	10 - < 15	$100		$9,000
		8	70	15 - < 20	$115		$8,050
	Gravity sewer manholes				$2,000	29	$58,720
	Grinder pumps				$7,500	14	$105,000
	Air release/cleanout manholes				$5,000	4	$20,000
	Force main	4	2,600		$50		$130,000
	cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pump Station (57 gpm)						$250,000
Subtotal			**12,360**				**$1,567,820**
3	Center Lane	8	120	< 10	$90		$10,800
		1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	300	LP	$45		$13,500
	Connors Road	8	1,180	< 10	$90		$106,200
		8	710	10 - < 15	$100		$71,000
		8	380	15 - < 20	$115		$43,700
		8	230	20 - 25	$140		$32,200
	Phinney's Lane (Conners to PS)	8	330	< 10	$90		$29,700
		8	140	10 - < 15	$100		$14,000
		8	200	15 - < 20	$115		$23,000
		8	50	20 - 25	$140		$7,000
	Phinney's Lane (PS to Old Farm Rd.)	8	80	15 - < 20	$115		$9,200
	Phinney's Lane (Old Farm Rd. to Loomis)	8	610	15 - < 20	$115		$70,150

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		8	260	20 - 25	$140		$36,400
	Phinney's Lane (Loomis to Strawberry)	8	250	20 - 25	$140		$35,000
	Loomis Lane	8	260	< 10	$90		$23,400
		8	360	10 - < 15	$100		$36,000
		8	360	15 - < 20	$115		$41,400
		8	250	20 - 25	$140		$35,000
	Richards Lane	8	290	< 10	$90		$26,100
		8	70	10 - < 15	$100		$7,000
		8	230	15 - < 20	$115		$26,450
	Old Farm Road	8	460	< 10	$90		$41,400
		8	260	10 - < 15	$100		$26,000
		8	130	15 - < 20	$115		$14,950
		8	270	20 - 25	$140		$37,800
	Crosby Road	8	360	< 10	$90		$32,400
	Tellegen Trail	8	740	< 10	$90		$66,600
		8	40	10 - < 15	$100		$4,000
	Sail-a-way	8	480	< 10	$90		$43,200
	Phinney's Lane (Strawberry to Tellegen)	8	230	10 - < 15	$100		$23,000
		8	370	15 - < 20	$115		$42,550
		8	340	20 - 25	$140		$47,600
	Phinney's Lane (Tellegen to Crosby)	8	780	< 10	$90		$70,200
		8	40	10 - < 15	$100		$4,000
	Gravity sewer manholes				$2,000	43	$86,880
	Grinder pumps				$7,500	4	$30,000
	Air release/cleanout manholes				$5,000	1	$5,000
	Force main	6	6,500		$60		$390,000
	Odor control feed equipment						$60,000
	cofferdam for pump station						$80,000
	Land acquisition						$100,000
	Pumping Station (283 gpm)						$290,000
Subtotal			**18,010**				**$2,206,780**
4	Yatch Club Road	1.5	135	LP	$40		$5,400
		2	135	LP	$40		$5,400
	Indian Trail	1.5	80	LP	$40		$3,200
		2	80	LP	$40		$3,200
		2.5	120	LP	$45		$5,400
	Old Way	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
	Red Wing Trail	1.5	75	LP	$40		$3,000
		2	75	LP	$40		$3,000
		2.5	120	LP	$45		$5,400
	Johny Cake Road	1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	170	LP	$45		$7,650
	Annable Point Road	1.5	225	LP	$40		$9,000

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2	225	LP	$40		$9,000
		2.5	260	LP	$45		$11,700
		3	1,060	LP	$45		$47,700
	Willow Run (End of AOC to Thread Needle)	8	210	< 10	$90		$18,900
	Willow Run (end to Thread Needle)	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	370	LP	$45		$16,650
		3	250	LP	$45		$11,250
	Thread Needle Lane	8	560	< 10	$90		$50,400
		8	390	10 - < 15	$100		$39,000
	Great Marsh Road (Thread Needle to Hayes Road)	8	1,160	10 - < 15	$100		$116,000
	Hayes Road	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	450	LP	$45		$20,250
		3	560	LP	$45		$25,200
	Great Marsh / Juniper (Hayes to Laurel)	8	180	10 - < 15	$100		$18,000
		8	910	15 - < 20	$115		$104,650
	Laurel Road	8	240	<10	$90		$21,600
		8	440	10-<15	$100		$44,000
	Juniper Road (Laurel to Lake Dr.)	8	320	10 - < 15	$100		$32,000
	Point of Pines Ave.	8	770	< 10	$90		$69,300
		8	380	10 - < 15	$100		$38,000
	Juniper (Point of Pines to Lake Dr.)	8	180	< 10	$90		$16,200
		8	140	10 - < 15	$100		$14,000
	Lake Drive (Juniper to PS)	8	310	10 - < 15	$100		$31,000
	Brezner Lane (Northern part)	8	240	< 10	$90		$21,600
	Pond Street	8	450	< 10	$90		$40,500
			60	10 - < 15	$100		$6,000
	Lake Drive (Pond St. to PS)	8	350	10 - < 15	$100		$35,000
	Lake Drive (end to Pond St.)	8	140	< 10	$90		$12,600
		8	30	10 - < 15	$100		$3,000
	Gravity sewer manholes				$2,000	30	$59,680
	Grinder pumps				$7,500	55	$412,500
	Force main	4	850		$50		$42,500
	Air release/cleanout manholes				$5,000	11	$55,000
	cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pumping Station (169 gpm)						$270,000
Subtotal			**13,930**				**$1,983,030**
5	Lakewood Drive	8	200	< 10	$90		$18,000
		8	300	10 - < 15	$100		$30,000
		1.5	105	LP	$40		$4,200
		2	105	LP	$40		$4,200

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2.5	420	LP	$45		$18,900
	Shootflying Hill Road (Lakewood to Tern Lane)	8	200	< 10	$90		$18,000
		8	280	10 - < 15	$100		$28,000
		8	800	15 - < 20	$115		$92,000
	Tern Lane	1.5	340	LP	$40		$13,600
		2	340	LP	$40		$13,600
		2.5	290	LP	$45		$13,050
		3	1,080	LP	$45		$48,600
	Shootflying Hill Road (Tern Ln. to Johnson Ln.)	8	800	< 10	$90		$72,000
		8	260	10 - < 15	$100		$26,000
	Johnson Lane	1.5	110	LP	$40		$4,400
		2	110	LP	$40		$4,400
		2.5	260	LP	$45		$11,700
	Shootflying Hill Road (Johnson Ln. to PS)	8	860	< 10	$90		$77,400
		8	730	10 - < 15	$100		$73,000
	Shootflying Hill Road (End of line back to PS)	8	740	< 10	$90		$66,600
	Gravity sewer manholes				$2,000	21	$41,360
	Grinder pumps				$7,500	35	$262,500
	Force main	4	700		$50		$35,000
	Air release/cleanout manholes				$5,000	7	$35,000
	cofferdam for pump station						$60,000
	Land acquisition						$100,000
	Pump Station (162 gpm)						$270,000
Subtotal			**9,030**				**$1,441,510**
6	Shootflying Hill Road (F.M. to Lakeview Drive)	8	100	< 10	$90		$9,000
	Lakeview Avenue	8	560	< 10	$90		$50,400
		8	1,190	10 - < 15	$100		$119,000
		8	50	15 - < 20	$115		$5,750
	Pleasant Pines (Shootflying to Lakeview)	8	700	< 10	$90		$63,000
	Pleasnt Pines (Lakeview to Nyes Neck)	8	510	< 10	$90		$45,900
		8	360	10 - < 15	$100		$36,000
	Nyes Neck Rd. (East)	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	950	LP	$45		$42,750
	Nyes Neck Rd. (West)	1.5	435	LP	$40		$17,400
		2	435	LP	$40		$17,400
		2.5	1,090	LP	$45		$49,050
	Nyes Neck (where east & west combine to Nyes Point Way)	3	640	LP	$45		$28,800
	Nyes Point Way	1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2.5	330	LP	$45		$14,850
	Nyes Neck (Nyes Point Way to Shirley Point Rd.)	8	250	< 10	$90		$22,500
		8	200	10 - < 15	$100		$20,000
	Shirley Point Road	8	230	< 10	$90		$20,700
		8	380	10 - < 15	$100		$38,000
	Nyes Neck (Shirley Point to Pleasant Pines)	8	400	< 10	$90		$36,000
		8	200	10 - < 15	$100		$20,000
	Pleasant Pines (Nyes Neck to PS) from west	8	570	< 10	$90		$51,300
	Pleasant Pines (Flow to PS) from east	8	300	< 10	$90		$27,000
		8	110	10 - < 15	$100		$11,000
	Gravity sewer manholes				$2,000	24	$48,880
	Grinder pumps				$7,500	32	$240,000
	Air release/cleanout manholes				$5,000	6	$30,000
	Force main	6	1,400		$60		$84,000
	Force main	8	1,250		$80		$100,000
	cofferdam for pump station						$60,000
	Land acquisition						$100,000
	Pumping Station (260 gpm)						$290,000
Subtotal			**13,790**				**$1,744,680**
7	Pleasant Pines (High Point to Bunny Run)	8	720	< 10	$90		$64,800
	Chickadee Lane	8	400	< 10	$90		$36,000
	Bunny Run (End to Chickadee)	8	530	< 10	$90		$47,700
	Bunny Run (Chickadee to Point of Pines)	8	260	< 10	$90		$23,400
	Pleasant Pines (Bunny Run to Huckins Neck)	8	180	< 10	$90		$16,200
	Shallow Pond	8	1,100	< 10	$90		$99,000
		8	250	10 - < 15	$100		$25,000
		1.5	280	LP	$40		$11,200
	Huckins Neck (Shallow Pond to Water View Circle)	8	210	< 10	$90		$18,900
		8	230	10 - < 15	$100		$23,000
		8	70	15 - < 20	$115		$8,050
	Water View Circle	8	720	< 10	$90		$64,800
		8	220	10 - < 15	$100		$22,000
	Blue Water Drive	8	520	< 10	$90		$46,800
		1.5	350	LP	$40		$14,000
		2	350	LP	$40		$14,000
	Pondside Circle	8	560	< 10	$90		$50,400
			430	10 - < 15	$100		$43,000
	Huckins Neck Road (Water View to Holly Point)	8	430	< 10	$90		$38,700

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		8	590	10 - < 15	$100		$59,000
		8	1,160	15 - < 20	$115		$133,400
	Holly Point Road	8	790	< 10	$90		$71,100
		8	610	10 - < 15	$100		$61,000
		8	210	15 - < 20	$115		$24,150
	Huckins Neck Road (Holly Point to PS)	8	190	10 - < 15	$100		$19,000
		8	140	15 - < 20	$115		$16,100
		8	150	20-25	$140		$21,000
	Sheeting & dewatering deep sewer sections	15-20 ft deep	L=	1,970	$500		$985,000
		20-25 ft deep	L=	650	$600		$390,000
	Beachwood - South of Huckins Neck (High Point to Huckins Neck)	8	330	< 10	$90		$29,700
		8	370	10 - < 15	$100		$37,000
	Huckins Neck (Conners to Beechwood)	8	580	< 10	$90		$52,200
	Beechwood - North of Huckins Neck	8	210	< 10	$90		$18,900
		8	140	10 - < 15	$100		$14,000
	Huckins Neck (Beachwood to Cottonwood)	8	90	< 10	$90		$8,100
		8	290	10 - < 15	$100		$29,000
		8	290	15 - < 20	$115		$33,350
	Cottonwood	8	550	< 10	$90		$49,500
		8	300	10 - < 15	$100		$30,000
	Huckins Neck (Cottonwood to Lakeside Drive East)	8	200	< 10	$90		$18,000
		8	170	10 - < 15	$100		$17,000
		8	30	15 - < 20	$115		$3,450
	Lakeside Drive West	1.5	465	LP	$40		$18,600
		2	465	LP	$40		$18,600
		2.5	1,140	LP	$45		$51,300
		3	430	LP	$45		$19,350
	Vine Street	1.5	65	LP	$40		$2,600
		2	65	LP	$40		$2,600
	Lakeside Drive East	8	600	< 10	$90		$54,000
		8	300	10 - < 15	$100		$30,000
		1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
	Holly Point Road (Vine St. to Lakeside Drive East)	1.5	185	LP	$40		$7,400
		2	185	LP	$40		$7,400
		2.5	800	LP	$45		$36,000
		3	420	LP	$45		$18,900
	Lakeview Avenue	8	230	< 10	$90		$20,700
		8	650	10 - < 15	$100		$65,000

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Huckins Neck (Lakeside Dr. East to P.S.)	8	380	15 - < 20	$115		$43,700
		8	500	20-25	$140		$70,000
	Gravity sewer manholes				$2,000	69	$137,280
	Grinder pumps				$7,500	54	$405,000
	Air release/cleanout manholes				$5,000	7	$35,000
	Force main	4	2,500		$60		$150,000
	cofferdam for pump station						$80,000
	Land acquisition						$100,000
	Pump Station (171 gpm)						$270,000
Subtotal			**25,080**				**$4,450,330**
8	Goose Point Road	1.5	220	LP	$40		$8,800
		2	220	LP	$40		$8,800
	Crestview Circle	2.5	890	LP	$45		$40,050
	Regatta Drive (Phinney's La. To Crestview Cir.)	1.5	180	LP	$40		$7,200
		2	180	LP	$40		$7,200
		2.5	500	LP	$45		$22,500
	Dacey Lane	1.5	120	LP	$40		$4,800
		2	120	LP	$40		$4,800
	Regatta Drive (Crestview Cir. To Old Strawberry Hill Rd.)	3	530	LP	$45		$23,850
	Old Strawberry Hill Road (Regatta Dr. to Rte. 132)	8	1,050	< 10	$90		$94,500
		8	500	10 - < 15	$100		$50,000
		8	340	15 - < 20	$115		$39,100
	Route 132 (Old Strawberry Hill Rd. to PS)	8	160	< 10	$90		$14,400
	Route 132 (Old Route 132 to PS)	8	1,800	< 10	$90		$162,000
	Gravity sewer manholes				$2,000	15	$30,800
	Grinder pumps				$7,500	34	$255,000
	Air release/cleanout manholes				$5,000	6	$30,000
	Force main	4	100		$50		$5,000
	cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pump Station (226 gpm)						$280,000
Subtotal			**6,910**				**$1,238,800**
9	Scottsdale Circle	1.5	145	LP	$40		$5,800
		2	145	LP	$40		$5,800
		2.5	180	LP	$45		$8,100
	Route 28 (FM to Kenesaw)	8	1,640	< 10	$90		$147,600
	Childs Street (FM to Kenesaw/ Rt. 28)	8	620	< 10	$90		$55,800
		8	180	10 - < 15	$100		$18,000
	Route 28 (Kenesaw to Existing Pipe)	8	330	< 10	$90		$29,700
		8	280	10 - < 15	$100		$28,000

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1 - Gravity & LP Sewers - Eight Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		8	770	15 - < 20	$115		$88,550
	Gravity sewer manholes				$2,000	15	$30,560
	Grinder pumps				$7,500	4	$30,000
	Air release/cleanout manholes				$5,000	1	$5,000
Subtotal			**4,290**				**$452,910**
Incremental Cost to increase CCCC force main from 4 inch diameter							
	Huckins Neck Rd. to Phinney's Lane	10	5,300		$40		$212,000
	Phinney's Lane to existing 12" FM	12	1,000		$50		$50,000
Subtotal			**6,300**				**$262,000**
Houses adjacent to gravity sewers requiring pumping							
	Grinder pumps				$7,500	84	**$630,000**
Improvements to existing sewerage system							
Replace Main St. Pump Station							$400,000
Divert pumped flow to Old Colony Rd. PS FM		8	1,400		$80		$112,000
Subtotal			**1,400**				**$512,000**
Total			**125,500**				**$18,321,870**

LIFE CYCLE COST ANALYSIS SUMMARY SHEET - ALTERNATIVE 1

Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
Preparer: DJP/DRP
Date: 29-Aug-03

CAPITAL COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.33%
Effective Discount Rate:	3.46%
Terms of Analysis (years)	50
Construction Duration (years):	2
Replacement Cost Period:	

Base Construction Cost:	$21,444,744
Misc. Reserve Prelim. Design	$0
Engineering Cost:	$0
Replacement Capital Cost:	$1,545,488
Total Capital Cost:	$22,990,232
Total NPV- Capital Cost:	$22,274,286

OPERATING COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.42%
Effective Discount Rate:	3.37%
Terms of Analysis:	50
Labor Cost/year:	$50,000
Total Labor Cost:	$2,500,000
Total O& M Cost/year:	$182,473
Total O & M Cost:	$9,123,630
Total NPV - O & M Costs:	$4,379,538

	Total Cost	NPV
Capital Costs	$22,990,232	$22,274,286
O & M Costs	$9,123,630	$4,379,538
TOTAL:	$32,113,862	$26,653,824

Notes/Assumptions:

ECONOMIC ASSUMPTIONS - ALTERNATIVE 1

CAPITAL COSTS:	
*Discount rate:	5.875%
Inflation rate:	2.33%
**Effective Discount rate:	3.46%

OPERATIONS & MAINTENANCE:	
*Discount rate:	5.875%
Inflation rate:	2.42%
**Effective Discount rate:	3.37%

*** Term of analysis:	50 years

Average Salary:	$50,000

NOTE:

* The discount rate reflects the long-term cost of capital.

** The effective discount rate anticipates the effect of the time value of money and inflation by removing inflation from the discount rate.

*** The analysis period for the project is 50 years.

PROJECT INFORMATION

1) Preparer: DJP/DRP
2) Name of Capital Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
3) List Assumptions Below:

Input cells are highlighed in light yellow.

CAPITAL COSTS WORKSHEET - ALTERNATIVE 1

1) **Enter First Year of Capital Spending:** 2004

2) **Using table below, enter project Design Status.** Prelim. Design

Design Status	Miscellaneous Reserve
Prelim. Design	Add 20%
50-75% Design	Add 15%
90-95% Design	Add 10%
100% Design	Add 10%

CAPITAL COST

		Capital Cost Line Item	Useful Life *See menu below*	Base Construction Costs	Construction Schedule START	Construction Schedule END	IS REPLACMENT COST NEEDED? IF YES, THEN INPUT COST IN CELL TO RIGHT	REPLACEMENT COSTS (Input Replacement Costs)	BASE CONSTRUCTION COST: Spread over ___ years	Spread per year	Beginning in Year ____	REPLACEMENT: Replace in Year _____	Replace in Year _____	Replace in Year _____		Replace in Year _____	2004	2005	2006	2007	2008	2009	2010	2011	2012
3)	LINE ITEM 1:	Pipeline and Noe-Mech.	50	$13,985,244	2004	2005	NO REPLACEMENT	0	2	6,992,622	2004	0					6,992,622	6,992,622							
																	0	0	0	0	0	0	0	0	0
4)	LINE ITEM 2:	Pump Stations - Non-Mech.	50	$1,932,000	2004	2005	NO REPLACEMENT	0	2	966,000	2004	0					966,000	966,000							
																	0	0	0	0	0	0	0	0	0
5)	LINE ITEM 3:	Pump Stations - Mech. Equip.	25	$1,308,000	2004	2005	REPLACEMENT >>>>>>	784,800	2	654,000	2004	2029	2053				654,000	654,000							
																	0	0	0	0	0	0	0	0	0
6)	LINE ITEM 4:	Grinder Pumps - Non-Mech.	50	$1,353,750	2004	2005	NO REPLACEMENT	0	2	676,875	2004	0					676,875	676,875							
																	0	0	0	0	0	0	0	0	0
7)	LINE ITEM 5:	Grinder Pumps - Mech. Equip.	10	$1,353,750	2004	2005	REPLACEMENT >>>>>>	717,488	2	676,875	2004	2014	2124	2034	2044	2053	676,875	676,875							
																	0	0	0	0	0	0	0	0	0
8)	LINE ITEM 6:	Replace Main St. PS		480,000	2004	2005	REPLACEMENT >>>>>>		2	240,000	2004	0					240,000	240,000							
																	0	0	0	0	0	0	0	0	0
9)	LINE ITEM 7:	Odor control equipment.	25	72,000	2004	2005	REPLACEMENT >>>>>>	43,200	1	36,000	2004	2029	2053				36,000	36,000							
																	0	0	0	0	0	0	0	0	0
10)	LINE ITEM 8:	Land acquisition	50	960,000	2004	2005	REPLACEMENT >>>>>>		2	480,000	2004	0					480,000	480,000							
																	0	0	0	0	0	0	0	0	0
11)	LINE ITEM 9:						REPLACEMENT >>>>>>		1	0	0	0													
																	0	0	0	0	0	0	0	0	0
12)	LINE ITEM 10:						REPLACEMENT >>>>>>		1	0	0	0													
																	0	0	0	0	0	0	0	0	0
13)	FIXED LINE ITEM	Base Construction Cost		21,444,744													10,722,372	10,722,372	0	0	0	0	0	0	0
14)	FIXED LINE ITEM	Replacement Costs		1,545,488													0	0	0	0	0	0	0	0	0
15)	FIXED LINE ITEM	Miscellaneous Reserve		0													0	0	0	0	0	0	0	0	0
16)	FIXED LINE ITEM	Engineering and CM Costs		0													0	0	0	0	0	0	0	0	0
		TOTAL CAPITAL COST		$22,990,232													$10,722,372	$10,722,372	$0	$0	$0	$0	$0	$0	$0

Expected Useful Life	
Type of Capital Improvement	Expected Useful Life (in years)
Pump station equip.	25
Grinder pump equip.	10
Pipeline	50
Pump station superstructure	50

Replacement Costs: The analysis will include equipment replacement costs required during the period of the analysis.

Salvage value: Zero salvage values assumed in this analysis

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	784,800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	784,800
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	717,488	0	0	0	0	0	0	0	0	0	717,488	0	0	0	0	0	0	0	0	0	717,488	0	0	0	0	0	0	0	0	0	717,488	0	0	0	0	0	0	0	717,488
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,200
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	717,488	0	0	0	0	0	0	0	0	0	717,488	0	0	0	0	828,000	0	0	0	0	717,488	0	0	0	0	0	0	0	0	0	717,488	0	0	0	0	0	0	0	1,545,488
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$717,488	$0	$0	$0	$0	$0	$0	$0	$0	$0	$717,488	$0	$0	$0	$0	$828,000	$0	$0	$0	$0	$717,488	$0	$0	$0	$0	$0	$0	$0	$0	$0	$717,488	$0	$0	$0	$0	$0	$0	$0	$1,545,488

OPERATIONS AND MAINTENANCE COSTS WORKSHEET - ALTERNATIVE 1

	O&M Cost Categories		Period (Calendar Yr.) From	To	Labor - FTE	Average Salary	Labor Cost Dollars per year	Total Labor Cost	A Spread over ..... many years	B Spread per year	C Beginning in Year	2004	2005	2006	2007	2008
1)	LINE ITEM 1	Labor	2004	2053	1	50,000	50,000	2,500,000	50	50,000	2004	50,000	50,000	50,000	50,000	50,000

Enter first year of O&M costs here:
(for each individual line item)

					Cost per year	Number of Years		Total Cost								
2)	LINE ITEM 2	Electricity	2004	2053	5,758	50		287,899	50	5,758	2004	5,758	5,758	5,758	5,758	5,758
3)	LINE ITEM 3	Chemical addition	2004	2053	12,600	50		630,000	50	12,600	2004	12,600	12,600	12,600	12,600	12,600
4)	LINE ITEM 4	General O&M	2004	2053	46,365	50		2,318,231	50	46,365	2004	46,365	46,365	46,365	46,365	46,365
5)	LINE ITEM 5	Generator-Equipped Service Truck	2004	2053	5,000	50		250,000	50	5,000	2004	5,000	5,000	5,000	5,000	5,000
6)	LINE ITEM 6	Sewer maintenance ($0.50/lf)	2004	2053	62,750	50		3,137,500	50	62,750	2004	62,750	62,750	62,750	62,750	62,750
							TOTAL O&M	$9,123,630				$182,473	$182,473	$182,473	$182,473	$182,473

Total Annual O&M $182,473

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000

5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750
$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000

5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750
$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473

MASTER SPREADSHEET - ALTERNATIVE 1

This data is used to calculate the NPV. Do not touch.

Capital Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pipeline and Non-Mech.	$13,290,654	$13,965,244	$6,982,622	$6,982,622																			
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pump Stations - Non-Mech.	$1,836,050	$1,932,000	966,000	966,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump Stations - Mech. Equip.	$1,243,040	$1,308,000	654,000	654,000																			
Replacement	$466,715	$754,800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Non-Mech.	$1,286,518	$1,353,750	676,875	676,875																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Mech. Equip.	$1,286,518	$1,353,750	676,875	676,875																			
Replacement	$1,402,182	$717,488	0	0	0	0	0	0	0	0	0	0	717,488	0	0	0	0	0	0	0	0	0	717,488
Replace Main St. PS	$456,161	$480,000	240,000	240,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor control equipment	$68,424	$72,000	36,000	36,000																			
Replacement	$25,691	$43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land acquisition	$912,323	$960,000	480,000	480,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Reserve	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineering and CM Costs		$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW - CAPITAL			$10,722,372	$10,722,372	$0	$0	$0	$0	$0	$0	$0	$0	$717,488	$0	$0	$0	$0	$0	$0	$0	$0	$0	$717,488
TOTAL CAPITAL COSTS	$22,890,232																						
Net Present Value - Capital	$22,274,286																						

Operating Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Labor	$1,200,054	$2,500,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000
Electricity	$138,198	$287,899	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758
Chemical addition	$302,413	$630,000	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
General O&M	$1,112,801	$2,318,231	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385	46,385
Generator-Equipped Service Truck	$120,005	$250,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Sewer maintenance ($3.50/lf)	$1,509,087	$3,137,500	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750
TOTAL CASH FLOW - O & M			$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473
TOTAL O & M COSTS	$9,123,930																						
Net Present Value - O & M	4,379,539																						

TOTAL NPV →	Capital Costs	$22,274,286
	O & M Costs	$4,379,539
	TOTAL	$26,653,824

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	784,800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	717,488	0	0	0	0	0	0	0	0	0	717,488	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$0	$828,000	$0	$0	$0	$0	$717,488	$0	$0	$0	$0	$0	$0	$0	$0	$0	$717,488	$0	$0	$0	$0	$0	$0	$0

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000
5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758	5,758
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365	46,365
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750
$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473	$182,473

2032	2057
$0	$0
0	0
0	784,800
0	0
0	717,488
0	0
0	43,200
0	0
0	0
0	0
0	0
0	0
30	$1,545,488

ZERO

2032	2033
$50,000	$50,000
5,758	5,758
12,600	12,600
46,365	46,365
5,000	5,000
62,750	62,750
$182,473	$182,473

CHECK

$0
$0
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$0 TOTAL CHECK

Alternative 1A

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1A - Gravity & LP Sewers - Eight Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
1	Harrison Rd.	1.5	325	LP	$40		$13,000
		2	325	LP	$40		$13,000
		2.5	270	LP	$45		$12,150
	Cottage Lane	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	200	LP	$45		$9,000
	Route 28 (Harrison to Phinney's)	8	1,900	< 10	$90		$171,000
	Route 28 (W. Main St. to Harrison)	8	140	< 10	$90		$12,600
	Sachem Drive	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	830	LP	$45		$37,350
		3	230	LP	$45		$10,350
	Phinney's Lane (Rt. 28 to PS)	8	1,380	< 10	$90		$124,200
	Piney Point Drive	1.5	295	LP	$40		$11,800
		2	295	LP	$40		$11,800
		2.5	420	LP	$45		$18,900
	Pine Street (High Point to Long Pond Cir.)	8	850	< 10	$90		$76,500
		8	520	10 - < 15	$100		$52,000
		8	20	15-<20	$115		$2,300
	Long Pond Circle	8	770	< 10	$90		$69,300
		8	410	10 - < 15	$100		$41,000
		8	80	15 - < 20	$115		$9,200
	Pine Street (Long Pond Circle to PS)	8	290	< 10	$90		$26,100
		8	120	15 - < 20	$115		$13,800
		8	280	20 - 25	$140		$39,200
	Gravity sewer manholes				$2,000	26	$52,960
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	9	$45,000
	Force main	4	3,400		$50		$170,000
	cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pumping Station (119 gpm)						$260,000
Subtotal			**14,400**				**$1,494,510**
2	Dunaskin Rd.	8	520	< 10	$90		$46,800
		1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	350	LP	$45		$15,750
	Pine Street (High Point to Blantyre Ave.)	8	500	< 10	$90		$45,000
	Blantyre Avenue	8	260	< 10	$90		$23,400
		8	200	10 - < 15	$100		$20,000
		8	410	15 - < 20	$115		$47,150
		8	180	20 - 25	$140		$25,200
	Argyle Ave.	8	320	<10	$90		$28,800

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1A - Gravity & LP Sewers - Eight Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Pine Street (Blantyre Ave. to PS) from west	8	380	15 - < 20	$115		$43,700
	Horatio Lane	8	410	< 10	$90		$36,900
		8	80	10 - < 15	$100		$8,000
		1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	250	LP	$45		$11,250
	Pine Street (Horatio to Herring Run Dr.)	8	300	10 - < 15	$100		$30,000
		8	150	15 - < 20	$115		$17,250
	Herring Run Drive	1.5	445	LP	$40		$17,800
		2	445	LP	$40		$17,800
		2.5	450	LP	$45		$20,250
	Pine Street (Herring Run to Pondview Dr.)	8	70	< 10	$90		$6,300
		8	520	10 - < 15	$100		$52,000
	Pondview Drive	8	1,070	< 10	$90		$96,300
		8	700	10 - < 15	$100		$70,000
		8	190	15 - < 20	$115		$21,850
	Holly Lane	8	30	< 10	$90		$2,700
		8	580	10 - < 15	$100		$58,000
		8	310	15 - < 20	$115		$35,650
	Pine Street (Pondview to PS)	8	90	10 - < 15	$100		$9,000
		8	70	15 - < 20	$115		$8,050
	Gravity sewer manholes				$2,000	29	$58,720
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	4	$20,000
	Force main	4	2,600		$50		$130,000
	cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pump Station (57 gpm)						$250,000
Subtotal			**12,360**				**$1,462,820**
3	Center Lane	8	120	< 10	$90		$10,800
		1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	300	LP	$45		$13,500
	Connors Road	8	1,180	< 10	$90		$106,200
		8	710	10 - < 15	$100		$71,000
		8	380	15 - < 20	$115		$43,700
		8	230	20 - 25	$140		$32,200
	Phinney's Lane (Conners to PS)	8	330	< 10	$90		$29,700
		8	140	10 - < 15	$100		$14,000
		8	200	15 - < 20	$115		$23,000
		8	50	20 - 25	$140		$7,000
	Phinney's Lane (PS to Old Farm Rd.)	8	80	15 - < 20	$115		$9,200
	Phinney's Lane (Old Farm Rd. to Loomis)	8	610	15 - < 20	$115		$70,150

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1A - Gravity & LP Sewers - Eight Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		8	260	20 - 25	$140		$36,400
	Phinney's Lane (Loomis to Strawberry)	8	250	20 - 25	$140		$35,000
	Loomis Lane	8	260	< 10	$90		$23,400
		8	360	10 - < 15	$100		$36,000
		8	360	15 - < 20	$115		$41,400
		8	250	20 - 25	$140		$35,000
	Richards Lane	8	290	< 10	$90		$26,100
		8	70	10 - < 15	$100		$7,000
		8	230	15 - < 20	$115		$26,450
	Old Farm Road	8	460	< 10	$90		$41,400
		8	260	10 - < 15	$100		$26,000
		8	130	15 - < 20	$115		$14,950
		8	270	20 - 25	$140		$37,800
	Crosby Road	8	360	< 10	$90		$32,400
	Tellegen Trail	8	740	< 10	$90		$66,600
		8	40	10 - < 15	$100		$4,000
	Sail-a-way	8	480	< 10	$90		$43,200
	Phinney's Lane (Strawberry to Tellegen)	8	230	10 - < 15	$100		$23,000
		8	370	15 - < 20	$115		$42,550
		8	340	20 - 25	$140		$47,600
	Phinney's Lane (Tellegen to Crosby)	8	780	< 10	$90		$70,200
		8	40	10 - < 15	$100		$4,000
	Gravity sewer manholes				$2,000	43	$86,880
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	1	$5,000
	Force main	6	6,500		$60		$390,000
	Odor control feed equipment						$60,000
	cofferdam for pump station						$80,000
	Land acquisition						$100,000
	Pumping Station (283 gpm)						$290,000
Subtotal			**18,010**				**$2,176,780**
4	Yatch Club Road	1.5	135	LP	$40		$5,400
		2	135	LP	$40		$5,400
	Indian Trail	1.5	80	LP	$40		$3,200
		2	80	LP	$40		$3,200
		2.5	120	LP	$45		$5,400
	Old Way	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
	Red Wing Trail	1.5	75	LP	$40		$3,000
		2	75	LP	$40		$3,000
		2.5	120	LP	$45		$5,400
	Johny Cake Road	1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	170	LP	$45		$7,650
	Annable Point Road	1.5	225	LP	$40		$9,000

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1A - Gravity & LP Sewers - Eight Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2	225	LP	$40		$9,000
		2.5	260	LP	$45		$11,700
		3	1,060	LP	$45		$47,700
	Willow Run (End of AOC to Thread Needle)	8	210	< 10	$90		$18,900
	Willow Run (end to Thread Needle)	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	370	LP	$45		$16,650
		3	250	LP	$45		$11,250
	Thread Needle Lane	8	560	< 10	$90		$50,400
		8	390	10 - < 15	$100		$39,000
	Great Marsh Road (Thread Needle to Hayes Road)	8	1,160	10 - < 15	$100		$116,000
	Hayes Road	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	450	LP	$45		$20,250
		3	560	LP	$45		$25,200
	Great Marsh / Juniper (Hayes to Laurel)	8	180	10 - < 15	$100		$18,000
		8	910	15 - < 20	$115		$104,650
	Laurel Road	8	240	<10	$90		$21,600
		8	440	10-<15	$100		$44,000
	Juniper Road (Laurel to Lake Dr.)	8	320	10 - < 15	$100		$32,000
	Point of Pines Ave.	8	770	< 10	$90		$69,300
		8	380	10 - < 15	$100		$38,000
	Juniper (Point of Pines to Lake Dr.)	8	180	< 10	$90		$16,200
		8	140	10 - < 15	$100		$14,000
	Lake Drive (Juniper to PS)	8	310	10 - < 15	$100		$31,000
	Brezner Lane (Northern part)	8	240	< 10	$90		$21,600
	Pond Street	8	450	< 10	$90		$40,500
			60	10 - < 15	$100		$6,000
	Lake Drive (Pond St. to PS)	8	350	10 - < 15	$100		$35,000
	Lake Drive (end to Pond St.)	8	140	< 10	$90		$12,600
		8	30	10 - < 15	$100		$3,000
	Gravity sewer manholes				$2,000	30	$59,680
	Grinder pumps				$7,500	0	$0
	Force main	4	850		$50		$42,500
	Air release/cleanout manholes				$5,000	11	$55,000
	cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pumping Station (169 gpm)						$270,000
Subtotal			**13,930**				**$1,570,530**
5	Lakewood Drive	8	200	< 10	$90		$18,000
		8	300	10 - < 15	$100		$30,000
		1.5	105	LP	$40		$4,200
		2	105	LP	$40		$4,200

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1A - Gravity & LP Sewers - Eight Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2.5	330	LP	$45		$14,850
	Nyes Neck (Nyes Point Way to Shirley Point Rd.)	8	250	< 10	$90		$22,500
		8	200	10 - < 15	$100		$20,000
	Shirley Point Road	8	230	< 10	$90		$20,700
		8	380	10 - < 15	$100		$38,000
	Nyes Neck (Shirley Point to Pleasant Pines)	8	400	< 10	$90		$36,000
		8	200	10 - < 15	$100		$20,000
	Pleasant Pines (Nyes Neck to PS) from west	8	570	< 10	$90		$51,300
	Pleasant Pines (Flow to PS) from east	8	300	< 10	$90		$27,000
		8	110	10 - < 15	$100		$11,000
	Gravity sewer manholes				$2,000	24	$48,880
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	6	$30,000
	Force main	6	1,400		$60		$84,000
	Force main	8	1,250		$80		$100,000
	cofferdam for pump station						$60,000
	Land acquisition						$100,000
	Pumping Station (260 gpm)						$290,000
Subtotal			**13,790**				**$1,504,680**
7	Pleasant Pines (High Point to Bunny Run)	8	720	< 10	$90		$64,800
	Chickadee Lane	8	400	< 10	$90		$36,000
	Bunny Run (End to Chickadee)	8	530	< 10	$90		$47,700
	Bunny Run (Chickadee to Point of Pines)	8	260	< 10	$90		$23,400
	Pleasant Pines (Bunny Run to Huckins Neck)	8	180	< 10	$90		$16,200
	Shallow Pond	8	1,100	< 10	$90		$99,000
		8	250	10 - < 15	$100		$25,000
		1.5	280	LP	$40		$11,200
	Huckins Neck (Shallow Pond to Water View Circle)	8	210	< 10	$90		$18,900
		8	230	10 - < 15	$100		$23,000
		8	70	15 - < 20	$115		$8,050
	Water View Circle	8	720	< 10	$90		$64,800
		8	220	10 - < 15	$100		$22,000
	Blue Water Drive	8	520	< 10	$90		$46,800
		1.5	350	LP	$40		$14,000
		2	350	LP	$40		$14,000
	Pondside Circle	8	560	< 10	$90		$50,400
			430	10 - < 15	$100		$43,000
	Huckins Neck Road (Water View to Holly Point)	8	430	< 10	$90		$38,700

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1A - Gravity & LP Sewers - Eight Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Huckins Neck (Lakeside Dr. East to P.S.)	8	380	15 - < 20	$115		$43,700
		8	500	20-25	$140		$70,000
	Gravity sewer manholes				$2,000	69	$137,280
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	7	$35,000
	Force main	4	2,500		$60		$150,000
	cofferdam for pump station						$80,000
	Land acquisition						$100,000
	Pump Station (171 gpm)						$270,000
Subtotal			**25,080**				**$4,045,330**
8	Goose Point Road	1.5	220	LP	$40		$8,800
		2	220	LP	$40		$8,800
	Crestview Circle	2.5	890	LP	$45		$40,050
	Regatta Drive (Phinney's La. To Crestview Cir.)	1.5	180	LP	$40		$7,200
		2	180	LP	$40		$7,200
		2.5	500	LP	$45		$22,500
	Dacey Lane	1.5	120	LP	$40		$4,800
		2	120	LP	$40		$4,800
	Regatta Drive (Crestview Cir. To Old Strawberry Hill Rd.)	3	530	LP	$45		$23,850
	Old Strawberry Hill Road (Regatta Dr. to Rte. 132)	8	1,050	< 10	$90		$94,500
		8	500	10 - < 15	$100		$50,000
		8	340	15 - < 20	$115		$39,100
	Route 132 (Old Strawberry Hill Rd. to PS)	8	160	< 10	$90		$14,400
	Route 132 (Old Route 132 to PS)	8	1,800	< 10	$90		$162,000
	Gravity sewer manholes				$2,000	15	$30,800
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	6	$30,000
	Force main	4	100		$50		$5,000
	cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pump Station (226 gpm)						$280,000
Subtotal			**6,910**				**$983,800**
9	Scottsdale Circle	1.5	145	LP	$40		$5,800
		2	145	LP	$40		$5,800
		2.5	180	LP	$45		$8,100
	Route 28 (FM to Kenesaw)	8	1,640	< 10	$90		$147,600
	Childs Street (FM to Kenesaw/ Rt. 28)	8	620	< 10	$90		$55,800
		8	180	10 - < 15	$100		$18,000
	Route 28 (Kenesaw to Existing Pipe)	8	330	< 10	$90		$29,700
		8	280	10 - < 15	$100		$28,000

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 1A - Gravity & LP Sewers - Eight Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		8	770	15 - < 20	$115		$88,550
	Gravity sewer manholes				$2,000	15	$30,560
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	1	$5,000
Subtotal			**4,290**				**$422,910**
Incremental Cost to increase CCCC force main from 4 inch diameter							
	Huckins Neck Rd. to Phinney's Lane	10	5,300		$40		$212,000
	Phinney's Lane to existing 12" FM	12	1,000		$50		$50,000
Subtotal			**6,300**				**$262,000**
Houses adjacent to gravity sewers requiring pumping							
	Grinder pumps				$7,500	0	**$0**
Improvements to existing sewerage system							
Replace Main St. Pump Station							$400,000
Divert pumped flow to Old Colony Rd. PS FM		8	1,400		$80		$112,000
Subtotal			**1,400**				**$512,000**
Total			**125,500**				**$15,614,370**

LIFE CYCLE COST ANALYSIS SUMMARY SHEET
ALTERNATIVE 1A - Grinder Pumps Purchased and Maintained by Residents

Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
Preparer: DJP/DRP
Date: 29-Aug-03

CAPITAL COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.33%
Effective Discount Rate:	3.46%
Terms of Analysis (years)	50
Construction Duration (years):	2
Replacement Cost Period:	
Base Construction Cost:	$18,737,244
Misc. Reserve Prelim. Design	$0
Engineering Cost:	$0
Replacement Capital Cost:	$828,000
Total Capital Cost:	$19,565,244
Total NPV- Capital Cost:	$18,299,088

OPERATING COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.42%
Effective Discount Rate:	3.37%
Terms of Analysis:	50
Labor Cost/year:	$25,000
Total Labor Cost:	$1,250,000
Total O& M Cost/year:	$128,000
Total O & M Cost:	$6,400,013
Total NPV - O & M Costs:	$3,072,143

	Total Cost	NPV
Capital Costs	$19,565,244	$18,299,088
O & M Costs	$6,400,013	$3,072,143
TOTAL:	$25,965,257	$21,371,231

Notes/Assumptions:

ECONOMIC ASSUMPTIONS - ALTERNATIVE 1A - Grinder Pumps Purchased and Maintained by Residents

CAPITAL COSTS:	
*Discount rate:	5.875%
Inflation rate:	2.33%
**Effective Discount rate:	3.46%

OPERATIONS & MAINTENANCE:	
*Discount rate:	5.875%
Inflation rate:	2.42%
**Effective Discount rate:	3.37%

*** Term of analysis:	50 years

Average Salary:	$25,000

NOTE:

* The discount rate reflects the long-term cost of capital.

** The effective discount rate anticipates the effect of the time value of money and inflation by removing inflation from the discount rate.

*** The analysis period for the project is 50 years.

PROJECT INFORMATION

1) Preparer: DJP/DRP
2) Name of Capital Project: Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
3) List Assumptions Below:

Input cells are highlighed in light yellow.

CAPITAL COSTS WORKSHEET - ALTERNATIVE 1A

1) Enter First Year of Capital Spending: 2004

2) Using table below, enter project Design Status. Prelim. Design

Design Status	Miscellaneous Reserve
Prelim. Design	Add 20%
50-75% Design	Add 15%
90-95% Design	Add 10%
100% Design	Add 10%

CAPITAL COST

		Capital Cost Line Item	Useful Life (see specs below)	Base Construction Costs	Construction Schedule START	Construction Schedule END	IS REPLACEMENT COST NEEDED? IF YES, THEN INPUT COST IN CELL TO RIGHT	REPLACEMENT COSTS (Input Replacement Costs)	BASE CONSTRUCTION COST Spread over ____ years	Spread per year	Beginning in Year ____	REPLACEMENT Replace in Year ____	Replace in Year ____	Replace in Year ____		Replace in Year ____	2004	2005	2006	2007	2008	2009	2010	2011	2012
3)	LINE ITEM 1:	Pipeline and Non-Mech.	50	$13,965,244	2004	2005	NO REPLACEMENT	0	2	6,982,622	2004	0					6,982,622	6,982,622							
																	0	0	0	0	0	0	0	0	0
4)	LINE ITEM 2:	Pump Stations - Non-Mech.	50	$1,932,000	2004	2005	NO REPLACEMENT	0	2	966,000	2004	0					966,000	966,000							
																	0	0	0	0	0	0	0	0	0
5)	LINE ITEM 3:	Pump Stations - Mech. Equip.	25	$1,308,000	2004	2005	REPLACEMENT >>>>>>	784,500	2	654,000	2004	2029	2053				654,000	654,000							
																	0	0	0	0	0	0	0	0	0
6)	LINE ITEM 4:	Grinder Pumps - Non-Mech.	50	50	2004	2005	NO REPLACEMENT	0	2	0	2004	0					0	0							
																	0	0	0	0	0	0	0	0	0
7)	LINE ITEM 5:	Grinder Pumps - Mech. Equip.	10	50	2004	2005	REPLACEMENT >>>>>>	0	2	0	2004	2014	2124	2034	2044	2053	0	0							
																	0	0	0	0	0	0	0	0	0
8)	LINE ITEM 6:	Replace Main St. PS		480,000	2004	2005	REPLACEMENT >>>>>>		2	240,000	2004	0					240,000	240,000							
																	0	0	0	0	0	0	0	0	0
9)	LINE ITEM 7:	Odor control equipment	25	72,000	2004	2005	REPLACEMENT >>>>>>	43,200	2	36,000	2004	2029	2053				36,000	36,000							
																	0	0	0	0	0	0	0	0	0
10)	LINE ITEM 8:	Land acquisition	50	960,000	2004	2005	REPLACEMENT >>>>>>		2	480,000	2004	0					480,000	480,000							
																	0	0	0	0	0	0	0	0	0
11)	LINE ITEM 9:						REPLACEMENT >>>>>>		1	0	0	0													
																	0	0	0	0	0	0	0	0	0
12)	LINE ITEM 10:						REPLACEMENT >>>>>>		1	0	0	0													
																	0	0	0	0	0	0	0	0	0

13)	FIXED LINE ITEM	Base Construction Cost	18,737,244
14)	FIXED LINE ITEM	Replacement Costs	828,000
15)	FIXED LINE ITEM	Miscellaneous Reserve	0
16)	FIXED LINE ITEM	Engineering and CM Costs	0
		TOTAL CAPITAL COST	$19,565,244

																	9,368,622	9,368,622	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0
																	$9,368,622	$9,368,622	$0	$0	$0	$0	$0	$0

Expected Useful Life

Type of Capital Improvement	Expected Useful Life (in years)
Pump station equip.	25
Grinder pump equip.	10
Pipeline	50
Pump station superstructure	50

Replacement Costs: The analysis will include equipment replacement costs required during the period of the analysis.

Salvage value: Zero salvage values assumed in this analysis

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	784,800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	784,800
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	828,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	828,000
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$828,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$828,000

OPERATIONS AND MAINTENANCE COSTS WORKSHEET - ALTERNATIVE 1A

	O&M Cost Categories		Period (Calendar Yr.) From	To	Labor - FTE	Average Salary	Labor Cost Dollars per year	Total Labor Cost	A Spread over ..... many years	B Spread per year	C Beginning in Year	2004	2005	2006	2007	2008
1)	LINE ITEM 1	Labor	2004	2053	1	25,000	25,000	1,250,000	50	25,000	2004	25,000	25,000	25,000	25,000	25,000

Enter first year of O&M costs here:

(for each individual line item)

					Cost per year	Number of Years		Total Cost								
2)	LINE ITEM 2	Electricity	2004	2053	2,810	50		140,513	50	2,810	2004	2,810	2,810	2,810	2,810	2,810
3)	LINE ITEM 3	Chemical addition	2004	2053	12,600	50		630,000	50	12,600	2004	12,600	12,600	12,600	12,600	12,600
4)	LINE ITEM 4	General O&M	2004	2053	24,840	50		1,242,000	50	24,840	2004	24,840	24,840	24,840	24,840	24,840
5)	LINE ITEM 5	Generator-Equipped Service Truck	2004	2053	0	50		0	50	0	2004	0	0	0	0	0
6)	LINE ITEM 6	Sewer maintenance ($0.50/lf)	2004	2053	62,750	50		3,137,500	50	62,750	2004	62,750	62,750	62,750	62,750	62,750
							TOTAL O&M	$6,400,013				$128,000	$128,000	$128,000	$128,000	$128,000

Total Annual O&M $128,000

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000

2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750
$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000

2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750
$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000

MASTER SPREADSHEET - ALTERNATIVE 1A

This data is used to calculate the NPV. Do not touch.

Capital Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pipeline and Non-Mech.	$13,290,884	$13,985,244	$6,992,622	$6,992,622																			
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pump Stations - Non-Mech.	$1,835,050	$1,933,000	966,500	966,500																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump Stations - Mech. Equip.	$1,243,040	$1,308,300	654,000	654,000																			
Replacement	$468,715	$784,800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Non-Mech.	$0	$0	0	0																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Mech. Equip.	$0	$0	0	0																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Replace Main St. PS	$456,151	$480,000	240,000	240,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor control equipment	$68,424	$72,000	36,000	36,000																			
Replacement	$25,691	$43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land acquisition	$912,323	$960,000	480,000	480,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Reserve	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineering and CM Costs		$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW - CAPITAL			$8,368,822	$8,368,822	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL CAPITAL COSTS	$19,565,244																						
Net Present Value - Capital	$13,290,884																						

Operating Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Labor	$800,027	$1,250,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Electricity	$87,449	$140,513	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810
Chemical addition	$302,413	$630,000	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
General O&M	$599,187	$1,242,000	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840
Generator-Equipped Service Truck	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sewer maintenance (50.50/l)	$1,585,087	$3,137,500	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750
TOTAL CASH FLOW - O & M			$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000
TOTAL O & M COSTS	$3,400,013																						
Net Present Value - O & M	2,072,143																						

TOTAL NPV		
	Capital Costs	$13,290,884
	O & M Costs	$2,072,143
	TOTAL	$21,371,221

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	784,800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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$0	$0	$0	$0	$828,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810	2,810
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840	24,840
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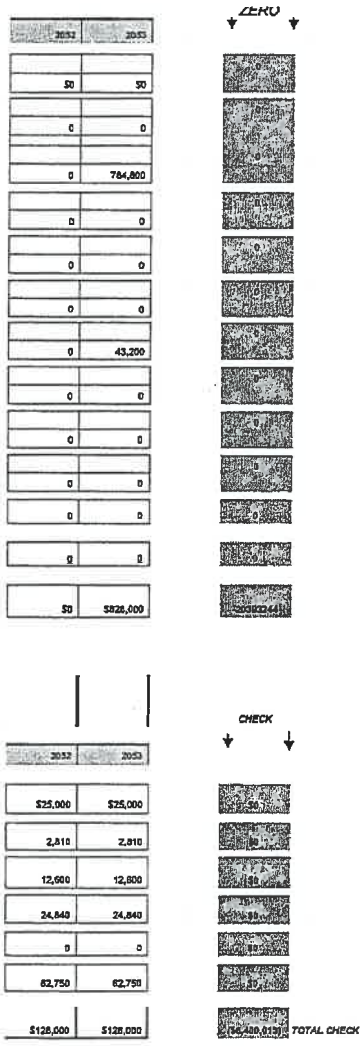
62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750	62,750
$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000	$128,000



2052	2053	ZERO
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0	0	
0	0	
0	0	
0	43,200	
0	0	
0	0	
0	0	
0	0	
$0	$828,000	

2052	2053	CHECK
$25,000	$25,000	
2,810	2,810	
12,600	12,600	
24,840	24,840	
0	0	
62,750	62,750	
$128,000	$128,000	TOTAL CHECK

Alternative 2

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
1	Harrison Rd.	1.5	325	LP	$40		$13,000
		2	325	LP	$40		$13,000
		2.5	270	LP	$45		$12,150
	Cottage Lane	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	200	LP	$45		$9,000
	Route 28 (Harrison to Phinney's)	8	1,900	< 10	$90		$171,000
	Route 28 (West Main St. to Harrison)		140	< 10	$90		$12,600
	Sachem Drive	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	830	LP	$45		$37,350
		3	230	LP	$45		$10,350
	Phinney's Lane (Rt. 28 to PS)	8	1,080	< 10	$90		$97,200
		8	300	10 - < 15	$100		$30,000
	Piney Point Drive	1.5	295	LP	$40		$11,800
		2	295	LP	$40		$11,800
		2.5	420	LP	$45		$18,900
	Pine Street (High Point to Long Pond Cir.)	8	850	< 10	$90		$76,500
		8	520	10 - < 15	$100		$52,000
		8	20	15 - < 20	$115		$2,300
	Long Pond Circle	1.5	225	LP	$40		$9,000
		2	225	LP	$40		$9,000
		2.5	390	LP	$45		$17,550
		3	420	LP	$45		$18,900
	Pine Street (Long Pond Circle to PS)	8	320	< 10	$90		$28,800
		8	120	10 - < 15	$100		$12,000
		8	250	15 - < 20	$115		$28,750
	Gravity sewer manholes				$2,000	22	$44,000
	Grinder pumps				$7,500	57	$427,500
	Air release/cleanout manholes				$5,000	11	$55,000
	Force main	4	3,400		$50		$170,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pumping Station (119 gpm)						$260,000
Subtotal			**14,400**				**$1,851,450**
2	Dunaskin Rd.	8	520	< 10	$90		$46,800
		1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	350	LP	$45		$15,750
	Pine Street (High Point to Blantyre Ave.)	8	500	< 10	$90		$45,000
	Blantyre Avenue	8	230	< 10	$90		$20,700
		8	370	10 - < 15	$100		$37,000
		1.5	115	LP	$40		$4,600
		2	115	LP	$40		$4,600
		2.5	220	LP	$45		$9,900
	Argyle Ave.	8	320	< 10	$90		$28,800

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Pine Street (Blantyre Ave. to PS) from west	8	340	< 10	$90		$30,600
		8	40	15 - < 20	$115		$4,600
	Horatio Lane	8	80	10 - < 15	$100		$8,000
		8	410	<10	$90		$36,900
		1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	250	LP	$45		$11,250
	Pine Street (Horatio to Herring Run Dr.)	8	300	10 - < 15	$100		$30,000
		8	150	15 - < 20	$115		$17,250
	Herring Run Drive	1.5	445	LP	$40		$17,800
		2	445	LP	$40		$17,800
		2.5	450	LP	$45		$20,250
	Pine Street (Herring Run to Pondview Dr.)	8	70	< 10	$90		$6,300
		8	520	10 - < 15	$100		$52,000
	Pondview Drive	8	1,070	< 10	$90		$96,300
		8	700	10 - < 15	$100		$70,000
		8	190	15 - < 20	$115		$21,850
	Holly Lane	8	470	< 10	$90		$42,300
		8	450	10 - < 15	$100		$45,000
	Pine Street (Pondview to PS)	8	90	10 - < 15	$100		$9,000
		8	70	15 - < 20	$115		$8,050
	Gravity sewer manholes				$2,000	26	$51,840
	Grinder pumps				$7,500	18	$135,000
	Air release/cleanout manholes				$5,000	7	$35,000
	Force main	4	2,600		$50		$130,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pump Station (57 gpm)						$250,000
Subtotal			**12,360**				**$1,549,440**
3A	Center Lane	1.5	235	LP	$40		$9,400
		2	235	LP	$40		$9,400
		2.5	300	LP	$45		$13,500
	Connors Road	1.5	105	LP	$40		$4,200
		2	105	LP	$40		$4,200
		2.5	660	LP	$45		$29,700
		3	1,630	LP	$45		$73,350
	Phinney's Lane (Conners to PS)	8	720	< 10	$90		$64,800
	Phinney's Lane (PS to Old Farm Rd.)	8	80	< 10	$90		$7,200
	Phinney's Lane (Old Farm Rd. to Loomis)	8	870	< 10	$90		$78,300
	Phinney's Lane (Loomis to Strawberry)	8	250	< 10	$90		$22,500
	Loomis Lane	1.5	105	LP	$40		$4,200
		2	105	LP	$40		$4,200
		2.5	560	LP	$45		$25,200
		3	460	LP	$45		$20,700

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Richards Lane	1.5	295	LP	$40		$11,800
		2	295	LP	$40		$11,800
	Old Farm Road	1.5	145	LP	$40		$5,800
		2	145	LP	$40		$5,800
		2.5	350	LP	$45		$15,750
		3	480	LP	$45		$21,600
	Gravity sewer manholes				$2,000	8	$15,360
	Grinder pumps				$7,500	42	$315,000
	Air release/cleanout manholes				$5,000	8	$40,000
	Force main	4	100		$50		$5,000
	Force main	6	6,500		$60		$390,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pumping Station (159 gpm)						$270,000
Subtotal			**14,730**				**$1,628,760**
3B	Crosby Road	8	360	< 10	$90		$32,400
	Tellegen Trail	8	740	< 10	$90		$66,600
		8	40	10 - < 15	$100		$4,000
	Sail-a-way	8	480	< 10	$90		$43,200
	Phinney's Lane (Strawberry to Tellegen)	8	700	< 10	$90		$63,000
		8	240	10 - < 15	$100		$24,000
	Phinney's Lane (Tellegen to Crosby)	8	560	< 10	$90		$50,400
		8	260	10 - < 15	$100		$26,000
	Gravity sewer manholes				$2,000	14	$27,040
	Force main	6	2,400		$60		$144,000
	Odor control feed equipment						$60,000
	Cofferdam for pump station						$60,000
	Land acquisition						$100,000
	Pumping Station (216 gpm)						$280,000
Subtotal			**5,780**				**$980,640**
4	Yachyt Club Road	1.5	135	LP	$40		$5,400
		2	135	LP	$40		$5,400
	Indian Trail	1.5	80	LP	$40		$3,200
		2	80	LP	$40		$3,200
		2.5	120	LP	$45		$5,400
	Old Way	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
	Red Wing Trail	1.5	75	LP	$40		$3,000
		2	75	LP	$40		$3,000
		2.5	120	LP	$45		$5,400
	Johny Cake Road	1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	170	LP	$45		$7,650
	Annable Point Road	1.5	225	LP	$40		$9,000
		2	225	LP	$40		$9,000
		2.5	260	LP	$45		$11,700
		3	1,060	LP	$45		$47,700

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Willow Run (end to Thread Needle)	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	370	LP	$45		$16,650
		3	250	LP	$45		$11,250
	Willow Run (End of AOC to Thread Needle)	8	210	< 10	$90		$18,900
	Thread Needle Lane	8	560	< 10	$90		$50,400
		8	390	10 - < 15	$100		$39,000
	Great Marsh Road (Thread Needle to Hayes Road)	8	1,160	10 - < 15	$100		$116,000
	Hayes Road	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	450	LP	$45		$20,250
		3	560	LP	$45		$25,200
	Great Marsh / Juniper (Hayes to Laurel)	8	180	10 - < 15	$100		$18,000
		8	910	15 - < 20	$115		$104,650
	Laurel Road	8	240	< 10	$90		$21,600
		8	440	10 - < 15	$100		$44,000
	Juniper Road (Laurel to Lake Dr.)	8	320	10 - < 15	$100		$32,000
	Point of Pines Ave.	8	770	< 10	$90		$69,300
		8	380	10 - < 15	$100		$38,000
	Juniper (Point of Pines to Lake Dr.)	8	180	< 10	$90		$16,200
		8	140	10 - < 15	$100		$14,000
	Lake Drive (Juniper to PS)	8	310	10 - < 15	$100		$31,000
	Brezner Lane (Northern part)	8	240	< 10	$90		$21,600
	Pond Street	8	450	< 10	$90		$40,500
		8	60	10 - < 15	$100		$6,000
	Lake Drive (Pond St. to PS)	8	350	10 - < 15	$100		$35,000
	Lake Drive (end to Pond St.)	8	140	< 10	$90		$12,600
		8	30	10 - < 15	$100		$3,000
	Gravity sewer manholes				$2,000	30	$59,680
	Grinder pumps				$7,500	55	$412,500
	Air release/cleanout manholes				$5,000	11	$55,000
	Force main	4	850		$50		$42,500
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pumping Station (169 gpm)						$270,000
Subtotal			**13,930**				**$1,983,030**
5	Lakewood Drive	8	200	< 10	$90		$18,000
		8	300	10 - < 15	$100		$30,000
		1.5	105	LP	$40		$4,200
		2	105	LP	$40		$4,200
		2.5	420	LP	$45		$18,900
	Shootflying Hill Road (Lakewood to Tern Lane)	8	200	< 10	$90		$18,000
		8	280	10 - < 15	$100		$28,000
		8	800	15 - < 20	$115		$92,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Tern Lane	1.5	340	LP	$40		$13,600
		2	340	LP	$40		$13,600
		2.5	290	LP	$45		$13,050
		3	1,080	LP	$45		$48,600
	Shootflying Hill Road (Tern Ln. to Johnson Ln.)	8	800	< 10	$90		$72,000
		8	260	10 - < 15	$100		$26,000
	Johnson Lane	1.5	110	LP	$40		$4,400
		2	110	LP	$40		$4,400
		2.5	260	LP	$45		$11,700
	Shootflying Hill Road (Johnson Ln. to PS)	8	860	< 10	$90		$77,400
		8	730	10 - < 15	$100		$73,000
	Shootflying Hill Road (End of line back to PS)	8	740	< 10	$90		$66,600
	Gravity sewer manholes				$2,000	21	$41,360
	Grinder pumps				$7,500	35	$262,500
	Air release/cleanout manholes				$5,000	7	$35,000
	Force main	4	700		$50		$35,000
	Cofferdam for pump station						$60,000
	Land acquisition						$100,000
	Pump Station (162 gpm)						$270,000
Subtotal			**9,030**				**$1,441,510**
6	Shootflying Hill Road (F.M. to Lakeview Drive)	8	100	< 10	$90		$9,000
	Lakeview Drive	8	560	< 10	$90		$50,400
		8	1,190	10 - < 15	$100		$119,000
		8	50	15 - < 20	$115		$5,750
	Pleasant Pines (Shootflying to Lakeview)	8	700	< 10	$90		$63,000
	Pleasnt Pines (Lakeview to Nyes Neck)	8	510	< 10	$90		$45,900
		8	360	10 - < 15	$100		$36,000
	Nyes Neck Rd. (East)	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	950	LP	$45		$42,750
	Nyes Neck Rd. (West)	1.5	435	LP	$40		$17,400
		2	435	LP	$40		$17,400
		2.5	1,090	LP	$45		$49,050
	Nyes Neck Rd. (where east & west combine to Nyes Point Way)	3	640	LP	$45		$28,800
	Nyes Point Way	1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	330	LP	$45		$14,850
	Nyes Neck Rd. (Nyes Point Way to Shirley Point Rd.)	8	250	< 10	$90		$22,500
		8	200	10 - < 15	$100		$20,000
	Shirley Point Road	8	230	< 10	$90		$20,700
		8	380	10 - < 15	$100		$38,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Nyes Neck (Shirley Point to Pleasant Pines)	8	400	< 10	$90		$36,000
		8	200	10 - < 15	$100		$20,000
	Pleasant Pines (Nyes Neck to PS) from west	8	570	< 10	$90		$51,300
	Pleasant Pines (Flow to PS) from east	8	300	< 10	$90		$27,000
		8	110	10 - < 15	$100		$11,000
	Gravity sewer manholes				$2,000	24	$48,880
	Grinder pumps				$7,500	32	$240,000
	Air release/cleanout manholes				$5,000	6	$30,000
	Force main	6	1,400		$60		$84,000
	Force main	8	1,250		$80		$100,000
	Cofferdam for pump station						$60,000
	Land acquisition						$100,000
	Pumping Station (260 gpm)						$290,000
Subtotal			**13,790**				**$1,744,680**
7A	Pleasant Pines (High Point to Bunny Run)	8	720	< 10	$90		$64,800
	Chickadee Lane	8	400	< 10	$90		$36,000
	Bunny Run (End to Chickadee)	8	530	< 10	$90		$47,700
	Bunny Run (Chickadee to Point of Pines)	8	260	< 10	$90		$23,400
	Pleasant Pines (Bunny Run to Huckins Neck)	8	180	< 10	$90		$16,200
	Shallow Pond	8	1,140	< 10	$90		$102,600
		8	210	10 - < 15	$100		$21,000
		1.5	280	LP	$40		$11,200
	Huckins Neck (Shallow Pond to Water View Circle)	8	230	< 10	$90		$20,700
		8	280	10 - < 15	$100		$28,000
	Water View Circle	8	750	< 10	$90		$67,500
		8	190	10 - < 15	$100		$19,000
	Blue Water Drive	8	520	< 10	$90		$46,800
		1.5	350	LP	$40		$14,000
		2	350	LP	$40		$14,000
	Pondside Circle	8	560	< 10	$90		$50,400
		8	430	10 - < 15	$100		$43,000
	Huckins Neck Road (Water View to High Point)	8	520	< 10	$90		$46,800
		8	770	10 - < 15	$100		$77,000
	Gravity sewer manholes				$2,000	31	$61,520
	Grinder pumps				$7,500	6	$45,000
	Air release/cleanout manholes				$5,000	1	$5,000
	Force main	4	150		$50		$7,500
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pump Station (65 gpm)						$250,000
Subtotal			**8,820**				**$1,269,120**

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
7B	Huckins Neck Road (High Point to Holly Point Rd.)	8	840	< 10	$90		$75,600
		8	50	10 - < 15	$100		$5,000
	Holly Point Road (Lakeside Dr. East to Huckins Neck Rd.)	8	790	< 10	$90		$71,100
		8	610	10 - < 15	$100		$61,000
		8	210	15 - < 20	$115		$24,150
	Huckins Neck Road (Holly Point to High Point)	8	320	< 10	$90		$28,800
	Lakeview Avenue (High Point to Holly Point)	8	130	< 10	$90		$11,700
	Gravity sewer manholes				$2,000	12	$23,600
	Force main	4	100		$50		$5,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pump Station (20 gpm)						$125,000
Subtotal			**3,050**				**$580,950**
7C	Beachwood - South of Huckins Neck (High Point to Huckins Neck)	8	230	< 10	$90		$20,700
		8	470	10 - < 15	$100		$47,000
	Huckins Neck (Conners to Beechwood)	8	580	< 10	$90		$52,200
	Huckins Neck (Beechwood to Cottonwood)	8	70	< 10	$90		$6,300
		8	240	10 - < 15	$100		$24,000
		8	360	15 - < 20	$115		$41,400
	Cottonwood	8	480	< 10	$90		$43,200
		8	370	10 - < 15	$100		$37,000
	Beechwood - North of Huckins Neck	8	210	< 10	$90		$18,900
		8	140	10 - < 15	$100		$14,000
	Huckins Neck (Cottonwood to Lakeside Drive East)	8	310	< 10	$90		$27,900
		8	90	10 - < 15	$100		$9,000
	Holly Point Road (Vine St. to Lakeside Dr. East)	1.5	185	LP	$40		$7,400
		2	185	LP	$40		$7,400
		2.5	800	LP	$45		$36,000
		3	420	LP	$45		$18,900
	Lakeside Drive West	1.5	465	LP	$40		$18,600
		2	465	LP	$40		$18,600
		2.5	1,140	LP	$45		$51,300
		3	430	LP	$45		$19,350
	Vine Street	1.5	65	LP	$40		$2,600
		2	65	LP	$40		$2,600
	Lakeside Drive East	8	530	< 10	$90		$47,700
		8	370	10 - < 15	$100		$37,000
		1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Lakeview Avenue	8	320	< 10	$90		$28,800
		8	430	10 - < 15	$100		$43,000
	Huckins Neck (Lakeside Dr. East to High Point)	8	380	< 10	$90		$34,200
		8	440	10 - < 15	$100		$44,000
		8	220	15 - < 20	$115		$25,300
	Sheeting & dewatering deep sewer sections	15-20 ft deep	L=	440	$500		$220,000
	Gravity sewer manholes				$2,000	25	$49,920
	Grinder pumps				$7,500	48	$360,000
	Air release/cleanout manholes				$5,000	6	$30,000
	Force main	4	3,800		$50		$190,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pump Station (79 gpm)						$250,000
Subtotal			**14,760**				**$2,054,270**
8	Goose Point Road	1.5	220	LP	$40	---	$8,800
		2	220	LP	$40		$8,800
	Crestview Circle	2.5	890	LP	$45	---	$40,050
	Regatta Drive (Phinney's La. To Crestview Cir.)	1.5	180	LP	$40	---	$7,200
		2	180	LP	$40		$7,200
		2.5	500	LP	$45		$22,500
	Regatta Drive (Crestview Cir. To Old Strawberry Hill Rd.)	3	530	LP	$45	---	$23,850
	Dacey Lane	1.5	120	LP	$40	---	$4,800
		2	120	LP	$40		$4,800
	Old Strawberry Hill Road (Regatta Dr. to Rte. 132)	8	1,050	< 10	$90	---	$94,500
		8	500	10 - < 15	$100		$50,000
		8	340	15 - < 20	$115		$39,100
	Route 132 (Old Strawberry Hill Rd. to PS)	8	160	< 10	$90	---	$14,400
	Route 132 (Old Route 132 to PS)	8	1,800	< 10	$90		$162,000
	Gravity sewer manholes				$2,000	15	$30,800
	Grinder pumps				$7,500	34	$255,000
	Air release/cleanout manholes				$5,000	6	$30,000
	Force main	4	100		$50		$5,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pump Station (226 gpm)						$280,000
Subtotal			**6,910**				**$1,238,800**
9	Scottsdale Circle	1.5	145	LP	$40		$5,800
		2	145	LP	$40		$5,800
		2.5	180	LP	$45		$8,100
	Route 28 (FM to Kenesaw)	8	1,640	< 10	$90		$147,600
	Childs Street (FM to Kenesaw/ Rt. 28)	8	620	< 10	$90		$55,800
		8	180	10 - < 15	$100		$18,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2 - Gravity & LP Sewers - Eleven Pump Stations

Sub-Area	Street	Pipe Diameter (Inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Route 28 (Kenesaw to Existing Pipe)	8	330	< 10	$90		$29,700
		8	280	10 - < 15	$100		$28,000
		8	770	15 - < 20	$115		$88,550
	Gravity sewer manholes				$2,000	15	$30,560
	Grinder pumps				$7,500	4	$30,000
	Air release/cleanout manholes				$5,000	1	$5,000
Subtotal			**4,290**				**$452,910**
Incremental Cost to increase CCCC force main from 4 inch diameter							
	Huckins Neck Rd. to Phinney's Lane	10	5,300		$40		$212,000
	Phinney's Lane to existing 12" FM	12	1,000		$50		$50,000
Subtotal			**6,300**				**$262,000**
Houses adjacent to gravity sewers requiring pumping							
	Grinder pumps				$7,500	70	**$525,000**
Improvements to existing sewerage system							
Replace Main St. Pump Station							$400,000
Divert pumped flow to Old Colony Rd. PS FM		8	1,400		$80		$112,000
Subtotal							**$512,000**
Total			**129,550**				**18,074,560**

LIFE CYCLE COST ANALYSIS SUMMARY SHEET - ALTERNATIVE 2

Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
Preparer: DJP/DRP
Date: 29-Aug-03

CAPITAL COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.33%
Effective Discount Rate:	3.46%
Terms of Analysis (years)	50
Construction Duration (years):	2
Replacement Cost Period:	

Base Construction Cost:	$21,087,972
Misc. Reserve Prelim. Design	$0
Engineering Cost:	$0
Replacement Capital Cost:	$1,846,388
Total Capital Cost:	$22,934,360
Total NPV- Capital Cost:	$22,222,262

OPERATING COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.42%
Effective Discount Rate:	3.37%
Terms of Analysis:	50
Labor Cost/year:	$60,000
Total Labor Cost:	$3,000,000
Total O& M Cost/year:	$205,146
Total O & M Cost:	$10,257,315
Total NPV - O & M Co	$4,923,731

	Total Cost	NPV
Capital Costs	$22,934,360	$22,222,262
O & M Costs	$10,257,315	$4,923,731
TOTAL:	$33,191,675	$27,145,993

Notes/Assumptions:

ECONOMIC ASSUMPTIONS - ALTERNATIVE 2

CAPITAL COSTS:	
*Discount rate:	5.875%
Inflation rate:	2.33%
**Effective Discount rate:	3.46%

OPERATIONS & MAINTENANCE:	
*Discount rate:	5.875%
Inflation rate:	2.42%
**Effective Discount rate:	3.37%

*** Term of analysis:	50 years

Average Salary:	$60,000

NOTE:

* The discount rate reflects the long-term cost of capital.

** The effective discount rate anticipates the effect of the time value of money and inflation by removing inflation from the discount rate.

*** The analysis period for the project is 50 years.

PROJECT INFORMATION

1) Preparer: DJP/DRP
2) Name of Capital Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
3) List Assumptions Below:

Input cells are highlighed in light yellow.

CAPITAL COSTS WORKSHEET - ALTERNATIVE 2

1) Enter First Year of Capital Spending: 2004

2) Using table below, enter project Design Status. Prelim. Design

Design Status	Miscellaneous Reserve
Prelim. Design	Add 20%
50-75% Design	Add 15%
90-95% Design	Add 10%
100% Design	Add 10%

CAPITAL COST

		Capital Cost Line Item	Useful Life See menu below	Base Construction Costs	Construction Schedule START	Construction Schedule END	IS REPLACMENT COST NEEDED? IF YES, THEN INPUT COST IN CELL TO RIGHT	REPLACEMENT COSTS (Input Replacement Costs)	BASE CONSTRUCTION COST Spread over ___ years	Spread per year	Beginning in Year ___	REPLACEMENT Replace in Year ____	Replace in Year ____		Replace in Year ____	Replace in Year ____	2004	2005	2006	2007	2008	2009	2010	2011	2012
3)	LINE ITEM 1:	Pipeline and Non-Mech.	50	$12,110,472	2004	2005	NO REPLACEMENT	0	2	6,055,236	2004	0					6,055,236	6,055,236							
																	0	0	0	0	0	0	0	0	0
4)	LINE ITEM 2:	Pump Stations - Non-Mech.	50	$2,421,000	2004	2005	NO REPLACEMENT	0	2	1,210,500	2004	0					1,210,500	1,210,500							
																	0	0	0	0	0	0	0	0	0
5)	LINE ITEM 3:	Pump Stations - Mech. Equip.	25	$1,677,000	2004	2005	REPLACEMENT >>>>>>	1,006,200	2	838,500	2004	2029	2053				838,500	838,500							
																	0	0	0	0	0	0	0	0	0
6)	LINE ITEM 4:	Grinder Pumps - Non-Mech.	50	$1,503,750	2004	2005	NO REPLACEMENT	0	2	751,875	2004	0					751,875	751,875							
																	0	0	0	0	0	0	0	0	0
7)	LINE ITEM 5:	Grinder Pumps - Mech. Equip.	10	$1,503,750	2004	2005	REPLACEMENT >>>>>>	796,988	2	751,875	2004	2014	2024	2034	2044	2053	751,875	751,875							
																	0	0	0	0	0	0	0	0	0
8)	LINE ITEM 6:	Replace Main St. PS		$480,000	2004	2005	REPLACEMENT >>>>>>		2	240,000	2004	2005					240,000	240,000							
																	0	0	0	0	0	0	0	0	0
9)	LINE ITEM 7:	Odor Control Equipment	25	72,000	2004	2005	REPLACEMENT >>>>>>	43,200	2	36,000	2004	2029	2053				36,000	36,000							
																	0	0	0	0	0	0	0	0	0
10)	LINE ITEM 8:	Land acquisition	50	1,320,000	2004	2005	REPLACEMENT >>>>>>		2	660,000	2004	0					660,000	660,000							
																	0	0	0	0	0	0	0	0	0
11)	LINE ITEM 9:						REPLACEMENT >>>>>>		1	0	0	0													
																	0	0	0	0	0	0	0	0	0
12)	LINE ITEM 10:						REPLACEMENT >>>>>>		1	0	0	0													
																	0	0	0	0	0	0	0	0	0

13)	FIXED LINE ITEM	Base Construction Cost	21,667,972
14)	FIXED LINE ITEM	Replacement Costs	1,546,365
15)	FIXED LINE ITEM	Miscellaneous Reserve	0
16)	FIXED LINE ITEM	Engineering and CM Costs	0

																	19,543,986	19,543,986	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0

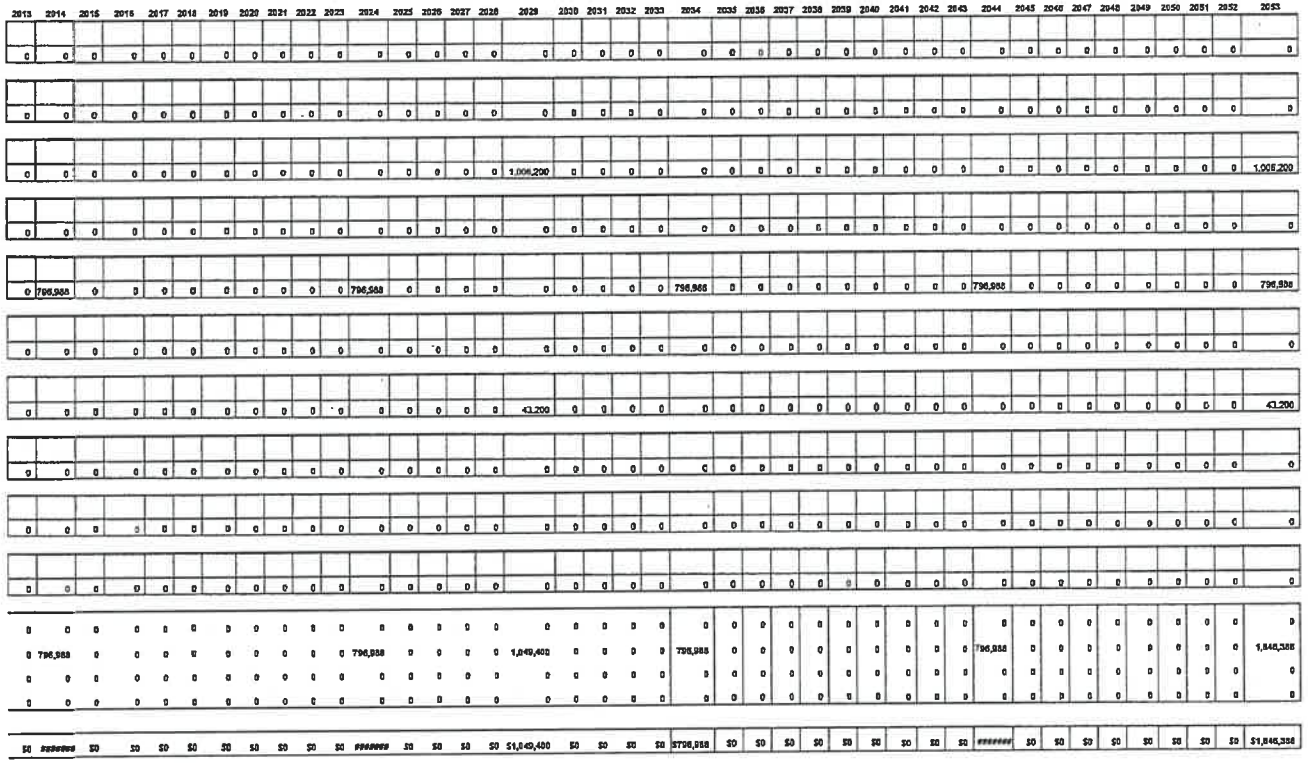
TOTAL CAPITAL COST	$22,934,360

Expected Useful Life	
Type of Capital Improvement	Expected Useful Life (in years)
Pump station equip.	25
Grinder pump equip.	10
Pipeline	50
Pump station superstructure	50

																	$19,543,986	$19,543,986	$0	$0	$0	$0	$0	$0	$0

Replacement Costs: The analysis will include equipment replacement costs required during the period of the analysis.

Salvage value: Zero salvage values assumed in this analysis



2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,008,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,008,200
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0	796,988	0	0	0	0	0	0	0	0	0	796,988	0	0	0	0	0	0	0	0	0	796,988	0	0	0	0	0	0	0	0	0	796,988	0	0	0	0	0	0	0	0	796,988
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	796,988	0	0	0	0	0	0	0	0	0	796,988	0	0	0	0	1,049,400	0	0	0	0	796,988	0	0	0	0	0	0	0	0	0	796,988	0	0	0	0	0	0	0	1,846,388
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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$0	#######	$0	$0	$0	$0	$0	$0	$0	$0	$0	#######	$0	$0	$0	$0	$1,049,400	$0	$0	$0	$0	$796,988	$0	$0	$0	$0	$0	$0	$0	$0	$0	#######	$0	$0	$0	$0	$0	$0	$0	$0	$1,846,388

OPERATIONS AND MAINTENANCE COSTS WORKSHEET - ALTERNATIVE 2

	O&M Cost Categories		Period (Calendar Yr.) From	To	Labor - FTE	Average Salary	Labor Cost Dollars per year	Total Labor Cost	A Spread over ..... many years	B Spread per year	C Beginning in Year	2004	2005	2006	2007	2008
1)	LINE ITEM 1	Labor	2004	2053	1	60,000	60,000	3,000,000	50	60,000	2004	60,000	60,000	60,000	60,000	60,000

Enter first year of O&M costs here:

(for each individual line item)

					Cost per year	Number of Years		Total Cost								
2)	LINE ITEM 2	Electricity	2004	2053	7,380	50		368,984	50	7,380	2004	7,380	7,380	7,380	7,380	7,380
3)	LINE ITEM 3	Chemical addition	2004	2053	12,600	50		630,000	50	12,600	2004	12,600	12,600	12,600	12,600	12,600
4)	LINE ITEM 4	General O&M	2004	2053	55,392	50		2,769,581	50	55,392	2004	55,392	55,392	55,392	55,392	55,392
5)	LINE ITEM 5	Generator-Equipped Service Truck	2004	2053	5,000	50		250,000	50	5,000	2004	5,000	5,000	5,000	5,000	5,000
6)	LINE ITEM 6	Sewer maintenance ($0.50/lf)	2004	2053	64,775	50		3,238,750	50	64,775	2004	64,775	64,775	64,775	64,775	64,775
							TOTAL O&M	$10,257,315				$205,146	$205,146	$205,146	$205,146	$205,146

Total Annual Cost $205,146

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000

7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775
$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000

7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775
$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146

MASTER SPREADSHEET - ALTERNATIVE 2

This data is used to calculate the NPV. Do not touch.

Capital Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pipeline and Non-Mech.	$11,509,029	$12,110,472	$8,055,236	$8,055,236																			
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pump Stations - Non-Mech.	$2,300,764	$2,421,000	1,210,500	1,210,500																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump Stations - Mech. Equip.	$1,593,714	$1,677,000	838,500	838,500																			
Replacement	$598,381	$1,008,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Non-Mech.	$1,429,068	$1,503,750	751,875	751,875																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Mech. Equip.	$1,429,068	$1,503,750	751,875	751,875																			
Replacement	$1,557,527	$796,988	0	0	0	0	0	0	0	0	0	0	796,988	0	0	0	0	0	0	0	0	0	796,988
Replace Main St. PS	$456,161	$480,000	240,000	240,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Equipment	$68,424	$72,000	36,000	36,000																			
Replacement	$25,691	$43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land acquisition	$1,254,444	$1,320,000	660,000	660,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Reserve	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineering and CM Costs		$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW - CAPITAL			$10,543,988	$10,543,986	$0	$0	$0	$0	$0	$0	$0	$0	$796,988	$0	$0	$0	$0	$0	$0	$0	$0	$0	$796,988
TOTAL CAPITAL COSTS	$22,934,388																						
Net Present Value - Capital	$22,222,262																						

Operating Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Labor	$1,440,064	$3,000,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000
Electricity	$177,120	$368,984	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380
Chemical addition	$302,413	$630,000	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
General O&M	$1,329,458	$2,769,531	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392
Sewer maintenance ($0.30/lf)	$120,005	$250,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Sewer maintenance ($0.30/lf)	$1,554,689	$3,238,750	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775
TOTAL CASH FLOW - O & M			$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148	$205,148
TOTAL O & M COSTS	$10,257,315																						
Net Present Value - O & M	4,923,731																						

TOTAL NPV		
	Capital Costs	$22,222,262
	O & M Costs	$4,923,731
	TOTAL:	$27,145,993

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1,008,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	796,988	0	0	0	0	0	0	0	0	0	796,988	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$0	$1,049,400	$0	$0	$0	$0	$796,988	$0	$0	$0	$0	$0	$0	$0	$0	$0	$796,988	$0	$0	$0	$0	$0	$0	$0

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000
7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380	7,380
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392	55,392
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775
$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146	$205,146

2032	2033	ZERO
$0	$0	0
0	0	0
0	1,006,200	0
0	0	0
0	796,988	0
0	0	0
0	43,200	0
0	0	0
0	0	0
0	0	0
0	0	0
$0	$1,846,388	$1,846,388

2032	2033	CHECK
$60,000	$60,000	$0
7,380	7,380	$0
12,600	12,600	$0
55,392	55,392	$0
5,000	5,000	$0
84,775	84,775	$0
$205,146	$205,146	($10,257,300) TOTAL CHECK

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 2A - Gravity & LP Sewers - Eleven Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Route 28 (Kenesaw to Existing Pipe)	8	330	< 10	$90		$29,700
		8	280	10 - < 15	$100		$28,000
		8	770	15 - < 20	$115		$88,550
	Gravity sewer manholes				$2,000	15	$30,560
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	1	$5,000
Subtotal			**4,290**				**$422,910**
Incremental Cost to increase CCCC force main from 4 inch diameter							
	Huckins Neck Rd. to Phinney's Lane	10	5,300		$40		$212,000
	Phinney's Lane to existing 12" FM	12	1,000		$50		$50,000
Subtotal			**6,300**				**$262,000**
Houses adjacent to gravity sewers requiring pumping							
	Grinder pumps				$7,500	0	**$0**
Improvements to existing sewerage system							
Replace Main St. Pump Station							$400,000
Divert pumped flow to Old Colony Rd. PS FM		8	1,400		$80		$112,000
Subtotal							**$512,000**
Total			**129,550**				**15,067,060**

CAPITAL COSTS WORKSHEET - ALTERNATIVE 2A

1) Enter First Year of Capital Spending: 2004

2) Using table below, enter project Design Status. Prelim. Design

Design Status	Miscellaneous Reserve
Prelim. Design	Add 20%
50-75% Design	Add 15%
90-95% Design	Add 10%
100% Design	Add 10%

CAPITAL COST

		Capital Cost Line Item	Useful Life *See menu below*	Base Construction Costs	Construction Schedule START	Construction Schedule END	IS REPLACMENT COST NEEDED? IF YES, THEN INPUT COST IN CELL TO RIGHT	REPLACEMENT COSTS (Input Replacement Costs)	BASE CONSTRUCTION COST Spread over ____ years	Spread per year	Beginning in Year ____	REPLACEMENT Replace in Year ____	Replace in Year ____		Replace in Year ____	Replace in Year ____	2004	2005	2006	2007	2008	2009	2010	2011	2012
3)	LINE ITEM 1:	Pipeline and Non-Mech.	50	$12,110,472	2004	2005	NO REPLACEMENT	0	2	6,055,236	2004	0					6,055,236	6,055,236							
																	0	0	0	0	0	0	0	0	0
4)	LINE ITEM 2:	Pump Stations - Non-Mech.	50	$2,421,000	2004	2005	NO REPLACEMENT	0	2	1,210,500	2004	0					1,210,500	1,210,500							
																	0	0	0	0	0	0	0	0	0
5)	LINE ITEM 3:	Pump Stations - Mech. Equip.	25	$1,677,000	2004	2005	REPLACEMENT >>>>>>	1,006,200	2	838,500	2004	2029	2053				838,500	838,500							
																	0	0	0	0	0	0	0	0	0
6)	LINE ITEM 4:	Grinder Pumps - Non-Mech.	50	$0	2004	2005	NO REPLACEMENT	0	2	0	2004	0					0	0							
																	0	0	0	0	0	0	0	0	0
7)	LINE ITEM 5:	Grinder Pumps - Mech. Equip.	10	$0	2004	2005	REPLACEMENT >>>>>>	0	2	0	2004	2014	2024	2034	2044	2054	0	0							
																	0	0	0	0	0	0	0	0	0
8)	LINE ITEM 6:	Replace Main St. PS		$480,000	2004	2005	REPLACEMENT >>>>>>		2	240,000	2004	2005					240,000	240,000							
																	0	0	0	0	0	0	0	0	0
9)	LINE ITEM 7:	Odor Control Equipment	25	$72,000	2004	2005	REPLACEMENT >>>>>>	43,200	2	36,000	2004	2029	2053				36,000	36,000							
																	0	0	0	0	0	0	0	0	0
10)	LINE ITEM 8:	Land acquisition	50	$1,320,000	2004	2005	REPLACEMENT >>>>>>		2	660,000	2004	0					660,000	660,000							
																	0	0	0	0	0	0	0	0	0
11)	LINE ITEM 9:						REPLACEMENT >>>>>>		1	0	0	0					0	0							
																	0	0	0	0	0	0	0	0	0
12)	LINE ITEM 10:						REPLACEMENT >>>>>>		1	0	0	0					0	0							
																	0	0	0	0	0	0	0	0	0
																	9,840,236	9,840,236	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	$9,840,236	$9,840,236	$0	$0	$0	$0	$0	$0	$0

13)	FIXED LINE ITEM	Base Construction Cost	18,880,472
14)	FIXED LINE ITEM	Replacement Costs	1,049,400
15)	FIXED LINE ITEM	Miscellaneous Reserve	0
16)	FIXED LINE ITEM	Engineering and CM Costs	0
		TOTAL CAPITAL COST	$19,129,872

Expected Useful Life

Type of Capital Improvement	Expected Useful Life (in years)
Pump station equip.	25
Grinder pump equip.	10
Pipeline	50
Pump station superstructure	50

Replacement Costs: The analysis will include equipment replacement costs required during the period of the analysis.

Salvage value: Zero salvage values assumed in this analysis

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,006,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,006,200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,049,400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,049,400
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,049,400	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,049,400

OPERATIONS AND MAINTENANCE COSTS WORKSHEET - ALTERNATIVE 2A

	O&M Cost Categories		Period (Calendar Yr.) From	To	Labor - FTE	Average Salary	Labor Cost Dollars per year	Total Labor Cost	A Spread over ..... many years	B Spread per year	C Beginning in Year	2004	2005	2006	2007	2008
1)	LINE ITEM 1	Labor	2004	2053	1	25,000	25,000	1,250,000	50	25,000	2004	25,000	25,000	25,000	25,000	25,000

Enter first year of O&M costs here:
(for each individual line item)

					Cost per year	Number of Years		Total Cost								
2)	LINE ITEM 2	Electricity	2004	2053	4,106	50		205,284	50	4,106	2004	4,106	4,106	4,106	4,106	4,106
3)	LINE ITEM 3	Chemical addition	2004	2053	12,600	50		630,000	50	12,600	2004	12,600	12,600	12,600	12,600	12,600
4)	LINE ITEM 4	General O&M	2004	2053	31,482	50		1,574,100	50	31,482	2004	31,482	31,482	31,482	31,482	31,482
5)	LINE ITEM 5	Generator-Equipped Service Truck	2004	2053	0	50		0	50	0	2004	0	0	0	0	0
6)	LINE ITEM 6	Sewer maintenance ($0.50/lf)	2004	2053	64,775	50		3,238,750	50	64,775	2004	64,775	64,775	64,775	64,775	64,775
							TOTAL O&M	$6,898,134				$137,963	$137,963	$137,963	$137,963	$137,963

Total Annual Cost $137,963

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000

4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775
$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000

4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775
$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963

MASTER SPREADSHEET - ALTERNATIVE 2A

This data is used to calculate the NPV. Do not touch.

Capital Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pipeline and Non-Mech.	$11,509,020	$12,110,472	$6,055,236	$6,055,236																			
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pump Stations - Non-Mech.	$2,300,754	$2,421,000	1,210,500	1,210,500																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump Stations - Mech. Equip.	$1,583,714	$1,877,000	838,500	838,500																			
Replacement	$588,381	$1,006,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Non-Mech.	$0	$0	0	0																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Mech. Equip.	$0	$0	0	0																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Replace Main St. PS	$456,161	$480,000	240,000	240,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Equipment	$68,424	$72,000	36,000	36,000																			
Replacement	$25,691	$43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land acquisition	$1,254,444	$1,320,000	660,000	660,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Reserve	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineering and CM Costs		$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW - CAPITAL			$8,040,236	$8,040,236	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL CAPITAL COSTS	$19,129,572																						
Net Present Value - Capital	$17,806,599																						

Operating Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Labor	$800,027	$1,250,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Electricity	$98,541	$205,284	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106
Chemical addition	$302,413	$638,000	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
General O&M	$755,602	$1,574,[illegible]	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482
Generator-Equipped Service Truck	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sewer maintenance ($0.30/lf)	$1,554,689	$3,238,750	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775	64,775
TOTAL CASH FLOW - O & M			$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963
TOTAL O & M COSTS	$6,898,134																						
Net Present Value - O & M	3,311,252																						

TOTAL NPV →	Capital Costs	$17,806,599
	O & M Costs	$3,311,252
	TOTAL	$21,117,851

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1,006,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	43,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$0	$1,049,400	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106	4,106
12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482	31,482
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775	84,775
$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963	$137,963

2052	2053	ZERO
$0	$0	
0	0	
0	1,036,200	
0	0	
0	0	
0	0	
0	43,200	
0	0	
0	0	
0	0	
0	0	
$0	$1,049,400	

2052	2053	CHECK
$25,000	$25,000	
4,100	4,100	
12,000	12,000	
31,482	31,482	
0	0	
64,775	64,775	
$137,963	$137,963	TOTAL CHECK

Alternative 3

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3 - Gravity & LP Sewers - Five Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
1	Harrison Rd.	1.5	325	LP	$40		$13,000
		2	325	LP	$40		$13,000
		2.5	270	LP	$45		$12,150
	Cottage Lane	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	200	LP	$45		$9,000
	Route 28 (Harrison to Phinney's)	8	1,900	< 10	$90		$171,000
	Route 28 (W. Main St. to Harrison)	8	140	< 10	$90		$12,600
	Sachem Drive	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	830	LP	$45		$37,350
		3	230	LP	$45		$10,350
	Phinney's Lane (Rt. 28 to PS)	8	1,380	< 10	$90		$124,200
	Piney Point Drive	1.5	295	LP	$40		$11,800
		2	295	LP	$40		$11,800
		2.5	420	LP	$45		$18,900
	Pine Street (High Point to Long Pond Cir.)	8	850	< 10	$90		$76,500
		8	520	10 - < 15	$100		$52,000
		8	20	15-<20	$115		$2,300
	Long Pond Circle	8	770	< 10	$90		$69,300
		8	410	10 - < 15	$100		$41,000
		8	80	15 - < 20	$115		$9,200
	Pine Street (Long Pond Circle to PS)	8	290	< 10	$90		$26,100
		8	120	15 - < 20	$115		$13,800
		8	280	20 - 25	$140		$39,200
	Gravity sewer manholes				$2,000	26	$52,960
	Grinder pumps				$7,500	45	$337,500
	Air release/cleanout manholes				$5,000	9	$45,000
	Force main	4	3,400		$50		$170,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pumping Station (119 gpm)						$260,000
Subtotal			**14,400**				**$1,832,010**
2	Dunaskin Rd.	8	520	< 10	$90		$46,800
		1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	350	LP	$45		$15,750
	Pine Street (High Point to Blantyre Ave.)	8	500	< 10	$90		$45,000
	Blantyre Avenue	8	260	< 10	$90		$23,400
		8	200	10 - < 15	$100		$20,000
		8	410	15 - < 20	$115		$47,150
		8	180	20 - 25	$140		$25,200
	Argyle Ave.	8	320	<10	$90		$28,800
	Pine Street (Blantyre Ave. to PS) from west	8	380	15 - < 20	$115		$43,700
	Horatio Lane	8	410	< 10	$90		$36,900
		8	80	10 - < 15	$100		$8,000
		1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	250	LP	$45		$11,250
	Pine Street (Horatio to Herring Run Dr.)	8	300	10 - < 15	$100		$30,000
		8	150	15 - < 20	$115		$17,250

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3 - Gravity & LP Sewers - Five Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Herring Run Drive	1.5	445	LP	$40		$17,800
		2	445	LP	$40		$17,800
		2.5	450	LP	$45		$20,250
	Pine Street (Herring Run to Pondview Dr.)	8	70	< 10	$90		$6,300
		8	520	10 - < 15	$100		$52,000
	Pondview Drive	8	1,070	< 10	$90		$96,300
		8	700	10 - < 15	$100		$70,000
		8	190	15 - < 20	$115		$21,850
	Holly Lane	8	30	< 10	$90		$2,700
		8	580	10 - < 15	$100		$58,000
		8	310	15 - < 20	$115		$35,650
	Pine Street (Pondview to PS)	8	90	10 - < 15	$100		$9,000
		8	70	15 - < 20	$115		$8,050
	Gravity sewer manholes				$2,000	29	$58,720
	Grinder pumps				$7,500	14	$105,000
	Air release/cleanout manholes				$5,000	4	$20,000
	Force main	4	2,600		$50		$130,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pump Station (57 gpm)						$250,000
Subtotal			12,360				$1,567,820
3	Center Lane	8	120	< 10	$90		$10,800
		1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	300	LP	$45		$13,500
	Connors Road	8	1,180	< 10	$90		$106,200
		8	710	10 - < 15	$100		$71,000
		8	380	15 - < 20	$115		$43,700
		8	230	20 - 25	$140		$32,200
	Phinney's Lane (Conners to PS)	8	330	< 10	$90		$29,700
		8	140	10 - < 15	$100		$14,000
		8	200	15 - < 20	$115		$23,000
		8	50	20 - 25	$140		$7,000
	Phinney's Lane (PS to Old Farm Rd.)	8	80	15 - < 20	$115		$9,200
	Phinney's Lane (Old Farm Rd. to Loomis)	8	610	15 - < 20	$115		$70,150
		8	260	20 - 25	$140		$36,400
	Phinney's Lane (Loomis to Strawberry)	8	250	20 - 25	$140		$35,000
	Loomis Lane	8	260	< 10	$90		$23,400
		8	360	10 - < 15	$100		$36,000
		8	360	15 - < 20	$115		$41,400
		8	250	20 - 25	$140		$35,000
	Richards Lane	8	290	< 10	$90		$26,100
		8	70	10 - < 15	$100		$7,000
		8	230	15 - < 20	$115		$26,450
	Old Farm Road	8	460	< 10	$90		$41,400
		8	260	10 - < 15	$100		$26,000
		8	130	15 - < 20	$115		$14,950
		8	270	20 - 25	$140		$37,800
	Crosby Road	8	360	< 10	$90		$32,400
	Tellegen Trail	8	740	< 10	$90		$66,600
		8	40	10 - < 15	$100		$4,000
	Sail-a-way	8	480	< 10	$90		$43,200

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3 - Gravity & LP Sewers - Five Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Phinney's Lane (Strawberry to Tellegen)	8	230	10 - < 15	$100		$23,000
		8	370	15 - < 20	$115		$42,550
		8	340	20 - 25	$140		$47,600
	Phinney's Lane (Tellegen to Crosby)	8	780	< 10	$90		$70,200
		8	40	10 - < 15	$100		$4,000
	Gravity sewer manholes				$2,000	43	$86,880
	Grinder pumps				$7,500	4	$30,000
	Air release/cleanout manholes				$5,000	1	$5,000
	Force main	6	6,500		$60		$390,000
	Odor control feed equipment						$60,000
	Cofferdam for pump station						$80,000
	Land acquisition						$100,000
	Pumping Station (283 gpm)						$290,000
Subtotal			**18,010**				$2,206,780
4	Yatch Club Road	1.5	135	LP	$40		$5,400
		2	135	LP	$40		$5,400
	Indian Trail	1.5	80	LP	$40		$3,200
		2	80	LP	$40		$3,200
		2.5	120	LP	$45		$5,400
	Old Way	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
	Red Wing Trail	1.5	75	LP	$40		$3,000
		2	75	LP	$40		$3,000
		2.5	120	LP	$45		$5,400
	Johny Cake Road	1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	170	LP	$45		$7,650
	Annable Point Road	1.5	225	LP	$40		$9,000
		2	225	LP	$40		$9,000
		2.5	260	LP	$45		$11,700
		3	1,060	LP	$45		$47,700
	Willow Run (End of AOC to Thread Needle)	8	210	< 10	$90		$18,900
	Willow Run (end to Thread Needle)	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	370	LP	$45		$16,650
		3	250	LP	$45		$11,250
	Thread Needle Lane	8	560	< 10	$90		$50,400
		8	390	10 - < 15	$100		$39,000
	Great Marsh Road (Thread Needle to Hayes Road)	8	1,160	10 - < 15	$100		$116,000
	Hayes Road	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	450	LP	$45		$20,250
		3	560	LP	$45		$25,200
	Great Marsh / Juniper (Hayes to Laurel)	8	180	10 - < 15	$100		$18,000
		8	910	15 - < 20	$115		$104,650
	Laurel Road	8	240	<10	$90		$21,600
		8	440	10-<15	$100		$44,000
	Juniper Road (Laurel to Lake Dr.)	8	320	10 - < 15	$100		$32,000
	Point of Pines Ave.	8	770	< 10	$90		$69,300
		8	380	10 - < 15	$100		$38,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3 - Gravity & LP Sewers - Five Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Juniper (Point of Pines to Lake Dr.)	8	180	< 10	$90		$16,200
		8	140	10 - < 15	$100		$14,000
	Lake Drive (Juniper to PS)	8	310	10 - < 15	$100		$31,000
	Brezner Lane (Northern part)	8	240	< 10	$90		$21,600
	Pond Street	8	450	< 10	$90		$40,500
			60	10 - < 15	$100		$6,000
	Lake Drive (Pond St. to PS)	8	350	10 - < 15	$100		$35,000
	Lake Drive (end to Pond St.)	8	140	< 10	$90		$12,600
		8	30	10 - < 15	$100		$3,000
	Gravity sewer manholes				$2,000	30	$59,680
	Grinder pumps				$7,500	55	$412,500
	Force main	4	850		$50		$42,500
	Air release/cleanout manholes				$5,000	11	$55,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pumping Station (169 gpm)						$270,000
Subtotal			13,930				$1,983,030
5	Lakewood Drive	1.5	115	LP	$40		$4,600
		2	115	LP	$40		$4,600
		2.5	300	LP	$45		$13,500
		3	600	LP	$45		$27,000
	Shootflying Hill Road (Lakewood to Tern Lane)	3	1,280	LP	$45		$57,600
	Tern Lane	1.5	340	LP	$40		$13,600
		2	340	LP	$40		$13,600
		2.5	290	LP	$45		$13,050
		3	1,080	LP	$45		$48,600
	Shootflying Hill Road (Tern Ln. to Johnson Ln.)	4	1,060	LP	$50		$53,000
	Johnson Lane	1.5	110	LP	$40		$4,400
		2	110	LP	$40		$4,400
		2.5	260	LP	$45		$11,700
	Shootflying Hill Road (Johnson Ln. to Lakeview Dr.)	4	2,330	LP	$50		$116,500
	Grinder pumps				$7,500	46	$345,000
	Air release/cleanout manholes				$5,000	11	$55,000
Subtotal			**8,330**				**$786,150**
6	Shootflying Hill Rd. to Lakeview Dr.	4	100	LP	$50		$5,000
	Lakeview Avenue	4	1,800	LP	$50		$90,000
	Pleasant Pines (Shootflying to Lakeview)	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	450	LP	$50		$22,500
	Pleasnt Pines (Lakeview to Nyes Neck)	4	870	LP	$50		$43,500
	Nyes Neck Rd. (East)	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	950	LP	$45		$42,750
	Nyes Neck Rd. (West)	1.5	435	LP	$40		$17,400
		2	435	LP	$40		$17,400
		2.5	1,090	LP	$45		$49,050
	Nyes Neck Rd. (where east & west combine to Nyes Point Way)	3	640	LP	$45		$28,800
	Nyes Point Way	1.5	175	LP	$40		$7,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3 - Gravity & LP Sewers - Five Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2	175	LP	$40		$7,000
		2.5	330	LP	$45		$14,850
	Nyes Neck Rd. (Nyes Point Way to Shirley Point Rd.)	3	450	LP	$45		$20;250
	Shirley Point Road	1.5	175	LP	$40		$7,000
		2	175	LP	$40		
		2.5	260	LP	$45		$11,700
	Nyes Neck Rd. (Shirley Point to Pleasant Pines)	3	100	LP	$45		$4,500
		4	500	LP	$50		$25,000
	Pleasant Pines (Nyes Neck to SA7)	4	980	LP	$50		$49,000
	Grinder pumps				$7,500	67	$502,500
	Air release/cleanout manholes				$5,000	13	$65,000
Subtotal			11,140				$1,072,200
7	Pleasant Pines (SA6 to Bunny Lane)	4	720	LP	$50		$36,000
	Chickadee Lane	1.5	200	LP	$40		$8,000
		2	200	LP	$40		$8,000
	Bunny Run (End to Chickadee)	1.5	265	LP	$40		$10,600
		2	265	LP	$40		$10,600
	Bunny Run (Chickadee to Point of Pines)	2.5	260	LP	$45		$11,700
	Pleasant Pines (Bunny Run to Huckins Neck)	4	180	LP	$50		$9,000
	Shallow Pond	1.5	280	LP	$40		$11,200
		2	280	LP	$40		$11,200
		2.5	1,070	LP	$45		$48,150
	Huckins Neck Rd. (Rte 132 to Water View Circle)	6	1,070	LP	$60		$64,200
	Water View Circle	1.5	200	LP	$40		$8,000
		2	200	LP	$40		$8,000
		2.5	540	LP	$45		$24,300
	Blue Water Drive	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	720	LP	$45		$32,400
	Pondside Circle	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	740	LP	$45		$33,300
	Huckins Neck Road (Water View to Holly Point)	4	2,180	LP	$50		$109,000
	Holly Point Road	1.5	300	LP	$40		$12,000
		2	300	LP	$40		$12,000
		2.5	720	LP	$45		$32,400
		3	290	LP	$45		$13,050
	Huckins Neck Road (Holly Point to Lakeside Dr. East)	4	1,360	LP	$50		$68,000
	Beachwood - South of Huckins Neck (High Point to Huckins Neck)	1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	350	LP	$45		$15,750
	Huckins Neck (Conners to Beechwood)	2.5	230	LP	$45		$10,350
		1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3 - Gravity & LP Sewers - Five Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Beechwood (North of Huckins Neck)	1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
	Huckins Neck (Cottonwood to Lakeside Drive East)	3	400	LP	$45		$18,000
	Cottonwood	1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	500	LP	$45		$22,500
	Huckins Neck (Beachwood to Cottonwood)	3	670	LP	$45		$30,150
	Lakeside Drive West	1.5	465	LP	$40		$18,600
		2	465	LP	$40		$18,600
		2.5	1,140	LP	$45		$51,300
		3	430	LP	$45		$19,350
	Vine Street	1.5	65	LP	$40		$2,600
		2	65	LP	$40		$2,600
	Lakeside Drive East	4	1,400	LP	$50		$70,000
	Holly Point Road (Vine St. to Lakeside Drive East)	1.5	185	LP	$40		$7,400
		2	185	LP	$40		$7,400
		2.5	800	LP	$45		$36,000
		3	420	LP	$45		$18,900
	Lakeview Avenue	2.5	880	LP	$45		$39,600
	Grinder pumps				$7,500	244	$1,830,000
	Force main	10	100		$90		$9,000
	Air release/cleanout manholes				$5,000	32	$160,000
	Odor control feed equipment						$60,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pump Station (593 gpm)						$400,000
Subtotal			**23,240**				**$3,665,200**
8	Goose Point Road	1.5	220	LP	$40		$8,800
		2	220	LP	$40		$8,800
	Crestview Circle	2.5	890	LP	$45		$40,050
	Regatta Drive (Phinney's La. To Crestview Cir.)	1.5	180	LP	$40		$7,200
		2	180	LP	$40		$7,200
		2.5	500	LP	$45		$22,500
	Dacey Lane	1.5	120	LP	$40		$4,800
		2	120	LP	$40		$4,800
	Regatta Drive (Crestview Cir. To Old Strawberry Hill Rd.)	3	530	LP	$45		$23,850
	Old Strawberry Hill Road (Regatta Dr. to Rte. 132)	3	730	LP	$45		$32,850
		4	1,160	LP	$50		$58,000
	Route 132	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	1,000	LP	$45		$45,000
		3	660	LP	$45		$29,700
	Grinder pumps				$7,500	50	$375,000
	Grinder pumps at condominium				$15,000	15	$225,000
	Air release/cleanout manholes				$5,000	8	$40,000
Subtotal			**6,810**				**$945,550**
9	Scottsdale Circle	1.5	145	LP	$40		$5,800
		2	145	LP	$40		$5,800
		2.5	180	LP	$45		$8,100
	Route 28 (FM to Kenesaw)	8	1,640	< 10	$90		$147,600

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3 - Gravity & LP Sewers - Five Pump Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Childs Street (FM to Kenesaw/ Rt. 28)	8	620	< 10	$90		$55,800
		8	180	10 - < 15	$100		$18,000
	Route 28 (Kenesaw to Existing Pipe)	8	330	< 10	$90		$29,700
		8	280	10 - < 15	$100		$28,000
		8	770	15 - < 20	$115		$88,550
	Gravity sewer manholes				$2,000	15	$30,560
	Grinder pumps				$7,500	4	$30,000
	Air release/cleanout manholes				$5,000	1	$5,000
Subtotal			**4,290**				**$452,910**
Incremental Cost to increase CCCC force main from 4 inch diameter							
	Huckins Neck Rd. to Phinney's Lane	10	5,300		$40		$212,000
	Phinney's Lane to existing 12" FM	12	1,000		$50		$50,000
Subtotal			**6,300**				**$262,000**
Houses adjacent to gravity sewers requiring pumping							
	Grinder pumps				$7,500	39	**$292,500**
Improvements to existing sewerage system							
Replace Main St. Pump Station							$400,000
Divert pumped flow to Old Colony Rd. PS FM		8	1,400		$80		$112,000
Subtotal							**$512,000**
Total			**120,210**				**$15,578,150**

LIFE CYCLE COST ANALYSIS SUMMARY SHEET - ALTERNATIVE 3

Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
Preparer: DJP/DRP
Date: 29-Aug-03

CAPITAL COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.33%
Effective Discount Rate:	3.46%
Terms of Analysis (years)	50
Construction Duration (years):	2
Replacement Cost Period:	
Base Construction Cost:	$17,796,780
Misc. Reserve Prelim. Design	$0
Engineering Cost:	$0
Replacement Capital Cost:	$1,804,125
Total Capital Cost:	$19,600,905
Total NPV- Capital Cost:	$19,601,714

OPERATING COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.42%
Effective Discount Rate:	3.37%
Terms of Analysis:	50
Labor Cost/year:	$100,000
Total Labor Cost:	$5,000,000
Total O& M Cost/year:	$280,985
Total O & M Cost:	$14,049,259
Total NPV - O & M Co	$6,743,945

	Total Cost	NPV
Capital Costs	$19,600,905	$19,601,714
O & M Costs	$14,049,259	$6,743,945
TOTAL:	$33,650,164	$26,345,659

Notes/Assumptions:

ECONOMIC ASSUMPTIONS - ALTERNATIVE 3

CAPITAL COSTS:	
*Discount rate:	5.875%
Inflation rate:	2.33%
**Effective Discount rate:	3.46%

OPERATIONS & MAINTENANCE:	
*Discount rate:	5.875%
Inflation rate:	2.42%
**Effective Discount rate:	3.37%

*** Term of analysis:	50 years

Average Salary:	$100,000

NOTE:

* The discount rate reflects the long-term cost of capital.

** The effective discount rate anticipates the effect of the time value of money and inflation by removing inflation from the discount rate.

*** The analysis period for the project is 50 years.

PROJECT INFORMATION

1) Preparer: DJP/DRP
2) Name of Capital Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
3) List Assumptions Below:

Input cells are highlighed in light yellow.

CAPITAL COSTS WORKSHEET - ALTERNATIVE 3

1) Enter First Year of Capital Spending: 2004

2) Using table below, enter project Design Status. Prelim. Design

Design Status	Miscellaneous Reserve
Prelim. Design	Add 20%
50-75% Design	Add 15%
90-95% Design	Add 10%
100% Design	Add 10%

CAPITAL COST

		Capital Cost Line Item	Useful Life See inserts below	Base Construction Costs	Construction Schedule START	Construction Schedule END	IS REPLACEMENT COST NEEDED? IF YES, THEN INPUT COST IN CELL TO RIGHT	REPLACEMENT COSTS (Input Replacement Costs)	BASE CONSTRUCTION COST Spread over ____ years	Spread per year	Beginning in Year ____	REPLACEMENT Replace in Year ____	Replace in Year ____		Replace in Year ____	Replace in Year ____	2004	2005	2006	2007	2008	2009	2010	2011	2012
3)	LINE ITEM 1:	Pipeline and Non-Mech.	50	$9,939,780	2004	2005	NO REPLACEMENT	0	2	4,969,890	2004	0					4,969,890	4,969,890							
																	0	0	0	0	0	0	0	0	0
4)	LINE ITEM 2:	Pump Stations - Non-Mech.	50	$1,266,000	2004	2005	NO REPLACEMENT	0	2	633,000	2004	0					633,000	633,000							
																	0	0	0	0	0	0	0	0	0
5)	LINE ITEM 3:	Pump Stations - Mech. Equip.	25	$882,000	2004	2005	REPLACEMENT >>>>>>	529,200	2	441,000	2004	2029	2053				441,000	441,000							
																	0	0	0	0	0	0	0	0	0
6)	LINE ITEM 4:	Grinder Pumps - Non-Mech.	50	$2,242,500	2004	2005	NO REPLACEMENT	0	2	1,121,250	2004	0					1,121,250	1,121,250							
																	0	0	0	0	0	0	0	0	0
7)	LINE ITEM 5:	Grinder Pumps - Mech. Equip.	10	$2,242,500	2004	2005	REPLACEMENT >>>>>>	1,166,525	2	1,121,250	2004	2014	2024	2034	2044	2053	1,121,250	1,121,250							
																	0	0	0	0	0	0	0	0	0
8)	LINE ITEM 6:	Replace Main St. PS		480,000	2004	2005	REPLACEMENT >>>>>>		2	240,000	2004	2005					240,000	240,000							
																	0	0	0	0	0	0	0	0	0
9)	LINE ITEM 7:	Odor Control Fac. - Non-Mech.	50	0	2004	2005	NO REPLACEMENT	0	2	0	2004	0					0	0							
																	0	0	0	0	0	0	0	0	0
10)	LINE ITEM 8:	Odor Control Fac. - Mech. Equip.	25	144,000	2004	2005	REPLACEMENT >>>>>>	86,400	2	72,000	2004	2029	2053				72,000	72,000							
																	0	0	0	0	0	0	0	0	0
11)	LINE ITEM 9:	Land acquisition	50	600,000	2004	2005	NO REPLACEMENT		2	300,000	2004	0					300,000	300,000							
																	0	0	0	0	0	0	0	0	0
12)	LINE ITEM 10:						REPLACEMENT >>>>>>		1	0	0	0					0	0	0	0	0	0	0	0	0
																	8,898,390	8,898,390	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	$8,898,390	$8,898,390	$0	$0	$0	$0	$0	$0	$0

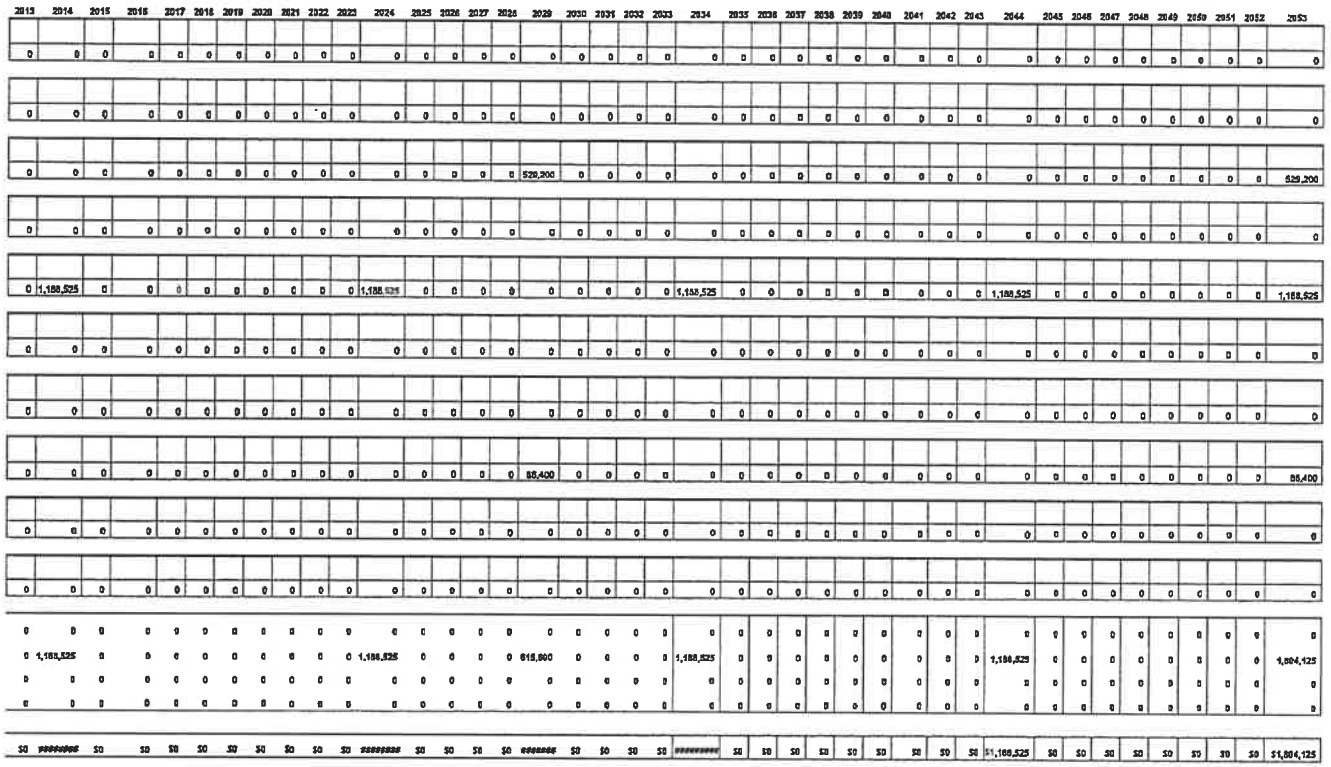
13)	FIXED LINE ITEM	Base Construction Cost	17,796,780
14)	FIXED LINE ITEM	Replacement Costs	1,904,125
15)	FIXED LINE ITEM	Miscellaneous Reserve	0
16)	FIXED LINE ITEM	Engineering and CM Costs	0
		TOTAL CAPITAL COST	$19,600,905

Expected Useful Life

Type of Capital Improvement	Expected Useful Life (in years)
Pump station equip.	25
Grinder pump equip.	10
Pipeline	50
Pump station superstructure	50

Replacement Costs: The analysis will include equipment replacement costs required during the period of the analysis.

Salvage value: Zero salvage values assumed in this analysis



2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88,400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88,400
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1,188,525	0	0	0	0	0	0	0	0	0	1,188,525	0	0	0	0	618,600	0	0	0	0	1,188,525	0	0	0	0	0	0	0	0	0	1,188,525	0	0	0	0	0	0	0	0	1,804,125
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	########	$0	$0	$0	$0	$0	$0	$0	$0	$0	########	$0	$0	$0	$0	######	$0	$0	$0	$0	########	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,188,525	$0	$0	$0	$0	$0	$0	$0	$0	$1,804,125

OPERATIONS AND MAINTENANCE COSTS WORKSHEET - ALTERNATIVE 3

	O&M Cost Categories		Period (Calendar Yr.) From	To	Labor - FTE	Average Salary	Labor Cost Dollars per year	Total Labor Cost	A Spread over ..... many years	B Spread per year	C Beginning In Year	2004	2005	2006	2007	2008
1)	LINE ITEM 1	Labor	2004	2053	1	100,000	100,000	5,000,000	50	100,000	2004	100,000	100,000	100,000	100,000	100,000

Enter first year of O&M costs here:
(for each individual line item)

					Cost per year	Number of Years	Total Cost								
2)	LINE ITEM 2	Electricity	2004	2053	6,356	50	317,822	50	6,356	2004	6,356	6,356	6,356	6,356	6,356
3)	LINE ITEM 3	Chemical addition	2004	2053	55,400	50	2,770,000	50	55,400	2004	55,400	55,400	55,400	55,400	55,400
4)	LINE ITEM 4	General O&M	2004	2053	54,124	50	2,706,188	50	54,124	2004	54,124	54,124	54,124	54,124	54,124
5)	LINE ITEM 5	Generator-Equipped Service Truck	2004	2053	5,000	50	250,000	50	5,000	2004	5,000	5,000	5,000	5,000	5,000
6)	LINE ITEM 6	Sewer maintenance ($0.50/lf)	2004	2053	60,105	50	3,005,250	50	60,105	2004	60,105	60,105	60,105	60,105	60,105
						TOTAL O&M	$14,049,259				$280,985	$280,985	$280,985	$280,985	$280,985

Total Annual Cost $280,985

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000

6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356
55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400
54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105
$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000

6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356
55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400
54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105
$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985

MASTER SPREADSHEET - ALTERNATIVE 3

This data is used to calculate the NPV. Do not touch.

Capital Costs:	NPV:	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pipeline and Non-Mech.	$9,446,133	$9,939,780	$4,969,890	$4,969,890																			
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pump Stations - Non-Mech.	$1,203,126	$1,266,000	633,000	633,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump Stations - Mech. Equip.	$838,197	$882,000	441,000	441,000																			
Replacement	$314,712	$529,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Non-Mech.	$2,131,129	$2,242,500	1,121,250	1,121,250																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Mech. Equip.	$2,131,129	$2,242,500	1,121,250	1,121,250																			
Replacement	$2,322,696	$1,188,525	0	0	0	0	0	0	0	0	0	0	1,188,525	0	0	0	0	0	0	0	0	0	1,188,525
Replace Main SL PS	$456,161	$480,000	240,000	240,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Fac. - Non-Mech.	$0	$0	0	0																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Fac. - Mech. Equip.	$136,848	$144,000	72,000	72,000																			
Replacement	$51,382	$86,400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land acquisition	$570,202	$600,000	300,000	300,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Reserve	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineering and CM Costs		$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW - CAPITAL			$8,896,390	$8,896,390	$0	$0	$0	$0	$0	$0	$0	$0	$1,188,525	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,188,525

TOTAL CAPITAL COSTS	$19,500,965
Net Present Value - Capital	$10,601,714

Operating Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Labor	$2,400,107	$5,000,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
Electricity	$152,581	$317,822	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358	6,358
Chemical addition	$1,329,659	$2,770,000	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400
General O&M	$1,299,026	$2,706,188	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124
Generator-Equipped Service Truck	$120,005	$250,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Sewer maintenance ($2.50/lf)	$1,442,564	$3,005,250	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105
TOTAL CASH FLOW - O & M			$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985

TOTAL O & M COSTS	$14,049,259
Net Present Value - O & M	8,743,945

TOTAL NPV →	Capital Costs	$19,601,714
	O & M Costs	$8,743,945
	TOTAL:	$28,345,659

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	529,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1,188,525	0	0	0	0	0	0	0	0	0	1,188,525	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	88,400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$0	$615,600	$0	$0	$0	$0	$1,188,525	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,188,525	$0	$0	$0	$0	$0	$0	$0

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356	6,356
55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400
54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124	54,124
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105
$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985	$280,985

2052	2053	ZERO
$0	$0	
0	0	
0	529,200	
0	0	
0	1,166,525	
0	0	
0	0	
0	86,400	
0	0	
0	0	
0	0	
0	0	
$0	$1,804,125	

2052	2053	CHECK
$100,000	$100,000	
8,358	8,358	
55,400	55,400	
54,124	54,124	
5,000	5,000	
60,105	60,105	
$280,985	$280,985	TOTAL CHECK

Alternative 3A

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3A - Gravity & LP Sewers - Five Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
1	Harrison Rd.	1.5	325	LP	$40		$13,000
		2	325	LP	$40		$13,000
		2.5	270	LP	$45		$12,150
	Cottage Lane	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	200	LP	$45		$9,000
	Route 28 (Harrison to Phinney's)	8	1,900	< 10	$90		$171,000
	Route 28 (W. Main St. to Harrison)	8	140	< 10	$90		$12,600
	Sachem Drive	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	830	LP	$45		$37,350
		3	230	LP	$45		$10,350
	Phinney's Lane (Rt. 28 to PS)	8	1,380	< 10	$90		$124,200
	Piney Point Drive	1.5	295	LP	$40		$11,800
		2	295	LP	$40		$11,800
		2.5	420	LP	$45		$18,900
	Pine Street (High Point to Long Pond Cir.)	8	850	< 10	$90		$76,500
		8	520	10 - < 15	$100		$52,000
		8	20	15-<20	$115		$2,300
	Long Pond Circle	8	770	< 10	$90		$69,300
		8	410	10 - < 15	$100		$41,000
		8	80	15 - < 20	$115		$9,200
	Pine Street (Long Pond Circle to PS)	8	290	< 10	$90		$26,100
		8	120	15 - < 20	$115		$13,800
		8	280	20 - 25	$140		$39,200
	Gravity sewer manholes				$2,000	26	$52,960
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	9	$45,000
	Force main	4	3,400		$50		$170,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pumping Station (119 gpm)						$260,000
Subtotal			**14,400**				**$1,494,510**
2	Dunaskin Rd.	8	520	< 10	$90		$46,800
		1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	350	LP	$45		$15,750
	Pine Street (High Point to Blantyre Ave.)	8	500	< 10	$90		$45,000
	Blantyre Avenue	8	260	< 10	$90		$23,400
		8	200	10 - < 15	$100		$20,000
		8	410	15 - < 20	$115		$47,150
		8	180	20 - 25	$140		$25,200
	Argyle Ave.	8	320	<10	$90		$28,800
	Pine Street (Blantyre Ave. to PS) from west	8	380	15 - < 20	$115		$43,700
	Horatio Lane	8	410	< 10	$90		$36,900
		8	80	10 - < 15	$100		$8,000
		1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	250	LP	$45		$11,250
	Pine Street (Horatio to Herring Run Dr.)	8	300	10 - < 15	$100		$30,000
		8	150	15 - < 20	$115		$17,250

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3A - Gravity & LP Sewers - Five Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Herring Run Drive	1.5	445	LP	$40		$17,800
		2	445	LP	$40		$17,800
		2.5	450	LP	$45		$20,250
	Pine Street (Herring Run to Pondview Dr.)	8	70	< 10	$90		$6,300
		8	520	10 - < 15	$100		$52,000
	Pondview Drive	8	1,070	< 10	$90		$96,300
		8	700	10 - < 15	$100		$70,000
		8	190	15 - < 20	$115		$21,850
	Holly Lane	8	30	< 10	$90		$2,700
		8	580	10 - < 15	$100		$58,000
		8	310	15 - < 20	$115		$35,650
	Pine Street (Pondview to PS)	8	90	10 - < 15	$100		$9,000
		8	70	15 - < 20	$115		$8,050
	Gravity sewer manholes				$2,000	29	$58,720
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	4	$20,000
	Force main	4	2,600		$50		$130,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pump Station (57 gpm)						$250,000
Subtotal			**12,360**				**$1,462,820**
3	Center Lane	8	120	< 10	$90		$10,800
		1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	300	LP	$45		$13,500
	Connors Road	8	1,180	< 10	$90		$106,200
		8	710	10 - < 15	$100		$71,000
		8	380	15 - < 20	$115		$43,700
		8	230	20 - 25	$140		$32,200
	Phinney's Lane (Conners to PS)	8	330	< 10	$90		$29,700
		8	140	10 - < 15	$100		$14,000
		8	200	15 - < 20	$115		$23,000
		8	50	20 - 25	$140		$7,000
	Phinney's Lane (PS to Old Farm Rd.)	8	80	15 - < 20	$115		$9,200
	Phinney's Lane (Old Farm Rd. to Loomis)	8	610	15 - < 20	$115		$70,150
		8	260	20 - 25	$140		$36,400
	Phinney's Lane (Loomis to Strawberry)	8	250	20 - 25	$140		$35,000
	Loomis Lane	8	260	< 10	$90		$23,400
		8	360	10 - < 15	$100		$36,000
		8	360	15 - < 20	$115		$41,400
		8	250	20 - 25	$140		$35,000
	Richards Lane	8	290	< 10	$90		$26,100
		8	70	10 - < 15	$100		$7,000
		8	230	15 - < 20	$115		$26,450
	Old Farm Road	8	460	< 10	$90		$41,400
		8	260	10 - < 15	$100		$26,000
		8	130	15 - < 20	$115		$14,950
		8	270	20 - 25	$140		$37,800
	Crosby Road	8	360	< 10	$90		$32,400
	Tellegen Trail	8	740	< 10	$90		$66,600
		8	40	10 - < 15	$100		$4,000
	Sail-a-way	8	480	< 10	$90		$43,200

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3A - Gravity & LP Sewers - Five Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Phinney's Lane (Strawberry to Tellegen)	8	230	10 - < 15	$100		$23,000
		8	370	15 - < 20	$115		$42,550
		8	340	20 - 25	$140		$47,600
	Phinney's Lane (Tellegen to Crosby)	8	780	< 10	$90		$70,200
		8	40	10 - < 15	$100		$4,000
	Gravity sewer manholes				$2,000	43	$86,880
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	1	$5,000
	Force main	6	6,500		$60		$390,000
	Odor control feed equipment						$60,000
	Cofferdam for pump station						$80,000
	Land acquisition						$100,000
	Pumping Station (283 gpm)						$290,000
Subtotal			**18,010**				**$2,176,780**
4	Yatch Club Road	1.5	135	LP	$40		$5,400
		2	135	LP	$40		$5,400
	Indian Trail	1.5	80	LP	$40		$3,200
		2	80	LP	$40		$3,200
		2.5	120	LP	$45		$5,400
	Old Way	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
	Red Wing Trail	1.5	75	LP	$40		$3,000
		2	75	LP	$40		$3,000
		2.5	120	LP	$45		$5,400
	Johny Cake Road	1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	170	LP	$45		$7,650
	Annable Point Road	1.5	225	LP	$40		$9,000
		2	225	LP	$40		$9,000
		2.5	260	LP	$45		$11,700
		3	1,060	LP	$45		$47,700
	Willow Run (End of AOC to Thread Needle)	8	210	< 10	$90		$18,900
	Willow Run (end to Thread Needle)	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	370	LP	$45		$16,650
		3	250	LP	$45		$11,250
	Thread Needle Lane	8	560	< 10	$90		$50,400
		8	390	10 - < 15	$100		$39,000
	Great Marsh Road (Thread Needle to Hayes Road)	8	1,160	10 - < 15	$100		$116,000
	Hayes Road	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	450	LP	$45		$20,250
		3	560	LP	$45		$25,200
	Great Marsh / Juniper (Hayes to Laurel)	8	180	10 - < 15	$100		$18,000
		8	910	15 - < 20	$115		$104,650
	Laurel Road	8	240	<10	$90		$21,600
		8	440	10-<15	$100		$44,000
	Juniper Road (Laurel to Lake Dr.)	8	320	10 - < 15	$100		$32,000
	Point of Pines Ave.	8	770	< 10	$90		$69,300
		8	380	10 - < 15	$100		$38,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3A - Gravity & LP Sewers - Five Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Juniper (Point of Pines to Lake Dr.)	8	180	< 10	$90		$16,200
		8	140	10 - < 15	$100		$14,000
	Lake Drive (Juniper to PS)	8	310	10 - < 15	$100		$31,000
	Brezner Lane (Northern part)	8	240	< 10	$90		$21,600
	Pond Street	8	450	< 10	$90		$40,500
			60	10 - < 15	$100		$6,000
	Lake Drive (Pond St. to PS)	8	350	10 - < 15	$100		$35,000
	Lake Drive (end to Pond St.)	8	140	< 10	$90		$12,600
		8	30	10 - < 15	$100		$3,000
	Gravity sewer manholes				$2,000	30	$59,680
	Grinder pumps				$7,500	0	$0
	Force main	4	850		$50		$42,500
	Air release/cleanout manholes				$5,000	11	$55,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pumping Station (169 gpm)						$270,000
Subtotal			**13,930**				**$1,570,530**
5	Lakewood Drive	1.5	115	LP	$40		$4,600
		2	115	LP	$40		$4,600
		2.5	300	LP	$45		$13,500
		3	600	LP	$45		$27,000
	Shootflying Hill Road (Lakewood to Tern Lane)	3	1,280	LP	$45		$57,600
	Tern Lane	1.5	340	LP	$40		$13,600
		2	340	LP	$40		$13,600
		2.5	290	LP	$45		$13,050
		3	1,080	LP	$45		$48,600
	Shootflying Hill Road (Tern Ln. to Johnson Ln.)	4	1,060	LP	$50		$53,000
	Johnson Lane	1.5	110	LP	$40		$4,400
		2	110	LP	$40		$4,400
		2.5	260	LP	$45		$11,700
	Shootflying Hill Road (Johnson Ln. to Lakeview Dr.)	4	2,330	LP	$50		$116,500
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	11	$55,000
Subtotal			**8,330**				**$441,150**
6	Shootflying Hill Rd. to Lakeview Dr.	4	100	LP	$50		$5,000
	Lakeview Avenue	4	1,800	LP	$50		$90,000
	Pleasant Pines (Shootflying to Lakeview)	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	450	LP	$50		$22,500
	Pleasnt Pines (Lakeview to Nyes Neck)	4	870	LP	$50		$43,500
	Nyes Neck Rd. (East)	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	950	LP	$45		$42,750
	Nyes Neck Rd. (West)	1.5	435	LP	$40		$17,400
		2	435	LP	$40		$17,400
		2.5	1,090	LP	$45		$49,050
	Nyes Neck Rd. (where east & west combine to Nyes Point Way)	3	640	LP	$45		$28,800
	Nyes Point Way	1.5	175	LP	$40		$7,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3A - Gravity & LP Sewers - Five Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2	175	LP	$40		$7,000
		2.5	330	LP	$45		$14,850
	Nyes Neck Rd. (Nyes Point Way to Shirley Point Rd.)	3	450	LP	$45		$20,250
	Shirley Point Road	1.5	175	LP	$40		$7,000
		2	175	LP	$40		
		2.5	260	LP	$45		$11,700
	Nyes Neck Rd. (Shirley Point to Pleasant Pines)	3	100	LP	$45		$4,500
		4	500	LP	$50		$25,000
	Pleasant Pines (Nyes Neck to SA7)	4	980	LP	$50		$49,000
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	13	$65,000
Subtotal			**11,140**				**$569,700**
7	Pleasant Pines (SA6 to Bunny Lane)	4	720	LP	$50		$36,000
	Chickadee Lane	1.5	200	LP	$40		$8,000
		2	200	LP	$40		$8,000
	Bunny Run (End to Chickadee)	1.5	265	LP	$40		$10,600
		2	265	LP	$40		$10,600
	Bunny Run (Chickadee to Point of Pines)	2.5	260	LP	$45		$11,700
	Pleasant Pines (Bunny Run to Huckins Neck)	4	180	LP	$50		$9,000
	Shallow Pond	1.5	280	LP	$40		$11,200
		2	280	LP	$40		$11,200
		2.5	1,070	LP	$45		$48,150
	Huckins Neck Rd. (Rte 132 to Water View Circle)	6	1,070	LP	$60		$64,200
	Water View Circle	1.5	200	LP	$40		$8,000
		2	200	LP	$40		$8,000
		2.5	540	LP	$45		$24,300
	Blue Water Drive	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	720	LP	$45		$32,400
	Pondside Circle	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	740	LP	$45		$33,300
	Huckins Neck Road (Water View to Holly Point)	4	2,180	LP	$50		$109,000
	Holly Point Road	1.5	300	LP	$40		$12,000
		2	300	LP	$40		$12,000
		2.5	720	LP	$45		$32,400
		3	290	LP	$45		$13,050
	Huckins Neck Road (Holly Point to Lakeside Dr. East)	4	1,360	LP	$50		$68,000
	Beachwood - South of Huckins Neck (High Point to Huckins Neck)	1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	350	LP	$45		$15,750
	Huckins Neck (Conners to Beechwood)	2.5	230	LP	$45		$10,350
		1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3A - Gravity & LP Sewers - Five Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Beechwood (North of Huckins Neck)	1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
	Huckins Neck (Cottonwood to Lakeside Drive East)	3	400	LP	$45		$18,000
	Cottonwood	1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	500	LP	$45		$22,500
	Huckins Neck (Beachwood to Cottonwood)	3	670	LP	$45		$30,150
	Lakeside Drive West	1.5	465	LP	$40		$18,600
		2	465	LP	$40		$18,600
		2.5	1,140	LP	$45		$51,300
		3	430	LP	$45		$19,350
	Vine Street	1.5	65	LP	$40		$2,600
		2	65	LP	$40		$2,600
	Lakeside Drive East	4	1,400	LP	$50		$70,000
	Holly Point Road (Vine St. to Lakeside Drive East)	1.5	185	LP	$40		$7,400
		2	185	LP	$40		$7,400
		2.5	800	LP	$45		$36,000
		3	420	LP	$45		$18,900
	Lakeview Avenue	2.5	880	LP	$45		$39,600
	Grinder pumps				$7,500	0	$0
	Force main	10	100		$90		$9,000
	Air release/cleanout manholes				$5,000	32	$160,000
	Odor control feed equipment						$60,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pump Station (593 gpm)						$400,000
Subtotal			**23,240**				**$1,835,200**
8	Goose Point Road	1.5	220	LP	$40		$8,800
		2	220	LP	$40		$8,800
	Crestview Circle	2.5	890	LP	$45		$40,050
	Regatta Drive (Phinney's La. To Crestview Cir.)	1.5	180	LP	$40		$7,200
		2	180	LP	$40		$7,200
		2.5	500	LP	$45		$22,500
	Dacey Lane	1.5	120	LP	$40		$4,800
		2	120	LP	$40		$4,800
	Regatta Drive (Crestview Cir. To Old Strawberry Hill Rd.)	3	530	LP	$45		$23,850
	Old Strawberry Hill Road (Regatta Dr. to Rte. 132)	3	730	LP	$45		$32,850
		4	1,160	LP	$50		$58,000
	Route 132	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	1,000	LP	$45		$45,000
		3	660	LP	$45		$29,700
	Grinder pumps				$7,500	0	$0
	Grinder pumps at condominium				$15,000	0	$0
	Air release/cleanout manholes				$5,000	8	$40,000
Subtotal			**6,810**				**$345,550**
9	Scottsdale Circle	1.5	145	LP	$40		$5,800
		2	145	LP	$40		$5,800
		2.5	180	LP	$45		$8,100
	Route 28 (FM to Kenesaw)	8	1,640	< 10	$90		$147,600

Engineer's Opinion of Probable Capital Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 3A - Gravity & LP Sewers - Five Pump Stations (Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Childs Street (FM to Kenesaw/ Rt. 28)	8	620	< 10	$90		$55,800
		8	180	10 - < 15	$100		$18,000
	Route 28 (Kenesaw to Existing Pipe)	8	330	< 10	$90		$29,700
		8	280	10 - < 15	$100		$28,000
		8	770	15 - < 20	$115		$88,550
	Gravity sewer manholes				$2,000	15	$30,560
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	1	$5,000
Subtotal			**4,290**				**$422,910**
Incremental Cost to increase CCCC force main from 4 inch diameter							
	Huckins Neck Rd. to Phinney's Lane	10	5,300		$40		$212,000
	Phinney's Lane to existing 12" FM	12	1,000		$50		$50,000
Subtotal			**6,300**				**$262,000**
Houses adjacent to gravity sewers requiring pumping							
	Grinder pumps				$7,500	0	**$0**
Improvements to existing sewerage system							
Replace Main St. Pump Station							$400,000
Divert pumped flow to Old Colony Rd. PS FM		8	1,400		$80		$112,000
Subtotal							**$512,000**
Total			**120,210**				**$11,093,150**

LIFE CYCLE COST ANALYSIS SUMMARY SHEET
ALTERNATIVE 3A - Grinder Pumps Purchased and Maintained by Residents

Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
Preparer: DJP/DRP
Date: 29-Aug-03

CAPITAL COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.33%
Effective Discount Rate:	3.46%
Terms of Analysis (years)	50
Construction Duration (years):	2
Replacement Cost Period:	
Base Construction Cost:	$13,311,780
Misc. Reserve Prelim. Design	$0
Engineering Cost:	$0
Replacement Capital Cost:	$615,600
Total Capital Cost:	$13,927,380
Total NPV- Capital Cost:	$13,016,760

OPERATING COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.42%
Effective Discount Rate:	3.37%
Terms of Analysis:	50
Labor Cost/year:	$25,000
Total Labor Cost:	$1,250,000
Total O& M Cost/year:	$160,046
Total O & M Cost:	$8,002,321
Total NPV - O & M Co	$3,841,285

	Total Cost	NPV
Capital Costs	$13,927,380	$13,016,760
O & M Costs	$8,002,321	$3,841,285
TOTAL:	$21,929,701	$16,858,045

Notes/Assumptions:

ECONOMIC ASSUMPTIONS - ALTERNATIVE 3A - Grinder Pumps Purchased and Maintained by Residents

CAPITAL COSTS:	
*Discount rate:	5.875%
Inflation rate:	2.33%
**Effective Discount rate:	3.46%

OPERATIONS & MAINTENANCE:	
*Discount rate:	5.875%
Inflation rate:	2.42%
**Effective Discount rate:	3.37%

*** Term of analysis:	50 years

Average Salary:	$50,000

NOTE:

* The discount rate reflects the long-term cost of capital.

** The effective discount rate anticipates the effect of the time value of money and inflation by removing inflation from the discount rate.

*** The analysis period for the project is 50 years.

PROJECT INFORMATION

1) Preparer: DJP/DRP
2) Name of Capital Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
3) List Assumptions Below:

Input cells are highlighed in light yellow.

CAPITAL COSTS WORKSHEET - ALTERNATIVE 3A

1) Enter First Year of Capital Spending: 2004

2) Using table below, enter project Design Status. Prelim. Design

Design Status	Miscellaneous Reserve
Prelim. Design	Add 20%
50-75% Design	Add 15%
90-95% Design	Add 10%
100% Design	Add 10%

CAPITAL COST

		Capital Cost Line Item	Useful Life See menu below	Base Construction Costs	Construction Schedule START	Construction Schedule END	IS REPLACEMENT COST NEEDED? IF YES, THEN INPUT COST IN CELL TO RIGHT	REPLACEMENT COSTS (Input Replacement Costs)	BASE CONSTRUCTION COST: Spread over ____ years	Spread per year	Beginning in Year ____	REPLACEMENT: Replace in Year ____	Replace in Year ____		Replace in Year ____	Replace in Year ____	2004	2005	2006	2007	2008	2009	2010	2011	2012
3)	LINE ITEM 1:	Pipeline and Non-Mech.	50	38,839,780	2004	2005	NO REPLACEMENT	0	2	4,969,890	2004	0					4,969,890	4,969,890							
																	0	0	0	0	0	0	0	0	0
4)	LINE ITEM 2:	Pump Stations - Non-Mech.	50	$1,266,000	2004	2005	NO REPLACEMENT	0	2	633,000	2004	0					633,000	633,000							
																	0	0	0	0	0	0	0	0	0
5)	LINE ITEM 3:	Pump Stations - Mech. Equip.	25	$882,000	2004	2005	REPLACEMENT >>>>>>	529,200	2	441,000	2004	2029	2053				441,000	441,000							
																	0	0	0	0	0	0	0	0	0
6)	LINE ITEM 4:	Grinder Pumps - Non-Mech.	50	$0	2004	2005	NO REPLACEMENT	0	2	0	2004	0					0	0							
																	0	0	0	0	0	0	0	0	0
7)	LINE ITEM 5:	Grinder Pumps - Mech. Equip.	10	$0	2004	2005	REPLACEMENT >>>>>>	0	2	0	2004	2014	2024	2034	2044	2053	0	0							
																	0	0	0	0	0	0	0	0	0
8)	LINE ITEM 6:	Replace Main St. PS		$480,000	2004	2005	REPLACEMENT >>>>>>		1	240,000	2004	2005					240,000	240,000							
																	0	0	0	0	0	0	0	0	0
9)	LINE ITEM 7:	Odor Control Fac. - Non-Mech.	50	$0	2004	2005	NO REPLACEMENT	0	2	0	2004	0					0	0							
																	0	0	0	0	0	0	0	0	0
10)	LINE ITEM 8:	Odor Control Fac. - Mech. Equip.	25	$144,000	2004	2005	REPLACEMENT >>>>>>	86,400	2	72,000	2004	2029	2053				72,000	72,000							
																	0	0	0	0	0	0	0	0	0
11)	LINE ITEM 9:	Land acquisition	50	$600,000	2004	2005	NO REPLACEMENT		1	300,000	2004	0					300,000	300,000							
																	0	0	0	0	0	0	0	0	0
12)	LINE ITEM 10:						REPLACEMENT >>>>>>		1	0	0	0													
																	0	0	0	0	0	0	0	0	0
																	6,655,890	6,655,890	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	0
																	$6,655,890	$6,655,890	$0	$0	$0	$0	$0	$0	$0

13)	FIXED LINE ITEM	Base Construction Cost	13,311,780
14)	FIXED LINE ITEM	Replacement Costs	615,600
15)	FIXED LINE ITEM	Miscellaneous Reserve	0
16)	FIXED LINE ITEM	Engineering and CM Costs	0

TOTAL CAPITAL COST $13,927,380

Expected Useful Life

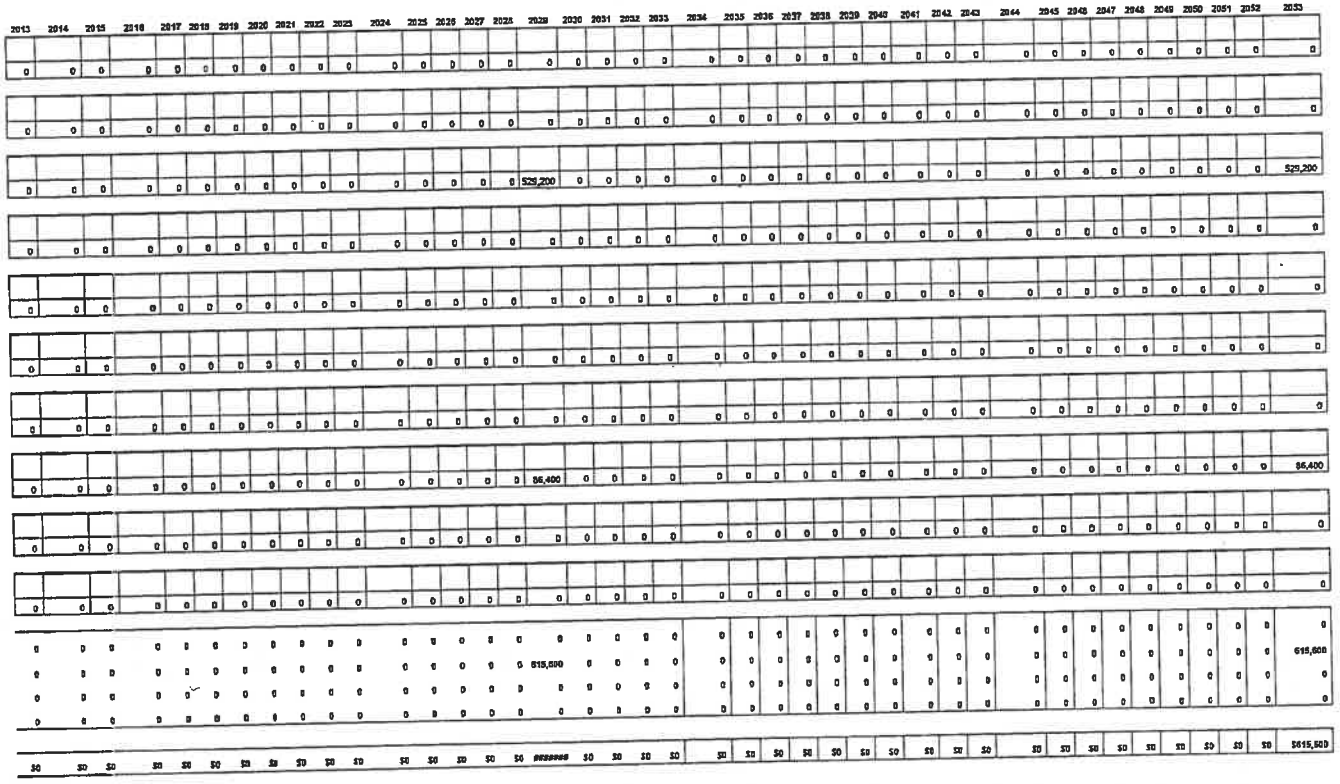
Type of Capital Improvement	Expected Useful Life (in years)
Pump station equip.	25
Grinder pump equip.	10
Pipeline	50
Pump station superstructure	50

Replacement Costs: The analysis will include equipment replacement costs required during the period of the analysis.

Salvage value: Zero salvage values assumed in this analysis

8/29/03

J:\8331\Cost\LifeCycleCosts-Alt3A-NoCPs.xls\Input Capital



OPERATIONS AND MAINTENANCE COSTS WORKSHEET - ALTERNATIVE 3A

	O&M Cost Categories	Period (Calendar Yr.) From	To	Labor - FTE	Average Salary	Labor Cost Dollars per year	Total Labor Cost	A Spread over ..... many years	B Spread per year	C Beginning in Year	2004	2005	2006	2007	2008
1)	LINE ITEM 1 Labor	2004	2053	1	25,000	25,000	1,250,000	50	25,000	2004	25,000	25,000	25,000	25,000	25,000

Enter first year of O&M costs here:

(for each individual line item)

				Cost per year	Number of Years	Total Cost								
2)	LINE ITEM 2 Electricity	2004	2053	1,073	50	53,671	50	1,073	2004	1,073	1,073	1,073	1,073	1,073
3)	LINE ITEM 3 Chemical addition	2004	2053	55,400	50	2,770,000	50	55,400	2004	55,400	55,400	55,400	55,400	55,400
4)	LINE ITEM 4 General O&M	2004	2053	18,468	50	923,400	50	18,468	2004	18,468	18,468	18,468	18,468	18,468
5)	LINE ITEM 5 Generator-Equipped Service Truck	2004	2053	0	50	0	50	0	2004	0	0	0	0	0
6)	LINE ITEM 6 Sewer maintenance ($0.50/lf)	2004	2053	60,105	50	3,005,250	50	60,105	2004	60,105	60,105	60,105	60,105	60,105
					TOTAL O&M	$8,002,321				$160,046	$160,046	$160,046	$160,046	$160,046

Total Annual Cost **$160,046**

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000

1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400
18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105
$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000

1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400
18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105
$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046

MASTER SPREADSHEET - ALTERNATIVE 3A

This data is used to calculate the NPV. Do not touch.

Capital Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pipeline and Non-Mech.	$9,448,133	$9,939,780	$4,969,890	$4,969,890																			
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pump Stations - Non-Mech.	$1,209,126	$1,256,000	633,000	633,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump Stations - Mech. Equip.	$838,197	$882,000	441,000	441,000																			
Replacement	$314,712	$529,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Non-Mech.	$0	$0	0	0																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Mech. Equip.	$0	$0	0	0																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Replace Main St. PS	$458,151	$480,000	240,000	240,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Fac. - Non-Mech.	$0	$0	0	0																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Fac. - Mech. Equip.	$136,846	$144,000	72,000	72,000																			
Replacement	$51,382	$88,400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land acquisition	$570,202	$600,000	300,000	300,000																			
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0																					
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Reserve	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineering and CM Costs		$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW - CAPITAL			$5,655,890	$5,655,890	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL CAPITAL COSTS	$13,927,380																						
Net Present Value - Capital	$13,016,760																						

Operating Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Labor	$800,027	$1,250,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Electricity	$25,763	$33,671	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
Chemical addition	$1,329,059	$2,770,000	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400
General O&M	$443,252	$923,400	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468
Generator-Equipped Service Truck	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sewer maintenance (50,000)	$1,442,594	$3,005,250	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105
TOTAL CASH FLOW - O & M			$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046
TOTAL O & M COSTS	$8,002,321																						
Net Present Value - O & M	3,841,285																						

TOTAL NPV →	Capital Costs	$13,016,760
	O & M Costs	$3,841,285
	TOTAL	$16,858,045

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
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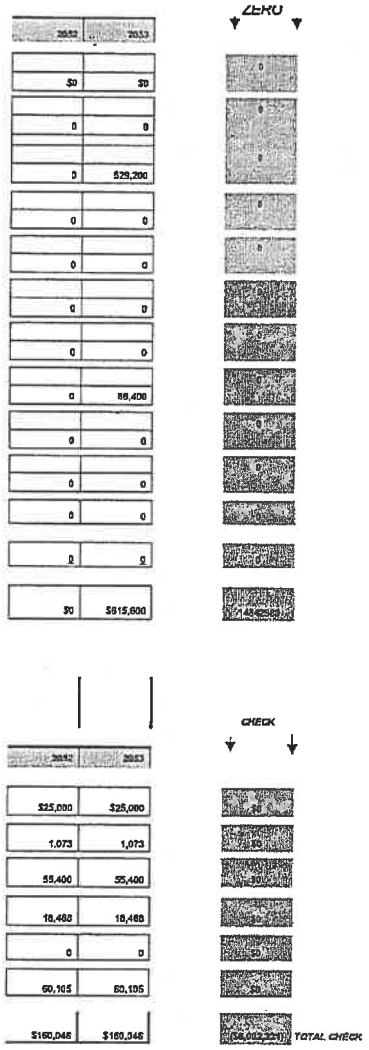
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$0	$615,600	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400	55,400
18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468	18,468
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105	60,105
$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046	$160,046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Alternative 4

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4 - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
1	Harrison Rd.	1.5	325	LP	$40		$13,000
		2	325	LP	$40		$13,000
		2.5	270	LP	$45		$12,150
	Cottage Lane	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
		2.5	200	LP	$45		$9,000
	Route 28 (Harrison to Phinney's)	8	1,900	< 10	$90		$171,000
	Route 28 (W. Main St. to Harrison)	8	140	< 10	$90		$12,600
	Sachem Drive	1.5	400	LP	$40		$16,000
		2	400	LP	$40		$16,000
		2.5	830	LP	$45		$37,350
		3	230	LP	$45		$10,350
	Phinney's Lane (Rt. 28 to PS)	8	1,380	< 10	$90		$124,200
	Piney Point Drive	1.5	295	LP	$40		$11,800
		2	295	LP	$40		$11,800
		2.5	420	LP	$45		$18,900
	Pine Street (High Point to Long Pond Cir.)	8	850	< 10	$90		$76,500
		8	520	10 - < 15	$100		$52,000
		8	20	15-<20	$115		$2,300
	Long Pond Circle	8	770	< 10	$90		$69,300
		8	410	10 - < 15	$100		$41,000
		8	80	15 - < 20	$115		$9,200
	Pine Street (Long Pond Circle to PS)	8	290	< 10	$90		$26,100
		8	120	15 - < 20	$115		$13,800
		8	280	20 - 25	$140		$39,200
	Gravity sewer manholes				$2,000	26	$52,960
	Grinder pumps				$7,500	45	$337,500
	Air release/cleanout manholes				$5,000	9	$45,000
	Force main	4	3,400		$50		$170,000
	Cofferdam for pump station						$50,000
	Land acquisition						$100,000
	Pumping Station (119 gpm)						$260,000
Subtotal			**14,400**				**$1,832,010**
2	Dunaskin Rd.	8	520	< 10	$90		$46,800
		1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	350	LP	$45		$15,750
	Pine Street (High Point to Blantyre Ave.)	8	500	< 10	$90		$45,000
	Blantyre Avenue	8	260	< 10	$90		$23,400
		8	200	10 - < 15	$100		$20,000
		8	410	15 - < 20	$115		$47,150
		8	180	20 - 25	$140		$25,200
	Argyle Ave.	8	320	<10	$90		$28,800

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4 - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Pine Street (Blantyre Ave. to PS) from west	8	380	15 - < 20	$115		$43,700
	Horatio Lane	8	410	< 10	$90		$36,900
		8	80	10 - < 15	$100		$8,000
		1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	250	LP	$45		$11,250
	Pine Street (Horatio to Herring Run Dr.)	8	300	10 - < 15	$100		$30,000
		8	150	15 - < 20	$115		$17,250
	Herring Run Drive	1.5	445	LP	$40		$17,800
		2	445	LP	$40		$17,800
		2.5	450	LP	$45		$20,250
	Pine Street (Herring Run to Pondview Dr.)	8	70	< 10	$90		$6,300
		8	520	10 - < 15	$100		$52,000
	Pondview Drive	8	1,070	< 10	$90		$96,300
		8	700	10 - < 15	$100		$70,000
		8	190	15 - < 20	$115		$21,850
	Holly Lane	8	30	< 10	$90		$2,700
		8	580	10 - < 15	$100		$58,000
		8	310	15 - < 20	$115		$35,650
	Pine Street (Pondview to PS)	8	90	10 - < 15	$100		$9,000
		8	70	15 - < 20	$115		$8,050
	Gravity sewer manholes				$2,000	29	$58,720
	Grinder pumps				$7,500	14	$105,000
	Air release/cleanout manholes				$5,000	4	$20,000
	Force main	4	2,600		$50		$130,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pump Station (57 gpm)						$250,000
Subtotal			**12,360**				**$1,567,820**
3	Center Lane	8	120	< 10	$90		$10,800
		1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	300	LP	$45		$13,500
	Connors Road	8	1,180	< 10	$90		$106,200
		8	710	10 - < 15	$100		$71,000
		8	380	15 - < 20	$115		$43,700
		8	230	20 - 25	$140		$32,200
	Phinney's Lane (Conners to PS)	8	330	< 10	$90		$29,700
		8	140	10 - < 15	$100		$14,000
		8	200	15 - < 20	$115		$23,000
		8	50	20 - 25	$140		$7,000
	Phinney's Lane (PS to Old Farm Rd.)	8	80	15 - < 20	$115		$9,200
	Phinney's Lane (Old Farm Rd. to Loomis)	8	610	15 - < 20	$115		$70,150
		8	260	20 - 25	$140		$36,400

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4 - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Phinney's Lane (Loomis to Strawberry)	8	250	20 - 25	$140		$35,000
	Loomis Lane	8	260	< 10	$90		$23,400
		8	360	10 - < 15	$100		$36,000
		8	360	15 - < 20	$115		$41,400
		8	250	20 - 25	$140		$35,000
	Richards Lane	8	290	< 10	$90		$26,100
		8	70	10 - < 15	$100		$7,000
		8	230	15 - < 20	$115		$26,450
	Old Farm Road	8	460	< 10	$90		$41,400
		8	260	10 - < 15	$100		$26,000
		8	130	15 - < 20	$115		$14,950
		8	270	20 - 25	$140		$37,800
	Crosby Road	8	360	< 10	$90		$32,400
	Tellegen Trail	8	740	< 10	$90		$66,600
		8	40	10 - < 15	$100		$4,000
	Sail-a-way	8	480	< 10	$90		$43,200
	Phinney's Lane (Strawberry to Tellegen)	8	230	10 - < 15	$100		$23,000
		8	370	15 - < 20	$115		$42,550
		8	340	20 - 25	$140		$47,600
	Phinney's Lane (Tellegen to Crosby)	8	780	< 10	$90		$70,200
		8	40	10 - < 15	$100		$4,000
	Gravity sewer manholes				$2,000	43	$86,880
	Grinder pumps				$7,500	4	$30,000
	Air release/cleanout manholes				$5,000	1	$5,000
	Force main	6	6,500		$60		$390,000
	Odor control feed equipment						$60,000
	Cofferdam for pump station						$80,000
	Land acquisition						$100,000
	Pumping Station (283 gpm)						$290,000
Subtotal			**18,010**				**$2,206,780**
4	Yatch Club Road	1.5	135	LP	$40		$5,400
		2	135	LP	$40		$5,400
	Indian Trail	1.5	80	LP	$40		$3,200
		2	80	LP	$40		$3,200
		2.5	120	LP	$45		$5,400
	Old Way	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
	Red Wing Trail	1.5	75	LP	$40		$3,000
		2	75	LP	$40		$3,000
		2.5	120	LP	$45		$5,400
	Johny Cake Road	1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	170	LP	$45		$7,650
	Annable Point Road	1.5	225	LP	$40		$9,000
		2	225	LP	$40		$9,000
		2.5	260	LP	$45		$11,700

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4 - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		3	1,060	LP	$45		$47,700
	Willow Run (End of AOC to Thread Needle)	8	210	< 10	$90		$18,900
	Willow Run (end to Thread Needle)	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	370	LP	$45		$16,650
		3	250	LP	$45		$11,250
	Thread Needle Lane	8	560	< 10	$90		$50,400
		8	390	10 - < 15	$100		$39,000
	Great Marsh Road (Thread Needle to Hayes Road)	8	1,160	10 - < 15	$100		$116,000
	Hayes Road	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	450	LP	$45		$20,250
		3	560	LP	$45		$25,200
	Great Marsh / Juniper (Hayes to Laurel)	8	180	10 - < 15	$100		$18,000
		8	910	15 - < 20	$115		$104,650
	Laurel Road	8	240	<10	$90		$21,600
		8	440	10-<15	$100		$44,000
	Juniper Road (Laurel to Lake Dr.)	8	320	10 - < 15	$100		$32,000
	Point of Pines Ave.	8	770	< 10	$90		$69,300
		8	380	10 - < 15	$100		$38,000
	Juniper (Point of Pines to Lake Dr.)	8	180	< 10	$90		$16,200
		8	140	10 - < 15	$100		$14,000
	Lake Drive (Juniper to PS)	8	310	10 - < 15	$100		$31,000
	Brezner Lane (Northern part)	8	240	< 10	$90		$21,600
	Pond Street	8	450	< 10	$90		$40,500
			60	10 - < 15	$100		$6,000
	Lake Drive (Pond St. to PS)	8	350	10 - < 15	$100		$35,000
	Lake Drive (end to Pond St.)	8	140	< 10	$90		$12,600
		8	30	10 - < 15	$100		$3,000
	Gravity sewer manholes				$2,000	30	$59,680
	Grinder pumps				$7,500	55	$412,500
	Force main	4	850		$50		$42,500
	Air release/cleanout manholes				$5,000	11	$55,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pumping Station (165 gpm)						$270,000
Subtotal			**13,930**				**$1,983,030**
5	Lakewood Drive	1.5	115	LP	$40		$4,600
		2	115	LP	$40		$4,600
		2.5	300	LP	$45		$13,500
		3	600	LP	$45		$27,000
	Shootflying Hill Road (Lakewood to Tern Lane)	3	1,280	LP	$45		$57,600
	Tern Lane	1.5	340	LP	$40		$13,600

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4 - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2	340	LP	$40		$13,600
		2.5	290	LP	$45		$13,050
		3	1,080	LP	$45		$48,600
	Shootflying Hill Road (Tern Ln. to Johnson Ln.)	4	1,060	LP	$50		$53,000
	Johnson Lane	1.5	110	LP	$40		$4,400
		2	110	LP	$40		$4,400
		2.5	260	LP	$45		$11,700
	Shootflying Hill Road (Johnson Ln. to Lakeview Dr.)	4	2,330	LP	$50		$116,500
	Odor control feed station						$100,000
	Grinder pumps				$7,500	46	$345,000
	Air release/cleanout manholes				$5,000	11	$55,000
Subtotal			**8,330**				**$886,150**
6	Shootflying Hill Road (F.M. to Lakeview Drive)	8	100	Vacuum	$100		$10,000
	Lakeview Avenue	8	1,800	Vacuum	$100		$180,000
	Pleasant Pines (Shootflying to Lakeview)	4	700	Vacuum	$90		$63,000
	Pleasant Pines (Lakeview to Nyes Neck)	8	870	Vacuum	$100		$87,000
	Nyes Neck Rd. (East)	4	1,750	Vacuum	$90		$157,500
	Nyes Neck Rd. (West)	4	1,960	Vacuum	$90		$176,400
	Nyes Neck Rd. (where east & west combine to Nyes Point Way)	6	640	Vacuum	$95		$60,800
	Nyes Point Way	4	680	Vacuum	$90		$61,200
	Nyes Neck Rd. (Nyes Point Way to Shirley Point Rd.)	6	450	Vacuum	$95		$42,750
	Shirley Point Road	4	610	Vacuum	$90		$54,900
	Nyes Neck Rd. (Shirley Point to Pleasant Pines)	6	600	Vacuum	$95		$57,000
	Pleasant Pines (Nyes Neck to PS) from west	10	330	Vacuum	$105		$34,650
	Pleasant Pines (Flow to PS) from east	4	650	Vacuum	$90		$58,500
	Valve pits				$6,000	67	$402,000
	Dual buffer tank				$33,000	1	$33,000
	Force main	6	2,700		$60		$162,000
	Cofferdam for vacuum station						$50,000
	Land acquisition						$100,000
	Vacuum Station (422 gpm)						$450,000
Subtotal			**13,840**				**$2,240,700**
7	Pleasant Pines (High Point to Bunny Run)	4	720	Vacuum	$90		$64,800
	Chickadee Lane	4	400	Vacuum	$90		$36,000
	Bunny Run (End to Chickadee)	4	530	Vacuum	$90		$47,700

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4 - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Bunny Run (Chickadee to Point of Pines)	4	260	Vacuum	$90		$23,400
	Pleasant Pines (Bunny Run to Huckins Neck)	4	180	Vacuum	$90		$16,200
	Shallow Pond	4	1,630	Vacuum	$90		$146,700
	Huckins Neck (Shallow Pond to Water View Circle)	4	510	Vacuum	$90		$45,900
	Water View Circle	4	940	Vacuum	$90		$84,600
	Blue Water Drive	8	1,220	Vacuum	$100		$122,000
	Blue Water-Iyannough- XC	8	650	Vacuum	$100		$65,000
	Pondside Circle	4	350	Vacuum	$90		$31,500
		8	640	Vacuum	$100		$64,000
	Huckins Neck Road (Water View to Vac Station)	4	930	Vacuum	$90		$83,700
		8	940	Vacuum	$100		$94,000
	Holly Point Road	4	3,200	Vacuum	$90		$288,000
	Cottonwood Rd.	4	850	Vacuum	$90		$76,500
	Huckins Neck Road (Connors to Beechwood)	6	580	Vacuum	$95		$55,100
	Huckins Neck Road (Beechwood to Cottonwood)	6	670	Vacuum	$95		$63,650
	Huckins Neck Road (Cottonwood to Lakeside Dr. East)	6	400	Vacuum	$95		$38,000
	Huckins Neck Road (Lakeside Dr. East to Vac Station)	8	1,670	Vacuum	$100		$167,000
	Beachwood - South of Huckins Neck (High Point to Huckins Neck)	4	700	Vacuum	$90		$63,000
	Beechwood - North of Huckins Neck	4	350	Vacuum	$90		$31,500
	Lakeside Drive West	4	2,500	Vacuum	$90		$225,000
	Vine Street	4	130	Vacuum	$90		$11,700
	Lakeside Drive East	6	1,400	Vacuum	$95		$133,000
	Lakeview Avenue	4	880	Vacuum	$90		$79,200
	Valve pits				$6,000	244	$1,464,000
	Force main	6	2,500		$60		$150,000
	Cofferdam for vacuum station						$50,000
	Land acquisition						$100,000
	Vacuum Station (171 gpm)						$350,000
Subtotal			**25,730**				**$4,271,150**
8	Goose Point Road	1.5	220	LP	$40		$8,800
		2	220	LP	$40		$8,800
	Crestview Circle	2.5	890	LP	$45		$40,050
	Regatta Drive (Phinney's La. To Crestview Cir.)	1.5	180	LP	$40		$7,200
		2	180	LP	$40		$7,200
		2.5	500	LP	$45		$22,500
	Dacey Lane	1.5	120	LP	$40		$4,800

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4 - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2	120	LP	$40		$4,800
	Regatta Drive (Crestview Cir. To Old Strawberry Hill Rd.)	3	530	LP	$45		$23,850
	Old Strawberry Hill Road (Regatta Dr. to Rte. 132)	3	730	LP	$45		$32,850
		4	1,160	LP	$50		$58,000
	Route 132	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	1,000	LP	$45		$45,000
		3	660	LP	$45		$29,700
	Grinder pumps				$7,500	50	$375,000
	Grinder pumps at condominium				$15,000	15	$225,000
	Air release/cleanout manholes				$5,000	8	$40,000
Subtotal			**6,810**				**$945,550**
9	Scottsdale Circle	1.5	145	LP	$40		$5,800
		2	145	LP	$40		$5,800
		2.5	180	LP	$45		$8,100
	Route 28 (FM to Kenesaw)	8	1,640	< 10	$90		$147,600
	Childs Street (FM to Kenesaw/ Rt. 28)	8	620	< 10	$90		$55,800
		8	180	10 - < 15	$100		$18,000
	Route 28 (Kenesaw to Existing Pipe)	8	330	< 10	$90		$29,700
		8	280	10 - < 15	$100		$28,000
		8	770	15 - < 20	$115		$88,550
	Gravity sewer manholes				$2,000	15	$30,560
	Grinder pumps				$7,500	4	$30,000
	Air release/cleanout manholes				$5,000	1	$5,000
Subtotal			**4,290**				**$452,910**
Incremental Cost to increase CCCC force main from 4 inch diameter							
	Huckins Neck Rd. to Phinney's Lane	10	5,300		$40		$212,000
	Phinney's Lane to existing 12" FM	12	1,000		$50		$50,000
Subtotal			**6,300**				**$262,000**
Houses adjacent to gravity sewers requiring pumping							
	Grinder pumps				$7,500	39	**$292,500**
Improvements to existing sewerage system							
Replace Main St. Pump Station							$400,000
Divert pumped flow to Old Colony Rd. PS FM		8	1,400		$80		$112,000
Subtotal							**$512,000**
Total			**125,400**				**$17,452,600**

LIFE CYCLE COST ANALYSIS SUMMARY SHEET - ALTERNATIVE 4

Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
Preparer: DJP/DRP
Date: 29-Aug-03

CAPITAL COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.33%
Effective Discount Rate:	3.46%
Terms of Analysis (years)	50
Construction Duration (years):	2
Replacement Cost Period:	

Base Construction Cost:	$20,512,620
Misc. Reserve Prelim. Design	$0
Engineering Cost:	$0
Replacement Capital Cost:	$1,916,201
Total Capital Cost:	$22,428,821
Total NPV- Capital Cost:	$21,730,510

OPERATING COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.42%
Effective Discount Rate:	3.37%
Terms of Analysis:	50
Labor Cost/year:	$100,000
Total Labor Cost:	$5,000,000
Total O& M Cost/year:	$234,957
Total O & M Cost:	$11,747,844
Total NPV - O & M Co	$5,639,217

	Total Cost	NPV
Capital Costs	$22,428,821	$21,730,510
O & M Costs	$11,747,844	$5,639,217
TOTAL:	$34,176,664	$27,369,727

Notes/Assumptions:

ECONOMIC ASSUMPTIONS - ALTERNATIVE 4

CAPITAL COSTS:	
*Discount rate:	5.875%
Inflation rate:	2.33%
**Effective Discount rate:	3.46%

OPERATIONS & MAINTENANCE:	
*Discount rate:	5.875%
Inflation rate:	2.42%
**Effective Discount rate:	3.37%

*** Term of analysis:	50 years

Average Salary:	$100,000

NOTE:

* The discount rate reflects the long-term cost of capital.

** The effective discount rate anticipates the effect of the time value of money and inflation by removing inflation from the discount rate.

*** The analysis period for the project is 50 years.

PROJECT INFORMATION

1) Preparer: DJP/DRP
2) Name of Capital Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
3) List Assumptions Below:

Input cells are highlighed in light yellow.

CAPITAL COSTS WORKSHEET - ALTERNATIVE 4

1) Enter First Year of Capital Spending: 2004

2) Using table below, enter project Design Status. Prelim. Design

Design Status	Miscellaneous Reserve
Prelim. Design	Add 20%
50-75% Design	Add 15%
90-95% Design	Add 10%
100% Design	Add 10%

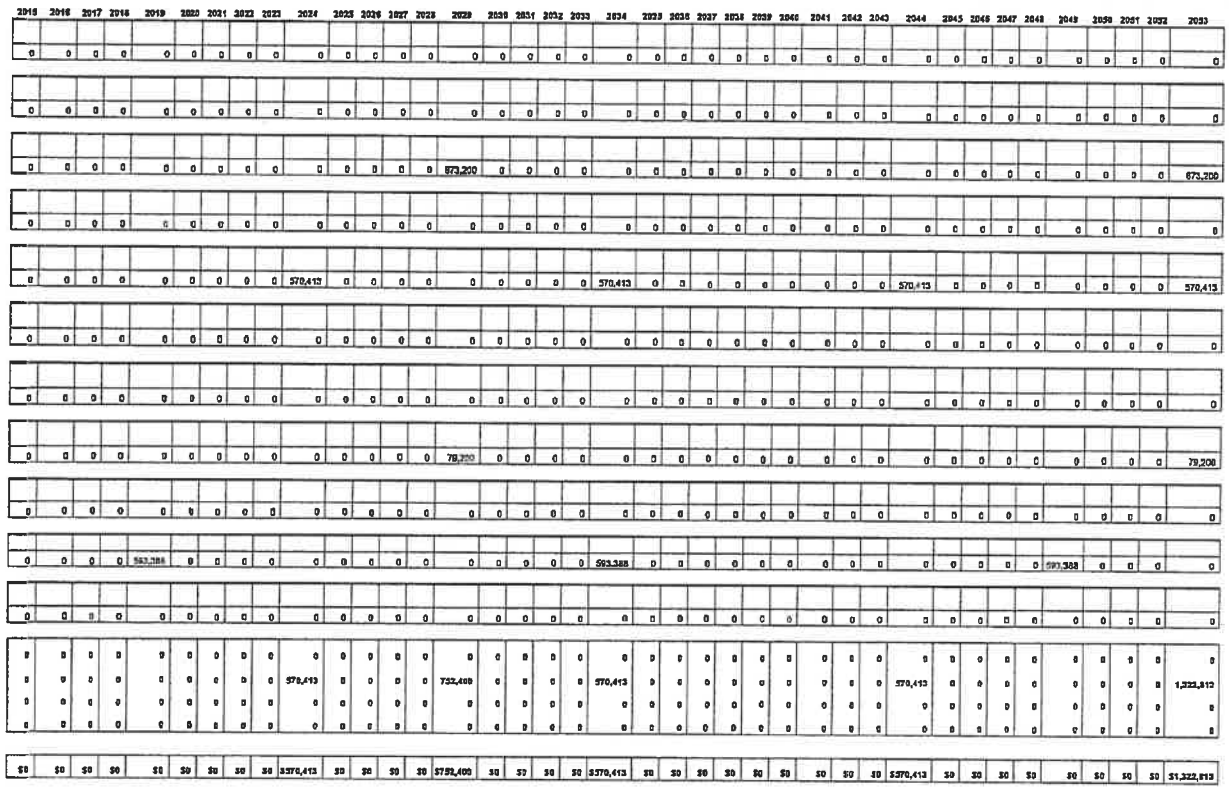
CAPITAL COST

		Capital Cost Line Item	Useful Life See menu below	Base Construction Costs	Construction Schedule START	Construction Schedule END	IS REPLACMENT COST NEEDED? IF YES, THEN INPUT COST IN CELL TO RIGHT	REPLACEMENT COSTS (Input Replacement Costs)	BASE CONSTRUCTION COST: Spread over ..... years	Spread per year	Beginning in Year	REPLACEMENT: Replace in Year	Replace in Year	Replace in Year	Replace in Year	Replace in Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
3)	LINE ITEM 1:	Pipeline and Non-Mech.	50	$12,040,920	2004	2005	NO REPLACEMENT	0	2	6,020,460	2004	0					6,020,460	6,020,460									
																	0	0	0	0	0	0	0	0	0	0	0
4)	LINE ITEM 2:	Pump Stations - Non-Mech.	50	$1,566,000	2004	2005	NO REPLACEMENT	0	2	783,000	2004	0					783,000	783,000									
																	0	0	0	0	0	0	0	0	0	0	0
5)	LINE ITEM 3:	Pump Stations - Mech. Equip.	25	$1,122,000	2004	2005	REPLACEMENT >>>>>>	673,200	2	561,000	2004	2029	2053				561,000	561,000									
																	0	0	0	0	0	0	0	0	0	0	0
6)	LINE ITEM 4:	Grinder Pumps - Non-Mech.	50	$1,076,250	2004	2005	NO REPLACEMENT	0	2	538,125	2004	0					538,125	538,125									
																	0	0	0	0	0	0	0	0	0	0	0
7)	LINE ITEM 5:	Grinder Pumps - Mech. Equip.	10	$1,076,250	2004	2005	REPLACEMENT >>>>>>	570,413	2	538,125	2004	2014	2024	2034	2044	2053	538,125	538,125									
																	0	0	0	0	0	0	0	0	0	0	570,413
8)	LINE ITEM 6:	Replace Main St. PS		$480,000	2004	2005	REPLACEMENT >>>>>>		2	240,000	2004	2005					240,000	240,000									
																	0	0	0	0	0	0	0	0	0	0	0
9)	LINE ITEM 7:	Odor Control Fac.-Non-Mech.	0	$60,000	2004	2005	REPLACEMENT >>>>>>		2	30,000	2004	2005					30,000	30,000									
																	0	0	0	0	0	0	0	0	0	0	0
10)	LINE ITEM 8:	Odor Control Fac.-Mech.	25	$132,000	2004	2005	REPLACEMENT >>>>>>	79,200	2	66,000	2004	2029	2053				66,000	66,000									
																	0	0	0	0	0	0	0	0	0	0	0
11)	LINE ITEM 9:	Vacuum Valves-Non-Mech.	50	$1,119,600	2004	2005	NO REPLACEMENT		2	559,800	2004	0					559,800	559,800									
																	0	0	0	0	0	0	0	0	0	0	0
12)	LINE ITEM 10:	Vacuum Valves-Mech	10	$1,119,600	2004	2005	REPLACEMENT >>>>>>	583,354	2	559,800	2004	2019	2034	2049			559,800	559,800									
																	0	0	0	0	0	0	0	0	0	0	0
13)	LINE ITEM 11:	Land acquisition	50	$720,000	2004	2005	NO REPLACEMENT		2	360,000	2004						360,000	360,000									
																	0	0	0	0	0	0	0	0	0	0	0
14)	FIXED LINE ITEM	Base Construction Cost		20,512,629													9,896,519	9,896,519	0	0	0	0	0	0	0	0	0
15)	FIXED LINE ITEM	Replacement Costs		1,910,201													0	0	0	0	0	0	0	0	0	0	570,413
16)	FIXED LINE ITEM	Miscellaneous Reserve		0													0	0	0	0	0	0	0	0	0	0	0
17)	FIXED LINE ITEM	Engineering and CM Costs		0													0	0	0	0	0	0	0	0	0	0	0
		TOTAL CAPITAL COST		$22,422,821													$9,896,519	$9,896,519	$0	$0	$0	$0	$0	$0	$0	$0	$570,413

Type of Capital Improvement	Expected Useful Life (in years)
Pump station equip.	25
Grinder pump equip.	10
Air valve pit equip.	10
Pipeline	50
Pump station superstructure	50

Replacement Costs: The analysis will include equipment replacement costs required during the period of the analysis.

Salvage value: Zero salvage values assumed in this analysis



2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	673,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	673,200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	570,413	0	0	0	0	0	0	0	0	0	570,413	0	0	0	0	0	0	0	0	0	570,413	0	0	0	0	0	0	0	0	570,413
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	79,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79,200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	563,388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	563,388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	563,388	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	570,413	0	0	0	0	732,400	0	0	0	0	570,413	0	0	0	0	0	0	0	0	0	570,413	0	0	0	0	0	0	0	0	1,323,813
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$570,413	$0	$0	$0	$0	$732,400	$0	$0	$0	$0	$570,413	$0	$0	$0	$0	$0	$0	$0	$0	$0	$570,413	$0	$0	$0	$0	$0	$0	$0	$0	$1,323,813

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000

5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773
21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800
39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700
$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957

MASTER SPREADSHEET - ALTERNATIVE 4

This data is used to calculate the NPV. Do not touch.

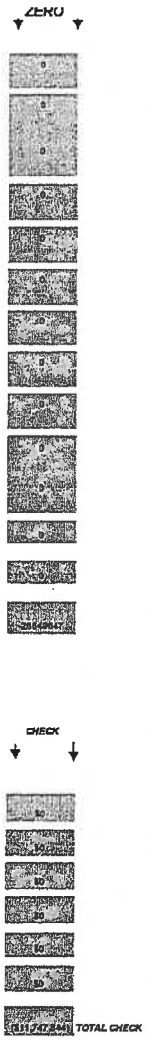
Capital Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Pipeline and Non-Mech.	$11,442,923	$12,040,920	$6,020,460	$6,020,460																				
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pump Stations - Non-Mech.	$1,488,227	$1,566,000	783,000	783,000																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump Stations - Mech. Equip.	$1,066,277	$1,122,000	561,000	561,000																				
Replacement	$400,348	$673,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Non-Mech.	$1,022,799	$1,076,250	538,125	538,125																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Mech. Equip.	$1,022,799	$1,076,250	538,125	538,125																				
Replacement	$1,114,739	$570,413	0	0	0	0	0	0	0	0	0	0	570,413	0	0	0	0	0	0	0	0	0	570,413	0
Replace Main St. PS	$456,161	$480,000	240,000	240,000																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Fac.-Non-Mech.	$57,020	$60,000	30,000	30,000																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Fac.-Mech.	$125,444	$132,000	66,000	66,000																				
Replacement	$47,100	$79,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vacuum Valves-Non-Mech.	$1,063,998	$1,119,600	559,800	559,800																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vacuum Valves-Mech.	$1,063,998	$1,119,600	559,800	559,800																				
Replacement	$674,438	$593,388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	593,388	0	0	0	0	0	0
Land acquisition	$684,242	$720,000	360,000	360,000																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Reserve	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineering and CM Costs		$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW - CAPITAL			$10,256,310	$10,256,310	$0	$0	$0	$0	$0	$0	$0	$0	$570,413	$0	$0	$0	$0	$593,388	$0	$0	$0	$0	$570,413	$0
TOTAL CAPITAL COSTS:	$22,426,821																							
Net Present Value - Capital	$21,730,510																							

Operating Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Labor	$2,409,187	$5,000,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
Electricity	$138,548	$288,625	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773
Chemical addition	$523,223	$1,090,000	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800
General O&M	$952,468	$1,954,219	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684
Generator-Equipped Service Truck	$120,005	$250,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Sewer maintenance ($0.50/lf)	$1,504,857	$3,135,000	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700
TOTAL CASH FLOW - O & M			$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957
TOTAL O & M COSTS:	$11,747,864																							
Net Present Value - O & M	9,039,217																							

TOTAL NPV →	Capital Costs	$21,730,510
	O & M Costs	$5,639,217
	TOTAL:	$27,369,727

2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	573,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	573,200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	570,413	0	0	0	0	0	0	0	0	570,413	0	0	0	0	0	0	0	0	0	570,413
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	79,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79,200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	593,388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	593,388	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$0	$0	$0	$732,400	$0	$0	$0	$0	$1,163,801	$0	$0	$0	$0	$0	$0	$0	$0	$570,413	$0	$0	$0	$0	$593,388	$0	$0	$0	$0	$1,322,813

2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773	5,773
21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800
39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684	39,684
5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700
$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957	$234,957


ZERO
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Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4A - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations
(Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Pine Street (Blantyre Ave. to PS) from west	8	380	15 - < 20	$115		$43,700
	Horatio Lane	8	410	< 10	$90		$36,900
		8	80	10 - < 15	$100		$8,000
		1.5	90	LP	$40		$3,600
		2	90	LP	$40		$3,600
		2.5	250	LP	$45		$11,250
	Pine Street (Horatio to Herring Run Dr.)	8	300	10 - < 15	$100		$30,000
		8	150	15 - < 20	$115		$17,250
	Herring Run Drive	1.5	445	LP	$40		$17,800
		2	445	LP	$40		$17,800
		2.5	450	LP	$45		$20,250
	Pine Street (Herring Run to Pondview Dr.)	8	70	< 10	$90		$6,300
		8	520	10 - < 15	$100		$52,000
	Pondview Drive	8	1,070	< 10	$90		$96,300
		8	700	10 - < 15	$100		$70,000
		8	190	15 - < 20	$115		$21,850
	Holly Lane	8	30	< 10	$90		$2,700
		8	580	10 - < 15	$100		$58,000
		8	310	15 - < 20	$115		$35,650
	Pine Street (Pondview to PS)	8	90	10 - < 15	$100		$9,000
		8	70	15 - < 20	$115		$8,050
	Gravity sewer manholes				$2,000	29	$58,720
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	4	$20,000
	Force main	4	2,600		$50		$130,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pump Station (57 gpm)						$250,000
Subtotal			**12,360**				**$1,462,820**
3	Center Lane	8	120	< 10	$90		$10,800
		1.5	175	LP	$40		$7,000
		2	175	LP	$40		$7,000
		2.5	300	LP	$45		$13,500
	Connors Road	8	1,180	< 10	$90		$106,200
		8	710	10 - < 15	$100		$71,000
		8	380	15 - < 20	$115		$43,700
		8	230	20 - 25	$140		$32,200
	Phinney's Lane (Conners to PS)	8	330	< 10	$90		$29,700
		8	140	10 - < 15	$100		$14,000
		8	200	15 - < 20	$115		$23,000
		8	50	20 - 25	$140		$7,000
	Phinney's Lane (PS to Old Farm Rd.)	8	80	15 - < 20	$115		$9,200

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4A - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations
(Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Phinney's Lane (Old Farm Rd. to Loomis)	8	610	15 - < 20	$115		$70,150
		8	260	20 - 25	$140		$36,400
	Phinney's Lane (Loomis to Strawberry)	8	250	20 - 25	$140		$35,000
	Loomis Lane	8	260	< 10	$90		$23,400
		8	360	10 - < 15	$100		$36,000
		8	360	15 - < 20	$115		$41,400
		8	250	20 - 25	$140		$35,000
	Richards Lane	8	290	< 10	$90		$26,100
		8	70	10 - < 15	$100		$7,000
		8	230	15 - < 20	$115		$26,450
	Old Farm Road	8	460	< 10	$90		$41,400
		8	260	10 - < 15	$100		$26,000
		8	130	15 - < 20	$115		$14,950
		8	270	20 - 25	$140		$37,800
	Crosby Road	8	360	< 10	$90		$32,400
	Tellegen Trail	8	740	< 10	$90		$66,600
		8	40	10 - < 15	$100		$4,000
	Sail-a-way	8	480	< 10	$90		$43,200
	Phinney's Lane (Strawberry to Tellegen)	8	230	10 - < 15	$100		$23,000
		8	370	15 - < 20	$115		$42,550
		8	340	20 - 25	$140		$47,600
	Phinney's Lane (Tellegen to Crosby)	8	780	< 10	$90		$70,200
		8	40	10 - < 15	$100		$4,000
	Gravity sewer manholes				$2,000	43	$86,880
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	1	$5,000
	Force main	6	6,500		$60		$390,000
	Odor control feed equipment						$60,000
	Cofferdam for pump station						$80,000
	Land acquisition						$100,000
	Pumping Station (283 gpm)						$290,000
Subtotal			**18,010**				**$2,176,780**
4	Yatch Club Road	1.5	135	LP	$40		$5,400
		2	135	LP	$40		$5,400
	Indian Trail	1.5	80	LP	$40		$3,200
		2	80	LP	$40		$3,200
		2.5	120	LP	$45		$5,400
	Old Way	1.5	125	LP	$40		$5,000
		2	125	LP	$40		$5,000
	Red Wing Trail	1.5	75	LP	$40		$3,000
		2	75	LP	$40		$3,000
		2.5	120	LP	$45		$5,400
	Johny Cake Road	1.5	90	LP	$40		$3,600

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4A - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations
(Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
		2	90	LP	$40		$3,600
		2.5	170	LP	$45		$7,650
	Annable Point Road	1.5	225	LP	$40		$9,000
		2	225	LP	$40		$9,000
		2.5	260	LP	$45		$11,700
		3	1,060	LP	$45		$47,700
	Willow Run (End of AOC to Thread Needle)	8	210	< 10	$90		$18,900
	Willow Run (end to Thread Needle)	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	370	LP	$45		$16,650
		3	250	LP	$45		$11,250
	Thread Needle Lane	8	560	< 10	$90		$50,400
		8	390	10 - < 15	$100		$39,000
	Great Marsh Road (Thread Needle to Hayes Road)	8	1,160	10 - < 15	$100		$116,000
	Hayes Road	1.5	250	LP	$40		$10,000
		2	250	LP	$40		$10,000
		2.5	450	LP	$45		$20,250
		3	560	LP	$45		$25,200
	Great Marsh / Juniper (Hayes to Laurel)	8	180	10 - < 15	$100		$18,000
		8	910	15 - < 20	$115		$104,650
	Laurel Road	8	240	<10	$90		$21,600
		8	440	10-<15	$100		$44,000
	Juniper Road (Laurel to Lake Dr.)	8	320	10 - < 15	$100		$32,000
	Point of Pines Ave.	8	770	< 10	$90		$69,300
		8	380	10 - < 15	$100		$38,000
	Juniper (Point of Pines to Lake Dr.)	8	180	< 10	$90		$16,200
		8	140	10 - < 15	$100		$14,000
	Lake Drive (Juniper to PS)	8	310	10 - < 15	$100		$31,000
	Brezner Lane (Northern part)	8	240	< 10	$90		$21,600
	Pond Street	8	450	< 10	$90		$40,500
			60	10 - < 15	$100		$6,000
	Lake Drive (Pond St. to PS)	8	350	10 - < 15	$100		$35,000
	Lake Drive (end to Pond St.)	8	140	< 10	$90		$12,600
		8	30	10 - < 15	$100		$3,000
	Gravity sewer manholes				$2,000	30	$59,680
	Grinder pumps				$7,500	0	$0
	Force main	4	850		$50		$42,500
	Air release/cleanout manholes				$5,000	11	$55,000
	Cofferdam for pump station						$70,000
	Land acquisition						$100,000
	Pumping Station (165 gpm)						$270,000
Subtotal			**13,930**				**$1,570,530**

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4A - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations
(Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (Inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
5	Lakewood Drive	1.5	115	LP	$40		$4,600
		2	115	LP	$40		$4,600
		2.5	300	LP	$45		$13,500
		3	600	LP	$45		$27,000
	Shootflying Hill Road (Lakewood to Tern Lane)	3	1,280	LP	$45		$57,600
	Tern Lane	1.5	340	LP	$40		$13,600
		2	340	LP	$40		$13,600
		2.5	290	LP	$45		$13,050
		3	1,080	LP	$45		$48,600
	Shootflying Hill Road (Tern Ln. to Johnson Ln.)	4	1,060	LP	$50		$53,000
	Johnson Lane	1.5	110	LP	$40		$4,400
		2	110	LP	$40		$4,400
		2.5	260	LP	$45		$11,700
	Shootflying Hill Road (Johnson Ln. to Lakeview Dr.)	4	2,330	LP	$50		$116,500
	Odor control feed station						$100,000
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	11	$55,000
Subtotal			**8,330**				**$541,150**
6	Shootflying Hill Road (F.M. to Lakeview Drive)	8	100	Vacuum	$100		$10,000
	Lakeview Avenue	8	1,800	Vacuum	$100		$180,000
	Pleasant Pines (Shootflying to Lakeview)	4	700	Vacuum	$90		$63,000
	Pleasant Pines (Lakeview to Nyes Neck)	8	870	Vacuum	$100		$87,000
	Nyes Neck Rd. (East)	4	1,750	Vacuum	$90		$157,500
	Nyes Neck Rd. (West)	4	1,960	Vacuum	$90		$176,400
	Nyes Neck Rd. (where east & west combine to Nyes Point Way)	6	640	Vacuum	$95		$60,800
	Nyes Point Way	4	680	Vacuum	$90		$61,200
	Nyes Neck Rd. (Nyes Point Way to Shirley Point Rd.)	6	450	Vacuum	$95		$42,750
	Shirley Point Road	4	610	Vacuum	$90		$54,900
	Nyes Neck Rd. (Shirley Point to Pleasant Pines)	6	600	Vacuum	$95		$57,000
	Pleasant Pines (Nyes Neck to PS) from west	10	330	Vacuum	$105		$34,650
	Pleasant Pines (Flow to PS) from east	4	650	Vacuum	$90		$58,500
	Valve pits				$6,000	67	$402,000
	Dual buffer tank				$33,000	1	$33,000
	Force main	6	2,700		$60		$162,000
	Cofferdam for vacuum station						$50,000

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4A - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations
(Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
	Land acquisition						$100,000
	Vacuum Station (422 gpm)						$450,000
Subtotal			**13,840**				**$2,240,700**
7	Pleasant Pines (High Point to Bunny Run)	4	720	Vacuum	$90		$64,800
	Chickadee Lane	4	400	Vacuum	$90		$36,000
	Bunny Run (End to Chickadee)	4	530	Vacuum	$90		$47,700
	Bunny Run (Chickadee to Point of Pines)	4	260	Vacuum	$90		$23,400
	Pleasant Pines (Bunny Run to Huckins Neck)	4	180	Vacuum	$90		$16,200
	Shallow Pond	4	1,630	Vacuum	$90		$146,700
	Huckins Neck (Shallow Pond to Water View Circle)	4	510	Vacuum	$90		$45,900
	Water View Circle	4	940	Vacuum	$90		$84,600
	Blue Water Drive	8	1,220	Vacuum	$100		$122,000
	Blue Water-Iyannough- XC	8	650	Vacuum	$100		$65,000
	Pondside Circle	4	350	Vacuum	$90		$31,500
		8	640	Vacuum	$100		$64,000
	Huckins Neck Road (Water View to Vac Station)	4	930	Vacuum	$90		$83,700
		8	940	Vacuum	$100		$94,000
	Holly Point Road	4	3,200	Vacuum	$90		$288,000
	Cottonwood Rd.	4	850	Vacuum	$90		$76,500
	Huckins Neck Road (Connors to Beechwood)	6	580	Vacuum	$95		$55,100
	Huckins Neck Road (Beechwood to Cottonwood)	6	670	Vacuum	$95		$63,650
	Huckins Neck Road (Cottonwood to Lakeside Dr. East)	6	400	Vacuum	$95		$38,000
	Huckins Neck Road (Lakeside Dr. East to Vac Station)	8	1,670	Vacuum	$100		$167,000
	Beachwood - South of Huckins Neck (High Point to Huckins Neck)	4	700	Vacuum	$90		$63,000
	Beechwood - North of Huckins Neck	4	350	Vacuum	$90		$31,500
	Lakeside Drive West	4	2,500	Vacuum	$90		$225,000
	Vine Street	4	130	Vacuum	$90		$11,700
	Lakeside Drive East	6	1,400	Vacuum	$95		$133,000
	Lakeview Avenue	4	880	Vacuum	$90		$79,200
	Valve pits				$6,000	244	$1,464,000
	Force main	6	2,500		$60		$150,000
	Cofferdam for vacuum station						$50,000
	Land acquisition						$100,000
	Vacuum Station (171 gpm)						$350,000

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4A - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations
(Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
Subtotal			**25,730**				**$4,271,150**
8	Goose Point Road	1.5	220	LP	$40		$8,800
		2	220	LP	$40		$8,800
	Crestview Circle	2.5	890	LP	$45		$40,050
	Regatta Drive (Phinney's La. To Crestview Cir.)	1.5	180	LP	$40		$7,200
		2	180	LP	$40		$7,200
		2.5	500	LP	$45		$22,500
	Dacey Lane	1.5	120	LP	$40		$4,800
		2	120	LP	$40		$4,800
	Regatta Drive (Crestview Cir. To Old Strawberry Hill Rd.)	3	530	LP	$45		$23,850
	Old Strawberry Hill Road (Regatta Dr. to Rte. 132)	3	730	LP	$45		$32,850
		4	1,160	LP	$50		$58,000
	Route 132	1.5	150	LP	$40		$6,000
		2	150	LP	$40		$6,000
		2.5	1,000	LP	$45		$45,000
		3	660	LP	$45		$29,700
	Grinder pumps				$7,500	0	$0
	Grinder pumps at condominium				$15,000	0	$0
	Air release/cleanout manholes				$5,000	8	$40,000
Subtotal			**6,810**				**$345,550**
9	Scottsdale Circle	1.5	145	LP	$40		$5,800
		2	145	LP	$40		$5,800
		2.5	180	LP	$45		$8,100
	Route 28 (FM to Kenesaw)	8	1,640	< 10	$90		$147,600
	Childs Street (FM to Kenesaw/ Rt. 28)	8	620	< 10	$90		$55,800
		8	180	10 - < 15	$100		$18,000
	Route 28 (Kenesaw to Existing Pipe)	8	330	< 10	$90		$29,700
		8	280	10 - < 15	$100		$28,000
		8	770	15 - < 20	$115		$88,550
	Gravity sewer manholes				$2,000	15	$30,560
	Grinder pumps				$7,500	0	$0
	Air release/cleanout manholes				$5,000	1	$5,000
Subtotal			**4,290**				**$422,910**
Incremental Cost to increase CCCC force main from 4 inch diameter							
	Huckins Neck Rd. to Phinney's Lane	10	5,300		$40		$212,000
	Phinney's Lane to existing 12" FM	12	1,000		$50		$50,000
Subtotal			**6,300**				**$262,000**
Houses adjacent to gravity sewers requiring pumping							
	Grinder pumps				$7,500	0	**$0**
Improvements to existing sewerage system							

Engineer's Opinion of Probable Construction Costs
Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension
Alternative 4A - Gravity, LP and Vacuum Sewers - Four Pump Stations, Two Vacuum Stations
(Excluding Grinder Pumps)

Sub-Area	Street	Pipe Diameter (inches)	Pipe Length (ft.)	Avg. Depth (ft.)	Unit Price	Quantity	Total Price
Replace Main St. Pump Station							$400,000
Divert pumped flow to Old Colony Rd. PS FM		8	1,400		$80		$112,000
Subtotal							**$512,000**
Total			**125,400**				**$15,300,100**

LIFE CYCLE COST ANALYSIS SUMMARY SHEET - ALTERNATIVE 4A
Grinder Pumps Purchased and Maintained by Residents

Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
Preparer: DJP/DRP
Date: 29-Aug-03

CAPITAL COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.33%
Effective Discount Rate:	3.46%
Terms of Analysis (years)	50
Construction Duration (years):	2
Replacement Cost Period:	
Base Construction Cost:	$18,360,120
Misc. Reserve Prelim. Design	$0
Engineering Cost:	$0
Replacement Capital Cost:	$1,345,788
Total Capital Cost:	$19,705,908
Total NPV- Capital Cost:	$18,570,173

OPERATING COST SUMMARY

Discount Rate:	5.88%
Inflation Rate:	2.42%
Effective Discount Rate:	3.37%
Terms of Analysis:	50
Labor Cost/year:	$25,000
Total Labor Cost:	$1,250,000
Total O& M Cost/year:	$135,134
Total O & M Cost:	$6,756,696
Total NPV - O & M Co	$3,243,359

	Total Cost	NPV
Capital Costs	$19,705,908	$18,570,173
O & M Costs	$6,756,696	$3,243,359
TOTAL:	$26,462,604	$21,813,532

Notes/Assumptions:

ECONOMIC ASSUMPTIONS - ALTERNATIVE 4A - Grinder Pumps Purchased and Maintained by Residents

CAPITAL COSTS:	
*Discount rate:	5.875%
Inflation rate:	2.33%
**Effective Discount rate:	3.46%

OPERATIONS & MAINTENANCE:	
*Discount rate:	5.875%
Inflation rate:	2.42%
**Effective Discount rate:	3.37%

*** Term of analysis:	50 years

Average Salary:	$50,000

NOTE:

* The discount rate reflects the long-term cost of capital.

** The effective discount rate anticipates the effect of the time value of money and inflation by removing inflation from the discount rate.

*** The analysis period for the project is 50 years.

PROJECT INFORMATION

1) Preparer: DJP/DRP
2) Name of Capital Project: Lake Wequaquet, Long Pond and Cape Cod Community Collge Sewer Extension
3) List Assumptions Below:

Input cells are highlighed in light yellow.

CAPITAL COSTS WORKSHEET - ALTERNATIVE 4A

1) Enter First Year of Capital Spending: 2004

2) Using table below, enter project Design Status. Prelim. Design

Design Status	Miscellaneous Reserve
Prelim. Design	Add 20%
50-75% Design	Add 15%
90-95% Design	Add 10%
100% Design	Add 10%

CAPITAL COST

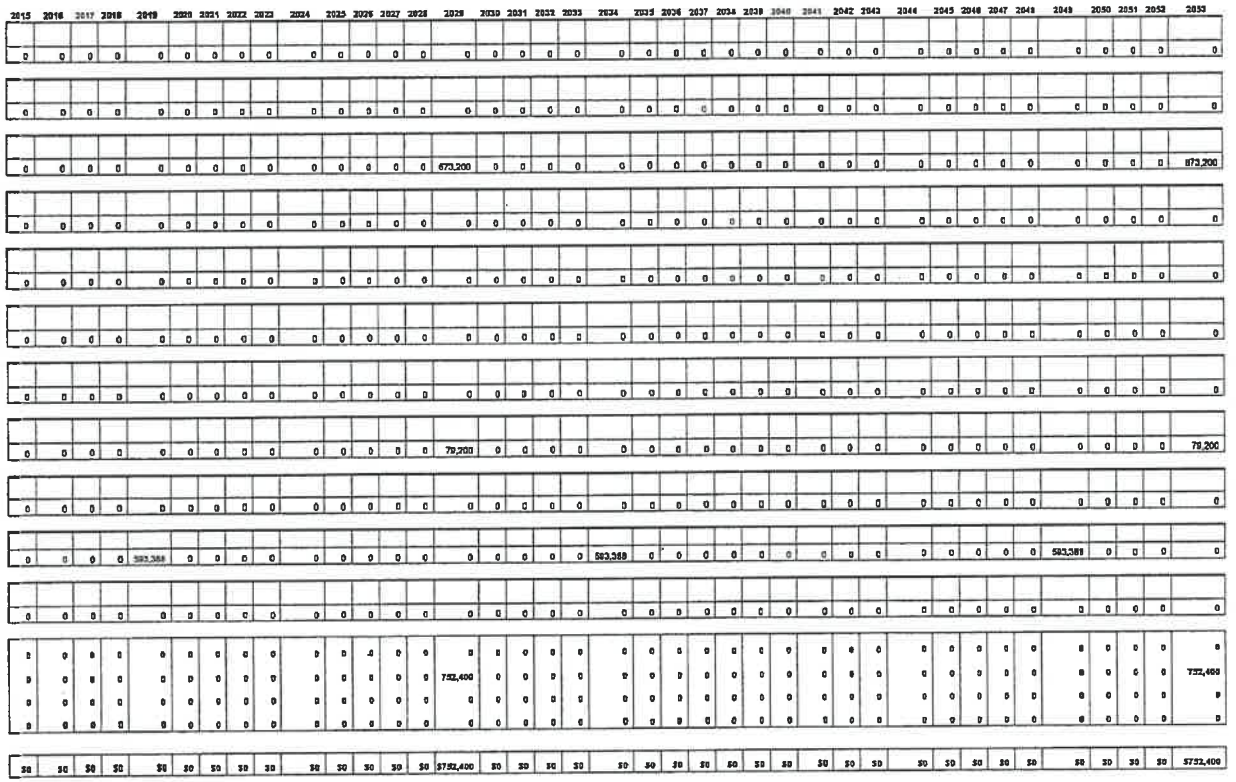
	Capital Cost Line Item	Useful Life (See menu below)	Base Construction Costs	Construction Schedule START	Construction Schedule END	IS REPLACEMENT COST NEEDED? IF YES, THEN INPUT COST IN CELL TO RIGHT (Input Replacement Costs)	REPLACEMENT COSTS	BASE CONSTRUCTION COST Spread over ..... years	Spread per year	Beginning in Year	REPLACEMENT Replace in Year	Replace in Year	Replace in Year	Replace in Year	Replace in Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
3)	LINE ITEM 1:	Pipeline and Non-Mech.	50	$12,040,920	2004	2005	NO REPLACEMENT	0	2	6,020,460	2004	0					6,020,460	6,020,460									
																	0	0	0	0	0	0	0	0	0	0	0
4)	LINE ITEM 2:	Pump Stations - Non-Mech.	50	$1,566,000	2004	2005	NO REPLACEMENT	0	2	783,000	2004	0					783,000	783,000									
																	0	0	0	0	0	0	0	0	0	0	0
5)	LINE ITEM 3:	Pump Stations - Mech. Equip.	25	$1,122,000	2004	2005	REPLACEMENT >>>>>>	673,200	2	561,000	2004	2029	2053				561,000	561,000									
																	0	0	0	0	0	0	0	0	0	0	0
6)	LINE ITEM 4:	Grinder Pumps - Non-Mech.	50	$0	2004	2005	NO REPLACEMENT	0	2	0	2004	0					0	0									
																	0	0	0	0	0	0	0	0	0	0	0
7)	LINE ITEM 5:	Grinder Pumps - Mech. Equip.	10	$0	2004	2005	REPLACEMENT >>>>>>	0	2	0	2004	2014	2024	2034	2044	2053	0	0									
																	0	0	0	0	0	0	0	0	0	0	0
8)	LINE ITEM 6:	Replace Main St. PS		$480,000	2004	2005	REPLACEMENT >>>>>>		2	240,000	2004	2005					240,000	240,000									
																	0	0	0	0	0	0	0	0	0	0	0
9)	LINE ITEM 7:	Odor Control Fac.-Non-Mech.	0	$60,000	2004	2005	REPLACEMENT >>>>>>		2	30,000	2004	2005					30,000	30,000									
																	0	0	0	0	0	0	0	0	0	0	0
10)	LINE ITEM 8:	Odor Control Fac.-Mech.	25	$132,000	2004	2005	REPLACEMENT >>>>>>	79,200	2	66,000	2004	2029	2053				66,000	66,000									
																	0	0	0	0	0	0	0	0	0	0	0
11)	LINE ITEM 9:	Vacuum Valves-Non-Mech.	50	$1,118,600	2004	2005	NO REPLACEMENT		2	559,300	2004	0					559,300	559,300									
																	0	0	0	0	0	0	0	0	0	0	0
12)	LINE ITEM 10:	Vacuum Valves-Mech.	15	$1,118,600	2004	2005	REPLACEMENT >>>>>>	503,388	2	559,300	2004	2019	2034	2049			559,300	559,300									
																	0	0	0	0	0	0	0	0	0	0	0
13)	LINE ITEM 11:	Land acquisition	50	$720,000	2004	2005	NO REPLACEMENT		2	360,000	2004						360,000	360,000									
																	0	0	0	0	0	0	0	0	0	0	0
14)	FIXED LINE ITEM	Base Construction Cost		15,360,120													8,820,260	8,820,260	0	0	0	0	0	0	0	0	0
15)	FIXED LINE ITEM	Replacement Costs		1,343,788													0	0	0	0	0	0	0	0	0	0	0
16)	FIXED LINE ITEM	Miscellaneous Reserve		0													0	0	0	0	0	0	0	0	0	0	0
17)	FIXED LINE ITEM	Engineering and CM Costs		0													0	0	0	0	0	0	0	0	0	0	0
		TOTAL CAPITAL COST		$17,703,908													$8,820,260	$8,820,260	$0	$0	$0	$0	$0	$0	$0	$0	$0

Expected Useful Life

Type of Capital Improvement	Expected Useful Life (in years)
Pump station equip.	25
Grinder pump equip.	10
Air valve pit equip.	15
Pipeline	50
Pump station superstructure	50

Replacement Costs: The analysis will include equipment replacement costs required during the period of the analysis.

Salvage value: Zero salvage values assumed in this analysis



2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$73,200	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$73,200
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

OPERATIONS AND MAINTENANCE COSTS WORKSHEET - ALTERNATIVE 4A

	O&M Cost Categories		Period (Calendar Yr.) From	To	Labor - FTE	Average Salary	Labor Cost Dollars per year	Total Labor Cost	A Spread over ..... many years	B Spread per year	C Beginning in Year	2004	2005	2006	2007	2008
1)	LINE ITEM 1	Labor	2004	2053	1	25,000	25,000	1,250,000	50	25,000	2004	25,000	25,000	25,000	25,000	25,000

Enter first year of O&M costs here:

(for each individual line item)

					Cost per year	Number of Years		Total Cost								
2)	LINE ITEM 2	Electricity	2004	2053	3,062	50		153,096	50	3,062	2004	3,062	3,062	3,062	3,062	3,062
3)	LINE ITEM 3	Chemical addition	2004	2053	21,800	50		1,090,000	50	21,800	2004	21,800	21,800	21,800	21,800	21,800
4)	LINE ITEM 4	General O&M	2004	2053	22,572	50		1,128,600	50	22,572	2004	22,572	22,572	22,572	22,572	22,572
5)	LINE ITEM 5	Generator-Equipped Service Truck	2004	2053	0	50		0	50	0	2004	0	0	0	0	0
6)	LINE ITEM 6	Sewer maintenance ($0.50/lf)	2004	2053	62,700	50		3,135,000	50	62,700	2004	62,700	62,700	62,700	62,700	62,700
							TOTAL O&M	$5,756,696				$135,134	$135,134	$135,134	$135,134	$135,134

Total Annual Cost $135,134

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000

3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062
21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800
22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700
$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000

3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062
21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800
22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700
$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134

MASTER SPREADSHEET - ALTERNATIVE 4A

This data is used to calculate the NPV. Do not touch.

Capital Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Pipeline and Non-Mech.	$11,442,923	$12,040,920	$6,020,460	$6,020,460																				
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pump Stations - Non-Mech.	$1,486,227	$1,566,000	783,000	783,000																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump Stations - Mech. Equip.	$1,066,277	$1,122,000	$61,000	$61,000																				
Replacement	$400,548	$673,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Non-Mech.	$0	$0	0	0																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grinder Pumps - Mech. Equip.	$0	$0	0	0																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Replace Main St. PS	$456,161	$460,000	240,000	240,000																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Fac.-Non-Mech.	$87,020	$60,000	30,000	30,000																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odor Control Fac.-Mech.	$125,444	$132,000	66,000	66,000																				
Replacement	$47,103	$79,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vacuum Valves-Non-Mech.	$1,063,998	$1,119,600	559,800	559,800																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vacuum Valves-Mech.	$1,063,998	$1,119,600	559,800	559,800																				
Replacement	$674,438	$593,388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	593,388	0	0	0	0	0	0
Land acquisition	$884,242	$720,000	360,000	360,000																				
Replacement	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Reserve	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineering and CM Costs		$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW - CAPITAL			$9,180,060	$9,180,060	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$593,388	$0	$0	$0	$0	$0	$0
TOTAL CAPITAL COSTS	$18,705,808																							
Net Present Value - Capital	$18,570,173																							

Operating Costs:	NPV	Capital Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Labor	$809,027	$1,250,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Electricity	$73,489	$153,096	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062	3,062
Chemical addition	$523,223	$1,090,000	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800	21,800
General O&M	$541,752	$1,126,800	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572
Overseer-Equipped Service Truck	$0	$0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sewer maintenance (52.5mi)	$1,504,857	$3,135,000	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700	62,700
TOTAL CASH FLOW - O & M			$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134	$135,134
TOTAL O & M COSTS	$8,750,899																							
Net Present Value - O & M	3,243,339																							

TOTAL NPV	Capital Costs	$18,570,173
	O & M Costs	$3,243,359
	TOTAL:	$21,813,532

Appendix J

Preliminary Evaluation of the Cape Cod Community College for Treated Water Recharge; November 2003

Stearns & Wheler, LLC
Environmental Engineers and Scientists

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November 5, 2003

Mr. Mark Giordano, P.E.
Senior Project Manager
Department of Public Works
Town of Barnstable
367 Main Street
Hyannis, MA 02601

Re: Effluent Mitigation Investigation Project
Task 4 – Cape Cod Community College Investigation
S&W No. 20190.0

Dear Mr. Giordano:

In accordance with your request and the Contract for Consultant Services for the Effluent Mitigation Investigation Project Task 4 – Cape Cod Community College (the College) Characterization, we have completed a preliminary evaluation of the College property off of Route 132 for the recharge of treated effluent. In accordance with paragraph 2.2.5.2 of the Contract for Consultant Services, QA/QC procedures of the Scope of Work were adhered to in the completion of this project. In accordance with paragraph 2.2.5.4 of the Contract, Stearns & Wheler is providing five (5) bound copies, one (1) unbound copy, and one computer copy of this letter report. The evaluation was completed consistent with the Barnstable Wastewater Facilities Plan (WWFP) recommendation to identify and utilize remote sites for the purpose of discharging treated wastewater to the subsurface.

BACKGROUND INFORMATION

The Town of Barnstable is in the process of completing a Wastewater Facilities Plan (WWFP) that evaluates future options for the Town to collect, treat and dispose of municipal wastewater. A component of the WWFP recommended for the identification of parcels of land, remote from the existing Water Pollution Control Facility (WPCF), where treated wastewater can be reclaimed by discharging it back to the subsurface in order to replenish groundwater resources in the Town. Utilization of remote sites was recommended because the WWFP and related work concluded that the recharge capacity of the effluent discharge beds at the existing plant may be limited due to potential adverse impacts related to groundwater mounding. In the course of completing the WWFP, the Town undertook a remote site screening process to identify areas of the Town where suitable parcels may exist. Following the completion of that screening process, the Town

began to identify specific parcels that could be further evaluated for suitability. One of those parcels being investigated is the Cape Cod Community College (College) property. Reference is made to Figure 1 for the location of the College property.

The subject parcel is located at the intersection of Routes 6 and 132 (Exit 6 of the Mid-Cape Highway). Two candidate areas were identified on the property. The first area was located at the athletic field on the north side of the campus. The other area is the wooded area on the northeast side of the college property. The field area was investigated through the installation of one boring and one test pit, and is referred to as Site A. The wooded area was investigated at two different sites located adjacent to the parking areas on the perimeter of the campus. The northerly site investigated is referred to as Site B and the southerly site investigated is referred to as Site C. During discussions between Stearns & Wheler, the College and the Town, it was decided that the stratigraphy of the wooded area could be sufficiently characterized for this screening process without cutting trees, grading and building access roads through the woods. For that reason, the investigation of the wooded site was accomplished with borings and test pits at the woods' edge.

SCOPE OF WORK

The Scope of Work for Task 4 that has been completed for this project is summarized below:

Subtask 4.1 Site Visit. Prior to initiating site work on the site, an initial reconnaissance trip to the site was conducted. Additionally, discussions were held with site representatives. The purpose of these discussions was to determine what restrictions the College might impose that could impact investigative efforts or future use of the site.

Subtask 4.2 Initial Screening. Following the site visit, an initial screening was completed that evaluated the suitability of the site in terms of siting criteria considered in earlier phases of the site identification and screening process, including but not limited to location with respect to:

1. In Wellhead Protection Zones I, II and III
2. In Areas of Critical Environmental Concern
3. Near vernal pools
4. Near wetland
5. In areas of rare and endangered plant and wildlife habitat
6. In conservation areas
7. In flood hazard zones
8. Releases of oil or hazardous materials
9. Drainage basin

Subtask 4.3 Test Pits. Three (3) backhoe test pits were completed at each of three investigation sites. Test pits were excavated to a depth of 8 to10 feet. A soil evaluator logged soil stratigraphy in the test pits. Percolation tests were completed at two of the three test pits. Conditions were not suitable for a percolation test at Site C, because of the presence of boulders and fill material. Test pit locations are shown on Figure 2.

Subtask 4.4 Soil Borings. Three (3) soil borings were drilled. One soil boring was installed in each of the three investigation sites. The proposed work plan specified the borings would be advanced to a depth at least 15 feet below the existing water table. Based on the depth at which the water table was encountered, the borings were advanced to depths of 94, 94, and 84 feet, respectively. Split spoon samples were collected at 5 foot intervals from each boring. Stearns & Wheler recorded soil types on a boring log. Boring locations are shown on Figure 2.

Subtask 4.5 Observation Wells/Slug Tests. Upon completion of the first soil boring, a field determination was made that the site is a likely candidate for effluent discharge, so the soil borings were completed as observation wells. In-situ hydraulic conductivity testing (slug testing) was completed in the two wooded area wells to determine the permeability of the deeper soils. Slug tests were not completed at the athletic field (Site A) because it was determined the soils were not suitable for the placement of discharge facilities because of the presence of boulders and low permeability soil. This data was obtained to support regional mapping data and in order to complete a groundwater mounding analysis, a requirement of a groundwater discharge permit application, should the Town decide it wants to pursue a permit for this parcel.

Subtask 4.6 Report of Findings. A written report for the Town that presents the field investigation results and provides recommendations regarding the use of the subject parcel for treated effluent disposal is included herein.

Subtask 4.7 Meetings. Time was allocated for meetings related to this site investigation. One meeting where preliminary results were presented was held on October 7, 2003. An additional meeting is anticipated.

EVALUATION RESULTS

The results of the Cape Cod Community College investigation are presented in this section. The results are organized in the following order:

- Location Considerations
  - Summary of initial site screening considerations and results.
- Site Characteristics

- Published Information from literature about the general characteristics of the site.

- Field Investigation Results – detailed results from the Stearns & Wheler field investigation.

Location Considerations

Location considerations relate to the suitability of the site based on its setting. These criteria were evaluated by the Town in their initial screening process and included those factors listed in the introduction section of this letter. Stearns & Wheler reviewed and updated these siting criteria.

The results of that screening process indicated that:

1. There are no public water supplies in the immediate vicinity of the College. The College is not in the Zone II of any public water supplies. (See Attachment A Map – Massachusetts GIS Water Supply Protection Area Map).

2. The College is not in an Area of Critical Environmental Concern or in any other designated environmentally sensitive area. (See Attachment B Map – MADEP Bureau of Waste Site Cleanup – Map showing sensitive environments and Attachment C, Map showing Natural Heritage Areas and Endangered Species Areas).

3. The College property has not been previously identified as being in a conservation area or a Flood Hazard Zone.

4. Groundwater flow direction at the College is near the north-south flow divide. Town GIS mapping shows the water table to be extremely flat in the area with the groundwater flow direction, north or south being indefinite. Water table mapping by Geraghty & Miller in 1992, indicates northward flow from the area of the College.

Site Characteristics

1. **Published Information**

a. Geologic Setting. The site is located on the Sandwich Moraine. Soils on the moraine are generally described as:

> Mostly sand and gravel. Abundant fine sand, silt and clay.
> Till and boulders generally occur above stratified drift.

b. Soil Type. The surficial soils in the undeveloped and undisturbed areas of the College property are classified as the Plymouth-Barnstable Complex. (USDA, SCS, 1993). The Plymouth Barnstable soils are characterized as being on rolling and undulating land. They are excessively and well drained soils on the side slopes of moraines. The subsoil grades from sandy loam to loose course sand. Boulders are common.

c. Site Topography. The majority of the College property, including the athletic field has been altered to accommodate the facility. Grading and filling is evident in the developed areas of the campus as the surrounding wooded area is comprised of irregular undulating topography. The land is comprised of rolling terrain with elevations ranging from approximately 95 to 130 feet above MSL.

d. Depth to Groundwater. The College property is in an area where groundwater has been mapped to be greater than 50 feet below the surface.

e. Hydraulic Conductivity. The College is in an area where earlier modeling efforts used a hydraulic conductivity of 50 - 200 feet per day.

2. Field Investigation Results

Investigations occurred at three sites: One (Site A) at the athletic field, one on the northerly end of the wooded area (Site B) and one at the southerly end of the wooded area (Site C). At each of the three areas, one test pit was completed and one deep soil boring and test well was installed. Percolation tests were completed at Areas A and B. The investigative efforts are described below.

a. Test Pit Observations. On September 8, 2003 three (3) test pits were excavated on the property. One test pit was excavated in each of the three investigation sites. Test pits were excavated to depths ranging from 8 to 12 feet. Test pit logs are included as Attachment D. Findings are summarized below.

- Site A – Athletic Field. Several large boulders were present in the interval from the surface to five feet below grade in test pit TP-3 at Site A. Medium to course sand was observed surrounding and below the boulders. At the test pit at Site A, fill material was observed to a depth of 30 inches. Groundwater was not observed.

- Site B – Woods North. At test pit TP-2 at Site B, fill material was observed to a depth of approximately 4 feet and boulders were encountered. No percolation test was performed in TP-2. The presence of boulders indicated the location was probably not suitable. Also, because native soils, the target for percolation tests were several feet below grade in the test pit, they could

not be safely accessed. Below the fill, the section was comprised of sandy loam. Boulders were encountered throughout the exposed section. Groundwater was not observed.

- Site C – Woods South. At test pit TP-1 at Site C, loamy sand was observed over the entire exposed section. Groundwater was not observed.

b. Percolation Tests. Percolation tests were conducted at test pits TP-1 at area B and TP-3 in Area A to obtain a generally qualitative assessment of the soil's capacity to allow water to infiltrate. Percolation test logs are included as Attachment E. Percolation rates are compared to standards in "Guidelines for the Design Construction, Operation and Maintenance of Small Sewage Treatment Facilities with Land Disposal".

- Site A – Athletic Field. Percolation rate at TP-3 in area A was 8.67 minutes per inch. At that percolation rate, (the range 5-10 minutes/inch) MADEP guidance recommends application rates of 4 gpd/sq ft for open beds and 1.5 gpd/sq ft for leaching trenches.

- Site C – Woods South. Percolation rate at TP-1 in area C was 0.67 minutes per inch. At that percolation rate, MADEP guidance recommends application rates of 5 gpd/sq ft for open beds and 2.5 gpd/sq ft for leaching trenches.

c. Deep Boring Observations. One deep soil boring was installed at each investigation site to characterize deep soil conditions and to determine the depth to groundwater. Each boring was completed as a test well. Each soil boring was advanced to a depth of approximately 84 to 94 feet based on the depth at which groundwater was encountered. The borings were advanced at least 15 additional feet when groundwater was encountered at a depth of approximately 65 to 70 feet in each boring. Soil boring logs are included as Attachment F.

- Site A – Athletic Field. Test Well TW-1 was drilled at investigation Site A at the athletic field to a depth of 94 feet. Due to several boulders in the shallow subsurface, the location of TW-1 had to be relocated two times. At the third site, boulders were still penetrated to a depth of 30 feet. After this depth, some boulders were present, but were not as prevalent as in the shallower material. The soils that were recovered were primarily medium to fine sands.

- Site B – Woods North. Test Well TW-3 was drilled at investigation Site C to a depth of 84 feet. TW-3 yielded similar conditions as TW-2 with well graded fine to medium sand comprising the majority of the samples.

- Site C – Woods South. Test Well TW-2 was drilled at investigation Site B to a depth of 94 feet. TW-2 had much more favorable conditions than TW-1. The bulk of the soil was well sorted medium to fine sand and no boulders were encountered.

d. Deep Hydraulic Conductivity. The mounding evaluation in this investigation is based on a hydraulic conductivity value of 100 feet per day. This value was obtained through in-situ hydraulic conductivity testing that was performed in the completed test wells. The hydraulic conductivity calculation is provided as Attachment G. This value is consistent with values between 50 and 200 feet per day that have been used in earlier groundwater models of the area.

e. Groundwater Flow Direction. Groundwater flow direction is relevant to this study to determine into which watershed the treated effluent will flow. Depth to water measurements and the calculated groundwater elevations may indicate a groundwater flow direction toward the southwest rather than toward the north as regionally mapped. The linear pattern of the well locations and the minor difference (< 0.4 feet in measured elevation) may limit the accuracy of the interpretation. However, it is also possible that on a very localized scale, flow could be toward Lake Wequaquet.

f. Infiltration Capacity. Based on the available area and the percolation test infiltration rates, potential treated wastewater infiltration rates have been estimated. The athletic field has been eliminated from further consideration because of the poor subsurface conditions. In the woods area, two proposed recharge facilities have been laid out as shown on Figure 3. One area is 600' x 280', representing 168,000 square feet or 3.8 acres. It has been estimated that 2.8 acres within that area would be used for recharge. The other area is 520' x 280', representing 145,600 square feet or 3.0 acres. It has been estimated that approximately 2.5 acres within that area could be available for recharge. Based on the percolation rate of less than 2 minutes per inch, infiltration rates of 5 gpd/sq. ft. for sand beds and 2.5 gpd/sq. ft. for infiltration trenches have been estimated for this site.

Sand Beds: If sand beds are constructed over an area of 4.5 acres, an infiltration capacity of 980,000 gpd is calculated (5 gpd/sq. ft. x 196,020 sq. ft.). For the purposes of additional discussion, this will be considered to be 1 MGD.

Trenches: Based on the dimensions of the two areas, it has been calculated that 17, 500 feet of trenches can be built. This is based on an eight-foot width for each trench (3 foot trench plus 3 foot reserve plus 2 foot space). The 280-foot width of the selected areas can hold 35 trenches each with a length of 520 or 600 feet respectively. If each foot of trench has 7 square feet of recharge area,(3 square feet on bottom and two square feet on each side wall) then the capacity of the 17,500 feet of trenches could be 665,000 gpd.

g. Potential Mounding. Because the depth to groundwater is approximately 70 feet below grade, groundwater mounding is not believed to be a limiting factor at this site. Using an analytical mounding calculator (the Hantaxis program, used by MADEP to calculate mounding impacts), a worst case-mounding scenario was completed. The mounding calculation was based on recharging one million gallons per day in an area 280' x 1,100 feet and a hydraulic conductivity value of 100 feet per day. The results of the preliminary mounding analysis are presented in Attachment H.

The preliminary mounding analyses indicate that if the site has a hydraulic conductivity around 100 feet per day, and 1 MGD are discharged over the proposed area, then a mound of approximately 12 feet can develop. A mound of this magnitude will not impact surface facilities such as proximal buildings or septic systems. Some radial flow would be induced, however, given the natural groundwater gradient in the area, water flowing radially away from the College property would ultimately be captured by the regional flow system.

CONCLUSIONS

The investigation described above has resulted in the following conclusions regarding use of Cape Cod Community College for the recharge of treated municipal wastewater:

1. The College is located in an area (Area "B") that was originally identified in the Town's remote site screening process. The College is located in an area remote from water supply wells and Zone IIs and other environmentally sensitive areas such as Areas of Critical Environmental Concern (ACECs), wetlands, or natural heritage sites.

2. The presence of fill material and the large number of boulders reduces the suitability of the athletic field area.

3. A percolation rate of less than 2 minutes per inch was obtained, suggesting suitable soils for recharge near the surface.

4. Groundwater is found at depths ranging from 65 to 70 feet. Groundwater mounding, resulting from recharge is not a concern at this site. Based on the application of 1 MGD at this site, distributed over 5 acres, a mound of 12 feet is projected.

5. The candidate site for wastewater recharge is comprised of approximately 5 acres. It is wooded and comprised of rolling hills indicating that there would be a significant amount of site work to clear and grade the site for the installation of recharge facilities.

6. If open sand beds are utilized a recharge capacity of approximately one million gallons per day is possible. If leaching trenches are used, the recharge capacity is reduced to approximately 660,000 gallons per day.

7. The site is located approximately 15,000 feet from the WPCF. The distance, in itself, is not an advantage or disadvantage, until compared to the distances of other candidate sites. Sewering the college is a component of a planned project. Piping for treated wastewater could be integrated into that project to lower costs.

To summarize, the College has the potential to be a suitable site to discharge treated effluent. The College will be included in the comparative analysis to be completed as part of the facilities plan.

Please call with any questions or comments.

Very truly yours,

STEARNS & WHELER, LLC

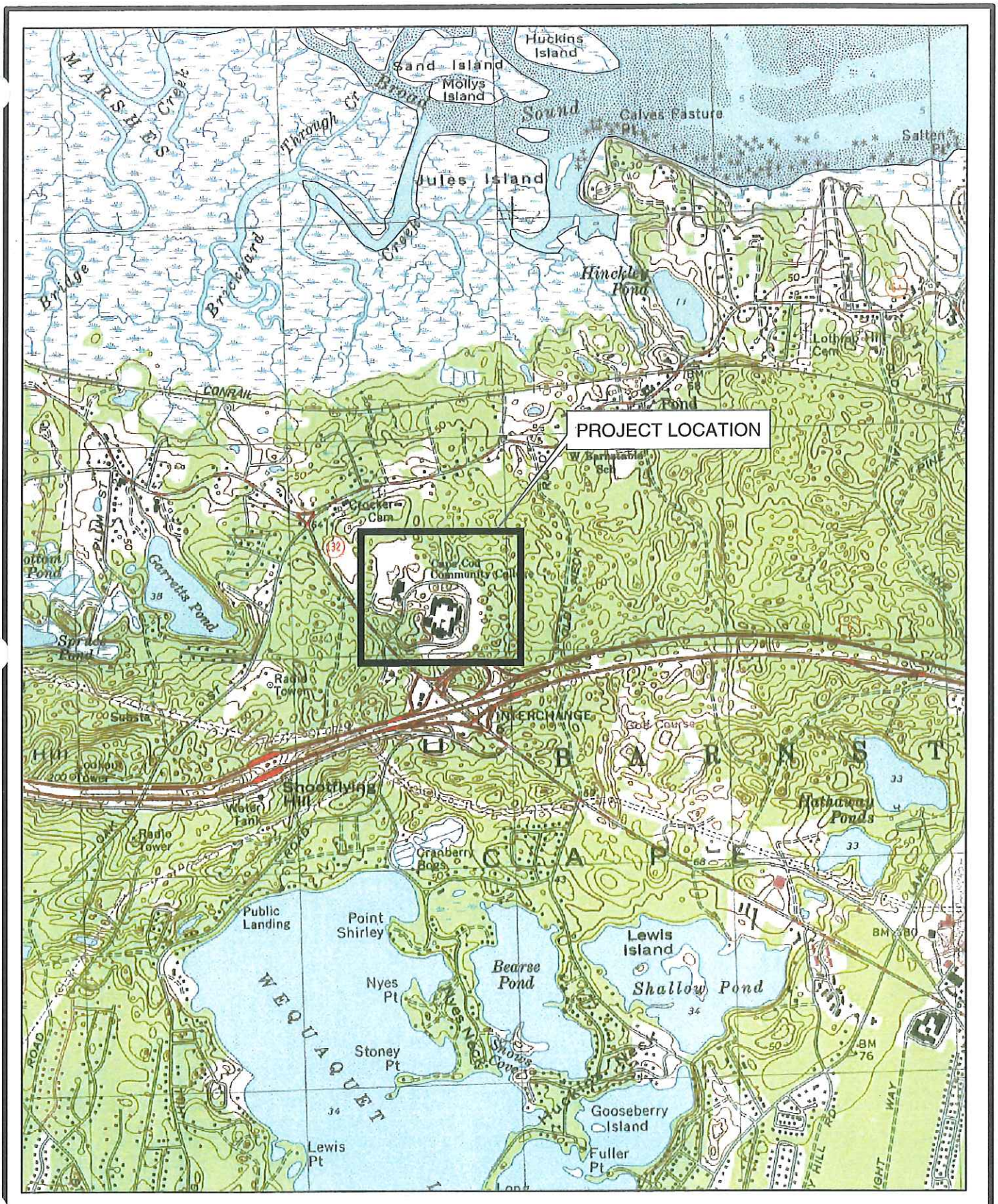
T. Lawrence Hineline, CPG
Associate
/tlh

J. Gage Muckleroy, P.E.
Associate

Attachments

cc: Robert Butterworth, P.E., DEE

Figures



1:24,000

N
W E
S

Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS
JOB NO.: 10290 DATE: 10/30/03

TOWN OF BARNSTABLE, MA
EFFLUENT MITIGATION
FIGURE 1 - SITE LOCATION MAP



D:\GIS PROJECT FOLDER\20190\FIGURE2

Stearns & Wheler, LLC
Environmental Engineers and Scientists
Hyannis, Massachusetts

Legend

- Well Location
- Test Pit
- Athletic Field
- Parking Area
- Wooded Area
- Building
- Parcel Boundary

N
W E
S

1 inch equals 300 feet

Date:10/30/03

TOWN OF BARNSTABLE, MA
CAPE COD COMMUNITY COLLEGE

EFFLUENT MITIGATION

SITE MAP

FIGURE 2



D:\GIS PROJECT FOLDER\20190\FIGURE2

Stearns & Wheler, LLC
Environmental Engineers and Scientists
Hyannis, Massachusetts

Legend

- Proposed Recharge Area
- Athletic Field
- Parking Area
- Building
- Parcel Boundary

N
W E
S

1 inch equals 300 feet

Date:10/30/03

TOWN OF BARNSTABLE, MA
CAPE COD COMMUNITY COLLEGE

EFFLUENT MITIGATION

PROPOSED RECHARGE AREAS

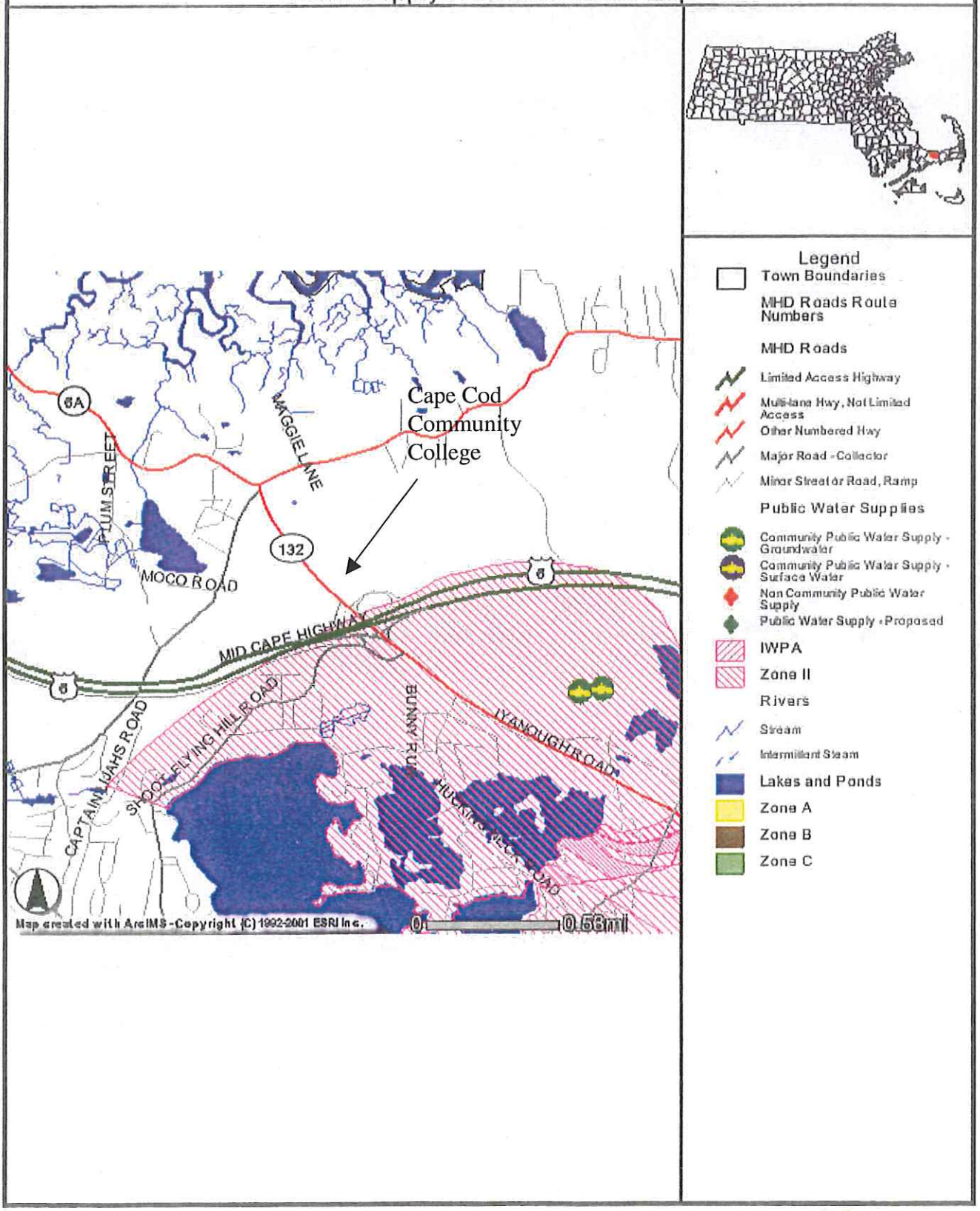
FIGURE 3

Attachments

Attachment A

Water Supply Protection Areas

Water Supply Protection Areas Map



Attachment B
Environmentally Sensitive Areas

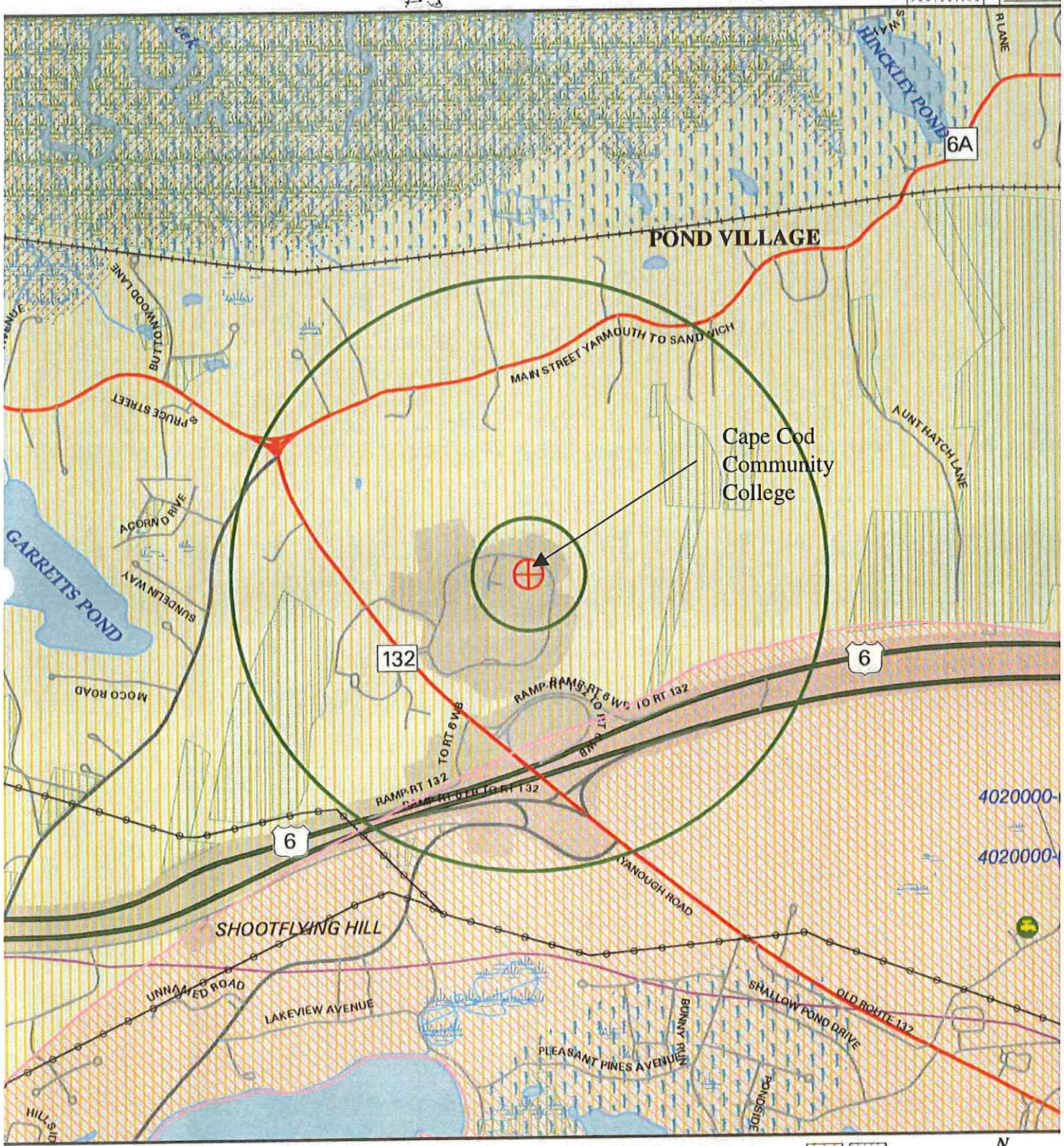
Site Scoring Map: 500 feet & 0.5 Mile Radii

TE NAME:
e Cod Community College
INSTABLE, MA
'33n 702012ew

Site Location

The information shown on this map is the best available at the date of printing. Please refer to the data source descriptions document.

MASS GIS — Massachusetts Geographic Information System
Massachusetts Executive Office of Environmental Affairs - 2003



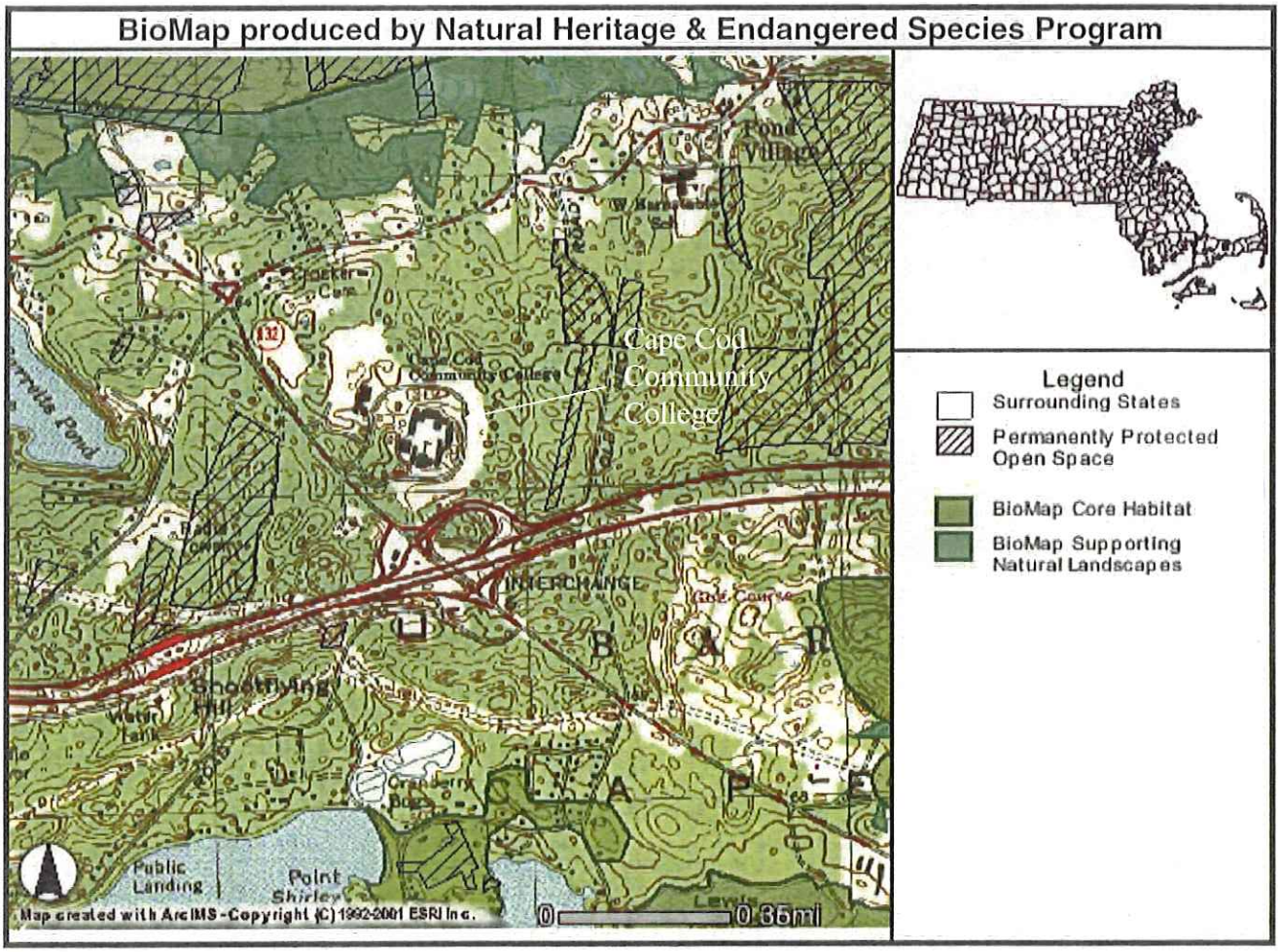
Roads: Limited Access, Divided, Major Road, Connector, Street, Track, Trail
Boundaries: Town, County, DEP Region; Train; Powerline; Pipeline; Aqueduct
Basins: Major, Sub; Streams: Perennial, Intermittent, Man Made Shore, Dams
Potentially Productive Aquifers: Medium,High Yield .....
Non-Potential Drinking Water Source Area: Medium,High Yield

EPA Sole Source Aquifer; FEMA 100-year floodplain .....
Public Water Supplies: Ground,Surface,Non Community
Approved Zone2; IWPA; Surface Water Supply Zone A
Hydrography: Water Features,Public Surface Water Supply ...
Wetlands: Fresh,Salt,NHESP Wetlands Habitat .....
Protected Open Space; ACEC .....
DEP Permitted Solid Waste Facilities; Certified Vernal Pools

N W E S

Attachment C

Natural Heritage and Endangered Species Areas


BioMap produced by Natural Heritage & Endangered Species Program
Cape Cod Community College
INTERCHANGE
Public Landing
Point Shirley
Map created with ArcIMS - Copyright (C) 1992-2001 ESRI Inc.
0
0.35mi
Legend
Surrounding States
Permanently Protected Open Space
BioMap Core Habitat
BioMap Supporting Natural Landscapes

Attachment D

Test Pit Logs

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

A. Facility Information

1. Facility Information

Cape Cod Community College
Owner Name

Street Address — Map/Lot

Barnstable — MA — Zip Code
City — State

B. Site Information

1. (Check one) New Construction ☐ Upgrade ☐ Repair ☐

2. Published Soil Survey available? Yes ☒ No ☐ If yes: 1993 (Year Published) 1:25000 (Publication Scale) PvC (Soil Map Unit)

Plymouth-Barnstable Complex (Soil Name) rolling, very bouldery (Soil limitations)

3. Surficial Geological Report available? Yes ☐ No ☐ If yes: (Year Published) (Publication Scale) (Map Unit)

(Geologic Material) (Landform)

4. Flood Rate Insurance Map:

Above the 500 year flood boundary? Yes ☐ No ☐ Within the 100 year flood boundary? Yes ☐ No ☐

Within the 500 year flood boundary? Yes ☐ No ☐ Within a Velocity Zone? Yes ☐ No ☒

5. Wetland Area: National Wetland Inventory Map (Map Unit) (Name)

Wetlands Conservancy Program Map (Map Unit) (Name)

6. Current Water Resource Conditions (USGS) (Month/Year) Range: Above Normal ☐ Normal ☐ Below Normal ☐

7. Other references reviewed:

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

C. On-Site Review

(minimum of two holes required at every proposed disposal area)

Deep Observation Hole A: 9/15/03 (Date) 9:15 am (Time) Partly Cloudy 75 degrees (Weather)

1. Deep Observation Hole Logs

   Deep Hole Number TP-1 Ground Elevation at Surface of Hole _____

   Location (Identify on Plan) _____

2. Land Use: Woodland (e.g. woodland, agricultural field, vacant lot, etc.) None Observed (Surface Stones) 0% (Slope (%))

   woods (Vegetation) _____ (Landform) _____ (Position on landscape (attach sheet))

3. Distances from: Open Water Body _____ feet Drainage Way _____ feet Possible Wet Area _____ feet

   Property Line _____ feet Drinking Water Well _____ feet Other _____

4. Parent Material: _____ Unsuitable Materials Present: Yes ☐ No ☒

   If Yes: Disturbed Soil ☐ Fill Material ☐ Impervious Layer(s) ☐ Weathered/Fractured Rock ☐ Bedrock ☐

5. Groundwater Observed: Yes ☐ No ☒

   If Yes: Depth Weeping from Pit _____ Depth Standing Water in Hole _____

   Estimated Depth to High Groundwater: _____ inches _____ elevation

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Deep Observation Hole A: Deep Hole Number:____TP-1_____

Depth (In.)	Soil Horizon/ Layer	Soil Matrix: Color-Moist (Munsell)	Redoximorphic Features (mottles)			Soil Texture (USDA)	Coarse Fragments % by Volume		Soil Structure	Soil Consistence (Moist)	Other
			Depth	Color	Percent		Gravel	Cobbles & Stones			
0-8	A	7.5YR 3/2	N/A			loamy sand (LS)			Structureless	Loose	
8-32	B	10YR 5/6	N/A			LS	10%	5%	Structureless	Loose	
32-105	C	2.5 Y 6/6	N/A			LS	5%		Structureless	Loose	

Additional Notes ___ Perc Test Performed_____

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

C. On-Site Review (Cont.)

Deep Observation Hole B: 9/15/03 (Date) 10:45 am (Time) partly cloudy, 75 (Weather)

1. Deep Observation Hole Logs

   Deep Hole Number TP-2 Ground Elevation at Surface of Hole _____

   Location (Identify on Plan) _____

2. Land Use: Lawn (parking lot island) (e.g. woodland, agricultural field, vacant lot, etc.) Yes- from fill (Surface Stones) <1% (Slope (%))

   grass (Vegetation) _____ (Landform) _____ (Position on landscape (attach sheet))

3. Distances from: Open Water Body _____ feet Drainage Way _____ feet Possible Wet Area _____ feet

   Property Line _____ feet Drinking Water Well _____ feet Other _____

4. Parent Material: _____ Unsuitable Materials Present: Yes ☒ No ☐

   If Yes: Disturbed Soil ☒ Fill Material ☒ Impervious Layer(s) ☐ Weathered/Fractured Rock ☐ Bedrock ☐

5. Groundwater Observed: Yes ☐ No ☒

   If Yes: Depth Weeping from Pit _____ Depth Standing Water in Hole _____

   Estimated Depth to High Groundwater: _____ inches _____ elevation

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Deep Observation Hole B: Deep Hole Number: TP-2

Depth (In.)	Soil Horizon/ Layer	Soil Matrix: Color-Moist (Munsell)	Redoximorphic Features (mottles)			Soil Texture (USDA)	Coarse Fragments % by Volume		Soil Structure	Soil Consistence (Moist)	Other
			Depth	Color	Percent		Gravel	Cobbles & Stones			
0-2	A										
2-48	FILL						20%	5-10%			
48-50	Ab										
50-96	B	10 YR 5/6	N/A			LS	20%	5-10%	Structureless	loose	
64-96	C	2.5 Y 6/6	N/A			LS	20%	5-10%	Structureless	loose	

Additional Notes No Perc test

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

C. On-Site Review (Cont.)

Deep Observation Hole C: 9/15/03 (Date) 12:35 PM (Time) Cloudy 70 light mist (Weather)

1. Deep Observation Hole Logs

   Deep Hole Number TP-3 Ground Elevation at Surface of Hole _____

   Location (Identify on Plan) _____

2. Land Use: Playing Field (e.g. woodland, agricultural field, vacant lot, etc.) None Observed (Surface Stones) 0% (Slope (%))

   grass (Vegetation) _____ (Landform) _____ (Position on landscape (attach sheet))

3. Distances from: Open Water Body _____ feet Drainage Way _____ feet Possible Wet Area _____ feet

   Property Line _____ feet Drinking Water Well _____ feet Other _____

4. Parent Material: _____ Unsuitable Materials Present: Yes ☒ No ☐

   If Yes: Disturbed Soil ☒ Fill Material ☒ Impervious Layer(s) ☐ Weathered/Fractured Rock ☐ Bedrock ☐

5. Groundwater Observed: Yes ☐ No ☒

   If Yes: Depth Weeping from Pit _____ Depth Standing Water in Hole _____

   Estimated Depth to High Groundwater: _____ inches _____ elevation

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Deep Observation Hole C: Deep Hole Number: TP-3

Depth (In.)	Soil Horizon/ Layer	Soil Matrix: Color-Moist (Munsell)	Redoximorphic Features (mottles)			Soil Texture (USDA)	Coarse Fragments % by Volume		Soil Structure	Soil Consistence (Moist)	Other
			Depth	Color	Percent		Gravel	Cobbles & Stones			
0-6	A						30%	10%			5% Boulders
6-30	Fill						30%	10%			5% Boulders
30-32	Ab						30%	10%			5% Boulders
32-60	B	10YR 5/6	N/A			LS	30%	10%	Structureless	Loose	5% Boulders
60-90	C	2.5Y 6/4	72	2.5Y 8/2 10YR 6/8	20%	Sandy Loam (SL)	30%	10%	Structureless	Friable	5% Boulders

Additional Notes Perc Test Performed

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

D. Determination of High Groundwater Elevation

1. Method used:

☐	Depth observed standing water in observation hole	A. _____ inches	B. _____ inches	C. _____ inches	D. _____ inches	E. _____ inches
☐	Depth weeping from side of observation hole	A. _____ inches	B. _____ inches	C. _____ inches	D. _____ inches	E. _____ inches
☐	Depth to soil redoximorphic features (mottles)	A. _____ inches	B. _____ inches	C. _____ inches	D. _____ inches	E. _____ inches
☒	Groundwater adjustment (USGS methodology)	A. _____ inches	B. _____ inches	C. _____ inches	D. _____ inches	E. _____ inches

2. Index Well Number _____ Reading Date _____ Index Well Level _____

Adjustment Factor _____ Adjusted Groundwater Level _____

E. Depth of Pervious Material

1. Depth of Naturally Occurring Pervious Material

   a. Does at least four feet of naturally occurring pervious material exist in all areas observed throughout the area proposed for the soil absorption system? Yes ☒ No ☐

   b. If yes, at what depth was it observed? Upper boundary: 32" inches _____ Lower boundary: 105" inches _____

F. Certification

I certify that I have passed the soil evaluator examination* approved by the Department of Environmental Protection and that the above analysis was performed by me consistent with the required training, expertise and experience described in 310 CMR 15.017.

_____ Signature of Soil Evaluator

_____ Date

J. Jefferson Gregg Typed or Printed Name of Soil Evaluator

_____ *Date of Soil Evaluator Exam

_____ Name of Board of Health Witness

_____ Board of Health

Note: This form must be submitted to the approving authority with Percolation Test Form 12

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Use this sheet for field diagrams:

Attachment E

Percolation Test Results

FORM 12 - PERCOLATION TEST

Location Address or Lot No. Cape Cod Community College

COMMONWEALTH OF MASSACHUSETTS

Barnstable, Massachusetts

Percolation Test*		
Date: 9/15/03	Time:9:15 AM	
Observation Hole#	TP-1	TP-3
Depth of Perc	42 inches	60 inches
Start Pre-soak	9:47 am	2:22 pm
End Pre-soak	10:02 am	2:37 pm
Time at 12"	10:02 am	2:39 pm
Time at 9"	10:05 am	2:59 pm
Time at 6"	10:07 am	3:25 pm
Time (9"-6")	2 min	26 min
Rate Min./Inch	0.67 min/inch	8.67 min/inch

*Minimum of 1 percolation test must be performed in both the primary area AND reserve area

Site Passed ☐ Site Failed ☐

Performed by: J. Jefferson Gregg

Witnessed by: _____

Comments: Unofficial Perc Tests, - not witnessed by State - TP-1 located adjacent to Parking Lot, TP-3 located on far side of athletic fields.

Attachment F
Boring Logs

Soil Boring Log
Barnstable Wastewater Mitigation
Cape Cod Community College
Town of Barnstable, MA

Boring/Well ID: Test Well 1, CCCC

Project Name:	Barnstable Effluent Mitigation	
Job. No.	20190.40.4000	
Start Date & Time:	9/15/2003	8:00 AM
Finish Date & Time:	9/17/2003	11:45 AM
Drilling Co.:	GeoLogic	
Driller:	John (foreman); Brett	
S&W Inspector:	RHK	
Rig Type:	Mobil B-57	
Drilling Method:	Casing w/ split spoon samples	
Weather:	9/15/2003	70's, overcast
	9/16/2003	70's, overcast, rain
	9/17/2003	70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water — Sample Description
0						
1						
2						
3						
4						
5	5,120		3			Light-Brown, FINE GRAVEL to COARSE SAND
6						
7						
8						
9						
10	5,3		10			Light-Brown, FINE SAND to SILT
11	15,16					
12						
13						
14						
15	22,34		14			Light-Brown, FINE SAND
16	29,35					
17						
18						
19						Top 9" Light-Brown FINE GRAVEL
20	105,35		12			Bot 9" Light-Brown FINE SAND
21	28,37					
22						
23						
24						
25	On Rock,		0			No Recovery
26	No B.C.					
27						
28						
29						
30	22,25		12			Light-Brown MEDIUM to FINE SAND
31	31,34					
32						
33						
34						
35	28,41		14			Light-Brown FINE SAND
36	33,40					
37						
38						
39						
40	18,26		10			Light-Brown FINE SAND
41	27,37					
42						
43						
44						
45	22,32		12			Light-Brown MEDIUM to FINE SAND
46	28,45					
47						
48						
49						Top 2" Light-Brown FINE SAND to SILT
50	20,29		6			Mid 2" Light-Brown FINE GRAVEL
51	44,54					Bot 2" Light Brown FINE GRAVEL to COARSE SAND
52						
53						
54						
55	23,34		12			Light-Brown MEDIUM to FINE SAND
56	37,50					
57						
58						
59						
60	39,46		12			Light-Brown MEDIUM to FINE SAND
61	62,80					

Soil Boring Log
Barnstable Wastewater Mitigation
Cape Cod Community College
Town of Barnstable, MA

Boring/Well ID: Test Well 1, CCCC

Project Name:	Barnstable Effluent Mitigation	
Job. No.	20190.40.4000	
Start Date & Time:	9/15/2003	8:00 AM
Finish Date & Time:	9/17/2003	11:45 AM
Drilling Co.:	GeoLogic	
Driller:	John (foreman); Brett	
S&W Inspector:	RHK	
Rig Type:	Mobil B-57	
Drilling Method:	Casing w/ split spoon samples	
Weather:	9/15/2003	70's, overcast
	9/16/2003	70's, overcast, rain
	9/17/2003	70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to ⎓ Ground Water
62						
63						
64						
65	27,270		15	▼		Light-Brown FINE GRAVEL to COARSE SAND
66	*25,23*					
67	*300 lb. Hammer*					
68						
69						Top 5" Light-Brown MEDIUM to FINE SAND
70	38,37		8			Bot 3" Grey FINE SAND to SILT
71	40,27					
72						
73						
74						
75	80,40		0			No Recovery
76	49,66					
77						
78						
79						
80	44,51		0			Rock Fragments
81	95,111					
82						
83						
84						
85	22,31		4			Light Brown COARSE to MEDIUM SAND
86	35,39					
87						
88						
89						
90	17,23		0			No Recovery
91	27,35					
92						
93						
94						
95	27,35		1			Light-Brown FINE GRAVEL to COARSE SAND
96	37,35					

Soil Boring Log
Barnstable Wastewater Mitigation
Cape Cod Community College
Town of Barnstable, MA

Boring/Well ID: Test Well 2, CCCC

Project Name:	Barnstable Effluent Mitigation	
Job. No.	20190.40.4000	
Start Date & Time:	9/18/2003	11:45 AM
Finish Date & Time:	9/23/2003	1:00 PM
Drilling Co.:	GeoLogic	
Driller:	John (foreman); Brett	
S&W Inspector:	RHK	
Rig Type:	Mobil B-57	
Drilling Method:	Casing w/ split spoon samples	
Weather:	9/18/2003	60's, partly cloudy
	9/22/2003	60's, sunny
	9/23/2003	70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water — Sample Description
0						
1						
2						
3						
4						
5	14,17		20			Light-Brown, FINE SAND
6	14,14					
7						
8						
9						
10	12,22		10			Light-Brown, MEDIUM to FINE SAND
11	36,46					
12						
13						
14						
15	23,30		12			Light-Brown, MEDIUM to FINE SAND
16	35,31					
17						
18						
19						Top 4" Light-Brown COARSE SAND
20	12,23		12			Bot 8" Light-Brown FINE to MEDIUM SAND
21	23,30					
22						
23						
24						
25	10,13		12			Light-Brown, MEDIUM to FINE SAND
26	19,24					
27						
28						
29						
30	14,20		10			Light-Brown MEDIUM SAND
31	21,29					
32						
33						
34						
35	33,28		0			Rock Fragments
36	30,20					
37						
38						
39						
40	20,26		0			No Recovery
41	32,35					
42						
43						
44						
45	23,42		10			Light-Brown FINE SAND to SILT
46	70,41					
47						
48						
49						
50	22,35		1			Some Light-Brown MEDIUM SAND
51	21,28					Mostly Rock Fragment
52						
53						
54						
55	30,41		12			Light-Brown FINE SAND
56	45,55					
57						
58						
59						
60	41,45		10			Light-Brown FINE SAND
61	64,85					

Soil Boring Log
Barnstable Wastewater Mitigation
Cape Cod Community College
Town of Barnstable, MA

Boring/Well ID: Test Well 2, CCCC

Project Name:	Barnstable Effluent Mitigation	
Job. No.	20190.40.4000	
Start Date & Time:	9/18/2003	11:45 AM
Finish Date & Time:	9/23/2003	1:00 PM
Drilling Co.:	GeoLogic	
Driller:	John (foreman); Brett	
S&W Inspector:	RHK	
Rig Type:	Mobil B-57	
Drilling Method:	Casing w/ split spoon samples	
Weather:	9/18/2003	60's, partly cloudy
	9/22/2003	60's, sunny
	9/23/2003	70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water
62						
63						
64						
65	160, *19*		2	▼		Light-Brown FINE GRAVEL
66	*17,16*					
67	***300 lb. Hammer***					
68						
69						
70	24,40		8			Light-Brown MEDIUM to FINE SAND
71	62,85					
72						
73						
74						
75	32,46		0			No Recovery
76	49,49					
77						
78						
79						
80	23,19		6			Light-Brown COARSE to MEDIUM SAND
81	19,21					
82						
83						
84						
85	53,58		0			No Recovery
86	72,93					
87						
88						
89						
90	42,66		0			No Recovery
91	113,109					
92						
93						
94						
95	65,58		10			Light-Brown COARSE to MEDIUM SAND
96	62,67					

Soil Boring Log
Barnstable Wastewater Mitigation
Cape Cod Community College
Town of Barnstable, MA

Boring/Well ID: Test Well 3, CCCC

Project Name:	Barnstable Effluent Mitigation
Job. No.	20190.40.4000
Start Date & Time:	9/23/2003 1:00 PM
Finish Date & Time:	9/25/2003 4:00 PM
Drilling Co.:	GeoLogic
Driller:	Glen (foreman); Brett, Amol
S&W Inspector:	RHK
Rig Type:	Mobil B-57
Drilling Method:	Casing w/ split spoon samples
Weather:	9/23/2003 70's, sunny 9/24/2003 60's, sunny 9/25/2003 70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water — Sample Description
0						
1						
2						
3						
4						
5						NO SAMPLE - ON ROCK
6						
7						
8						
9						
10	19,32		15			Light-Brown, MEDIUM SAND
11	49,59					
12						
13						
14						Top 4" Light-Brown FINE GRAVEL to COARSE SAND
15	16,36		12			Bot 8" Light-Brown MEDIUM SAND
16	44,46					
17						
18						
19						
20	120,*19*		14			Light-Brown, MEDIUM SAND
21	*15,19*					
22	*300 lb. HAMMER*					
23						
24						
25	61,70		12			Light-Brown, MEDIUM to FINE SAND
26	67,89					
27						
28						
29						
30	53,100		10			Light-Brown MEDIUM to FINE SAND
31						Some Light-Brown FINE GRAVEL
32						
33						
34						
35	56,57		1			Light-Brown FINE SAND
36	49,49					
37						
38						
39						Top 3" Light-Brown COARSE SAND
40	16,30		12			Bot 9" Light-Brown MEDIUM SAND
41	26,32					
42						
43						
44						
45	20,31		1			Light-Brown MEDIUM SAND
46	29,27					
47						
48						
49						
50	17,17		5			Light-Brown FINE GRAVEL to COARSE SAND
51	16,15					
52						
53						
54						
55	16,19		3			Light-Brown, MEDIUM SAND
56	20,28					
57						

Soil Boring Log
Barnstable Wastewater Mitigation
Cape Cod Community College
Town of Barnstable, MA

Boring/Well ID: Test Well 3, CCCC

Project Name:	Barnstable Effluent Mitigation
Job. No.	20190.40.4000
Start Date & Time:	9/23/2003 1:00 PM
Finish Date & Time:	9/25/2003 4:00 PM
Drilling Co.:	GeoLogic
Driller:	Glen (foreman); Brett, Amol
S&W Inspector:	RHK
Rig Type:	Mobil B-57
Drilling Method:	Casing w/ split spoon samples
Weather:	9/23/2003 70's, sunny 9/24/2003 60's, sunny 9/25/2003 70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

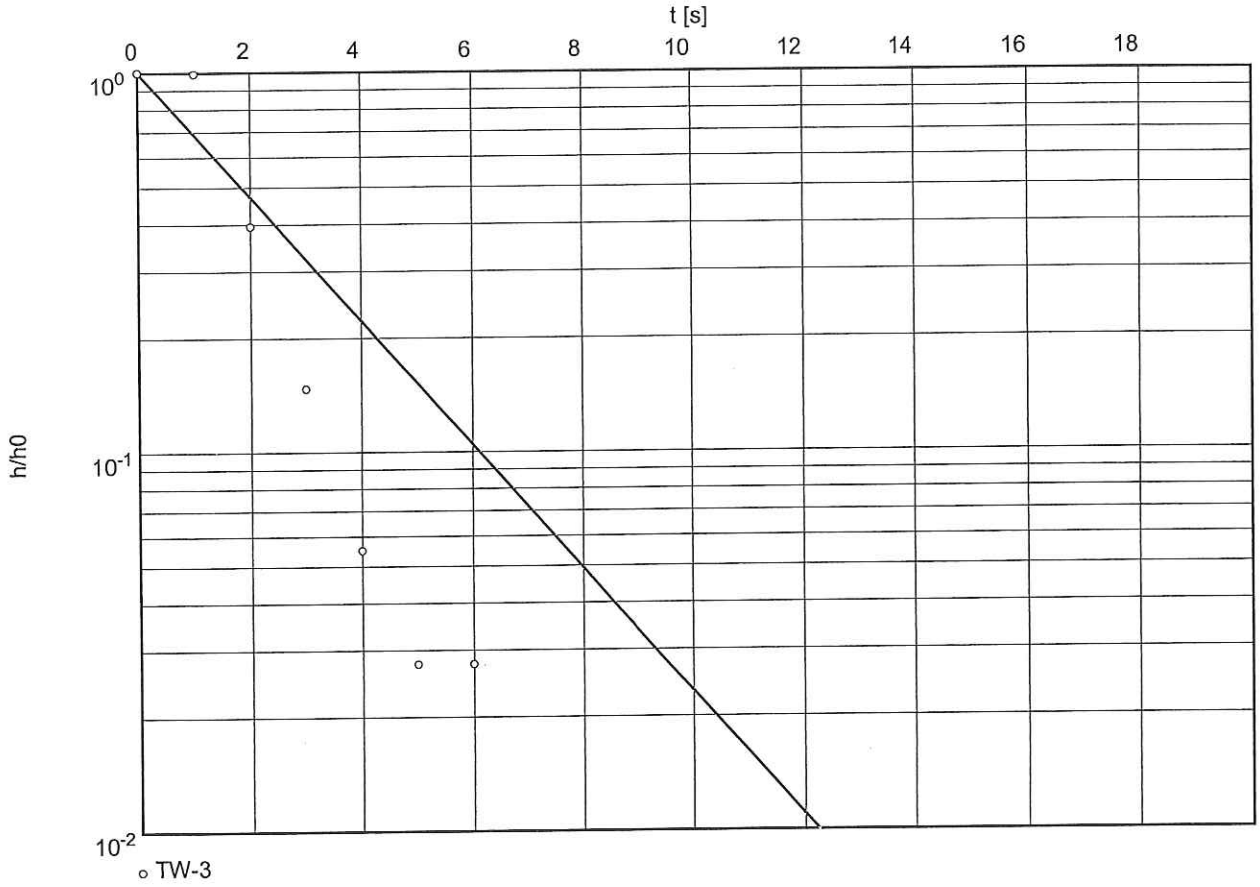
Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water
58						
59						
60	16,20		5			Light-Brown, MEDIUM SAND
61	19,24					
62						
63						
64						
65	20,38		12			Light-Brown, MEDIUM to FINE SAND
66	51,53					
67						
68						
69						
70	17,18		1	▼		Light-Brown, MEDIUM to FINE SAND
71	19,28					
72						
73						
74						
75	8,10		6			Light-Brown, COARSE to MEDIUM SAND
76	11,15					
77						
78						
79						
80	6,6		6			Light-Brown MEDIUM SAND
81	8,8					
82						
83						
84						
85	26,30		0			No Recovery
86	27,24					

Attachment G

Slug Test Calculations

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis BOUWER-RICE's method	Date: 21.10.2003	Page 1
		Project: Cape Cod Community College	
		Evaluated by: TLH	

Slug Test No. T-3	Test conducted on: 10/20/03
TW-3	



Hydraulic conductivity [ft/s]: 1.29×10^{-3}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis BOUWER-RICE's method	Date: 21.10.2003	Page 2
		Project: Cape Cod Community College	
		Evaluated by: TLH	

Slug Test No. T-3	Test conducted on: 10/20/03
TW-3	TW-3

Static water level: 10.20 ft below datum

	Pumping test duration [s]	Water level [ft]	Drawdown [ft]	
1	0	9.11	-1.09	
2	1	9.12	-1.08	
3	2	9.77	-0.43	
4	3	10.04	-0.16	
5	4	10.14	-0.06	
6	5	10.17	-0.03	
7	6	10.17	-0.03	
8	7	10.20	0.00	
9	8	10.20	0.00	
10	9	10.20	0.00	
11	10	10.20	0.00	
12	11	10.20	0.00	
13	12	10.20	0.00	
14	13	10.20	0.00	

Attachment H

Mounding Calculations

- HANTAXIS -

Groundwater Mounding Analysis (Hantush's Method using Glover's Solution)

PROJECT: CCCC2

ANALYST: TLH

DATE: 10-21-2003 TIME: 16:29:40

INPUT PARAMETERS

Application rate:	0.4300	cft/day/sft
Duration of application:	180	days
Fillable porosity:	0.25	
Hydraulic conductivity:	100.00	ft/day
Initial saturated thickness:	75.0	ft
Length of application area:	1100	ft
Width of application area:	500	ft
No constant head boundary used		
Plotting axis from Y-Axis:	90	degrees
Edge of recharge area:		
positive X:	250	ft
positive Y:	0	ft
Total volume applied:	425.7D+05	cft

MODEL RESULTS

X (ft)	Y (ft)	Plot Axis (ft)	Mound Height (ft)
-3000	-0	-3000	1.68
-2523	-0	-2523	2.28
-2046	-0	-2046	3.09
-1569	-0	-1569	4.21
-1194	-0	-1194	5.41
-903	-0	-903	6.64
-665	-0	-665	7.96
-465	-0	-465	9.38
-291	-0	-291	10.94
-174	-0	-174	12.04
-95	-0	-95	12.48
0	0	0	12.67
95	0	95	12.48
174	0	174	12.04
291	0	291	10.94
465	0	465	9.38
665	0	665	7.96
903	0	903	6.64
1194	0	1194	5.41
1569	0	1569	4.21
2046	0	2046	3.09
2523	0	2523	2.28
3000	0	3000	1.68

Appendix K

Preliminary Evaluation of the Lorusso Property for Treated Water Recharge; November 2003

Stearns & Wheler, LLC
Environmental Engineers and Scientists

255 Stevens Street
P.O. Box 975
Hyannis, MA 02601

tel. (508) 790-1707
fax. (508) 790-2707
web. www.stearnswheler.com

November 10, 2003

Mr. Mark Giordano, P.E.
Senior Project Manager
Department of Public Works
Town of Barnstable
367 Main Street
Hyannis, MA 02601

Re: Effluent Mitigation Investigation Project
Task 7 – Lorusso Property Investigation
S&W No. 20190.0

Dear Mr. Giordano:

In accordance with your request and the Contract for Consultant Services for the Effluent Mitigation Investigation Project Task 7 – Lorusso Property Characterization, we have completed a preliminary evaluation of the Lorusso property along the power lines, just south of Route 6, for the recharge of treated effluent. In accordance with paragraph 2.2.5.2 of the Contract for Consultant Services, QA/QC procedures of the Scope of Work were adhered to in the completion of this project. In accordance with paragraph 2.2.5.4 of the Contract, Stearns & Wheler is providing five (5) bound copies, one (1) unbound copy, and one computer copy of this letter report. The evaluation was completed consistent with the Barnstable Wastewater Facilities Plan (WWFP) recommendation to identify and utilize remote sites for the purpose of discharging treated wastewater to the subsurface.

BACKGROUND INFORMATION

The Town of Barnstable is in the process of completing a Wastewater Facilities Plan (WWFP) that evaluates future options for the Town to collect, treat and dispose of municipal wastewater. A component of the WWFP recommended the identification of parcels of land, remote from the existing Water Pollution Control Facility (WPCF), where treated wastewater can be reclaimed by discharging it back to the subsurface in order to replenish groundwater resources in the Town. Utilization of remote sites was recommended because the WWFP and related work concluded that the recharge capacity of the existing plant effluent discharge beds might be limited due to potential adverse impacts related to groundwater mounding. In the course of completing the WWFP, the Town undertook a remote site screening process to identify areas of the Town where suitable parcels may exist. Following the completion of that screening process, the Town

began to identify specific parcels that could be further evaluated for suitability. One of those parcels being investigated is the Lorusso property. Reference is made to Figure 1 for the location of the Lorusso property.

The subject property is located along the power line right-of-way, east of Phinney's Lane, just south of Route 6 and north of the Cape Cod Aggregate operation. The property consists of approximately 11 acres and is comprised of lightly vegetated, undulating terrain. Access for future development is somewhat limited by three sets of power lines that cross the site from east to west. The power line poles did not significantly limit investigation efforts other than having a 30-foot radius buffer around them. The presence of the power line poles could limit the areal extent of recharge facilities but sufficient areas of land for construction of recharge facilities appear to be present between the poles.

SCOPE OF WORK

The Scope of Work for the investigation included the following tasks:

Subtask 7.1 Site Visit. Prior to initiating site work on the site, an initial reconnaissance trip to the site was conducted. Additionally, discussions were held with site owners. The purpose of these discussions was to determine what restrictions the owner might impose that could impact investigative efforts or future use of the site.

Subtask 7.2 Initial Screening. Following the site visit, an initial screening was completed that evaluated the suitability of the site in terms of siting criteria considered in earlier phases of the site identification and screening process, including but not limited to location with respect to:

1. In Wellhead Protection Zones I, II and III
2. In Areas of Critical Environmental Concern
3. Near vernal pools
4. Near wetland
5. In areas of rare and endangered plant and wildlife habitat
6. In conservation areas
7. In flood hazard zones
8. Releases of oil or hazardous materials
9. Drainage basin

Under this subtask, Stearns & Wheler did not repeat the Town's earlier screening efforts but refined and updated the previous work.

Subtask 7.3 Test Pits. Five backhoe test pits were completed at representative locations across the property. Test pits were excavated to a depth of 7 to10 feet. A soil evaluator logged soil stratigraphy in the test pits. Percolation tests were completed at four of the five test pits. A percolation test was not completed at the second site because low permeability soils were present and the depth to natural soils precluded safely entering the test pit to conduct the test. Test pit locations are shown on Figure 2.

Subtask 7.4 Soil Borings. Three soil borings were drilled. Borings were distributed across the site to generally characterize the subsurface. The proposed work plan specified the borings would be advanced to a depth at least 10 feet below the existing water table. Based on the depth at which the water table was encountered, the borings were advanced to depths of 76, 76, and 86 feet, respectively. Split spoon samples were collected at 5 foot intervals from each boring. Stearns & Wheler recorded soil types on a boring log. Boring locations are shown on Figure 2.

Subtask 7.5 Observation Wells/Slug Tests. Upon completion of the first soil boring, a field determination was made that the site is a likely candidate for disposal, so the soil borings were completed as observation wells. In-situ hydraulic conductivity testing (slug testing) was completed in all of the wells to determine the permeability of the deeper soils. This data was obtained to support regional mapping data and in order to complete a groundwater mounding analysis, a requirement of a groundwater discharge permit application, should the Town decide it wants to pursue a permit for this parcel.

Subtask 7.6 Report of Findings. A written report for the Town that presents the field investigation results and provides recommendations regarding the use of the subject parcel for treated effluent disposal is included herein.

Subtask 7.7 Meetings. Time was allocated for meetings related to this site investigation. One meeting where preliminary results were presented was held on October 7, 2003. An additional meeting is anticipated.

EVALUATION RESULTS

The results of the Lorusso Property investigation are presented in this section. The results are organized in the following order:

- Location Considerations.
  - Summary of initial site screening considerations and results

- Site Characteristics

  - Published Information from literature about the general characteristics of the site.

  - Field Investigation Results – detailed results from the Stearns & Wheler field investigation.

A. Location Considerations

Location considerations relate to the suitability of the site based on its setting. These criteria were evaluated by the Town in their initial screening process and included those factors listed in the introduction section of this letter. Stearns & Wheler reviewed and updated these siting criteria.

The results of that screening process indicated that:

1. There are four public supply wells within one mile of the property. The property is located within the Zone II of one of those wells, the Barnstable Fire District (BFD) Well No. 1. The well is located approximately 2,000 feet from the property, near Phinney's Lane, north of Route 6 (See Attachment A – MADEP Water Supply Protection Areas Map). The BFD Well No. 1 is presently active and produces approximately 300 gallons per minute from the interval between 44 and 59 feet below grade.

2. The property is not in an Area of Critical Environmental Concern or in any other designated environmentally sensitive area. (See Attachment B Map – MADEP Bureau of Waste Site Cleanup – Map showing sensitive environments and Attachment C, Map showing Natural Heritage Areas and Endangered Species Areas).

3. The property has not been previously identified as being in a conservation area or a Flood Hazard Zone.

4. Town GIS mapping shows the groundwater flow direction at the property to be toward the northeast.

B. Site Characteristics

1. Published Information

a. Geologic Setting. The site is located on the Sandwich Moraine. Soils on the moraine are generally described as:

Mostly sand and gravel. Abundant fine sand, silt and clay.
Till and boulders generally occur above the stratified drift.

b. Soil Type. The surficial soils in the undeveloped and undisturbed areas of the Lorusso property are classified as the Plymouth-Barnstable Complex and as the Eastchop loamy sand. (USDA, SCS, 1993). The soils are similar and are characterized as being on rolling and undulating land. They are excessively and well-drained soils on the side slopes of moraines. The subsoil grades from sandy loam to loose course sand. Boulders are common in the Plymouth-Barnstable Complex according to the SCS description, but none were detected in the field investigation.

c. Site Topography. The property is comprised of rolling terrain with elevations ranging from approximately 80 to 120 feet above MSL.

d. Depth to Groundwater. The property is in an area where groundwater has been mapped to be greater than 5 feet below the surface. The site investigation revealed that the water table is at a depth of approximately 65 feet.

e. Hydraulic Conductivity. The property is in an area where earlier modeling efforts used a hydraulic conductivity of 50 to 200 feet per day.

2. Field Investigation Results

As described above, the investigation entailed the installation of five test pits, the completion of four percolation tests and the installation of three soil borings, which were completed as observation wells. The borings and test pits were distributed across the site to provide a general characterization of the entire property. The field work and observations are described below.

a. Test Pit Observations. On September 8, 2003 five test pits were excavated on the property. Test pit logs are provided in Attachment D. Two of the test pits (TP-1 and TP-2) were located at the eastern end of the property. Both of these test pits apparently penetrated fill material. Although there was no prior reason to believe that the property had been reworked in any way, the two eastern test pits revealed a buried topsoil horizon at a depth of about 6 feet. Above and below the buried soil horizon the subsurface was comprised of medium sand. At a depth of approximately 6 feet in test pit TP- 2, a low permeability, silt to clay layer was penetrated. The presence of the fill material does not necessarily prevent the use of the area for recharge facilities, although MADEP does specify certain construction requirements for facilities located in fill material. In those instances, the existing fill must be removed and the facilities located on the natural material or new fill with certain properties must be brought in to replace the removed fill. This would represent significant additional costs for grading and filling. A greater

restriction is the presence of the low permeability layer in test pit TP-2. In that particular location, the subsurface soils may not be ideal for the construction of a recharge facility.

The three test pits in the more westerly extremes of the property possessed more typical soil properties. No fill was present and the underlying soils were uniform, clean, medium to fine sands.

b. Percolation Tests. Percolation tests were conducted at test pits TP-1, 3, 4 and 5 to obtain a generally qualitative assessment of the soil's capacity to allow water to infiltrate. No percolation test was performed in TP-2 because of the presence of the low permeability layer at a depth of approximately six feet. Percolation test logs are included as Attachment E. Percolation rates are compared to standards in "Guidelines for the Design Construction, Operation and Maintenance of Small Sewage Treatment Facilities with Land Disposal".

The percolation rate at TP-1 was 4.6 minutes per inch which is acceptable for recharge facilities. The percolation rate at the remaining three test pits was under 2 minutes per inch, indicating rapidly draining soils and preferable conditions for recharge facilities.

c. Deep Boring Observations. Three deep soil borings were installed and completed as observation wells. The borings all penetrated similar sediments. Medium to fine sand was penetrated to a depth of 40 feet in TW-1 and TW-2. The silty to silty clay layer seen in TP-2 was not observed in TW-2 suggesting that it may not have been a continuous layer. In TW-1 and TW-2 the subsurface soils become much finer, grading to silt below 40 feet. The finer sand to silt was encountered at a depth of 70 feet in TW-3. The fine sand to silt will reduce the site's capacity to accept and disperse water but given the depth of groundwater, approximately 65 feet, mounding is not anticipated to be a concern.

d. Deep Hydraulic Conductivity. Mapped hydraulic conductivity values were confirmed through the completion of in-situ hydraulic conductivity testing. A value of approximately 50 feet per day was obtained (See Attachment G). This value is consistent with values between 50 and 200 feet per day that have been used in earlier groundwater models of the area. In earlier mapping (Geraghty & Miller 1993) a value of 50 feet per day was assigned to this area. In more recent mapping, USGS has used higher values but specific information was not available from USGS. The value of 50 feet per day has been used for mounding calculations to be conservative.

e. Groundwater Flow Direction. Groundwater flow direction is relevant to this study to determine into which watershed the treated effluent will flow. Depth to water measurements and the calculated groundwater elevations may indicate a groundwater flow direction toward the south, opposite current Town-wide mapping. The fact that the site is on the moraine, near the north-south flow divide explains why the flow direction is not definitively determined. At that location, flow could conceivably be in either

direction. It cannot be definitively stated at this time what the flow direction at the site is. If the site is in fact located on or near the flow divide, mounding will result in some radial flow, but eventually water will resume the regional flow direction.

f. Infiltration Capacity. Based on the available area and the percolation test infiltration rates, potential treated wastewater infiltration rates have been estimated. The available area is limited due to the presence of a number of utility poles on the property. The utility poles require recharge areas to be separated and laid out in between the lines of poles. For the purposes of developing a preliminary estimate of the recharge capacity of the property, potential leaching trench or sand bed areas were laid out on the property. Conceptual layouts are shown on Figure 3. The total area of the three recharge areas is approximately 5.0 acres. Allowing some of that area to be set aside for berms, buffers or related facilities, it is estimated that 4 acres within those areas would be available for recharge. Based on the percolation rate of less than 2 minutes per inch, infiltration rates of 5 gpd/sq. ft. for sand beds and 2.5 gpd/sq. ft. for infiltration trenches have been estimated for this site.

Sand Beds: If sand beds are constructed over an area of 4 acres, an infiltration capacity of 870,000 gpd is calculated (5 gpd/sq. ft. x 174,240 sq. ft.). For the purposes of additional discussion, this will be considered to be 0.9 MGD.

Trenches: Based on the dimensions of the three recharge areas, it has been calculated that 26,500 linear feet of trenches can be built. This is based on an eight foot width for each trench (3 foot trench plus 3 foot reserve plus 2 foot space). The selected areas can hold 32, 32 and 15 trenches respectively with lengths of 260, 400 or 360 feet respectively. If each foot of trench has 7 square feet of recharge area,(3 square feet on bottom and two square feet on each side wall) then the capacity of the 26,500 feet of trenches could be 460,000 gpd.

g. Potential Mounding. Because the depth to groundwater is approximately 65 feet below grade, groundwater mounding is not believed to be a limiting factor at this site. Using an analytical mounding calculator (the Hantaxis program, used by MADEP to calculate mounding impacts), a worst case mounding scenario was completed. The mounding calculation was based on recharging 900,000 gallons per day in an area 960 feet by 320 feet and a hydraulic conductivity value of 50 feet per day. The results of the preliminary mounding analysis are presented in Attachment H.

The preliminary mounding analyses indicate that if the site has a hydraulic conductivity around 50 feet per day, and 900,000 gpd are discharged over the proposed area, then a mound of approximately 12 feet can develop. A mound of this magnitude will not impact surface facilities such as proximal buildings or septic systems. Some radial flow would be induced, however, given the natural groundwater gradient in the area, water flowing

radially away from the property would ultimately be captured by the regional flow system.

CONCLUSIONS

The investigation described above has resulted in the following conclusions regarding use of the Lorusso for the recharge of treated municipal wastewater.

1. The Lorusso property consists of approximately 11 acres of undeveloped acreage that serves as a power line right-of-way and the owner has expressed willingness to have the Town use this acreage for wastewater recharge.

2. The property has a number of utility poles on it, which limits the area in which recharge facilities can be constructed. The property has very irregular terrain. Use of the site would take a significant amount of cutting and filling to create level areas suitable for leach field or trenches. The Town may want to consider the use of wick wells for discharge at this site. A discussion of the present status of wick well utilization is provided under separate cover.

3. The presence of fill material, albeit material that is generally indistinguishable from the native sand at the property, could impact the construction of recharge facilities based on MADEP requirements related to building recharge facilities in fill material.

4. A percolation rate of less than 2 minutes per inch was obtained over much of the area, suggesting suitable soils for recharge near the surface. A one acre site at the east end of the property is included in the conceptual layout, however, a percolation rate of closer to 5 minutes per inch was obtained in the test pit at the east end of the site. Soils with lower permeability at the east end of the site might preclude or limit the performance of recharge facilities.

5. Soils that comprise the aquifer at the site, at depths of 40 to 80 feet are very fine sands and silts. These soils are finer grained and less permeable than those seen at other sites. Slug testing indicated that the deeper hydraulic conductivity could be as low as 50 feet per day. Despite the low hydraulic conductivity, mounding is not considered to be an issue and the deeper subsurface soils should have the capacity to receive the recharged water.

6. Groundwater is found at depths ranging from 65 to 70 feet. Groundwater mounding, resulting from recharge is not a concern at this site. Based on the application of 0.9 MGD at this site, distributed over the total recharge area, a mound of 12 feet is projected.

7. The property is located in the Zone II of a proximal supply well that is located about 2,000 feet away. If a flow rate of approximately one foot per day is estimated, the property is located about 5 years travel time from the well. MADEP has established additional requirements if the travel time is less than two years.

8. The available area for wastewater recharge is comprised of approximately 4 acres. If open sand beds are utilized, a recharge capacity of approximately 900,000 gallons per day is possible. If leaching trenches are used, the recharge capacity is reduced to approximately 460,000 gallons per day.

9. The site is located approximately 15,000 feet from the WPCF. The distance, in itself, is not an advantage or disadvantage, until compared to the distances of other candidate sites.

To summarize, the Lorusso property has the potential to be a suitable site to discharge treated effluent. The Lorusso property will be included in the comparative analysis to be completed as part of the facilities plan.

Please call with any questions or comments.

Very truly yours,

STEARNS & WHELER, LLC

T. Lawrence Hineline, CPG
Associate

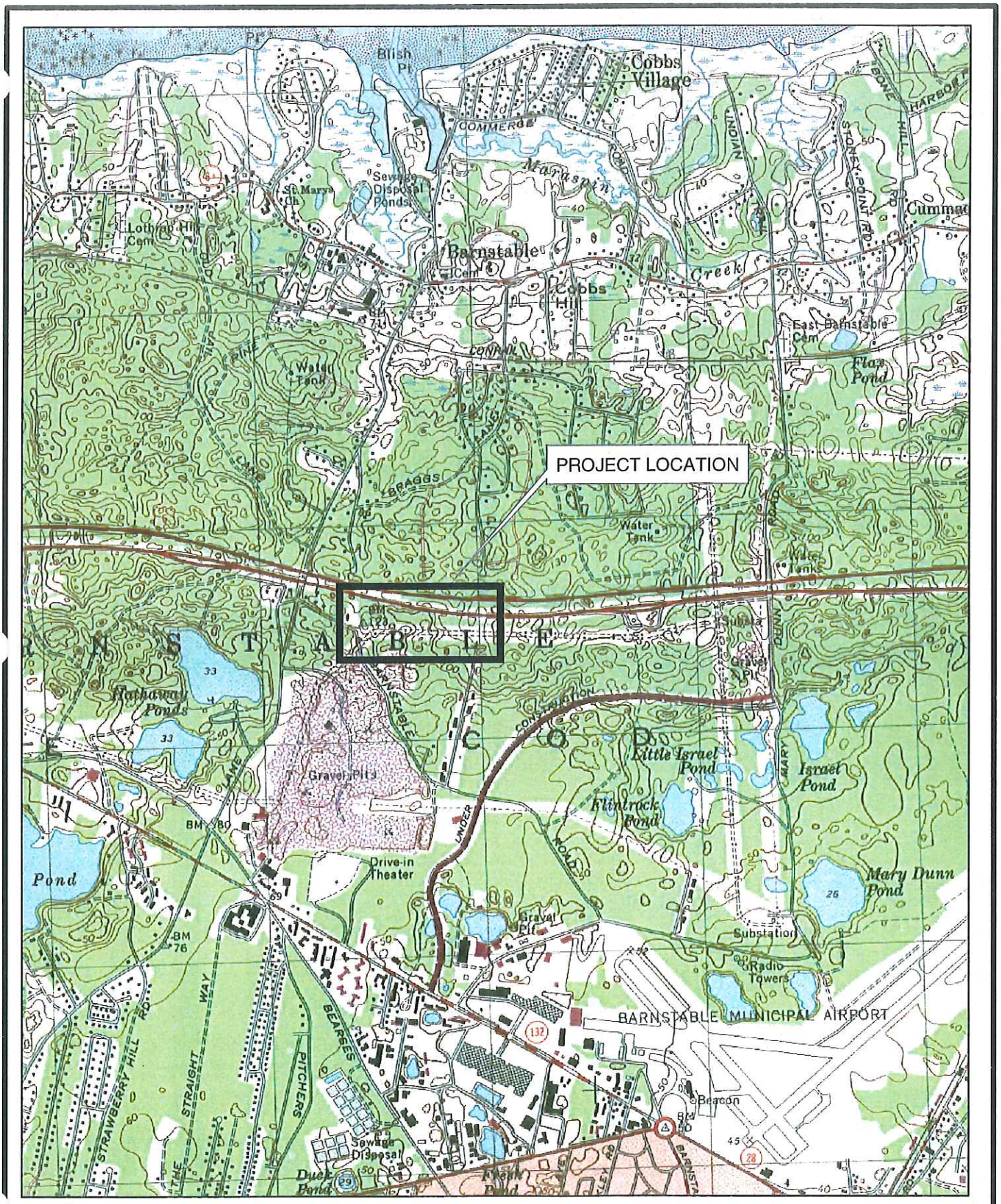
J. Gage Muckleroy, P.E.
Associate

/tlh

Attachments

cc: Robert Butterworth, P.E., DEE

Figures



N
W E
S

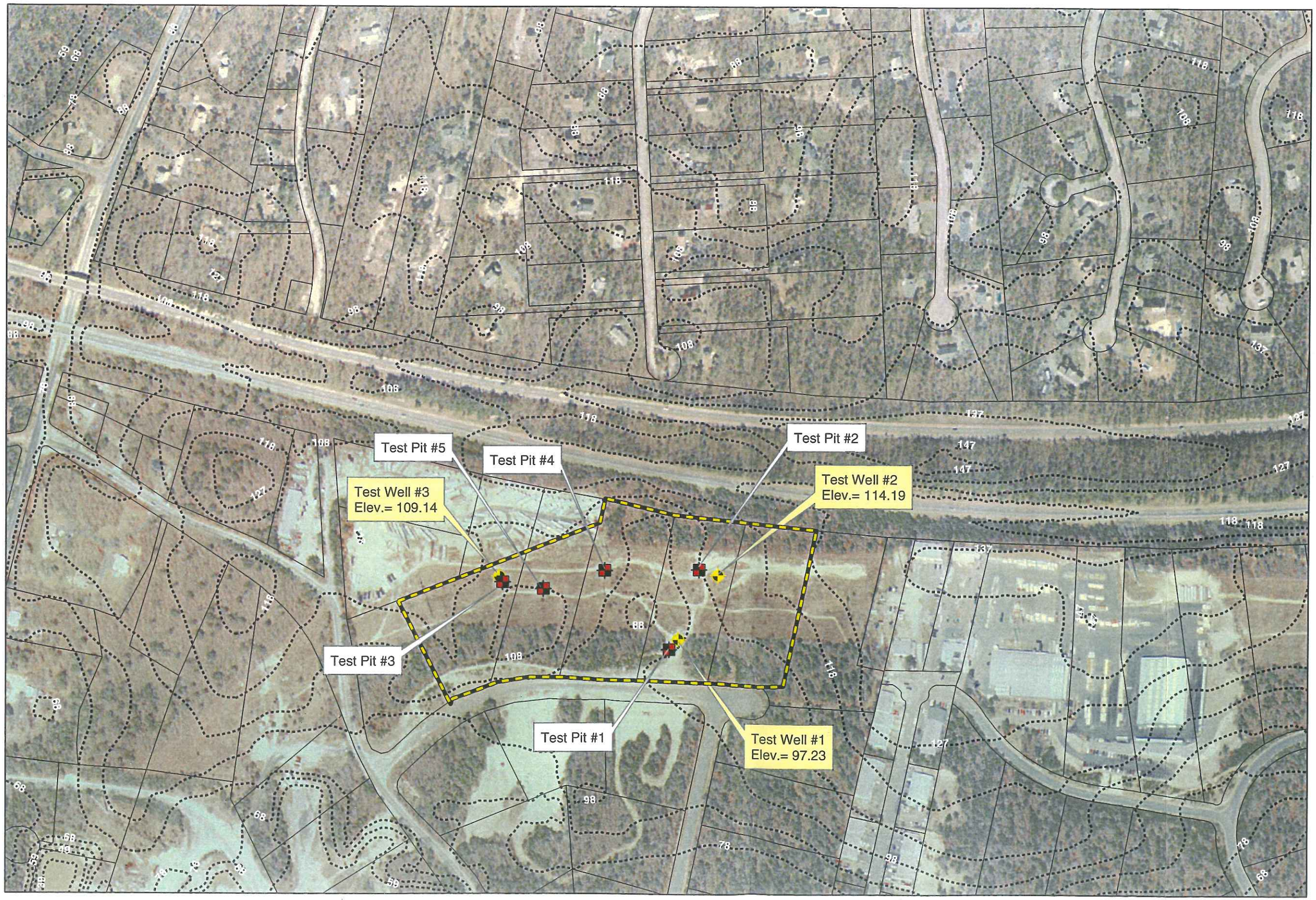
Scale: 1:24,000

D:\GIS Project Folder\Job#\20190\Locus map.mxd

Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS

JOB NO.: 20190 DATE: 11/8/03

TOWN OF BARNSTABLE, MA
EFFLUENT MITIGATION
FIGURE 1 - SITE LOCATION MAP



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Stearns & Wheler, LLC
Environmental Engineers and Scientists
Hyannis, Massachusetts

Legend

- Test Pit Location
- Test Well Location
- Parcel Boundary
- Contour

N
W E
S

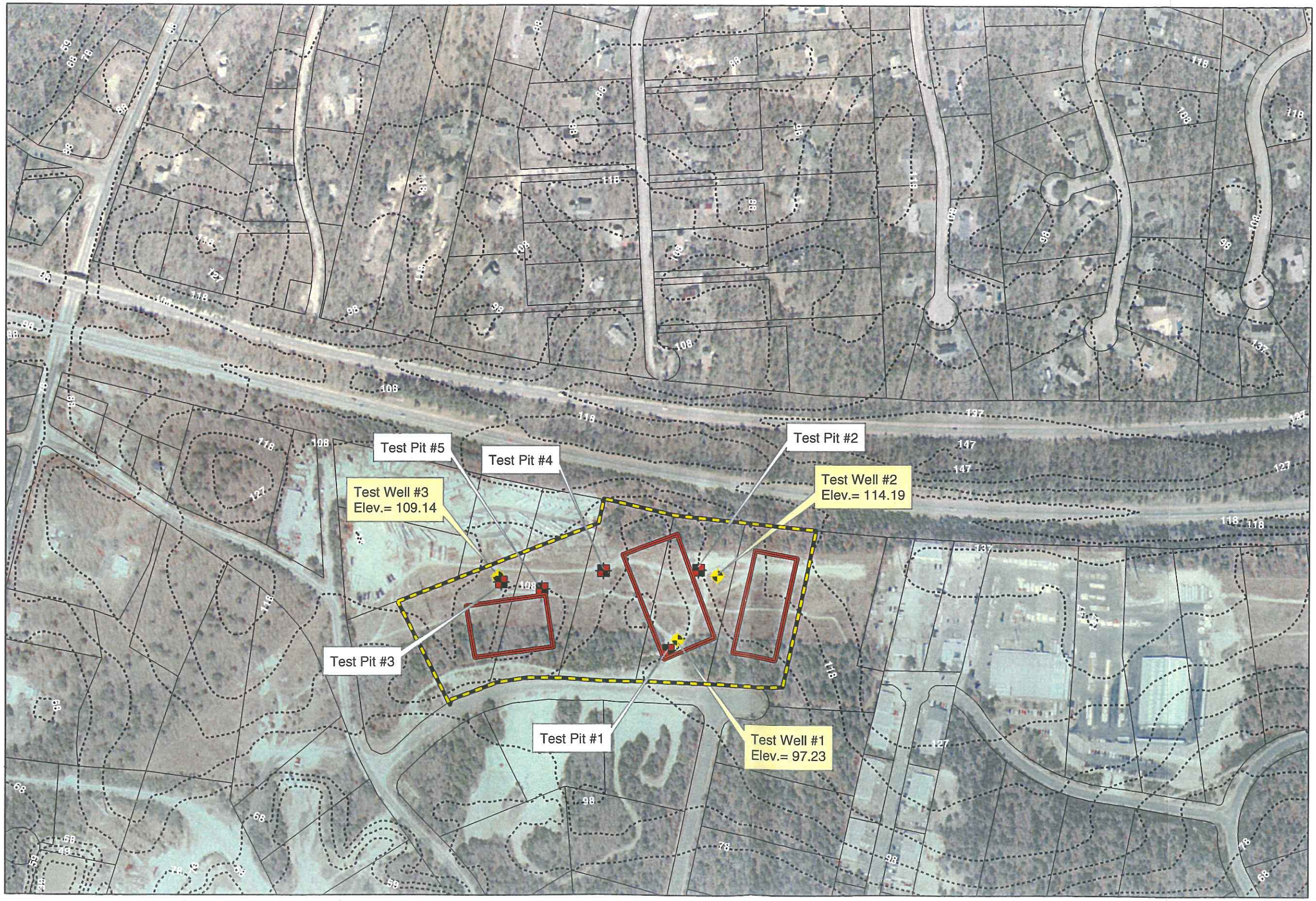
1 inch equals 300 feet

Date: 11/08/03

TOWN OF BARNSTABLE, MA

SITE MAP

FIGURE 2



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Stearns & Wheler, LLC
Environmental Engineers and Scientists
Hyannis, Massachusetts

Legend

- Test Pit Location
- Test Well Location
- Parcel Boundary
- Contour
- Recharge Area

N
W E
S

1 inch equals 300 feet

Date: 11/08/03

TOWN OF BARNSTABLE, MA

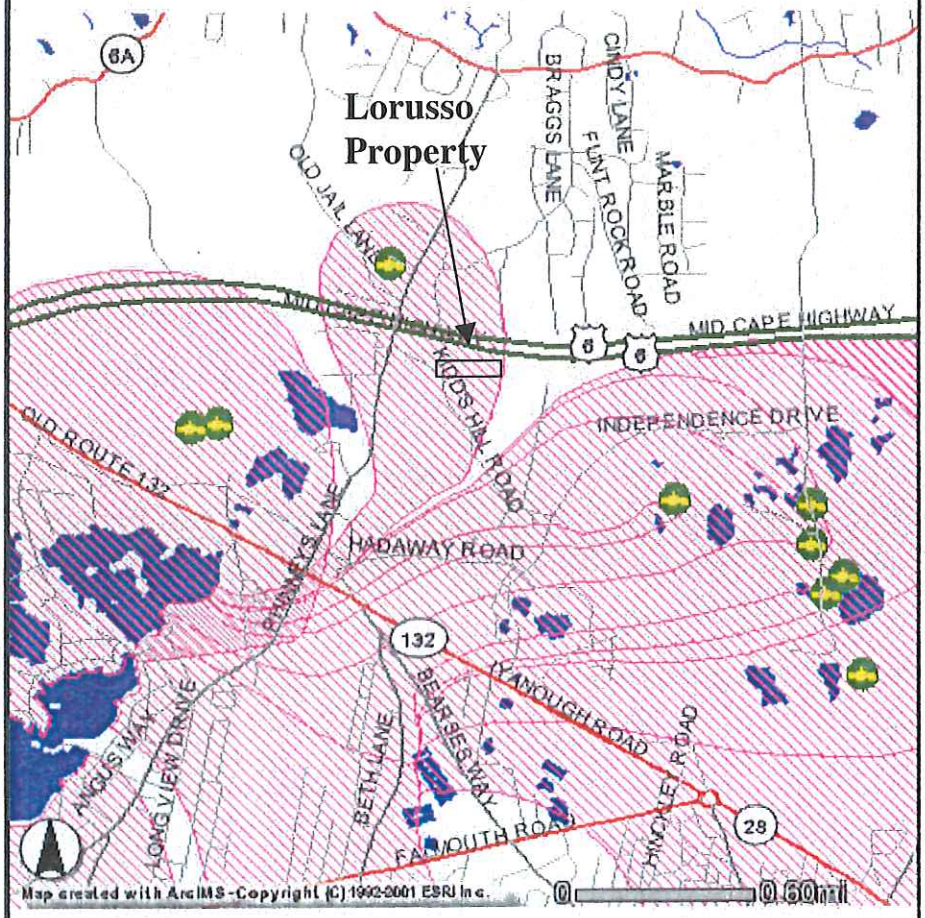
EFFLUENT MITIGATION

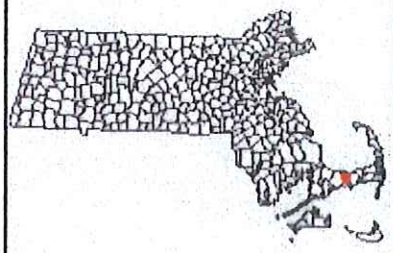
FIGURE 3 - RECHARGE AREAS

Attachment A

Water Supply Protection Area Maps

Water Supply Protection Areas Map





Legend

- Town Boundaries
- MHD Roads Route Numbers
- MHD Roads
  - Limited Access Highway
  - Multi-lane Hwy, Not Limited Access
  - Other Numbered Hwy
  - Major Road - Collector
  - Minor Street or Road, Ramp
- Public Water Supplies
  - Community Public Water Supply - Groundwater
  - Community Public Water Supply - Surface Water
  - Non Community Public Water Supply
  - Public Water Supply - Proposed
- IWPA
- Zone II
- Rivers
  - Stream
  - Intermittent Stream
- Lakes and Ponds
- Zone A
- Zone B
- Zone C

Attachment B

Environmentally Sensitive Areas

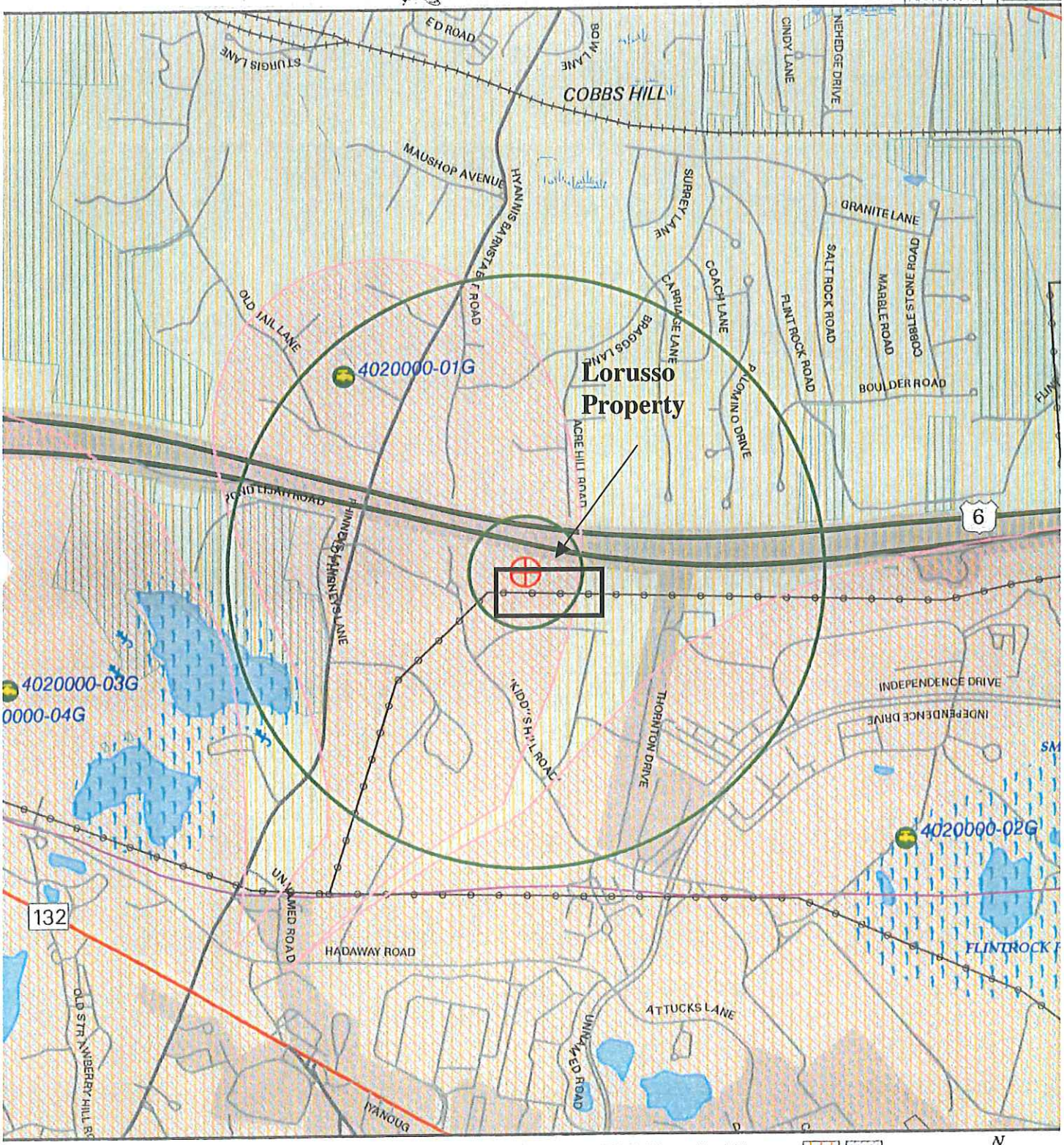
Site Scoring Map: 500 feet & 0.5 Mile Radii

TE NAME:
isso Property
INSTABLE, MA
11n 701808ew

Site Location

The information shown on this map is the best available at the date of printing. Please refer to the data source descriptions document.

MASS GIS — Massachusetts Geographic Information System
Massachusetts Executive Office of Environmental Affairs - 2003



Roads: Limited Access, Divided, Major Road, Connector, Street, Track, Trail

Boundaries: Town, County, DEP Region; Train; Powerline; Pipeline; Aqueduct

Basins: Major, Sub; Streams: Perennial, Intermittent, Man Made Shore, Dams

Potentially Productive Aquifers: Medium,High Yield .....

EPA Sole Source Aquifer; FEMA 100-year floodplain .....

Public Water Supplies: Ground,Surface,Non Community

Approved Zone2; IWPA; Surface Water Supply Zone A

Hydrography: Water Features,Public Surface Water Supply ...

Wetlands: Fresh,Salt,NHESP Wetlands Habitat .....

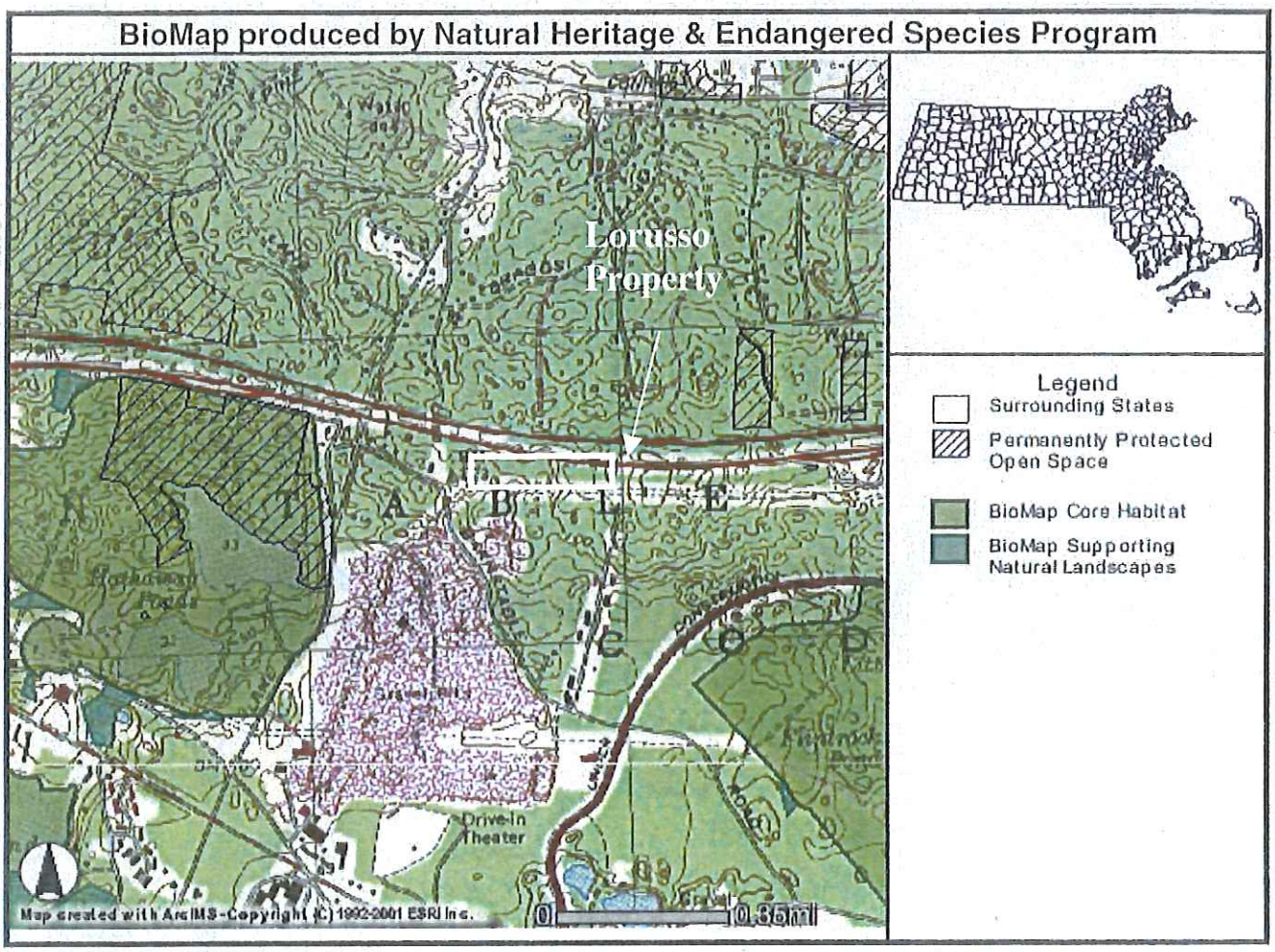
Protected Open Space; ACEC .....

DEP Permitted Solid Waste Facilities; Certified Vernal Pools ..

N W E S

Attachment C

Natural Heritage and Endangered Species Areas


BioMap produced by Natural Heritage & Endangered Species Program
Lorusso Property
Drive-In Theater
Map created with ArcIMS-Copyright (C) 1992-2001 ESRI Inc.
0
0.35mi
Legend
Surrounding States
Permanently Protected Open Space
BioMap Core Habitat
BioMap Supporting Natural Landscapes

Attachment D

Test Pit Logs

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

A. Facility Information

1. Facility Information

Lorusso Property
Owner Name

Street Address — Map/Lot

Barnstable — MA — Zip Code
City — State

B. Site Information

1. (Check one) New Construction ☐ Upgrade ☐ Repair ☐

2. Published Soil Survey available? Yes ☒ No ☐ If yes: 1993 (Year Published) 1:25000 (Publication Scale) EaC (Soil Map Unit)

Eastchop loamy find sand (Soil Name) — Soil limitations

3. Surficial Geological Report available? Yes ☐ No ☐ If yes: Year Published — Publication Scale — Map Unit

Geologic Material — Landform

4. Flood Rate Insurance Map:

Above the 500 year flood boundary?	Yes ☐	No ☐	Within the 100 year flood boundary?	Yes ☐	No ☐
Within the 500 year flood boundary?	Yes ☐	No ☐	Within a Velocity Zone?	Yes ☐	No ☒

5. Wetland Area: National Wetland Inventory Map — Map Unit — Name

Wetlands Conservancy Program Map — Map Unit — Name

6. Current Water Resource Conditions (USGS) Month/Year Range: Above Normal ☐ Normal ☐ Below Normal ☐

7. Other references reviewed:

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

C. On-Site Review *(minimum of two holes required at every proposed disposal area)*

Deep Observation Hole A: 9/8/03 (Date) 10:20 am (Time) Partly Cloudy 72 degrees – light wind (Weather)

1. Deep Observation Hole Logs

   Deep Hole Number TP-1 Ground Elevation at Surface of Hole _____

   Location (Identify on Plan) _____

2. Land Use: Powerline Easement (e.g. woodland, agricultural field, vacant lot, etc.) None Observed (Surface Stones) 5% (Slope (%))

   Scrub Pines (Vegetation) Moraine (Landform) _____ Position on landscape (attach sheet)

3. Distances from: Open Water Body _____ feet Drainage Way _____ feet Possible Wet Area _____ feet

   Property Line _____ feet Drinking Water Well _____ feet Other _____

4. Parent Material: _____ Unsuitable Materials Present: Yes ☒ No ☐

   If Yes: Disturbed Soil ☒ Fill Material ☐ Impervious Layer(s) ☐ Weathered/Fractured Rock ☐ Bedrock ☐

5. Groundwater Observed: Yes ☐ No ☒

   If Yes: Depth Weeping from Pit _____ Depth Standing Water in Hole _____

   Estimated Depth to High Groundwater: _____ inches _____ elevation

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Deep Observation Hole A: Deep Hole Number: TP-1

Depth (In.)	Soil Horizon/ Layer	Soil Matrix: Color-Moist (Munsell)	Redoximorphic Features (mottles)			Soil Texture (USDA)	Coarse Fragments % by Volume		Soil Structure	Soil Consistence (Moist)	Other
			Depth	Color	Percent		Gravel	Cobbles & Stones			
0-72"	Fill	2.5Y 6/4	N/A			loamy sand (LS)	15%	1%	Structureless	Loose	
72-120"	Buried Horizon										Roots observed at 96"

Additional Notes No information collected on soils below 72"- Perc Test Performed

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

C. On-Site Review (Cont.)

Deep Observation Hole B: 9/8/03 (Date) 12:20 pm (Time) Sunny, 75 (Weather)

1. Deep Observation Hole Logs

   Deep Hole Number TP-2 Ground Elevation at Surface of Hole _____

   Location (Identify on Plan) _____

2. Land Use: Powerline Easement (e.g. woodland, agricultural field, vacant lot, etc.) None Observed (Surface Stones) 5% (Slope (%))

   Scrub Pines (Vegetation) Moraine (Landform) _____ (Position on landscape (attach sheet))

3. Distances from: Open Water Body _____ feet Drainage Way _____ feet Possible Wet Area _____ feet

   Property Line _____ feet Drinking Water Well _____ feet Other _____

4. Parent Material: _____ Unsuitable Materials Present: Yes ☒ No ☐

   If Yes: Disturbed Soil ☒ Fill Material ☐ Impervious Layer(s) ☐ Weathered/Fractured Rock ☐ Bedrock ☐

5. Groundwater Observed: Yes ☐ No ☒

   If Yes: Depth Weeping from Pit _____ Depth Standing Water in Hole _____

   Estimated Depth to High Groundwater: _____ inches _____ elevation

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Deep Observation Hole B: Deep Hole Number: TP-2

Depth (In.)	Soil Horizon/ Layer	Soil Matrix: Color-Moist (Munsell)	Redoximorphic Features (mottles)			Soil Texture (USDA)	Coarse Fragments % by Volume		Soil Structure	Soil Consistence (Moist)	Other
			Depth	Color	Percent		Gravel	Cobbles & Stones			
0-4	A	5YR 5/1	N/A			LS			Structureless	loose	
4-46"	B	2.5 Y 6/6	N/A			LS			Structureless	loose	
46-72"	C1	10 YR 7/4	N/A			Sand			Structureless	loose	
72-82"	C2	2.5 Y 6/4	82	10 YR 3/6 10 YR 6/8	10%	Silty Clay			Moderate	Very Firm	

Additional Notes _____

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

C. On-Site Review (Cont.)

Deep Observation Hole C: 9/8/03 (Date) 1:45 PM (Time) Sunny 75 (Weather)

1. Deep Observation Hole Logs

   Deep Hole Number TP-4 Ground Elevation at Surface of Hole _____

   Location (Identify on Plan) _____

2. Land Use: Powerline Easement (e.g. woodland, agricultural field, vacant lot, etc.) None Observed (Surface Stones) 5% (Slope (%))

   Scrub Pines (Vegetation) Moraine (Landform) _____ (Position on landscape (attach sheet))

3. Distances from: Open Water Body _____ feet Drainage Way _____ feet Possible Wet Area _____ feet

   Property Line _____ feet Drinking Water Well _____ feet Other _____

4. Parent Material: _____ Unsuitable Materials Present: Yes ☒ No ☐

   If Yes: Disturbed Soil ☒ Fill Material ☐ Impervious Layer(s) ☐ Weathered/Fractured Rock ☐ Bedrock ☐

5. Groundwater Observed: Yes ☐ No ☒

   If Yes: Depth Weeping from Pit _____ Depth Standing Water in Hole _____

   Estimated Depth to High Groundwater: _____ inches _____ elevation

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Deep Observation Hole C: Deep Hole Number:_____TP-4_____

Depth (In.)	Soil Horizon/ Layer	Soil Matrix: Color-Moist (Munsell)	Redoximorphic Features (mottles)			Soil Texture (USDA)	Coarse Fragments % by Volume		Soil Structure	Soil Consistence (Moist)	Other
			Depth	Color	Percent		Gravel	Cobbles & Stones			
0-7	A	2.5 Y 3/1				LS			Structureless	Loose	
7-37	B	2.5Y 5/6				LS			Structureless	Loose	
37 – 66	C	2.5 Y 6/4				Sand			Structureles	Loose	

Additional Notes _____Perc Test Performed_____

_____
Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

C. On-Site Review (Cont.)

Deep Observation Hole D: __9/8/03_____ (Date) __2:15pm_____ (Time) __Sunny 75_____ (Weather)

1. Deep Observation Hole Logs

   Deep Hole Number _TP-3_____ Ground Elevation at Surface of Hole _____

   Location (Identify on Plan) _____

2. Land Use: ___Powerline Easement_____ (e.g. woodland, agricultural field, vacant lot, etc.) _None Observed_____ (Surface Stones) _5%_____ (Slope (%))

   ___Scrub Pines_____ (Vegetation) __Moraine_____ (Landform) _____ (Position on landscape (attach sheet))

3. Distances from: Open Water Body _____ feet Drainage Way _____ feet Possible Wet Area _____ feet

   Property Line _____ feet Drinking Water Well _____ feet Other _____

4. Parent Material: _____ Unsuitable Materials Present: Yes ☒ No ☐

   If Yes: Disturbed Soil☒ Fill Material☐ Impervious Layer(s) ☐ Weathered/Fractured Rock☐ Bedrock☐

5. Groundwater Observed: Yes ☐ No ☒

   If Yes: Depth Weeping from Pit _____ Depth Standing Water in Hole _____

   Estimated Depth to High Groundwater: _____ inches _____ elevation

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Deep Observation Hole D: Deep Hole Number: TP-3

Depth (In.)	Soil Horizon/ Layer	Soil Matrix: Color-Moist (Munsell)	Redoximorphic Features (mottles)			Soil Texture (USDA)	Coarse Fragments % by Volume		Soil Structure	Soil Consistence (Moist)	Other
			Depth	Color	Percent		Gravel	Cobbles & Stones			
0-6	A	10 YR 4/1				LS			Structureless	loose	roots
6-24	B	10 YR 6/8				LS	15%		Structureless	Loose	
24-84	C	2.5 Y 6/6				Sand			Structureless	Loose	

Additional Notes ____Perc Test Performed

C. On-Site Review (Cont.)

Deep Observation Hole E: 9/8/03 (Date) 3:15 pm (Time) Sunny 75 (Weather)

1. Deep Observation Hole Logs

   Deep Hole Number TP-5 Ground Elevation at Surface of Hole _____

   Location (Identify on Plan) _____

2. Land Use: Powerline Easement (e.g. woodland, agricultural field, vacant lot, etc.) None Observed (Surface Stones) 5% (Slope (%))

   Scrub Pines (Vegetation) Moraine (Landform) _____ (Position on landscape (attach sheet))

3. Distances from: Open Water Body _____ feet Drainage Way _____ feet Possible Wet Area _____ feet

   Property Line _____ feet Drinking Water Well _____ feet Other _____

4. Parent Material: _____ Unsuitable Materials Present: Yes ☒ No ☐

   If Yes: Disturbed Soil ☒ Fill Material ☐ Impervious Layer(s) ☐ Weathered/Fractured Rock ☐ Bedrock ☐

5. Groundwater Observed: Yes ☐ No ☒

   If Yes: Depth Weeping from Pit _____ Depth Standing Water in Hole _____

   Estimated Depth to High Groundwater: _____ inches _____ elevation

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Deep Observation Hole E: Deep Hole Number: TP-5

Depth (In.)	Soil Horizon/ Layer	Soil Matrix: Color-Moist (Munsell)	Redoximorphic Features (mottles)			Soil Texture (USDA)	Coarse Fragments % by Volume		Soil Structure	Soil Consistence (Moist)	Other
			Depth	Color	Percent		Gravel	Cobbles & Stones			
0-7	A	2.5 Y 4/1				LS			Structureless	Loose	
7-26	B	10 YR 5/8				LS			Structureless	Loose	
26-96	C	5 Y 7/3				Sand			Structureless	Loose	

Additional Notes Perc Test Performed

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Wastewater Permitting Program

Site Address or Map/Lot Number

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

D. Determination of High Groundwater Elevation

1. Method used:

☐	Depth observed standing water in observation hole	A. _____ inches	B. _____ inches	C. _____ inches	D. _____ inches	E. _____ inches
☐	Depth weeping from side of observation hole	A. _____ inches	B. _____ inches	C. _____ inches	D. _____ inches	E. _____ inches
☐	Depth to soil redoximorphic features (mottles)	A. _____ inches	B. _____ inches	C. _____ inches	D. _____ inches	E. _____ inches
☒	Groundwater adjustment (USGS methodology)	A. _____ inches	B. _____ inches	C. _____ inches	D. _____ inches	E. _____ inches

2. Index Well Number _____ Reading Date _____ Index Well Level _____

Adjustment Factor _____ Adjusted Groundwater Level _____

E. Depth of Pervious Material

1. Depth of Naturally Occurring Pervious Material

   a. Does at least four feet of naturally occurring pervious material exist in all areas observed throughout the area proposed for the soil absorption system? Yes ☒ No ☐ (EXCEPT TP-2)

   b. If yes, at what depth was it observed? Upper boundary: 24" inches _____ Lower boundary: 120" inches _____

F. Certification

I certify that I have passed the soil evaluator examination* approved by the Department of Environmental Protection and that the above analysis was performed by me consistent with the required training, expertise and experience described in 310 CMR 15.017.

_____ Signature of Soil Evaluator

_____ Date

_____ Typed or Printed Name of Soil Evaluator

_____ *Date of Soil Evaluator Exam

_____ Name of Board of Health Witness

_____ Board of Health

Note: This form must be submitted to the approving authority with Percolation Test Form 12

Form 11 - Soil Suitability Assessment for On-Site Sewage Disposal

Use this sheet for field diagrams:

Attachment E

Percolation Test Results

FORM 12 - PERCOLATION TEST

Location Address or Lot No. Lorusso Property

COMMONWEALTH OF MASSACHUSETTS

Barnstable, Massachusetts

Percolation Test*		
Date: 9/8/03	Time:11:02 AM	
Observation Hole#	TP-1	
Depth of Perc	32 inches	
Start Pre-soak	11:02 AM	
End Pre-soak	11:17 AM	
Time at 12"	11:17 AM	
Time at 9"	11:25 AM	
Time at 6"	11:39 AM	
Time (9"-6")	14 Min	
Rate Min./Inch	4.6 Min/Inch	

*Minimum of 1 percolation test must be performed in both the primary area AND reserve area

Site Passed ☐ Site Failed ☐

Performed by: J. Jefferson Gregg

Witnessed by: _____

Comments: Percolation test was performed in fill material.

FORM 12 - PERCOLATION TEST

Location Address or Lot No. Lorusso Property

COMMONWEALTH OF MASSACHUSETTS

Barnstable, Massachusetts

Percolation Test*		
Date: 9/8/03	Time:1:45 PM	
Observation Hole#	TP-3	TP-4
Depth of Perc	30 inches	39 Inches
Start Pre-soak	2:33 PM	2:02 PM
End Pre-soak	2:48 PM	25 gallons in less than 15 minutes
Time at 12"	2:48 PM	
Time at 9"	2:51 PM	
Time at 6"	2:54 PM	
Time (9"-6")	3	
Rate Min./Inch	1 Min/Inch	<2 Min/Inch

*Minimum of 1 percolation test must be performed in both the primary area AND reserve area

Site Passed ☒ Site Failed ☐

Performed by: J. Jefferson Gregg

Witnessed by: _____

Comments: _____

FORM 12 - PERCOLATION TEST

Location Address or Lot No. Lorusso Property

COMMONWEALTH OF MASSACHUSETTS

Barnstable, Massachusetts

Percolation Test*		
Date: 9/8/03	Time:3:15 PM	
Observation Hole#	TP-5	
Depth of Perc	36 inches	
Start Pre-soak	3:19 PM	
End Pre-soak	3:32 PM	
Time at 12"	25 gallons in less than 15 min	
Time at 9"		
Time at 6"		
Time (9"-6")		
Rate Min./Inch	<2 Min/Inch	

*Minimum of 1 percolation test must be performed in both the primary area AND reserve area

Site Passed ☒ Site Failed ☐

Performed by: J. Jefferson Gregg

Witnessed by: _____

Comments: _____

Attachment F

Boring Logs

Soil Boring Log
Barnstable Wastewater Mitigation
Lorusso Site
Town of Barnstable, MA

Boring/Well ID: Test Well 1, Lorusso Site

Project Name:	Barnstable Effluent Mitigation	
Job. No.	20190.70.7000	
Start Date & Time:	9/8/2003	8:40 AM
Finish Date & Time:	9/9/2003	10:00 AM
Drilling Co.:	GeoLogic	
Driller:	Ray (foreman); John	
S&W Inspector:	RHK	
Rig Type:	Mobil B-57	
Drilling Method:	Casing w/ split spoon samples	
Weather:	9/8/2003	70's, clear, breezy
	9/9/2003	70's, partly cloudy, breezy

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water — Sample Description
0						
1						
2						
3						
4						
5	7,8		15			Light-Brown, FINE SAND
6	9,9					
7						
8						
9						
10	5,4		12			Light-Brown, FINE SAND
11	2,5					Trace SILT
12						
13						
14						
15	14,10		3			Light-Brown, MEDIUM-FINE SAND
16	11,8					
17						
18						
19						Light-Brown to Yellowish-Orange
20	18,31		4			MEDIUM-FINE SAND with some COARSE SAND
21	22,24					trace SILTS
22						
23						
24						
25	26,35		12			Light-Brown, MEDIUM-FINE SAND
26	37,50					
27						
28						
29						
30	21,43		12			Light-Brown, MEDIUM-FINE SAND
31	52,50					
32						
33						
34						
35	24,35		18			Light-Brown, MEDIUM-FINE SAND
36	64,90					
37						
38						
39						Top 6" Light-Brown MEDIUM-FINE SAND
40	34,42		15			Mid 1" Light-Brown GRAVEL
41	48,66					Bot 8" Light-Brown FINE SAND to SILT
42						
43						
44						
45	27,42		12			Light-Brown SILT with Orange spotting
46	61,70					
47						
48						
49						
50	29,48		12			Light-Brown to Grey SILT
51	53,100					

Soil Boring Log
Barnstable Wastewater Mitigation
Lorusso Site
Town of Barnstable, MA

Boring/Well ID: Test Well 1, Lorusso Site

Project Name:	Barnstable Effluent Mitigation	
Job. No.	20190.70.7000	
Start Date & Time:	9/8/2003	8:40 AM
Finish Date & Time:	9/9/2003	10:00 AM
Drilling Co.:	GeoLogic	
Driller:	Ray (foreman); John	
S&W Inspector:	RHK	
Rig Type:	Mobil B-57	
Drilling Method:	Casing w/ split spoon samples	
Weather:	9/8/2003	70's, clear, breezy
	9/9/2003	70's, partly cloudy, breezy

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water
52						
53						
54						
55	22,34		9			Light-Brown to Grey SILT
56	53,74					
57						
58						
59						
60	20,31		8			Light-Brown to Grey SILT
61	40,47			▼		
62						
63						
64						
65	29,32		10			Light-Brown to Grey SILT
66	34,35					
67						
68						
69						
70	18,19		12			Light-Brown to Grey SILT
71	20,29					
72						
73						
74						Top 9" Light-Brown SILT
75	14,19		12			Bot 3" Light Brown COARSE SAND and
76	25,25					FINE GRAVEL

Soil Boring Log
Barnstable Wastewater Mitigation
Lorusso Site
Town of Barnstable, MA

Boring/Well ID: Test Well 2, Lorusso Site

Project Name:	Barnstable Effluent Mitigation	
Job. No.	20190.70.7000	
Start Date & Time:	9/9/2003	10:00 AM
Finish Date & Time:	9/10/2003	3:00 PM
Drilling Co.:	GeoLogic	
Driller:	Ray (foreman); John	
S&W Inspector:	RHK	
Rig Type:	Mobil B-57	
Drilling Method:	Casing w/ split spoon samples	
Weather:	9/9/2003	70's, partly cloudy, breezy
	9/10/2003	70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water — Sample Description
0						
1						
2						
3						
4						
5	2,2		15			Yellowish-Orange MEDIUM SAND
6	4,6					
7						
8						
9						
10	4,5		5			Yellowish-Orange to Light-Brown
11	7,10					MEDIUM to COARSE SAND
12						
13						
14						Top 6" Yellowish-Orange FINE GRAVEL to COARSE SAND
15	14,12		8			Bot 2" Light-Brown MEDIUM to FINE SAND
16	14,14					
17						
18						
19						
20	16,18		5			Light-Brown, MEDIUM-FINE SAND
21	18,17					
22						
23						
24						Top 6" Light-Brown FINE SAND
25	26,28		16			Mid 6" Light-Brown FINE GRAVEL to COARSE SAND
26	30,30					Bot 4" Light-Brown FINE SAND to SILT
27						
28						
29						
30	40,21		10			Light-Brown FINE SAND
31	23,19					
32						
33						
34						
35	22,26		15			Light Brown to Yellowish Orange FINE SAND
36	27,31					
37						
38						
39						
40	19,30		6			Light-Brown Silt
41	46,53					
42						
43						
44						Light-Brown to Grey SILT
45	18,15		12			Some variations in color - orange patches within sample
46	19,19					
47						
48						
49						
50	23,19		18			Light-Brown to Grey SILT
51	23,30					Some variations in color - orange patches within sample
52						
53						
54						
55	24,26		15			Light-Grey FINE SAND to SILT with trace CLAY
56	33,44					
57						

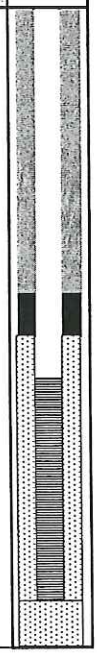
Soil Boring Log
Barnstable Wastewater Mitigation
Lorusso Site
Town of Barnstable, MA

Boring/Well ID: Test Well 2, Lorusso Site

Project Name:	Barnstable Effluent Mitigation	
Job. No.	20190.70.7000	
Start Date & Time:	9/9/2003	10:00 AM
Finish Date & Time:	9/10/2003	3:00 PM
Drilling Co.:	GeoLogic	
Driller:	Ray (foreman); John	
S&W Inspector:	RHK	
Rig Type:	Mobil B-57	
Drilling Method:	Casing w/ split spoon samples	
Weather:	9/9/2003	70's, partly cloudy, breezy
	9/10/2003	70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water
58						
59						
60	67,42		18			Light-Grey SILT to CLAY
61	58,41					
62						
63						
64						
65	47,44		18	▼		Light-Grey to Light-Brown SILT
66	39,52					
67						
68						
69						
70	35,26		22			Light-Grey SILT to CLAY
71	29,43					
72						
73						
74						
75	33,25		18			Light-Grey SILT
76	35,39					
77						
78						
79						
80	64,47		12			Top 1" Light-Grey SILT
81	53,58					Bot 11" Light-Brown MEDIUM SAND
82						
83						
84						
85	35,29		12			Light-Brown to Grey MEDIUM to FINE SAND
86	39,49					



Soil Boring Log
Barnstable Wastewater Mitigation
Lorusso Site
Town of Barnstable, MA

Boring/Well ID: Test Well 3, Lorusso Site

Project Name:	Barnstable Effluent Mitigation
Job. No.	20190.70.7000
Start Date & Time:	9/11/2003 7:00 AM
Finish Date & Time:	9/12/2003 9:00 AM
Drilling Co.:	GeoLogic
Driller:	Ray (foreman); John
S&W Inspector:	RHK
Rig Type:	Mobil B-57
Drilling Method:	Casing w/ split spoon samples
Weather:	9/11/2003 70's, sunny 9/12/2003 70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water / Sample Description
0						
1						
2						
3						
4						
5	2,4		15			Light-Brown FINE SAND
6	6,7					
7						
8						
9						
10	17,19		4			Light-Brown MEDIUM to FINE SAND
11	16,13					
12						
13						
14						Top 5" Light-Brown FINE GRAVEL
15	20,39		6			Bot 1" Light-Brown MEDIUM to FINE SAND
16	22,15					
17						
18						
19						
20	14,16		6			Light-Brown, MEDIUM SAND
21	16,23					
22						
23						
24						
25	52,30		8			Light-Brown MEDIUM to FINE SAND
26	29,31					
27						
28						
29						
30	25,20		10			Light-Brown MEDIUM to FINE SAND
31	30,33					
32						
33						
34						
35	21,27		10			Light-Brown MEDIUM to FINE SAND
36	32,33					
37						
38						
39						
40	19,25		12			Light-Brown FINE SAND
41	38,54					
42						
43						
44						
45	22,31		5			Light-Brown MEDIUM SAND
46	43,52					
47						
48						
49						Top 10" Light-Brown MEDIUM SAND
50	25,27		18			Bot 8" Light-Brown FINE GRAVEL to COARSE SAND
51	41,50					
52						
53						
54						
55	27,28		15			Light-Brown FINE SAND (WET)
56	37,39					
57						

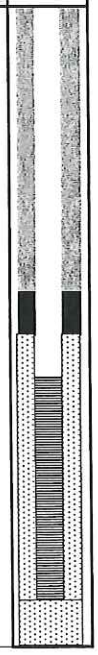
Soil Boring Log
Barnstable Wastewater Mitigation
Lorusso Site
Town of Barnstable, MA

Boring/Well ID: Test Well 3, Lorusso Site

Project Name:	Barnstable Effluent Mitigation
Job. No.	20190.70.7000
Start Date & Time:	9/11/2003 7:00 AM
Finish Date & Time:	9/12/2003 9:00 AM
Drilling Co.:	GeoLogic
Driller:	Ray (foreman); John
S&W Inspector:	RHK
Rig Type:	Mobil B-57
Drilling Method:	Casing w/ split spoon samples
Weather:	9/11/2003 70's, sunny 9/12/2003 70's, sunny

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Depth (ft)	Blow Counts (every 6")	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Ground Water
58						
59						
60	20,22		10			Top 7" Light-Brown SILT (WET)
61	26,29					Bot 3" Light-Brown FINE SAND (DRY)
62						
63						
64						
65	18,21		20	▼		Light-Brown FINE SAND to SILT (WET)
66	24,16					
67						
68						
69						
70	27,21		18			Light-Brown FINE SAND to SILT
71	27,42					
72						
73						
74						
75	19,24		18			Light-Brown SILT
76	22,20					
77						
78						
79						
80	29,28		18			Light-Brown SILT
81	26,33					
82						
83						
84						
85	36,31		18			Light-Brown SILT
86	39,37					

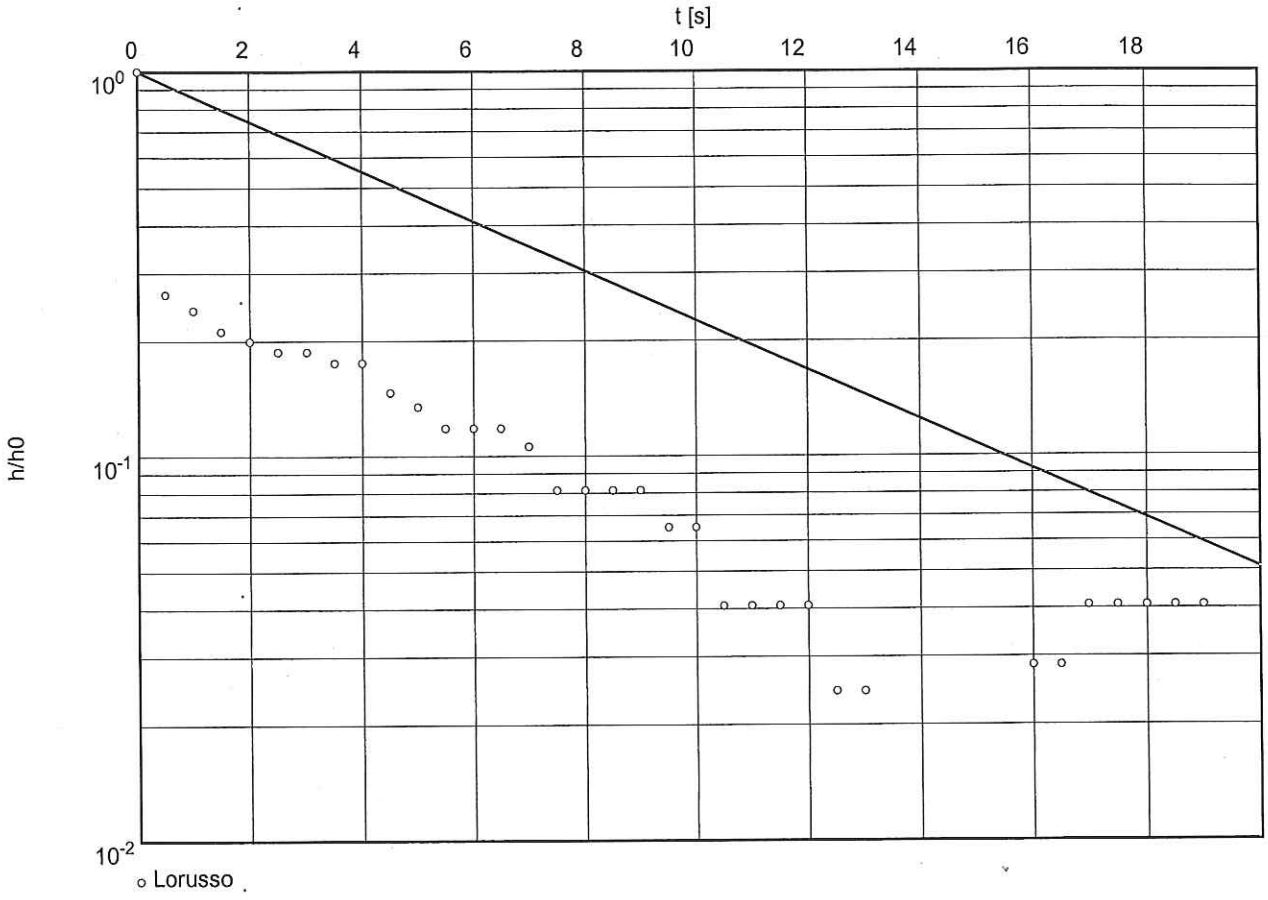


Attachment G

Hydraulic Conductivity Calculation

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis BOUWER-RICE's method	Date: 29.10.2003	Page 1
		Project: Lorusso	
		Evaluated by: TLH	

Slug Test No. TW-1 T-1	Test conducted on: 10-29-03



Hydraulic conductivity [ft/s]: 4.01×10^{-4}

Attachment H

Mounding Calculation

- HANTAXIS -

Groundwater Mounding Analysis (Hantush's Method using Glover's Solution)

PROJECT: Lorusso1

ANALYST: TLH

DATE: 10-29-2003 TIME: 14:24:21

INPUT PARAMETERS

Application rate:	0.3900	cft/day/sft
Duration of application:	180	days
Fillable porosity:	0.25	
Hydraulic conductivity:	50.00	ft/day
Initial saturated thickness:	75.0	ft
Length of application area:	960	ft
Width of application area:	320	ft
No constant head boundary used		
Plotting axis from Y-Axis:	90	degrees
Edge of recharge area:		
positive X:	160	ft
positive Y:	0	ft
Total volume applied:	215.7D+05	cft

MODEL RESULTS

X (ft)	Y (ft)	Plot Axis (ft)	Mound Height (ft)
-3000	-0	-3000	0.73
-2523	-0	-2523	1.17
-2046	-0	-2046	1.81
-1569	-0	-1569	2.78
-1194	-0	-1194	3.90
-903	-0	-903	5.10
-665	-0	-665	6.42
-465	-0	-465	7.89
-291	-0	-291	9.55
-174	-0	-174	10.94
-95	-0	-95	11.81
0	0	0	12.18
95	0	95	11.81
174	0	174	10.94
291	0	291	9.55
465	0	465	7.89
665	0	665	6.42
903	0	903	5.10
1194	0	1194	3.90
1569	0	1569	2.78
2046	0	2046	1.81
2523	0	2523	1.17
3000	0	3000	0.73

Appendix L

Effluent Mitigation Investigation Project – Candidate Site Evaluation and Comparison; December 2003

Stearns & Wheler, LLC
Environmental Engineers and Scientists

255 Stevens Street
P.O. Box 975
Hyannis, MA 02601

tel. (508) 790-1707
fax. (508) 790-2707
web. www.stearnswheler.com

December 30, 2003

Mr. Mark Giordano, P.E.
Senior Project Manager
Department of Public Works
Town of Barnstable
367 Main Street
Hyannis, MA 02601

Re: Effluent Mitigation Investigation Project
Task 8 Report – Candidate Site Evaluation and Comparison **Draft Report**
S&W No. 20190.0

Dear Mr. Giordano:

In accordance with the Town's Notice to Proceed dated October 28, 2003, and the Contract for Consultant Services for the Effluent Mitigation Investigation Project, dated July 23, 2003, we have completed this Task 8 Draft Report for the Candidate Site Evaluation and Comparison.

This report is prepared in accordance with paragraph 2.2.5.2 of the Contract, and QA/QC procedures of the Scope of Work were adhered to in the completion of this task. The evaluation was completed consistent with the Barnstable Wastewater Facilities Plan (WWFP) recommendation to identify and utilize remote sites for the purpose of recharging treated wastewater to the subsurface.

BACKGROUND INFORMATION

The Town of Barnstable (Town) is in the process of completing a WWFP that evaluates future options for the Town to collect, treat, and discharge municipal wastewater. A component of the WWFP called for the identification of parcels of land, remote from the existing water pollution control facility (WPCF) where treated advanced secondary wastewater can be reclaimed by discharging it back to the groundwater system. Utilization of remote sites for the recharge of treated wastewater was recommended because the WWFP and related work concluded the recharge capacity of the current effluent disposal beds at the existing plant may be limited due to potential adverse impacts resulting from groundwater mounding. In the course of completing the WWFP, the Town undertook a remote site screening process to identify areas of the Town where suitable parcels may exist. Following the completion of that screening process, the Town identified several specific sites and parcels for preliminary site evaluation for effluent discharge. Preliminary evaluations have been completed for the following four sites:

1. McManus property and adjacent parcels (Site B).
2. Barnstable Municipal Airport (Site C).
3. Cape Cod Community College (Site D).
4. Lorusso parcels at the powerline easement (Site E).

These sites are illustrated on Figure 1, along with Site A, which is the Hyannis WPCF. The preliminary evaluations for these sites were documented in previous task reports.

The purpose of this Task 8 Report is to summarize each site's effluent discharge characteristics and provide a comparison evaluation of the sites with various alternative discharge technologies.

SCOPE OF WORK

The Scope of Work for the investigation is summarized below:

Subtask 8.1 - Compilation of Data

Prepare a description of the alternatives analysis methodology employed in the technical evaluations of the remote effluent disposal sites. Compile the data from the completed preliminary site evaluations and identify advantages and disadvantages of each site. Compile data on each site to facilitate comparison including, but not limited to:

- Distance from Hyannis WPCF
- Available area for effluent discharge facilities.
- Site access considerations.
- Abutting land use.
- Distance to sensitive receptors, such as freshwater ponds, wetlands, residential neighborhoods, water supply contribution areas, historic districts, etc.

Subtask 8.2 - Technology Evaluation

Prepare a technology evaluation to develop effluent discharge technology data for each site. Perform a preliminary screening analysis to identify potential effluent discharge technologies. Develop and include conceptual design information (facility sizing, force main sizing and length, operations considerations, flow capacity, etc.). Develop capital and operation and maintenance (O&M) costs for each technology at each site. Incorporate data compiled in Subtask 8.1.

Subtask 8.3 - Comparative Evaluation

Upon completion of the technology evaluation, compare the sites and technologies to each other with respect to suitability for remote effluent disposal. Prepare a matrix to facilitate the comparison including, but not limited to, the following criteria:

- Distance from WPCF as a factor in determining effluent transmission construction costs.

- Site topography as an impact to constructability.

- Soil permeability to identify the site's ability to accept water.
- Depth to groundwater to identify where mounding will have the least impact.
- Abutting land use for compatibility of the proposed operation with surrounding land use.
- Aesthetic impacts related to potential odors, view, or noise.
- Proximity to sensitive receptors such as wetlands, surface water, or water supply wells.
- Capital costs, including property purchase, potential easements, construction, and fiscal/legal/engineering costs.
- O&M costs to operate the alternative facilities at the various sites.

Summarize the sites in a matrix according to the criteria listed above in addition to other relevant criteria identified during the course of the evaluation. Provide conceptual designs for the most favored technologies at each site and include proposed layouts of the facilities.

Subtask 8.4 - Draft Report Preparation

Prepare and submit a draft report summarizing the preceding subtasks.

Subtask 8.5 - Final Report Preparation

Prepare and submit a final report based on Town's comments.

EVALUATION RESULTS

The results of the Candidate Site Evaluation and Comparison are presented in this section. The results are organized in the following order:

1. Site description and data summary.
2. Effluent discharge technology identification and descriptions.
3. Screening of effluent discharge technologies.
4. Evaluation of feasible technologies at specific sites.
5. Wastewater treatment issues and requirements for effluent discharge at new remote sites.
6. Development and comparison of conceptual effluent discharge designs.
7. Summary and recommendations.

Site Description and Data Summary

As previously stated, the sites to be evaluated are designated as follows:

1. McManus property and adjacent parcels (Site B).
2. Barnstable Municipal Airport (Site C).
3. Cape Cod Community College (Site D).
4. Lorusso parcels at the powerline easement (Site E).

The sites are shown graphically on the attached figures:

Figure 1 - Potential Discharge Sites and Project Location Map
Figure 2 - Potential Discharge Sites and Land Use
Figure 3 - Potential Discharge Sites and Groundwater Considerations
Figure 4 - Potential Discharge Sites and Protected Habitats

1. The McManus property and adjacent parcels (Site B) are located just south of the intersection of Route 132 and Route 6. The site consists of four parcels owned by the Town, the State, and a private entity. The parcels are located approximately 1,100 feet south of the intersection on the northeast side of Route 132 and approximately 12,600 feet from the WPCF. The site is trapezoidal in shape and occupies approximately 23 acres.

2. The Barnstable Municipal Airport property is located at the intersection of Route 132 and Route 28, north of the "Airport Rotary." The property consists of one parcel owned by the Town which is located approximately 8,600 feet from the WPCF. Three portions of the airport property were chosen as the focus of our evaluation illustrated as Sites C on the attached figures. The sites are located to the east of the intersection of the two runways in the southern section of the facility. This area was chosen as the most appropriate effluent discharge locations on the property for the following reasons:

    a. It has the space for multiple recharge areas in close proximity to each other and will be easier to construct, operate, and maintain.

    b. Future airport construction in this area is unlikely.

    c. Groundwater elevations are lowest at this location.

    d. This portion of the property is a greater distance from protected priority habitats.

3. The Cape Cod Community College site (Site D) is located northeast of the intersection of Routes 6 and 132 (Exit 6 of the Mid-Cape Highway). The site consists of two parcels owned by the State, located approximately 1,200 feet north of the intersection of Route 132 and approximately 15,500 feet from the WPCF. The eastern portion of the site was chosen as the focus of our evaluation because it is the largest contiguous area; it is fairly remote; and it had the best

soils based on the test pits and soil borings performed during the preliminary evaluation. The focus area occupies approximately 27 acres.

4. The Lorusso site (Site E) is located along the power line right-of-way, east of Phinney's Lane, just south of Route 6 and north of the Cape Cod Aggregate operation. The site consists of five properties totaling approximately 11 acres and is privately owned. It is located approximately 10,400 feet from the WPCF.

Table 1 presents data collected for each site relating to the site locations, land uses, environmental sensitivity, topography, and soils.

Effluent Discharges Technology Identification and Descriptions

All wastewater treatment facilities require a means of discharging and/or reusing treated effluent. The technology selected for effluent disposal needs to be specific to the discharge site to minimize the impacts of treated effluent on nearby surface and groundwaters, while utilizing each site's unique features. This section describes available technologies and provides advantages and disadvantages for each in order to screen the technologies. A comparison of the effluent discharge technologies is summarized on Table 2.

1. **Sand Infiltration Beds.** Sand infiltration beds are open basins designed to allow treated effluent to flow across the bottom of the basin and percolate through the sand bed, through the unsaturated zone, and then to the groundwater. Bed maintenance is relatively easy because the bed is exposed at the surface and the sand surface can be raked or replaced if the sand becomes plugged with effluent solids. Hydraulic loading rates of 5 gallons per day per square foot (gpd/sf) of bed area are typical for the soils at the sites evaluated based on the preliminary evaluations.

   Effluent disposal in sand infiltration beds has the following advantages:

   - Bed construction is relatively simple.
   - Operation and maintenance (O&M) is relatively easy and O&M costs are lowest.
   - Hydraulic loading rates are typically higher than other disposal methods, which allows them to take up less area.

   Effluent disposal in sand infiltration beds has the following disadvantages:

   - Construction of new beds requires the clearing of large areas of land, which may have a visual impact.
   - Infiltration beds do not have secondary uses, such as parking lots and recreational areas (as subsurface leaching or spray irrigation facilities might have).



- Extensive site work may be required for construction of new beds at new sites.

- Disinfection is typically required.

2. **Subsurface Infiltration.** Large–scale subsurface infiltration facilities typically utilize pump and piping systems to pressure dose infiltration areas (trenches, beds, or galleries) where the effluent percolates to the groundwater. Maintenance and cleaning of these systems is more difficult because the infiltration area is not exposed to the surface and effluent solids cannot be easily removed. Subsurface infiltration beds can have secondary uses, such as parking lots, lawns, playing fields, and recreational areas. Hydraulic loading rates of 2.5 gpd/sf (to the trench or gallery base and side walls) are typical for the soils at the sites evaluated based on the preliminary evaluations.

   Subsurface infiltration facilities have the following advantages:

   - Disinfection is typically not required prior to discharge unless it is in a water supply recharge area.

   - Facilities are contained underground and can have a secondary use, such as parking lots and recreational areas.

   They have the following disadvantages:

   - Large land areas are required (larger than sand infiltration beds) due to lower hydraulic application rates.

   - Pressure dosing is typically required for large systems, which adds capital and O&M costs.

   - Extensive site work may be required for construction, particularly if the site is forested.

3. **Spray Irrigation**. Spray irrigation facilities are typically comprised of effluent pumps, distribution piping, and a spraying system consisting of risers and spray nozzles. Treated effluent is pumped through various distribution lines and discharged via spray nozzles to the surrounding area. Spray irrigation systems have often been used at golf courses and in large remote fields. Application rates for non-golf course areas are typically 2 inches per acre per week. Application rates for golf courses are typically based on the turf management needs.

   Effluent disposal using spray irrigation has the following advantages.

   - Allows for secondary use of land (i.e., golf courses).

   - Provides inexpensive means of irrigation, reducing clean water demands.



- Provides nitrogen uptake by plant life and also reduced nitrogen application at golf courses.

Effluent disposal using spray irrigation has the following disadvantages:

- Difficult to find locations suitable or willing to use spray irrigation.
- Limited cold weather use due to potential freezing problems.
- Disinfection is typically required.
- Spray nozzles may be subject to clogging.
- Requires secondary means of effluent disposal during winter months.
- Must meet more stringent MADEP requirements for reclaimed water use.
- Large areas are needed.

4. **Well Injection.** Well injection involves the discharge of treated effluent to groundwater below the land surface. The discharge is accomplished by pumping the effluent through wells that extend into permeable, saturated, and unsaturated geologic strata. When discharged into saturated strata, this type of discharge can be compared to the reverse of extracting water from a well.

   Wells can be designed to discharge a range of wastewater flows depending on site conditions, such as depth to groundwater and geological conditions. A potential concern of well injection is the mounding of groundwater in low elevation areas. As a result, well injection requires extensive testing prior to design and construction. This would include hydraulic conductivity tests, hydrogeologic surveys, and pilot testing.

   Well injection for effluent disposal has been implemented on a limited basis throughout the United States, and there are limited regulatory standards on the siting, design, construction, and operation of the wells. The recently completed pilot test for this technology at the Hyannis WPCF indicated that injection wells can become plugged with biological growth if the effluent is not chlorinated. Discussions with the Massachusetts Department of Environmental Protection indicate minimal support for the development of this technology because it requires chlorination that may create secondary impacts to the groundwater, such as the formation of disinfection byproducts, which may provide health risks.

   Effluent disposal with well injection has the following advantages:

   - The land area required would be much less than the area required for infiltration beds, subsurface infiltration, and spray irrigation. The effluent discharge would occur below the surface, and the surface would have minimal disruption.

   - Discharge points (wells) could be spread over a large area to minimize groundwater mounding.

   It has the following disadvantages:

- Effluent filtration is needed to provide a high level of nutrient and solids removal to minimize plugging in the wells.
- Relatively unproven technology in Massachusetts, with only recent testing at the Hyannis WPCF.
- Limited performance data is available.
- Chlorination is needed, which conflicts with guidance from the Massachusetts Department of Environmental Protection (MADEP).

Screening of Effluent Discharge Technologies

The screening of effluent discharge technologies is based on the description of each technology, the respective advantages and disadvantages, and the screening criteria discussed earlier in this report. A summary of effluent discharge technologies and a side-by-side comparison of screening criteria are included in Table 2. The following provides a brief discussion of the screening analysis.

Sand infiltration beds are a simple and reliable effluent discharge technology with relatively low operating costs.

Subsurface infiltration facilities are simple and reliable. These facilities are constructed below ground and therefore have minimal visual impacts, reduced potential for odors, and can provide secondary use of the land. Effluent discharge in subsurface infiltration facilities has higher land area requirements. Subsurface infiltration facilities are not easily cleaned. Therefore, the life of the facilities will be dependent on the quality of the effluent.

Spray irrigation is a simple and reliable effluent discharge technology with relatively low construction costs. It can provide additional nitrogen uptake and removal.

Effluent discharge through well injection has relatively low land requirements and relatively low construction costs. Well injection has the potential of plugging at the injection point due to build-up of fine solids and biofouling, and would require chlorination. This method does provide a means of effluent disposal at multiple potential sites with minimal land requirements; however, MADEP's resistance to support and permit this technology eliminates it from further consideration.

Therefore, only sand infiltration beds, subsurface infiltration, and spray irrigation technologies are recommended for further evaluation. These will be referred to as Technologies 1 through 3, respectively.

Evaluation of Feasible Technologies at Specific Sites

Each site (Sites B through E) was reviewed for the three technologies (Technology 1 through 3), and the results are as follows:

McManus Site (Site B): At this site, sand beds and subsurface infiltration were identified as appropriate technologies. Spray irrigation was identified as not appropriate due to the visual and misting impacts adjacent to Route 6.

Municipal Airport Site (Site C): At this site, subsurface infiltration was identified as an appropriate technology. Sand beds and spray irrigation were identified as inappropriate because they could produce areas of standing water which could attract birds and be a hazard to air traffic. Also, the sand bed technology would utilize above ground structures (berms) which are not allowed in close proximity to the runway.

Cape Cod Community College Site (Site D): At this site, sand beds and subsurface infiltration were identified as appropriate technologies. Spray irrigation was identified as not appropriate due to the visual and misting impacts adjacent to Route 6, the college center, and the interchange.

Lorusso Site (Site E): At this site, sand beds and spray irrigation were identified as appropriate technologies. Subsurface infiltration was identified as not appropriate because its lower hydraulic application rate in combination with the small site would result in a small discharge capacity.

Based on this evaluation, the following seven scenarios were developed for further evaluation:

B1: McManus site with sand beds
B2: McManus site with subsurface infiltration
C2: Municipal Airport site with subsurface infiltration
D1: Cape Cod Community College site with sand beds
D2: Cape Cod Community College site with subsurface infiltration
E1: Lorusso site with sand beds
E3: Lorusso site with spray irrigation

Wastewater Treatment Issues and Requirements for Effluent Discharge at New Remote Sites

As the Town considers developing new effluent discharge sites, potential future discharge limits must be considered. The following treatment issues and requirements are discussed with respect to the current Hyannis WPCF effluent quality:

1. Effluent that is discharged into subsurface leaching facilities must have low suspended solids to avoid plugging the soil infiltration system and requiring costly repairs. Effluent filtration would reduce this potential.

2. Effluent discharges upgradient of freshwater ponds and lakes would need phosphorus removal to avoid the creation of a phosphorus plume that could

migrate to the freshwater body and cause eutrophication. The Otis Air Force Base wastewater treatment facility discharge, and the eutrophication of Ashumet Pond in Falmouth and Mashpee is a recent Cape Cod example of this issue. This case study is described in the 2003 report by the U.S. Geological Survey entitled *"Reactive-Transport Simulation of Phosphorus in the Sewage Plume at the Massachusetts Military Reservation, Cape Cod, Massachusetts."* Groundwater modeling proposed for subsequent phases of the effluent mitigation evaluations will need to consider whether effluent discharge at the proposed sites would recharge into freshwater bodies and would require phosphorus removal.

3. Effluent discharge into Zone II areas will need to meet the MADEP *"Interim Guidelines on Reclaimed Water."* Effluent limits for this type of discharge would need to meet the following treatment and design standards:

   - pH: 6 to 9
   - BOD concentration: $\leq$30 mg/L
   - Turbidity: $\leq$5 Nephelometric turbidity units (NTU)
   - Fecal coliform content: $\leq$200 colonies/100 ml
   - TSS concentration: $\leq$10 mg/L
   - TN concentration: <10 mg/L

   These standards could be met by the addition of filtration facilities at the Hyannis WPCF and effluent chlorination.

   Effluent discharges in a Zone II area with less than a two-year travel time to a public water supply would need to meet the following more stringent treatment and design standards:

   - pH: 6 to 9
   - BOD concentration: $\leq$10 mg/L
   - Turbidity: $\leq$2 NTU
   - Fecal coliform content: median of no detectable colonies/100 ml and no single sample to exceed 14 colonies/100 ml
   - TSS concentration: $\leq$5 mg/L
   - TN concentration: $\leq$10 mg/L

   These standards are typically met by microfiltration and chlorination.

4. MADEP may not allow discharge of a chlorinated effluent into a Zone II area due the possible formation of disinfection byproducts. In this case, ultraviolet radiation disinfection would be needed.

These requirements and issues have been incorporated into the individual site evaluations and should be reviewed with MADEP to discuss potential permitting requirements.

Development and Comparison of Conceptual Effluent Discharge Designs

Infiltration Beds

Conceptual designs for sand infiltration beds were developed in accordance with the following guidance documents:

- *Guides for the Design of Wastewater Treatment Works, NEIWPCC*
- *Guidelines for the Design, Construction, Operation, and Maintenance of Small Sewage Treatment Facilities with Land Disposal* by the MADEP
- *Interim Guidelines on Reclaimed Water* by the MADEP

The following additional considerations were also used to develop the conceptual designs:

- Available areas were divided into cells approximately 200 feet by 200 feet in size in order to provide flexibility for operation and maintenance.
- Cell areas would be graded flat during construction and be separated by berms.
- Effluent flow would be pumped from the WPCF through the transport force main, into header pipes, and then into individual bed influent pipes.
- The header pipes would control areas of use, while the bed influent pipes would control flow to individual cells.
- Splashing would be prevented through the use of an end splash guard and pad. Pumping is only required at the WPCF.
- Header pipes and bed pipes are valved, allowing for individual cell use. Cell areas require 4 feet of clean sand for the infiltration surface. The site would contain access roads along the berms and the site area would be fenced.

Subsurface Infiltration Facilities

Conceptual designs for subsurface infiltration facilities were developed in accordance with the following guidance documents:

- *Guides for the Design of Wastewater Treatment Works, NEIWPCC*
- *Title 5 Pressure Distribution Guidance* from MADEP.
- *Interim Guidelines on Reclaimed Water* by the MADEP.

The following additional considerations were also used to develop the conceptual designs:

- Effluent flow would filtered at a new filter facility located (in the flow train) between the secondary clarifiers and the chlorine contact tank.
- If the effluent discharge is up gradient of a fresh water body and phosphorus removal is needed, the phosphorous would be precipitated and removed with the addition of a metal salt (alum, ferrous sulfate, etc) before the filter.
- The filtered effluent would be pumped from the WPCF, through the transport force main, and into a wet well and pump station located at the site.
- The effluent would be re-pumped through header piping, center manifold piping, and distribution piping in the infiltration cells. The header pipes control areas of use, while the center manifolds control the flow to individual cells.
- Infiltration areas are divided into cells approximately 200 feet by 200 feet in size in order to provide flexibility.
- Flows discharge from the distribution pipes located approximately 8 feet on center.
- Pumping is required at the WPCF and at the site.
- Header pipes and center manifolds are valved, allowing for individual cell use, periodic high-rate dosing, and the ability for cells to dry out between doses.

Spray Irrigation Facilities

Conceptual designs were investigated for spray irrigation facilities in accordance with the following guidance documents:

- *Interim Guidelines on Reclaimed Water* by the MADEP.
- *Guides for the Design of Wastewater Treatment Works, NEIWPCC*

The following additional considerations were also used to develop the conceptual designs:

- Hydraulic loading rate of 2 inches per acre per week.
- Nozzle spacing of 60 to 100 feet.
- Nominal nozzle pressure of 30 psi.

Each alternative conceptual design was developed as described below. Conceptual layout sketches are provided in Appendix A.

B1: The McManus site with sand beds. Approximately 7.5 acres would be available for effluent application and approximately 1.6 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include installation of primary and standby effluent pumps. Improvements along the route would include

the installation of a 12-inch force main with associated structures. Improvements at the site would include grading, piping, and sand bed construction.

B2: The McManus site with subsurface infiltration. Approximately 11.5 acres would be available for effluent application and approximately 0.9 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include new filtration facilities and effluent pumps. Improvements along the route would include the installation of a 10-inch force main with associated structures. Improvements at the site would include a receiving wet well, dry well with pumps, grading, piping, valves, and infiltration trench construction.

C2: The Municipal Airport site with subsurface infiltration. Approximately 28 acres would be available for effluent application and approximately 2.3 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include new filtration facilities and effluent pumps. Improvements along the route would include the installation of a 14-inch force main with associated structures. Improvements at the site would include a receiving wet well, dry well with pumps, grading, piping, valves, and infiltration trench construction.

D1: The Cape Cod Community College site with sand beds. Approximately 8.1 acres would be available for effluent application and approximately 1.7 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include installation of primary and standby effluent pumps. Improvements along the route would include the installation of a 10-inch force main with associated structures. Improvements at the site would include grading, piping, and sand bed construction.

D2: The Cape Cod Community College site with subsurface infiltration. Approximately 15 acres would be available for effluent application and approximately 1.1 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include new filtration facilities and effluent pumps. Improvements along the route would include the installation of a 10-inch force main with associated structures. Improvements at the site would include a receiving wet well, dry well with pumps, grading, piping, valves, and infiltration trench construction.

E1: The Lorusso site with site sand beds. Approximately 2.3 acres would be available for effluent application and approximately 0.5 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include installation of primary and standby effluent pumps. Improvements along the route would include the installation of a 8-inch force main with associated structures. Improvements at the site would include grading, piping, and sand bed construction.

E3: The Lorusso site with spray irrigation. Approximately 5.0 acres would be available for effluent application and approximately 0.04 mgd could be applied. Based on the limited application volumes, this scenario has not been developed further.

A summary of capital costs associated with each alternative is shown in Appendix B.

Comparison of each of the six alternatives (Sites B1 through E1) was performed based on the following criteria: available land area, estimated facility capacity, owner type, distance from the WPCF, soil permeability, site topography, depth to groundwater, abutting land use, aesthetic impacts, proximity to sensitive receptors, capital costs, O&M costs, present-worth costs, cost per mgd. Table 3 summarizes these findings.

SUMMARY AND RECOMMENDATIONS

Options **B1** (McManus site with sand beds) and **D1** (Cape Cod Community College site with sand beds) appear to be the most favorable of the alternatives evaluated. Advantages of these two alternatives include:

- They are the lowest cost alternatives on a dollar per flow basis.
- Each has an estimated capacity of over 1.5 mgd.
- They are located along the Route 132 corridor where road reconstruction and sewer installation is planned. If these projects are coordinated, the force main costs could be reduced.
- The sand bed technology is the easiest to maintain.

Disadvantages of these alternatives include:

- The sites are not completely owned by the Town; and therefore, the sites may not be available or could require long time periods to obtain.

- These sites are located in the Sandwich moraine, which is a geologic area of Cape Cod that is characterized by denser soils that do not allow water to infiltrate quickly. Geologic investigations performed during the preliminary investigations indicated sandy soils and adequate percolation rates. More extensive site testing will be needed if these sites are selected for new discharge facilities.

As discussed previously, USGS modeling of potential effluent discharges will be needed to investigate mounding impacts and potential groundwater recharge to freshwater bodies and public water supply wells. Additional site testing will also be needed to verify the hydraulic application rates that have been estimated. This is expected to be required as part of effluent discharge permitting or as part of the wastewater facilities planning and would include additional soil borings and
a hydraulic loading test.

We recommend that the findings of this evaluation be reviewed with the Citizens Advisory Committee and the owners of the properties to initiate the public education and decision-making process. Also, groundwater modeling with the USGS should be initiated as soon as possible to avoid delays in the evaluation of environmental impacts.

Please call with any questions or comments.

Very truly yours,

STEARNS & WHELER, LLC

Nathan C. Weeks, P.E.
Associate

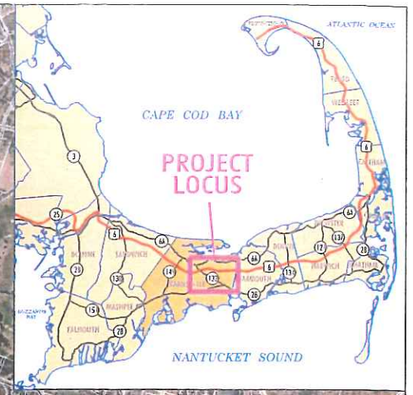
J. Gage Muckleroy, P.E.
Associate

NCW/JGM/ct

Attachments

cc: Mr. Robert Butterworth, P.E., DEE, w/encs.

FIGURES



D

B

E

A

C

C

C

LEGEND

- POTENTIAL DISCHARGE SITES
- PROPOSED FORCED MAIN
- PROPOSED PUMP STATION
- COASTAL RECHARGE AREAS
- FY 2003 PARCEL LINES
- AERIAL PHOTOGRAPHS TAKEN APRIL 2001

TOWN OF BARNSTABLE
G.I.S. UNIT

N
W E
S

SCALE: 1" = 1800'

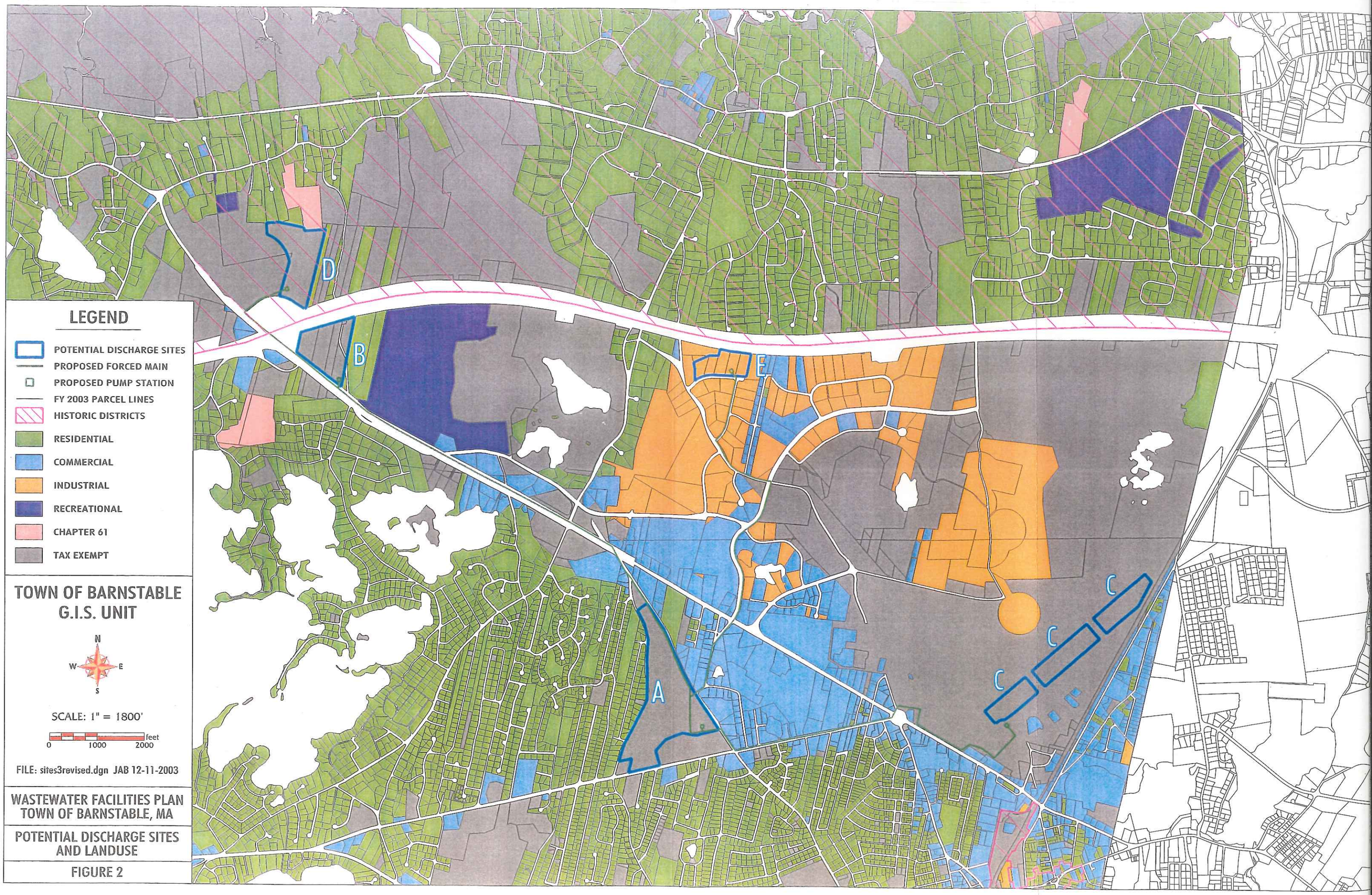
0 1000 2000 feet

FILE: sites1revised.dgn JAB 12-10-2003

WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA

POTENTIAL DISCHARGE SITES AND PROJECT LOCATION MAP

FIGURE 1


D
B
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C
C
LEGEND
POTENTIAL DISCHARGE SITES
PROPOSED FORCED MAIN
PROPOSED PUMP STATION
FY 2003 PARCEL LINES
HISTORIC DISTRICTS
RESIDENTIAL
COMMERCIAL
INDUSTRIAL
RECREATIONAL
CHAPTER 61
TAX EXEMPT
TOWN OF BARNSTABLE
G.I.S. UNIT
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SCALE: 1" = 1800'
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feet
FILE: sites3revised.dgn JAB 12-11-2003
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
POTENTIAL DISCHARGE SITES
AND LANDUSE
FIGURE 2

LEGEND

- POTENTIAL DISCHARGE SITES
- PROPOSED FORCED MAIN
- PROPOSED PUMP STATION
- TOWN APPROVED ZONE OF CONTRIBUTION
- STATE APPROVED ZONE OF CONTRIBUTION (ZONE 2)
- FY 2003 PARCEL LINES
- EXISTING WELL
- PROVEN FUTURE WELL
- PROPOSED FUTURE WELL
- GROUNDWATER CONTOURS FROM 1992 GROUNDWATER MODEL

TOWN OF BARNSTABLE
G.I.S. UNIT

N
W E
S

SCALE: 1" = 1800'

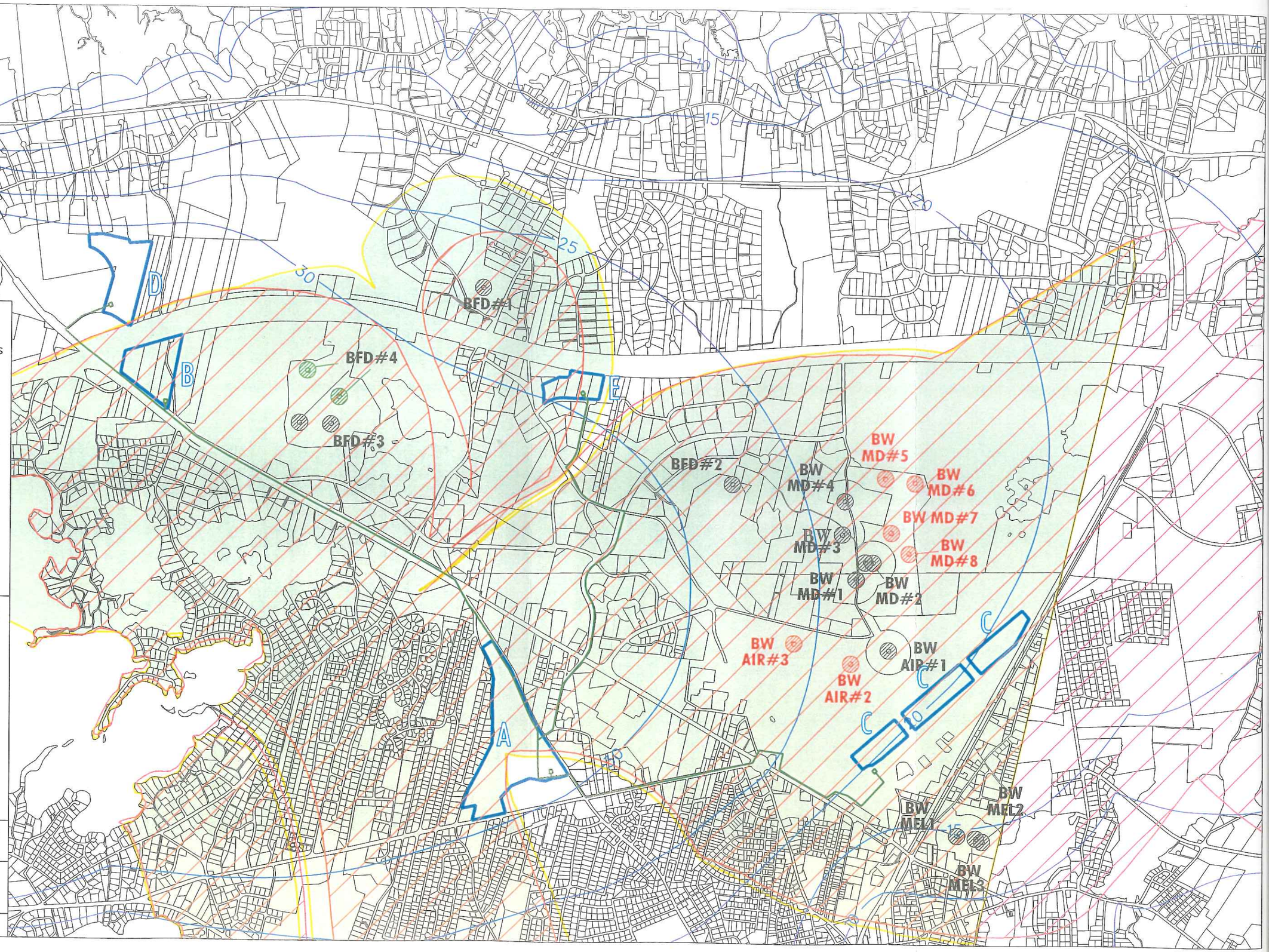
0 1000 2000 feet

FILE: sites2revised.dgn JAB 12-11-2003

WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA

POTENTIAL DISCHARGE SITES AND GROUNDWATER CONSIDERATIONS

FIGURE 3



LEGEND

- POTENTIAL DISCHARGE SITES
- PROPOSED FORCED MAIN
- PROPOSED PUMP STATION
- FY 2003 PARCEL LINES

NATURAL HERITAGE & ENDANGERED SPECIES PROGRAM (NHESP)

- NHESP 1999-2001 Estimated Habitats of Rare Wildlife: Use with Wetlands Protection Act
- NHESP 1999-2001 Priority Habitats of State-Listed Rare Species: NOT equivalent to 'Significant Habitat' as designated under the Massachusetts Endangered Species Act
- NHESP 1999-2001 Massachusetts Certified Vernal Pools

TOWN OF BARNSTABLE
G.I.S. UNIT

N
W E
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SCALE: 1" = 1800'

0 1000 2000 feet

FILE: sites5revised.dgn JAB 12-11-2003

WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA

POTENTIAL DISCHARGE SITES AND PROTECTED HABITAT

FIGURE 4

TABLES

TABLE 1

SUMMARY OF SITE INFORMATION
Watewater Facilities Plan
Town of Barnstable, MA

Site ID	Site Description	Approx. Land Area	Owner Type	Site Access	Abutting Land Use	Distance from WPCF (1) (Force Main Length)	Located Rare or Endangered Species Area	Flood Hazard Zone	Historic Significance (2)	Soil Type from Test Pits (3)	Geologic Setting from USGS Mapping	Soil Type from USDA Soil Survey	Site Topography and Ground Cover	Approx. Land Elev. (ft)	Depth to Groundwater from Field Boring	Percolation Rate	Hydraulic Conductivity per USGS and G&M	Groundwater Flow Direction Based on CCC Watershed Delineation
B	McManus Site	Total site area is 23 acres.	Town, State, and privately owned.	Access from State Route 132 Iyannough Road	Undeveloped and Road ROW	12,600	No	No	Potential	Fine to course SAND, some cobbles, 1 silty area, 1 fill area	Sandwich Moraine	Plymouth-Barnstable Complex	Irregular and undulating topography: tree vegetation	75' to 115' above MSL: Relief undulations of 15' +/-	58' +/-	4 tests with 4.3 minutes as maximum rate.	75 to 200 ft/day	North to Barnstable Harbor
C	Airport Site	Total site area is 400+ acres. The focus area is 28 ac.	Town owned.	Access from State Route 28 (Iyannough Road) and Willow Street	Commercial Property, Undeveloped Property and Road ROW	8,600	No	No	Minimal	Medium to Course SAND	Glacial outwash plain, south of Sandwich Moraine	Urban Land with Carver Soils below	Mostly flat with a slight slope from northwest to southeast, grassed	38' to 44' above MSL	20' +/- during drilling; 14 to 18 feet after drilling.	3 tests with 2 minutes as maximum rate.	200 to 250 ft/day	South and southeast to Lewis Bay
D	Cape Cod Community College Site	Total site area is 70+ acres. The focus area is 27 ac.	State owned.	Access through Community College Property off Rte 6 Mid Cape Highway	Undeveloped, road ROW, and Community College.	15,500	No	No	In Historic District	3 areas: A: M-C SAND, large boulders, fill to 30". B:fill material to 4' with boulders. C: loamy sand	Sandwich Moraine	Plymouth-Barnstable Complex	Natural topography is irregular and undulating: tree vegetation	85' to 130' above MSL: Relief undulations of 25' +/-	65' to 70' +/-	2 tests: 1 @ 8.7 minutes, 1 @ 0.67 minutes	50 to 200 ft/day	North to Barnstable Harbor
E	Lorusso Site	Total site area is 12 acres	Privately owned.	Access from Industrial Blvd off of Kidd's Hill Road	State Roadway and Undeveloped	10,400	No	No	Minimal	Fill at eastern end (topsoil at 6', silt-clay layer at 6'); western property M-F SAND	Sandwich Moraine	Plymouth-Barnstable Complex with Eastchop loamy sand	Lightly vegetated, rolling terrain, disturbed site with powerlines overhead	80 to 120' above MSL	65'+/-	3 tests with 4.6 minutes as the maximum rate.	50 to 200 ft/day	North to Barnstable Harbor

Notes:
(1) As measured along proposed routing
(2) Sites fall into one of three categories
- In Historic District
- Potential = May contain historical artifacts of significance
- Minimal = Not viewed as a historical site due to its disturbed nature.

(3) Soil abbreviations
"M-C" is medium to coarse
"M-F" is medium to fine

TABLE 2

SUMMARY OF EFFLUENT DISCHARGE TECHNOLOGIES
Wastewater Facilities Plan
Town of Barnstable, MA

ALTERNATIVE	REGULATORY REQUIREMENTS	EFFLUENT QUALITY	MAINTENANCE REQUIREMENTS AND COMPLEXITY OF OPERATION	FLEXIBILITY	ENERGY USE	LAND REQUIREMENTS	POTENTIAL FOR AIR EMISSIONS	PUBLIC ACCEPTANCE	RELATIVE CAPITAL COSTS	RELATIVE O&M COSTS	SELECTED FOR DETAILED EVALUATION
1. Sand infiltration beds	Permitting and monitoring of effluent discharges and design requirements. Disinfection may be required by MADEP.	Effluent is already treated and sand beds provide some additional treatment.	Effluent discharge is reliable throughout the year and easy to maintain.	Flexibility is possible with multiple beds.	Lowest energy requirements due to no need to repump the effluent at the sand beds.	Moderate at large wastewater flows when compared to subsurface leaching.	Effluent is treated to a high level and odors would be minimal.	Potential for low acceptance from residents who are impacted by bed siting and construction.	Relatively low due low land area and easier construction.	Low due to low energy requirements and minimal maintenance.	Yes; the technology is simple and reliable. O&M requirements are minimal.
2. Subsurface infiltration	Disinfection is not required prior to discharge, unless required to meet the Interim Guidelines for Reclaimed Water Use.	Effluent is already treated and infiltration facilities provide additional treatment. Effluent should be filtered before discharge.	Repair of the beds would be difficult because they are subsurface	Moderate depending on construction of dosing equipment and distribution piping.	Moderate due to effluent dosing pumps.	Relatively high. Land surface above the infiltration system can be used for other purposes	Minimal.	Acceptance should be high due to minimal visual impacts and potential reuse of land area.	Relatively high due to highest land area and extensive piping.	High due to pumping requirements and potential high repair/cleaning costs.	Yes; technology is reliable and provides secondary use of discharge area.
3. Spray irrigation	Permitting and monitoring of effluent discharges and design requirements. Disinfection may be required by MADEP.	Spray irrigation provides further uptake of nitrogen in the effluent.	Moderate maintenance to maintain piping. Spray irrigation cannot be used in freezing weather.	Must have redundant back-up facilities for winter discharge.	Moderate due to repumping requirements.	Relatively high. Land above system can be can be used for other purposes when spray irrigation is turned off.	Minimal.	The public will want to see recycling of the effluent though they may be concerned about possible health threats.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to maintenance and pumping requirements.	Yes; it provides additional nitrogen uptake and reuse of the effluent.
4. Deep well injection	Permitting and monitoring of effluent discharges and design requirements. MADEP is not supportive of this technology.	Effluent must be well treated (filtered and chlorinated) before discharge.	Uncertain reliability due to few operating installations and increased maintenance due to the potential of plugging of injection point with solids.	Installation of multiple wells would allow individual wells to rest or be repaired.	Moderate due to repumping requirements.	Relatively low compared to sand infiltration beds and subsurface leaching.	Minimal.	Land area requirements and visual impacts are minimal.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to pumping requirements. And maintenance needs.	No; MADEP is resistant to support the technology due to the need to chlorinate the effluent

TABLE 3

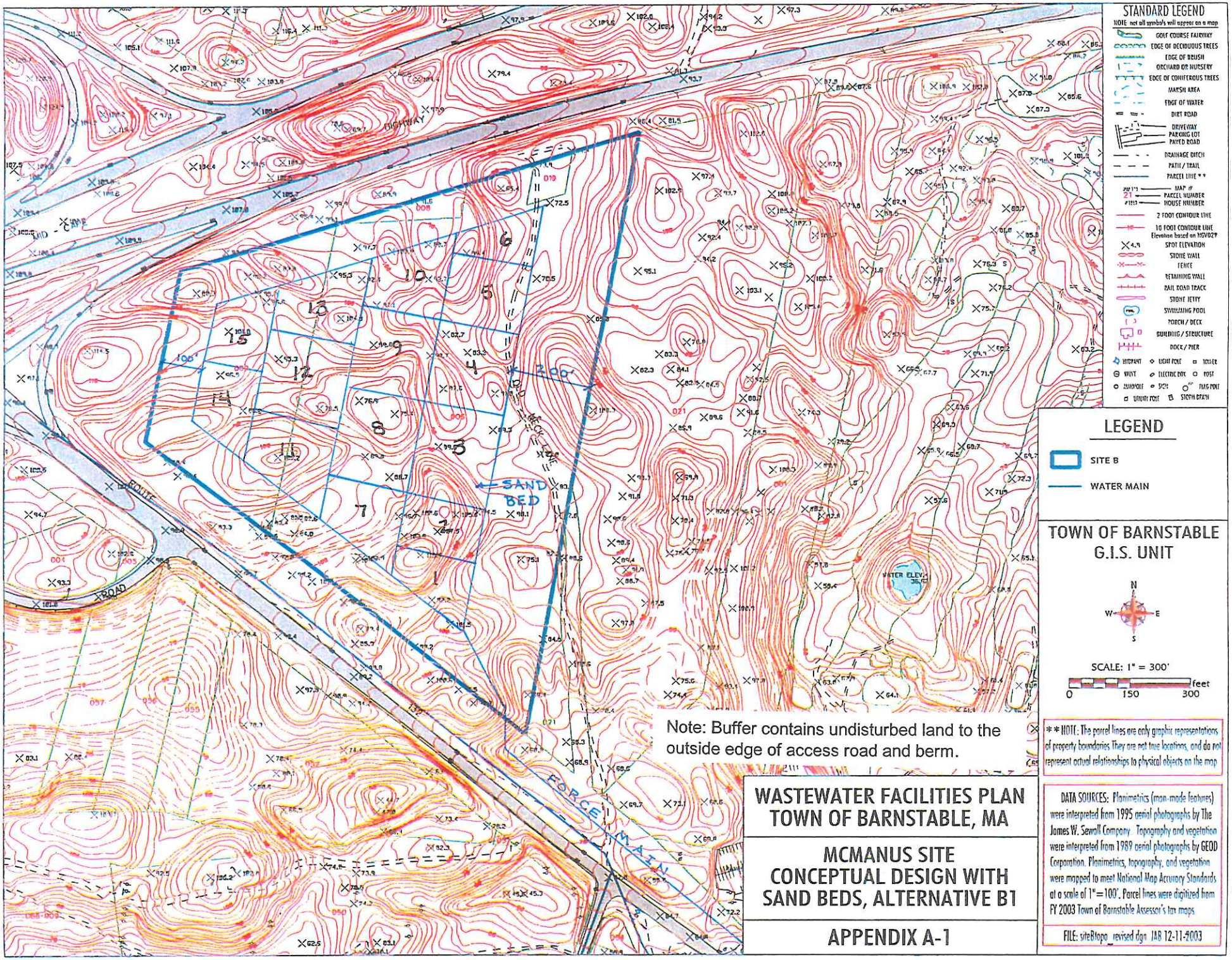
SUMMARY OF SITE EVALUATION
Wastewater Facilities Plan
Town of Barnstable, MA

Alternative Number	Alternative Name	Infiltration Land Area (acres)	Estimated Facility Capacity (mgd)	Distance from WPCF (LF)	Site Topography	Soil Permeability (Percolation Rate)	Depth to Groundwater	Abutting Land Use	Aesthetic Impacts	Proximity to Sensitive Receptors	Capital Costs	Capital Cost per MGD ($/mgd)	Estimated Annual O & M Costs	Present Worth Costs	Present Worth Cost per MGD ($/mgd)
B1	McManus Site with Sand Beds	7.5	1.6	12,600	Irregular and undulating topography: tree vegetation	Less than 5 minutes/inch	58' +/-	Undeveloped and Road ROW	Moderate due to deforestation and image of sand beds	2,700' to public water supply wells	$6,200,000	$3,900,000	$180,000	$8,100,000	$5,100,000
B2	McManus Site with Subsurface Infiltration	11	0.9	12,600	Irregular and undulating topography: tree vegetation	Less than 5 minutes/inch	58' +/-	Undeveloped and Road ROW	Minimal after construction	2,700' to public water supply wells	$13,000,000	$14,000,000	$180,000	$15,000,000	$17,000,000
C2	Airport Site with Subsurface Infiltration	28	2.3	8,600	Mostly flat with a slight slope from northwest to southeast, grassed	Less than 5 minutes/inch	20' +/- during drilling; 14 to 18 feet after.	Commercial Property, Undeveloped Property and Road ROW	Minimal after construction	1,100' to public water supply wells	$21,000,000	$9,100,000	$530,000	$27,000,000	$12,000,000
D1	Cape Cod Community College Site with Sand Beds	8.1	1.7	15,500	Natural topography is irregular and undulating: tree vegetation	Less than 5 minutes/inch	65' to 70' +/-	Undeveloped, Road ROW, and Community College	Moderate due to deforestation and image of sand beds	4,100' to public water supply wells	$7,000,000	$4,100,000	$190,000	$9,000,000	$5,300,000
D2	Cape Cod Community College Site with Subsurface Infiltration	14	1.1	15,500	Natural topography is irregular and undulating: tree vegetation	Less than 5 minutes/inch	65' to 70' +/-	Undeveloped and Road ROW	Minimal after construction	4,100' to public water supply wells	$16,000,000	$15,000,000	$220,000	$19,000,000	$17,000,000
E1	Lorusso Site with Sand Beds	2.3	0.5	10,400	Lightly vegetated, rolling terrain, disturbed site with powerlines overhead	Less than 5 minutes/inch	65'+/-	State Roadway and Undeveloped	Moderate due to deforestation and image of sand beds	2,300' to public water supply wells	$3,600,000	$7,200,000	$80,000	$4,500,000	$9,000,000
E3	Lorusso Site with Spray Irrigation	5	0.04	10,400	Lightly vegetated, rolling terrain, disturbed site with powerlines overhead	Less than 5 minutes/inch	65'+/-	Undeveloped	Moderate due to perception of sprayed wastewater	2,300' to public water supply wells	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow

Capital Costs are based on an Engineering News Record (ENR) Index of 6,800 for 2003 costs.
Present Worth Cost based on n = 20, I = 7.625%, P/A = 10.1.
All costs rounded to 2 significant digits.

APPENDIX A

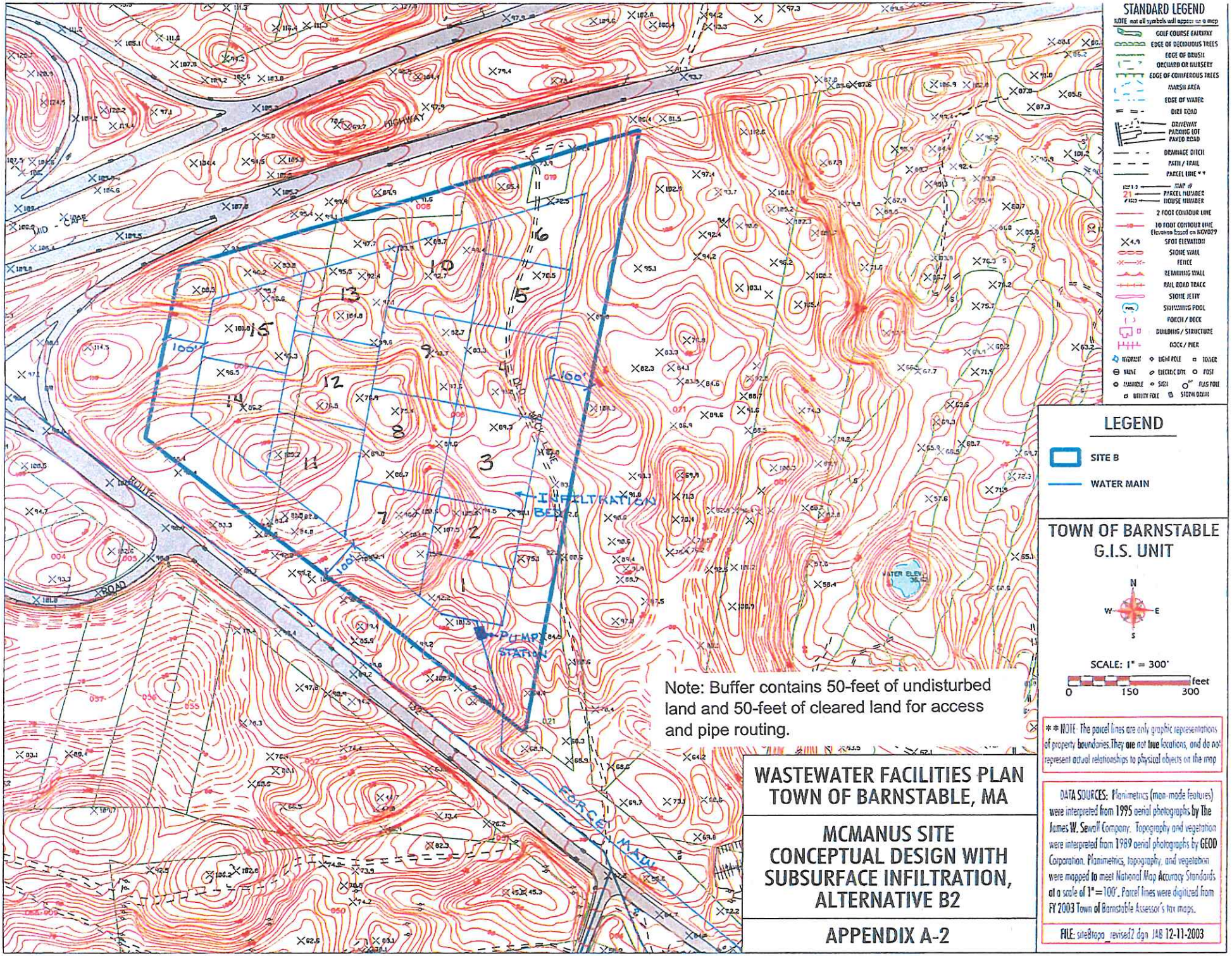
CONCEPTUAL DESIGN SKETCHES



WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA

MCMANUS SITE
CONCEPTUAL DESIGN WITH SAND BEDS, ALTERNATIVE B1

APPENDIX A-1


STANDARD LEGEND
NOTE: not all symbols will appear on a map
GOLF COURSE FAIRWAY
EDGE OF DECIDUOUS TREES
EDGE OF BRUSH
ORCHARD OR NURSERY
EDGE OF CONIFEROUS TREES
MARSH AREA
EDGE OF WATER
DIRT ROAD
DRIVEWAY
PARKING LOT
PAVED ROAD
DRAINAGE DITCH
PATH / TRAIL
PARCEL LINE**
MAP #
21 PARCEL NUMBER
HOUSE NUMBER
2 FOOT CONTOUR LINE
10 FOOT CONTOUR LINE
Elevation based on NGVD29
SPOT ELEVATION
STONE WALL
FENCE
RETAINING WALL
RAIL ROAD TRACK
STONE JETTY
SWIMMING POOL
PORCH / DECK
BUILDING / STRUCTURE
DOCK / PIER
HYDRANT
LIGHT POLE
TOWER
VALVE
ELECTRIC BOX
POST
MANHOLE
SIGN
FLAG POLE
UTILITY POLE
STORM DRAIN
LEGEND
SITE B
WATER MAIN
TOWN OF BARNSTABLE
G.I.S. UNIT
N
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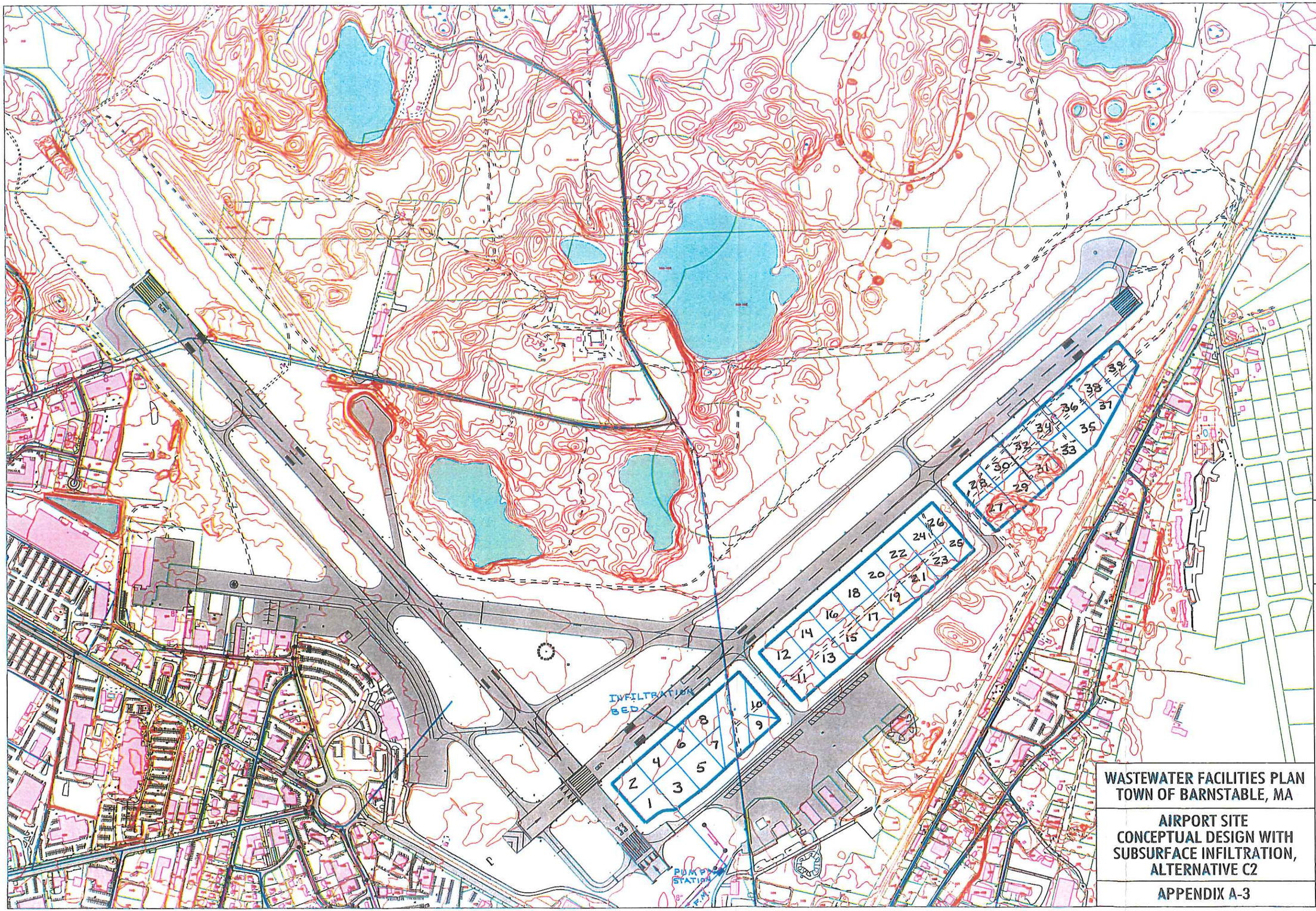
E
S
SCALE: 1" = 300'
feet
0
150
300
** NOTE: The parcel lines are only graphic representations of property boundaries. They are not true locations, and do not represent actual relationships to physical objects on the map
DATA SOURCES: Planimetrics (man-made features) were interpreted from 1995 aerial photographs by The James W. Sewall Company. Topography and vegetation were interpreted from 1989 aerial photographs by GEOD Corporation. Planimetrics, topography, and vegetation were mapped to meet National Map Accuracy Standards at a scale of 1"=100'. Parcel lines were digitized from FY 2003 Town of Barnstable Assessor's tax maps.
FILE: siteBtopo_revised2.dgn JAB 12-11-2003
Note: Buffer contains 50-feet of undisturbed land and 50-feet of cleared land for access and pipe routing.
INFILTRATION BED
PUMP STATION
FORCE MAIN
HIGHWAY
ROUTE
ROAD
WATER ELEV.
100'
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
MCMANUS SITE
CONCEPTUAL DESIGN WITH
SUBSURFACE INFILTRATION,
ALTERNATIVE B2
APPENDIX A-2



STANDARD LEGEND

NOTE: not all symbols will appear on a map

- GOLF COURSE FAIRWAY
- EDGE OF DECIDUOUS TREES
- EDGE OF BRUSH
- ORCHARD OR NURSERY
- EDGE OF CONIFEROUS TREES
- MARSH AREA
- EDGE OF WATER
- DIRT ROAD
- DRIVEWAY / PARKING LOT / PAVED ROAD
- DRAINAGE DITCH
- PATH / TRAIL
- PARCEL LINE **
- MAP 110 — MAP #
- 21 — PARCEL NUMBER
- @1869 — HOUSE NUMBER
- 2 FOOT CONTOUR LINE
- 10 — 10 FOOT CONTOUR LINE, Elevation based on NGVD29
- 4.9 — SPOT ELEVATION
- STONE WALL
- FENCE
- RETAINING WALL
- RAIL ROAD TRACK
- STONE JETTY
- POOL — SWIMMING POOL
- PORCH / DECK
- BUILDING / STRUCTURE
- DOCK / PIER
- HYDRANT, LIGHT POLE, TOWER
- VALVE, ELECTRIC BOX, POST
- MANHOLE, SIGN, FLAG POLE
- UTILITY POLE, STORM DRAIN

LEGEND

- SITE C
- WATER MAIN
- EXISTING GRAVITY SEWER

TOWN OF BARNSTABLE G.I.S. UNIT

N, W, E, S

SCALE: 1" = 600'

0 300 600 feet

** NOTE: The parcel lines are only graphic representations of property boundaries. They are not true locations, and do not represent actual relationships to physical objects on the map.

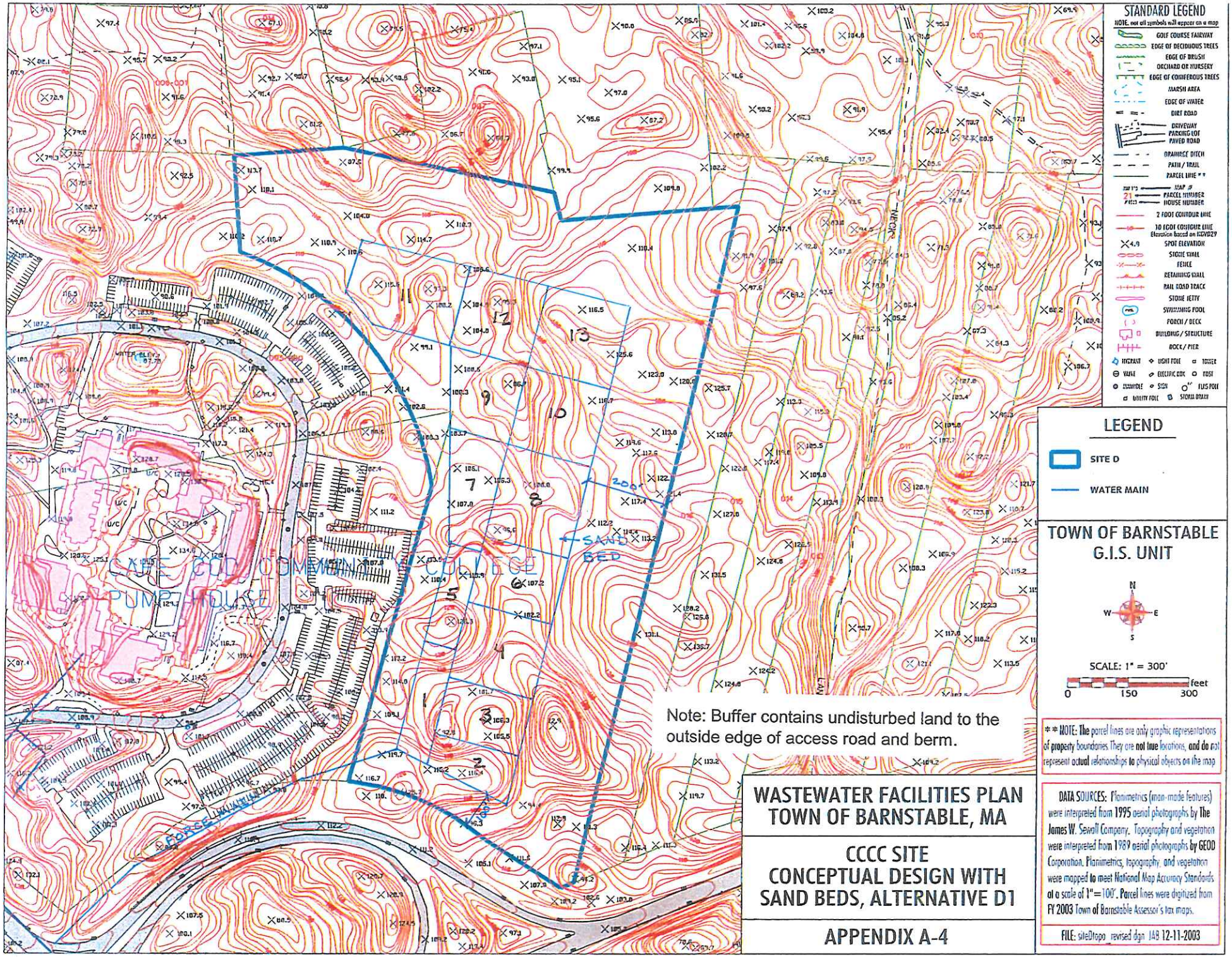
DATA SOURCES: Planimetrics (man-made features) were interpreted from 1995 aerial photographs by The James W. Sewall Company. Topography and vegetation were interpreted from 1989 aerial photographs by GEOD Corporation. Planimetrics, topography, and vegetation were mapped to meet National Map Accuracy Standards at a scale of 1"=100'. Parcel lines were digitized from FY 2003 Town of Barnstable Assessor's tax maps.

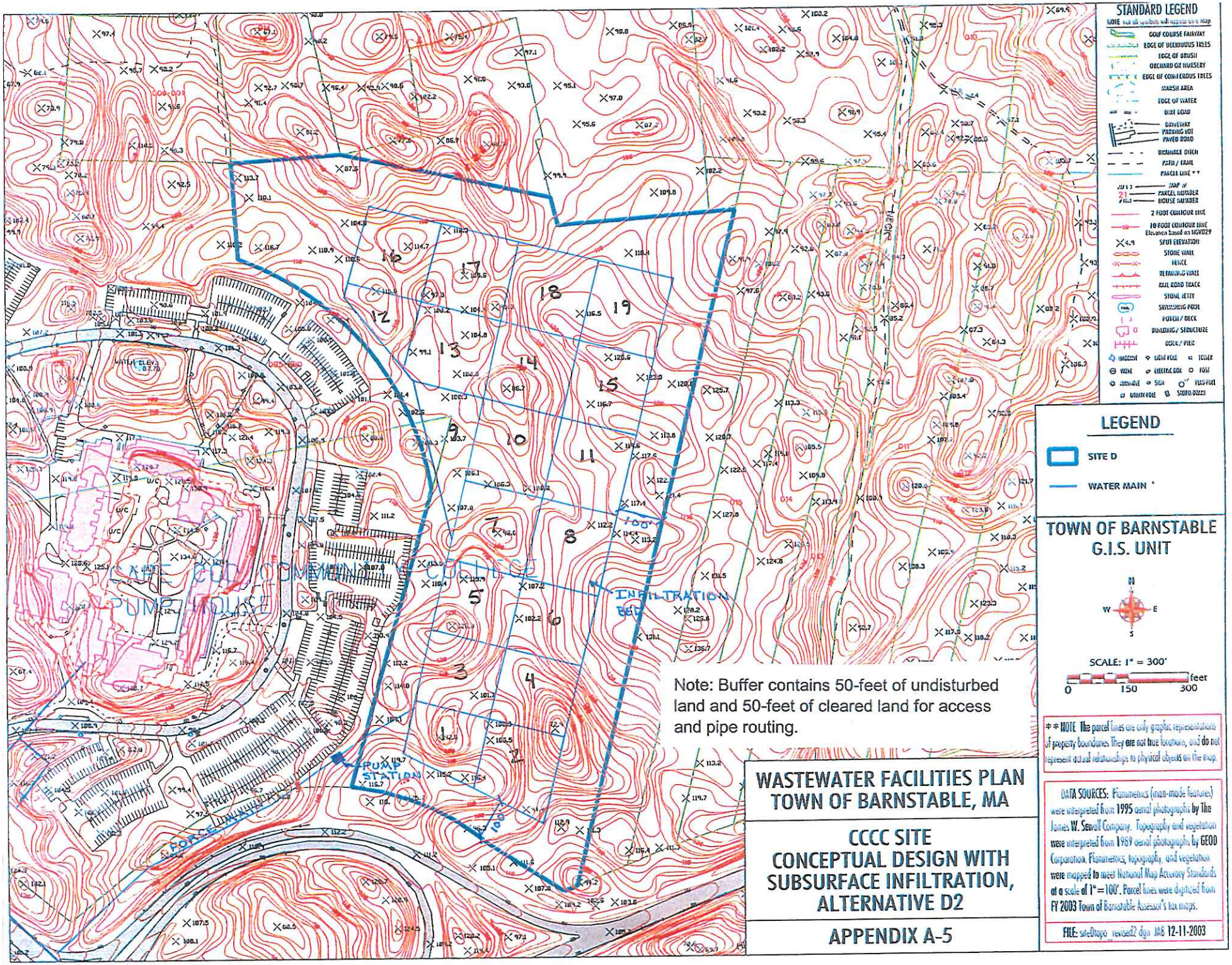
FILE: siteCbapa revised.dgn JAB 12-11-2003

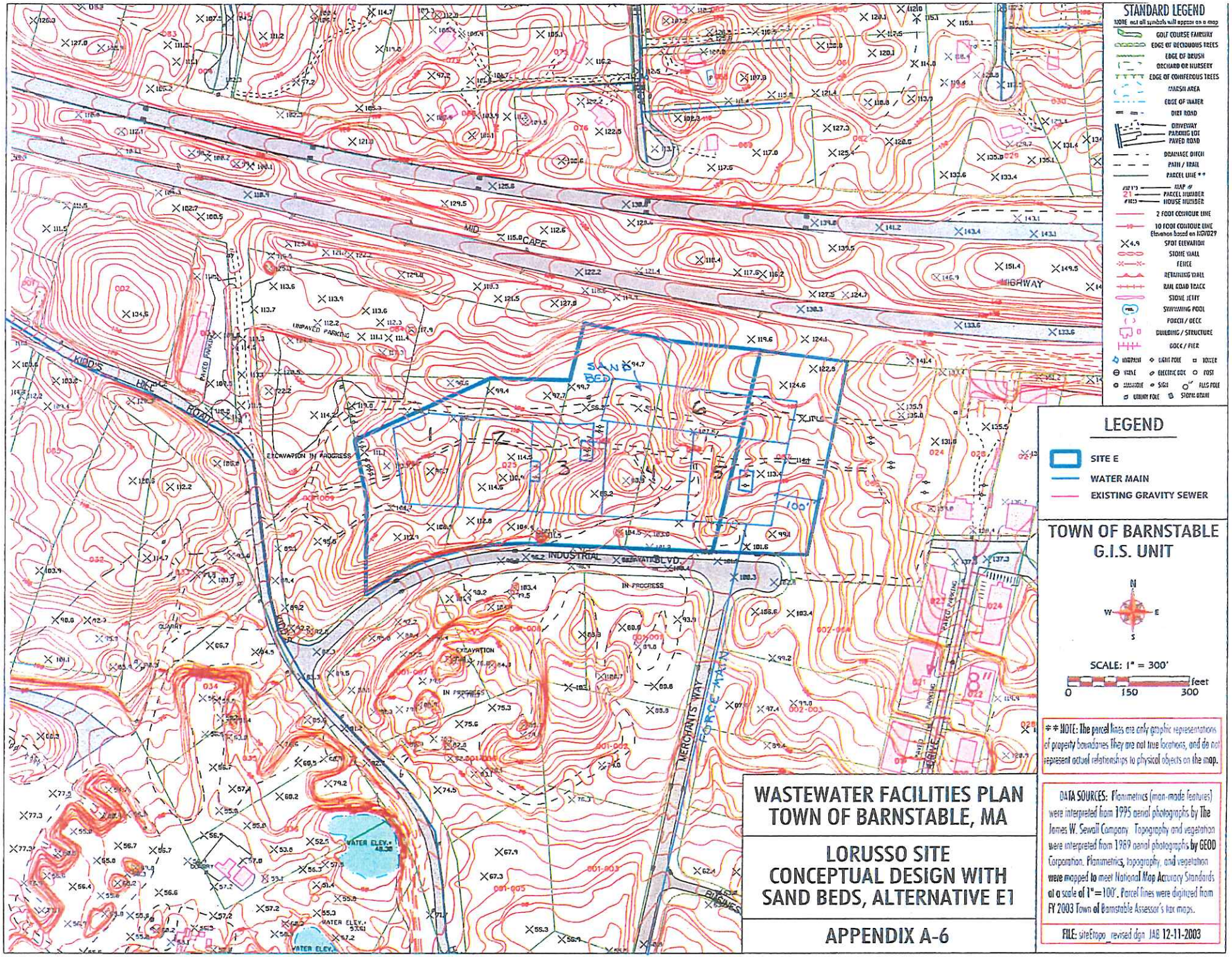
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA

AIRPORT SITE CONCEPTUAL DESIGN WITH SUBSURFACE INFILTRATION, ALTERNATIVE C2

APPENDIX A-3


STANDARD LEGEND
NOTE: not all symbols will appear on a map
GOLF COURSE FAIRWAY
EDGE OF DECIDUOUS TREES
EDGE OF BRUSH
ORCHARD OR NURSERY
EDGE OF CONIFEROUS TREES
MARSH AREA
EDGE OF WATER
DIRT ROAD
DRIVEWAY
PARKING LOT
PAVED ROAD
DRAINAGE DITCH
PATH / TRAIL
PARCEL LINE * *
MAP #
21 PARCEL NUMBER
PARCEL HOUSE NUMBER
2 FOOT CONTOUR LINE
10 FOOT CONTOUR LINE
Elevation based on NGVD29
SPOT ELEVATION
STONE WALL
FENCE
RETAINING WALL
RAIL ROAD TRACK
STONE JETTY
SWIMMING POOL
PORCH / DECK
BUILDING / STRUCTURE
DOCK / PIER
HYDRANT
LIGHT POLE
TOWER
VALVE
ELECTRIC BOX
POST
MANHOLE
SIGN
FLAG POLE
UTILITY POLE
STORM DRAIN
LEGEND
SITE D
WATER MAIN
TOWN OF BARNSTABLE
G.I.S. UNIT
N
W
E
S
SCALE: 1" = 300'
feet
0
150
300
Note: Buffer contains undisturbed land to the outside edge of access road and berm.
* * NOTE: The parcel lines are only graphic representations of property boundaries. They are not true locations, and do not represent actual relationships to physical objects on the map
DATA SOURCES: Planimetrics (man-made features) were interpreted from 1995 aerial photographs by The James W. Sewall Company. Topography and vegetation were interpreted from 1989 aerial photographs by GEOD Corporation. Planimetrics, topography, and vegetation were mapped to meet National Map Accuracy Standards at a scale of 1"=100'. Parcel lines were digitized from FY 2003 Town of Barnstable Assessor's tax maps.
FILE: siteDtopo revised.dgn JAB 12-11-2003
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
CCCC SITE
CONCEPTUAL DESIGN WITH
SAND BEDS, ALTERNATIVE D1
APPENDIX A-4


STANDARD LEGEND
NOTE not all symbols will appear on a map
GOLF COURSE FAIRWAY
EDGE OF DECIDUOUS TREES
EDGE OF BRUSH
ORCHARD OR NURSERY
EDGE OF CONIFEROUS TREES
MARSH AREA
EDGE OF WATER
DIKE ROAD
DRIVEWAY
PARKING LOT
PAVED ROAD
DRAINAGE DITCH
PATH / TRAIL
PARCEL LINE * *
MAP #
21 PARCEL NUMBER
HOUSE NUMBER
2 FOOT CONTOUR LINE
10 FOOT CONTOUR LINE
Elevation based on NGVD29
SPOT ELEVATION
STONE WALL
FENCE
RETAINING WALL
RAIL ROAD TRACK
STONE JETTY
SWIMMING POOL
PORCH / DECK
BUILDING / STRUCTURE
DOCK / PIER
UTILITY POLE
LIGHT POLE
TOWER
MANHOLE
ELECTRIC BOX
POST
SIGN
FLAGPOLE
CATCH BASIN
STORM DRAIN
LEGEND
SITE D
WATER MAIN
TOWN OF BARNSTABLE
G.I.S. UNIT
N
W
E
S
SCALE: 1" = 300'
feet
0
150
300
Note: Buffer contains 50-feet of undisturbed land and 50-feet of cleared land for access and pipe routing.
INFILTRATION BED
PUMP STATION
FORCE MAIN
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
CCCC SITE
CONCEPTUAL DESIGN WITH SUBSURFACE INFILTRATION, ALTERNATIVE D2
APPENDIX A-5
* * NOTE The parcel lines are only graphic representations of property boundaries. They are not true locations, and do not represent actual relationships to physical objects on the map.
DATA SOURCES: Planimetrics (man-made features) were interpreted from 1995 aerial photographs by The James W. Sewall Company. Topography and vegetation were interpreted from 1989 aerial photographs by GEOD Corporation. Planimetrics, topography, and vegetation were mapped to meet National Map Accuracy Standards at a scale of 1"=100'. Parcel lines were digitized from FY 2003 Town of Barnstable Assessor's tax maps.
FILE: siteDtopo_revised2.dgn JAB 12-11-2003


STANDARD LEGEND
NOTE not all symbols will appear on a map
GOLF COURSE FAIRWAY
EDGE OF DECIDUOUS TREES
EDGE OF BRUSH
ORCHARD OR NURSERY
EDGE OF CONIFEROUS TREES
MARSH AREA
EDGE OF WATER
DIRT ROAD
DRIVEWAY
PARKING LOT
PAVED ROAD
DRAINAGE DITCH
PATH / TRAIL
PARCEL LINE **
MAP #
PARCEL NUMBER
HOUSE NUMBER
2 FOOT CONTOUR LINE
10 FOOT CONTOUR LINE
Elevation based on NGVD29
SPOT ELEVATION
STONE WALL
FENCE
RETAINING WALL
RAIL ROAD TRACK
STONE JETTY
SWIMMING POOL
PORCH / DECK
BUILDING / STRUCTURE
DOCK / PIER
HYDRANT
LIGHT POLE
TOWER
VALVE
ELECTRIC BOX
POST
MANHOLE
SIGN
FLAG POLE
UTILITY POLE
STORM DRAIN
LEGEND
SITE E
WATER MAIN
EXISTING GRAVITY SEWER
TOWN OF BARNSTABLE
G.I.S. UNIT
N
W
E
S
SCALE: 1" = 300'
0
150
300
feet
** NOTE: The parcel lines are only graphic representations of property boundaries They are not true locations, and do not represent actual relationships to physical objects on the map.
DATA SOURCES: Planimetrics (man-made features) were interpreted from 1995 aerial photographs by The James W. Sewall Company. Topography and vegetation were interpreted from 1989 aerial photographs by GEOD Corporation. Planimetrics, topography, and vegetation were mapped to meet National Map Accuracy Standards at a scale of 1"=100'. Parcel lines were digitized from FY 2003 Town of Barnstable Assessor's tax maps.
FILE: siteEtopo_revised.dgn JAB 12-11-2003
MID CAPE
HIGHWAY
KIDD'S HILL ROAD
UNPAVED PARKING
PAVED PARKING
EXCAVATION IN PROGRESS
SAND BED
INDUSTRIAL BLVD.
MERCHANTS WAY
FORCE MAIN
100'
8"
WATER ELEV.
QUARRY
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
LORUSSO SITE
CONCEPTUAL DESIGN WITH
SAND BEDS, ALTERNATIVE E1
APPENDIX A-6

APPENDIX B

COST SUMMARY

Appendix B

SUMMARY OF CAPITAL COSTS
Watewater Facilities Plan
Town of Barnstable, MA

	B1 McManus Site with Sand Beds	B2 McManus Site with Subsurface Infiltration	C2 Airport Site with Subsurface Infiltration	D1 Cape Cod Community College Site with Sand Beds	D2 Cape Cod Community College Site with Subsurface Infiltration	E1 Lorusso Site with Sand Beds
Effluent Flow, mgd	1.6	0.9	2.3	1.7	1.1	0.5
WPCF Pump Room Modifications						
3 Effluent Pumps	$180,000	$120,000	$150,000	$180,000	$150,000	$120,000
Piping, electrical, and site work	$210,000	$210,000	$210,000	$210,000	$210,000	$210,000
SCADA and controls	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
Filtration Facilities at WPCF						
Filter equipment and building		$1,300,000	$2,800,000		$1,500,000	
Yard piping and pumps		$170,000	$320,000		$190,000	
Chemical Feed Facilities for Phosphorus Removal			$110,000			
Electrical and HVAC		$310,000	$680,000		$350,000	
Forcemain to the Site (1)						
Force Main Piping, Appurtenances, Restoration	$1,500,000	$1,500,000	$900,000	$1,900,000	$1,900,000	$1,000,000
Discharge Site						
Sand bed facility, piping, and monitoring wells	$1,900,000			$2,000,000		$560,000
Subsurface infiltration facility and monitoring wells		$3,400,000	$6,800,000		$4,400,000	
Header piping and dosing valves		$450,000	$1,000,000		$570,000	
Pump station, process pipe, electrical, HVAC		$860,000	$960,000		$860,000	
SCADA and controls	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
Mobilization and General Conditions (9%)	$400,000	$800,000	$1,300,000	$400,000	$900,000	$200,000
Subtotal Direct Costs	$4,400,000	$9,300,000	$15,000,000	$4,900,000	$11,000,000	$2,300,000
Indirect Costs						
Contingency (15%)	$700,000	$1,400,000	$2,300,000	$800,000	$1,700,000	$400,000
Fiscal, legal and engineering (25%)	$1,100,000	$2,400,000	$3,800,000	$1,300,000	$2,800,000	$600,000
Private property purchase (2 times assessed value)(2)	$20,000	$20,000				$300,000
Subtotal Indirect Costs	$1,800,000	$3,800,000	$6,100,000	$2,100,000	$4,500,000	$1,300,000
Total Capital Costs(3)	$6,200,000	$13,000,000	$21,000,000	$7,000,000	$16,000,000	$3,600,000
Cost per mgd	$3,900,000	$14,000,000	$9,100,000	$4,100,000	$15,000,000	$7,200,000

Notes: 1. Costs are based on the forcemain being located in the road ROW.
2. No purchase, rental or easement costs are estimated for Town or State property.
3. All costs are rounded to 2 significant digits.

Appendix M

Preliminary Evaluation of the McManus Property for Treated Water Recharge; May 2004

Stearns & Wheler, LLC
Environmental Engineers and Scientists

255 Stevens Street
P.O. Box 975
Hyannis, MA 02601

tel. (508) 790-1707
fax. (508) 790-2707
web. www.stearnswheler.com

May 13, 2004

Mr. Mark Giordano, P.E.
Senior Project Manager
Department of Public Works
Town of Barnstable
367 Main Street
Hyannis, MA 02601

Re: Preliminary Evaluation of McManus Property
S&W No. 20054
Final Report

Dear Mr. Giordano:

The Town of Barnstable has asked Stearns & Wheler to complete an evaluation of the McManus site to determine its suitability for wastewater reclamation through groundwater recharge. The evaluation was completed in accordance with the Barnstable Wastewater Facilities Plan (WWFP) recommendation to identify and utilize remote sites for the purpose of recharging treated wastewater to the subsurface. The initial Scope of Work for the investigation included:

- An initial screening of the site based on siting criteria used previously by the Town to identify and evaluate sites
- Completion of eight test pits
- Installation of two soil borings and, if warranted, two observation wells
- Completion of percolation tests and slug tests

The scope of work was adjusted based on field conditions. Access restrictions limited the number of final test pits to six and the number of borings and wells to one.

The balance of this letter report is comprised of four sections, which will discuss:

- Project Background
- Location Considerations
- Site Characteristics
- Conclusions

PROJECT BACKGROUND

The Town of Barnstable is in the process of completing a Wastewater Facilities Plan (WWFP) that evaluates future options for the Town to collect, treat and dispose of municipal wastewater. A component of the WWFP called for the identification of parcels of land, remote from the existing Water Pollution Control Facility (WPCF), where treated wastewater can be reclaimed by discharging it back to the subsurface in order to replenish groundwater resources in the Town. In the course of completing the WWFP, the Town undertook a remote site screening process to identify areas of the Town where suitable parcels may exist. Following the completion of that screening process, the Town began to identify specific parcels that could be further evaluated for suitability. The first of those parcels is the McManus property.

The subject parcel is located just south of the intersection of Route 132 (Iyanough Road) and Route 6 (Mid-Cape Highway). The parcel is located approximately 1,100 feet south of the intersection on the north side of Route 132 and is approximately 8,100 feet form the WPCF. It is trapezoidal in shape and occupies 6.63 acres. The location of the parcel is shown on Figure 1.

During this evaluation of the parcel, two different sets of characteristics were reviewed; characteristics associated with the location of the property and physical characteristics of the property itself. The location and site characteristics are discussed below.

LOCATION CONSIDERATIONS

Location considerations relate to the suitability of the site based on its setting. These criteria were evaluated by the Town in their initial screening process and included such factors as location relative to:

- Wellhead Protection Area
- Areas of Critical Environmental Concern
- Hyannis Coastal Plain Complex
- Vernal Pools
- Wetlands
- Areas of rare and endangered plant and wildlife habitat
- Conservation Areas
- Flood Hazard Zones
- Drainage basins

The results of that screening process indicated that:

- The McManus property is immediately adjacent to but not in an area identified as Area B, one of three sections of the Town that the 1998 site screening effort determined was appropriate for further evaluation of sites.
- The McManus property is located on the western edge of the Zone of Contribution of Barnstable Fire District Well #3, located approximately 3,000 feet to the south east of the McManus property.
- The McManus property is not in an Area of Critical Environmental Concern or an area excluded from wastewater discharge based on proximity to ponds, wetlands or coastal water.
- The McManus property has not been previously identified to be in areas of rare or endangered species or in a restricted wildlife habitat.
- The McManus property has not been previously identified as being in a conservation area or a Flood Hazard Zone.
- The McManus property is in an area that, based on current Town mapping, may drain toward Barnstable Harbor, to the north.

SITE CHARACTERISTICS

Published Information

Geologic Setting. The site is located on the Sandwich Moraine, a glacial deposit that is characterized by slopes and hills and heterogeneous soil comprised of sand, silt, clay, gravel cobbles and boulders. Location on the moraine also suggests more variable topography than would be found on the more southerly outwash plains.

Soil Type. The specific soil type at the site is mapped as the Plymouth-Barnstable complex, characterized as rolling and bouldery. These soil types are found on the side slopes of moraines. The surficial material is black, decomposed organic material overlying loamy sand, which is underlain by light yellowish brown, course sand (USDA, SCS, 1993).

Site Topography. The site is characterized by irregular topography. Even within the six acre parcel, there are a number of undulations with relief of approximately 20 feet.

Depth to Groundwater. The McManus property is in an area where groundwater has been mapped to be greater than 10 feet below the surface.

Hydraulic Conductivity. The McManus property is in an area where previous modeling efforts (Geraghty & Miller) assigned a hydraulic conductivity of 75 feet per day. The WWFP suggests that areas with hydraulic conductivities greater than 200 feet per day could be considered as viable recharge sites. Although this suggests that the site may not be ideal, both of these factors (the mapped hydraulic conductivity and the 200 foot per day criteria) are generalizations that should not, in themselves, rule out a site from further consideration.

Field Investigation Results

Test Pit Observations. On March 15, 2002 six test pits were excavated on the property. Test pit locations are shown on Figure 2 and test pit logs are attached. Test pit TP-6 was proposed further to the north but several attempts in that area indicated the presence of fill material rather than native soil. Test pit TP-6 was therefore located toward the south. The observations made of the test pits confirmed the general soil types presented in the SCS descriptions. A sequence of sandy loam to loamy sand to fine sand was observed in most of the test pits. In one of the test pits (TP-4) some silt was observed at the depth from 5 to 7 feet. Although the soils are characterized as bouldery, and some boulders are observed on the surface, none were encountered in the test pits. In some instances, cobbles up to 6 inches in diameter were encountered. The general observation from the test pits is that the prevalent soil at the site is sand. Groundwater or the indication of seasonal high groundwater was not observed in the test pits.

Percolation Tests. Percolation tests were conducted at four of the six test pits (TP-1, TP-3, TP-5 and TP-6) to obtain a generally qualitative assessment of the soil's capacity to allow water to infiltrate. Percolation test logs are attached. Percolation rates are compared to standards in "Guidelines for the Design Construction, Operation and Maintenance of Small Sewage Treatment Facilities with Land Disposal". Percolation rate at two of the test pits (TP-1 and TP-3) was 3 minutes per inch. At TP-5 the percolation rate was 1.33 minutes per inch and at TP-6 the percolation rate was 4.33 minutes per inch. According to the referenced guidance, percolation rates under 5 minutes per inch should allow the application of 5 gallons per day per square foot (gpd/sq ft). If the recharge facility has a design capacity of 500,000 gpd, 2.3 acres of sand beds would be needed. Additional, back up acreage would also need to be considered. If

trenches are being considered as a recharge mechanism, approximately 33,000 linear feet of trenches would be required if each linear foot of trench represents 6 square feet of infiltration area.

Deep Boring Observations. One deep soil boring was installed at the site to characterize deep soil conditions and to determine the depth to ground water. Because the soil character was generally favorable, the soil boring was completed as a test well. The soil boring was advanced to a depth of 85 feet. A soil boring log is attached. Virtually the entire 85 foot soil section penetrated was comprised of yellow-brown fine to coarse sand. As the boring was advanced, the sand became more and more tightly packed. Near the top of the boring, blow counts from 4 to 30 blows per 6-inch section were observed. In deeper sections of the boring, blow counts ranged from 60 to 100 blows per six inches, indicating a much more tightly packed matrix. Despite the tight nature of the material, it remained a generally clean, fine to coarse sand. At the bottom of the boring, two feet of light brown, silty clay was penetrated.

When the well was completed, the depth to groundwater was measured and found to be 58 feet below the ground surface.

Deep Hydraulic Conductivity. A slug test was completed in the test well to estimate hydraulic conductivity of the underlying formation. The slug test indicated the formation hydraulic conductivity to be approximately 1 foot/day. This measurement was confirmed by duplicating the test two additional times. Although this is a low value for relatively clean sands, it is within the range of hydraulic conductivities reported for fine sand (Fetter, 1994). Also, a slug test is a very preliminary and generalized means of determining hydraulic conductivity. It measures the conductivity only in the very immediate vicinity of the well bore and may not necessarily be representative of the formation as a whole. (Note: Public supply wells located south east of the site produce approximately 700 gallons per minute, suggesting a higher hydraulic conductivity, at least in that area. The Barnstable Fire District is attempting to locate hydraulic conductivity data for the project that may have been developed at the time of installation of those wells.)

CONCLUSIONS

The candidate site is comprised of approximately six acres.

It is located in a groundwater protection area and on the flanks of a Zone of Contribution of a Barnstable Fire District Well. DEP does not exclude reclamation/recharge within a Zone of Contribution but has set a standard of a two year travel time for groundwater flow from the recharge area to a public supply well. Based on the flat gradient and the Geraghty & Miller hydraulic conductivity for the area, flow rate has been preliminarily

calculated to be .225 feet per day or 164 feet in two years. Also, groundwater flow direction is presently mapped to be toward the east-northeast, not toward the wells.

The candidate site is not located in any other excluded areas identified during the site selection screening process.

The site has irregular topography, which would complicate but not prevent the use of the site for recharge facilities.

The site is located 8,100 feet from the WPCF. The distance, in itself, is not an advantage or disadvantage, until compared to the distances of other candidate sites.

The subsurface soils are comprised primarily of fine to coarse sand. Some cobbles were observed in test pits and a silty zone was observed in one of the test pits. A clay layer was encountered at 85 feet in the test boring.

Percolation rates of less than 5 minutes per inch were obtained, suggesting suitable soils for recharge near the surface.

Deeper sands (>30') are extremely dense as indicated by blow counts in the 60 – 100 counts range. The density of the deeper sands was supported by a relatively low hydraulic conductivity, as indicated by the slug tests.

Using an analytical mounding calculator used by MADEP for evaluating mounding at water recharge sites (Hantaxis®) and the measured hydraulic conductivity of 1 foot/day, a disposal rate of approximately 100,000 gpd over a 3 acre area would result in a calculated mound of approximately 50 feet, significant, but acceptable. Again, the measured hydraulic conductivity may not be representative of the formation. If a more reasonable estimate of hydraulic conductivity is assigned, (the Geraghty & Miller estimate of 75 feet/day) the site can accept 500,000 gallons per day with a resultant mound of approximately 12 feet. Further investigation of the hydraulic conductivity is warranted.

To conclude, the site has the advantages of proximity to the WPCF, not being located in exclusion areas and of being comprised of relatively clean sand. The site has the disadvantages of having irregular topography, of presumably draining to the north toward Barnstable Harbor, and of having potentially low hydraulic conductivity in the deeper sands, although the measured value may not necessarily be representative of the formation material. The disadvantages identified so far are not enough to eliminate the site from further consideration and the site should be considered a viable remote

discharge site. Additional testing to verify this conclusion would be required during the permitting process

If you have any questions regarding the procedures or interpretations presented in this letter, please call.

Very truly yours,

STEARNS & WHELER, LLC

T. Lawrence Hineline, CPG
Associate

Robert Butterworth, P.E., DEE
Principal
Director, Wastewater Services

/tlh

Attachments

TEST PIT LOGS

FORM 11 - SOIL EVALUATOR FORM
Job No 20054

Location Address or Lot No. McManus Property

On-site Review

Deep Hole Number TP-1 Date: 3/15/92 Time: 1500 Weather Cloudy
Location (identify on site plan) See attached
Land Use Woods Slope (%) 4-8% Surface Stones None visible
Vegetation Oak/Pine
Landform N/A
Position on landscape (sketch on the back) N/A
Distances from:

Open Water Body	N/A	feet	Drainage way	N/A	feet
Possible Wet Area	N/A	feet	Property Line	N/A	feet
Drinking Water Well	N/A	feet	Other	N/A	

Note: This information was not obtained in detail due to the preliminary nature of the investigation

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
4"-0"	O	—	—	—	—
0-8"	A	2.5Y 3/1	Sandy Loam	None	Loose, no gravel or stones
8"-24"	B	10YR 5/6	Sandy Loam	None	Loose, no gravel or stones
24"-86"	C	10YR 6/8	Loamy Sand	10%	6"-18" stones encountered throughout layer/horizon, blocky structure.

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) N/A Depth to Bedrock: >86"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: N/A

DEP

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. McManus Property

On-site Review

Deep Hole Number TP-2 Date: 3/15/02 Time: 0840 Weather Mostly Cloudy 40s
Location (identify on site plan) See attached
Land Use Woods Slope (%) 0-12% Surface Stones Some thinly/sparse
Vegetation Oak/Pine
Landform N/A
Position on landscape (sketch on the back) N/A
Distances from: See note TP-1

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistancy, % Gravel)
6"-0"	O	—	—	—	—
0-4"	A	Sandy Loam	2.5YR 3/1	None	No stones, no gravel, horizon variable in depth
4"-30"	B	Loamy Sand	7.5YR 5/8	None	friable, loose, no stones, no gravel
30"-80"	C	Fine Sand	2.5Y 6/4	15% @ 70" (7.5YR 5/8)	Several small stones (4"-6") and some large boulders (2'Ø). Small pockets of very ~~loose~~ fine dense Sand and Sandy Loam

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) N/A Depth to Bedrock: >80"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: >80"

DEP

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. McManus Property

On-site Review

Deep Hole Number TP-3 Date: 3/15/02 Time: 0914 Weather Sunny, 40s

Location (identify on site plan) See attached

Land Use Woods Slope (%) 0-4 Surface Stones Some scattered

Vegetation Oak/Pine

Landform N/A

Position on landscape (sketch on the back)

Distances from: N/A - see note on TP-1

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
2"-0"	O	—	—	—	—
0-6"	A	Sandy Loam	10YR 4/1	None	Loose, friable, no stones no gravel
6"-30"	B	Sandy Loam	7.5YR 5/8	None	Loose, <5% small stones/gravel 5-8% stones 2-4" ø
30"-60"	C_1	Loamy Sand	2.5Y 6/6	None	<5% small stones (<1" ø) Firm, friable
60"-86"	C_2	Fine Sand	2.5Y 6/6	<2% Mottles	Loose, friable, no stones

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) N/A Depth to Bedrock: >86"

Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None

Estimated Seasonal High Ground Water: >86"

DEP APPROVED FORM - 12/07/95

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. McManus Property

On-site Review

Deep Hole Number TP-4 Date: 3/15/02 Time: 1414 Weather Partly Cloudy 40s
Location (identify on site plan) See attached
Land Use Woods Slope (%) 0-4 Surface Stones None
Vegetation Oak/Pine 6-12" ϕ
Landform
Position on landscape (sketch on the back)
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

N/A - See Note on TP-1

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
6"-0"	O	—	—	—	—
0-4"	A	Sandy Loam	7.5YR 3/2	None	Loose, friable No stones/boulders
4"-24"	B	Sandy Loam	10YR 5/8	None	Loose, friable, no stones, boulders
24"-60"	C_1	Loamy Sand	10YR 5/6	None	<10% small stones (2-4" ϕ) Blocky structure
60"-84"	C_2	Silt Loam	2.5Y 5/3 / 7.5YR 5/8	<5% Mottles	<25% small (2-4") stones Firm - mixture of silt loam and loamy sand.

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) N/A Depth to Bedrock: > 84"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: > 84"

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. McManus Property

On-site Review

Deep Hole Number VP-5 Date: 3/15/02 Time: 1315 Weather Partly Cloudy, 40s

Location (identify on site plan) See attached

Land Use Woods Slope (%) 0-4 Surface Stones Scattered/Minimal

Vegetation Oak/Pine

Landform

Position on landscape (sketch on the back)

Distances from: N/A - see note VP-1

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
2"-0"	O	—	—	—	—
0-3"	A	Sandy Loam	10YR 3/4	None	No boulders/stones Loose, friable
3"-24"	B	Sandy Loam	10YR 5/6	None	No stones Loose, friable
24"-60"	C_1	Fine Sand	2.5Y 6/4	None	Loose, friable, no stones
60"-84"	C_2	Medium Sand	5% - 10YR 6/8; 95% - 5YR 5/8	<5%	40% Loose stones & boulders Stones (30%) 0-2" Boulders (10%) .6"

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) N/A Depth to Bedrock: >84"

Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None

Estimated Seasonal High Ground Water: >84"

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. McManus Property

Note: Initial test pits for TP-6 were started at 1040. However, the area had been previously disturbed and fill was encountered to a depth of roughly 4 feet.

On-site Review

Deep Hole Number TP-6 Date: 3/15/03 Time: 1210 Weather Clear, 40s

Location (identify on site plan) See attached

Land Use Woods Slope (%) 0-8% Surface Stones Minimal, some very large boulders emerging through surface (originally TP-6 site only)

Vegetation Oak/Pine

Landform

Position on landscape (sketch on the back)

Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

N/A - See note on TP-1

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
6"-0"	O	—	—	—	—
0"-6"	A	Sandy Loam	10YR 4/1	None	Loose, firm, no stones, no gravel
6"-36"	B	Loamy Sand	7.5YR 5/8	None	Loose, friable <5% gravel and small pebbles (1/4")
36"-96"	C	Medium Sand	2.5Y 5/4	None	25% small stones (1"-3" ø) 5% medium stones (3"-6" ø)

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) N/A Depth to Bedrock: >96"

Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None

Estimated Seasonal High Ground Water: >96"

PERCOLATION TEST LOGS

FORM 12 - PERCOLATION TEST

Location Address or Lot No. McManus Property

COMMONWEALTH OF MASSACHUSETTS

Barnstable, Massachusetts

Percolation Test*		
Date: 3/15/02	Time:	1330 (TP-5) 1220 (TP-6)
Observation Hole #	TP-5	TP-6
Depth of Perc	26"	72"
Start Pre-soak	1334	1227
End Pre-soak	1349	1242
Time at 12"	1349	1242
Time at 9"	1351	1254
Time at 6"	1355	1307
Time (9"-6")	4 minutes	13 minutes
Rate Min./Inch	1.33 min/inch	4.33 min/inch

* Minimum of 1 percolation test must be performed in both the primary area AND reserve area.

Site Passed ☑ Site Failed ☐

Performed By: Andrew D. Gronewold

Witnessed By: N/A

Comments: Preliminary test only, no witness required

DEP

DEP APPROVED FORM - 12/07/95

FORM 12 - PERCOLATION TEST

Location Address or Lot No. McManus Property

COMMONWEALTH OF MASSACHUSETTS

Barnstable, Massachusetts

Percolation Test*

Date: 3/15/02	Time: 1520 (TP-1) 0955 (TP-3) ~~1330 (TP-2)~~	
Observation Hole #	TP-1	TP-3
Depth of Perc	40"	36"
Start Pre-soak	1522	0958
End Pre-soak	1537	1013
Time at 12"	1537	1014
Time at 9"	1542	1021
Time at 6"	1551	1030
Time (9"-6")	9 minutes	9 minutes
Rate Min./Inch	3 min/inch	3 min/inch

* Minimum of 1 percolation test must be performed in both the primary area AND reserve area.

Site Passed ☑ Site Failed ☐

Performed By: Andrew D. Gronewold

Witnessed By: N/A

Comments: Preliminary test only, no witness required

DEP APPROVED FORM - 12/07/95

TEST BORING LOG

Boring/Well ID:	B-1

Project Name:	McManus Property
Job. No.	20054
Start Date & Time:	3/12/02 07:00
Finish Date & Time:	3/14/02 10:30
Drilling Co.:	Diedrich Drilling Company
Driller:	Charlie and Wally
S&W Inspector:	LNS
Rig Type:	Diedrich D-50
Drilling Method:	auger/ spinning
Weather:	cloudy/raining, 30-40 deg F

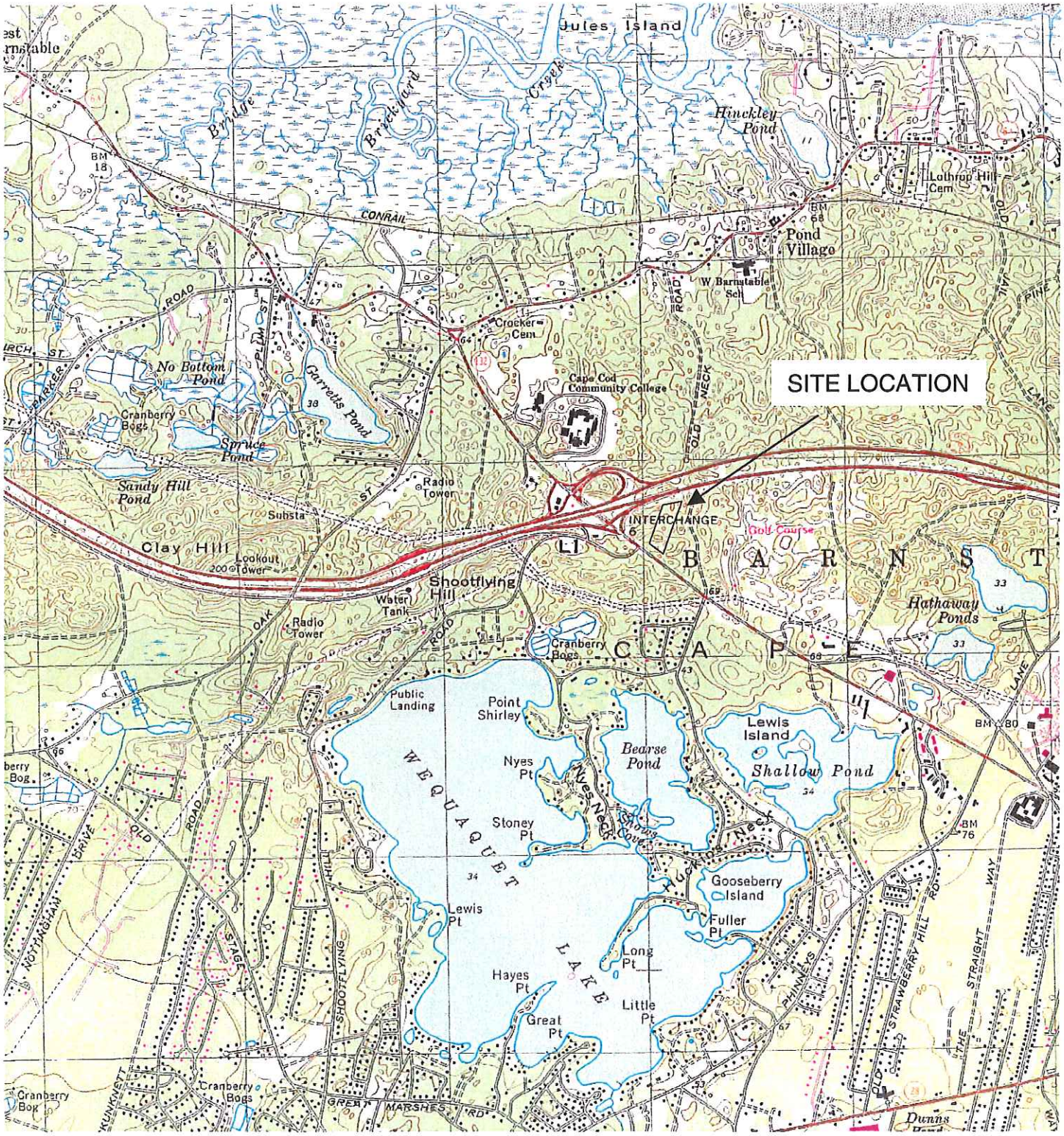
Groundwater Observations	
Time:	3/14/2002 7:00
Casing Depth:	
Boring Depth:	
Depth to Water:	
Below Surface:	49'
Below Meas. Point:	49'
Surface Elevation:	
Measuring Point Elevation:	
Groundwater Elevation:	

Depth (ft)	Blow Counts	PID (PPM)	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Groundwater **Sample Description**	Depth (ft)	Well Profile
0	4,4			18			yellow-brown fine to coarse SAND with traces of SILT and GRAVEL.	0	
1	6,6							1	
2								2	
3								3	
4								4	
5	11,21			24				5	
6	11,10							6	
7								7	
8								8	
9								9	
10	3,6			15				10	
11	8,12							11	
12								12	
13								13	
14								14	
15	5,6			14				15	
16	24,16						Very tightly packed yellow-gray medium to coarse SAND with 1" to 2" COBBLES and some GRAVEL	16	
17								17	
18								18	
19								19	
20				12				20	
21								21	
22	33,21							22	
23	19,31							23	
24								24	
25	14,20			15	orange streak			25	
26	19,31							26	
27								27	
28								28	
29								29	
30	66,65			10				30	
31	33,38							31	
32								32	
33								33	
34								34	
35	13,18			10				35	
36	24,26							36	
37								37	
38								38	
39								39	

Boring/Well ID: B-1 cont' 1

Depth (ft)	Blow Counts	PID (PPM)	Sample Log	Recovery (ft)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Groundwater / Sample Description	Depth (ft)	Deep Well
40	42,39			12				41	
41	37,34							42	
42								43	
43								44	
44								45	
45	45,25			12				46	
46	30,27							47	
47								48	
48								49	
49							▼	50	
50	30,34			8				51	
51	43,41							52	
52							Tightly-packed yellow-gray medium to coarse SAND, with some GRAVEL, trace SILT	53	
53								54	
54								55	
55	41,50			14				56	
56	56,58							57	
57								58	
58								59	
59								60	
60	36,43			12				61	
61	51,54							62	
62								63	
63								64	
64								65	
65	99,25			8	(1)			66	
66	20,38							67	
67								68	
68								69	
69							Tightly-packed, mostly fine to coarse SAND, with little GRAVEL and trace SILT	70	
70	49,37			10				71	
71	32,39							72	
72								73	
73								74	
74								75	
75	43,62			14				76	
76	81,120				(2)			77	
77								78	
78								79	
79								80	
80								81	
81	67,85			14				82	
82	96,83							83	
83								84	
84								85	
85	18,22			18				86	
86	68				(3)		Light brown CLAY, little SILT, trace GRAVEL	87	
87									

Notes:
1. Blowcount of 99 is likely explained by a large rock found in the sample
2. After 120 blowcounts, there was still no penetration for the final 6-inches of this sample.
3. Drillers only hammered 18-inches into the final sample.



Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS

DATE: 4/02 JOB No: 20054

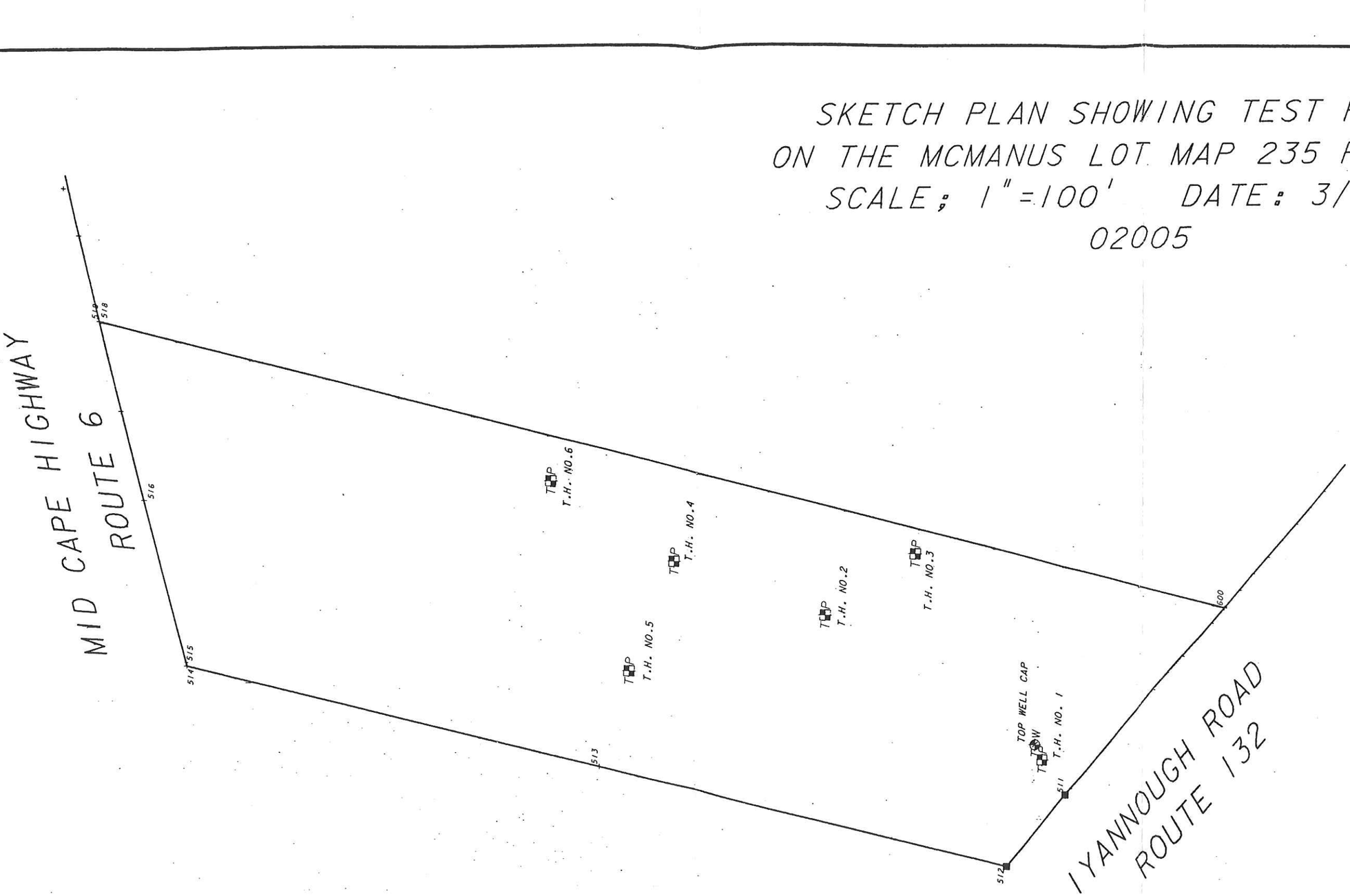
TOWN OF BARNSTABLE
EFFLUENT MITIGATION EVALUATIONS

FIGURE 1
McMANUS PROPERTY – SITE LOCATION

SKETCH PLAN SHOWING TEST HOLES ON THE MCMANUS LOT MAP 235 PARCEL 8

SCALE; 1"=100' DATE: 3/26/02

02005



Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS MASSACHUSETTS

DATE: 4/02 JOB No: 20054

TOWN OF BARNSTABLE
EFFLUENT MITIGATION EVALUATIONS

FIGURE 2
McMANUS PROPERTY – SITE MAP

Appendix N

Preliminary Evaluation of the Barnstable Municipal Airport for Treated Water Recharge; May 2004

Stearns & Wheler, LLC
Environmental Engineers and Scientists

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May 13, 2004

Mr. Mark Giordano, P.E.
Senior Project Manager
Department of Public Works
Town of Barnstable
367 Main Street
Hyannis, MA 02601

Re: Effluent Mitigation Investigation Project
Task 1 - Airport Investigation
S&W No. 20190.0
Final Report

Dear Mr. Giordano:

In accordance with your request and the Contract for Consultant Services for the Effluent Mitigation Investigation Project Task 1 – Airport Characterization, we have completed a preliminary evaluation of the Barnstable Municipal Airport for the recharge of treated effluent. In accordance with paragraph 2.2.5.2 of the Contract for Consultant Services, QA/QC procedures of the Scope of Work were adhered to in the completion of this project. The evaluation was completed consistent with the Barnstable Wastewater Facilities Plan (WWFP) recommendation to identify and utilize remote sites for the purpose of recharging treated wastewater to the subsurface.

BACKGROUND INFORMATION

The Town of Barnstable is in the process of completing a Wastewater Facilities Plan (WWFP) that evaluates future options for the Town to collect, treat and dispose of municipal wastewater. A component of the WWFP called for the identification of parcels of land, remote from the existing Water Pollution Control Facility (WPCF), where treated wastewater can be reclaimed by discharging it back to the subsurface in order to replenish groundwater resources in the Town. Utilization of remote sites for the recharge of treated wastewater was recommended because the WWFP and related work concluded that the recharge capacity of the existing plant is limited due to potential adverse impacts resulting from groundwater mounding. In the course of completing the WWFP, the Town undertook a remote site screening process to identify areas of the Town where suitable parcels may exist. Following the completion of that screening process, the Town

began to identify specific parcels that could be further evaluated for suitability. The second of those parcels being investigated is the Airport property. Reference is made to Figure for the location of the Airport property.

The subject parcel is located at the intersection of Route 132 (Iyanough Road) and Route 28, north of the "Airport Rotary". The location of the Airport is shown on Figure 1. Three candidate areas were identified at the Airport. The three candidate areas are located just to the northwest of the intersection of the two runways in the southern section of the facility (Candidate Area A), in the northeast corner of the facility (Candidate Area B), and in the northwest corner of the facility (Candidate Area C). Candidate area locations are shown on the Airport Site Map, Figure 2.

SCOPE OF WORK

The Scope of Work for the investigation included the following tasks:

Subtask 1.1 Site Visit. Prior to initiating site work on the site, an initial reconnaissance trip to the site was conducted. A Massachusetts Department of Environmental Protection (MADEP) representative was requested to attend this reconnaissance trip to refine boring and test pit locations and to provide preliminary opinions regarding the suitability of the site. MADEP received a seven-day notification of the site visit. MADEP provided input to the plan to utilize the Airport for wastewater discharge but opted not to be involved in any site visits. Additionally, discussions were held with site owners. The purpose of these discussions was to determine what restrictions (Federal Aviation Administration (FAA) or otherwise) could impact investigative efforts or future use of the site.

Subtask 1.2 Initial Screening. Following the site visit, an initial screening was completed that evaluated the suitability of the site in terms of siting criteria considered in earlier phases of the site identification and screening process, including but not limited to location with respect to:

1. In Wellhead Protection Zones I, II and III
2. In Areas of Critical Environmental Concern
3. Near vernal pools
4. Near wetland
5. In areas of rare and endangered plant and wildlife habitat
6. In conservation areas
7. In flood hazard zones
8. Releases of oil or hazardous materials

9. Drainage basin

Under this subtask, Stearns & Wheler did not redo the Town's earlier screening efforts but refined and updated the previous work.

Subtask 1.3 Test Pits. Nine (9) backhoe test pits were completed at the site. Three test pits were dug in each candidate area. Test pits were excavated to a depth of 8 to10 feet. A soil evaluator logged soil stratigraphy in the test pits. A percolation test was completed at one test pit in each area. Test pit locations are shown on Figure 2.

Subtask 1.4 Soil Borings. Three (3) soil borings were drilled to a depth 50 feet each. The proposed work plan specified the borings would be advanced to a depth up to 90 feet. Based on field observations, including the observation that the water table was encountered at a depth of less than 20 feet, the borings were advanced to a depth of 50 feet. One soil boring was installed in each of the three candidate areas. Split spoon samples were collected at 5 foot intervals from each boring. Stearns & Wheler recorded soil types on a boring log. Boring locations are shown on Figure 2.

Subtask 1.5 Observation Wells/Slug Tests. Upon completion of the first soil boring, a field determination was made that the site is a likely candidate for disposal, so the soil borings were completed as observation wells. In-situ hydraulic conductivity testing (slug testing) was attempted in each well to determine the permeability of the deeper soils. This data was needed in order to complete a groundwater mounding analysis, a requirement of a groundwater discharge permit application, should the Town decide it wants to pursue a permit for this parcel. Slug test results were determined to not be representative of the soil conditions at the site and were disregarded. The evaluation was therefore based on hydraulic conductivity values used by USGS in their current modeling efforts in the area. Additionally, the elevations of the wells were surveyed, water levels were measured, and the groundwater flow direction was determined.

Subtask 1.6 Report of Findings. A written report for the Town that presents the field investigation results and provides recommendations regarding the use of the subject parcel for treated effluent disposal is included herein.

Subtask 1.7 Meetings. Time was allocated for meetings related to this site investigation. One meeting where preliminary results were presented was held on January 16, 2003. An additional meeting is anticipated.

EVALUATION RESULTS

The results of the Airport Investigation are presented in this section. The results are organized in the following order:

- Location Considerations.
  - Summary of initial site screening considerations and results
- Site Characteristics
  - Published Information from literature about the general characteristics of the area of the site.
  - Field Investigation Results – detailed results from the Stearns & Wheler field investigation.

Location Considerations

Location considerations relate to the suitability of the site based on its setting. These criteria were evaluated by the Town in their initial screening process and included those factors listed in the introduction section of this letter. Stearns & Wheler reviewed and updated these siting criteria.

The results of that screening process indicated that:

1. There are several Public Water Supply production wells located on or adjacent to the Airport property, the Barnstable Water Company operates BWAIR #1, three (3) Mary Dunn (BWMD) wells north of the Airport and three (3) Maher (BWMEL) wells southeast of the Airport.

2. The Barnstable Fire District has a well, BFD #2 north of candidate area C, but this well is presently inactive.

3. The three (3) candidate areas at the Airport are in Town designated Groundwater Protection Zones and in the Approved Zone IIs of the proximal production wells. The candidate areas are in or immediately adjacent to Town designated Wellhead protection districts. (See Attachment A Map – Barnstable GIS Map of Groundwater Protection Areas and Wellhead Protection Areas).

4. The Airport property is not in an Area of Critical Environmental Concern based on GIS mapping provided by the Town.

5. The Airport property is adjacent to but not included in a Natural Heritage Endangered Species Priority Site. (See Attachment B Map – MADEP Bureau of Waste Site Cleanup – Map showing sensitive environments).

6. The Airport property has not been previously identified as being in a conservation area or a Flood Hazard Zone.

7. The Airport property is in an area where, based on current Town mapping, groundwater flows to the southwest.

8. Presence of the candidate sites within Zone IIs of production wells will define the recharge of treated wastewater as reclamation as defined in the DEP guidance Interim Guidelines on Reclaimed Water. This will necessitate additional water quality and monitoring requirements. These requirements are summarized on an excerpt from the cited Guidelines, included as Attachment C.

Site Characteristics

1. **Published Information**

a. Geologic Setting. The site is located on the glacial outwash plain south of the Sandwich Moraine. Well-sorted sand and gravel deposits characterize the outwash plains, formed by glacial melt water.

b. Soil Type. The surficial soils at the Airport are defined as Urban Land (USDA, SCS, 1993). This implies that the soils have been altered or obscured by anthropogenic activity. At the Airport, it is evident that the area to accommodate the runways has been cut or filled to make it level. Underlying the disturbed soils the Carver Soils are present. The Carver Soils are characterized as well drained, outwash plain, course sand.

c. Site Topography. The Airport site is essentially flat. Although it has been graded to accommodate construction of the Airport, it is in an area that has very little relief naturally.

d. Depth to Groundwater. The Airport property is in an area where groundwater has been mapped to be greater than 10 feet below the surface.

e. Hydraulic Conductivity. The Airport property is in an area where current USGS modeling efforts are using a hydraulic conductivity of 200-250 feet per day. The WWFP suggests that areas with hydraulic conductivities greater than 200 feet per day can be considered to be viable recharge sites.

2. Field Investigation Results

Each of the three candidate areas was investigated in the same manner, with three test pits, a percolation (perc) test, and a soil boring advanced to 50 feet. Each boring was completed as an observation well. A detailed description of the field investigation follows.

a. Test Pit Observations. On January 10, 2003 nine (9) test pits were excavated on the property. Three test pits were excavated in each of the three candidate areas. Test pits were excavated to depths ranging from 8 to 12 feet. Test Pit Logs are included as Attachment D. Medium to course sand was observed in all of the test pits. Groundwater was not observed in the test pits. Some soil mottling was seen at a depth of 7 feet in area A, at 4-5 feet in Area B and at 2 – 3 feet in Area C. The mottling may be indicative of possible high groundwater although the mottling is not particularly consistent or obvious.

b. Percolation Tests. Percolation tests were conducted at one test pit in each candidate area to obtain a generally qualitative assessment of the soil's capacity to allow water to infiltrate. Percolation test logs are included as Attachment D. Percolation rates are compared to standards in "Guidelines for the Design Construction, Operation and Maintenance of Small Sewage Treatment Facilities with Land Disposal". Percolation rate at each of the three test pits was 2 minutes per inch. According to the referenced guidance, percolation rates under 5 minutes per inch should allow the application of 5 gallons per day per square foot (gpd/sq ft).

c. Deep Boring Observations. One deep soil boring was installed at each candidate area to characterize deep soil conditions and to determine the depth to ground water. Because the soil characteristics were favorable, each boring was completed as a test well. Each soil boring was advanced to a depth of approximately 50 feet. The depth of the borings was decided in the field as the borings were advance and when groundwater was encountered at a depth of approximately 20 feet in each boring. Advancing the borings to 50 feet allowed a 30 feet section of the aquifer to be evaluated. Soil boring logs are included as Attachment F. Virtually the entire 50-foot soil section penetrated was comprised of yellow-ish white to tan, medium to coarse sand. In boring OW-B, a silt and clay layer was encountered between 43 and 48 feet. This layer was not seen in the other two borings and is not believed to be continuous across the area.

On March 12, 2003, depth to water was measured in the three observation wells. Water depths were:

- 18.14 feet below grade in well OW-A
- 14.17 feet below grade in well OW-B
- 17.36 feet below grade in well OW-C

d. Deep Hydraulic Conductivity. The evaluations in this investigation have been based on a hydraulic conductivity value of 200 feet per day as is being used by the USGS for their present modeling efforts in this area.

e. Groundwater Flow Direction and Rate. Groundwater flow direction and rate are germane to this study to assess the extent to which treated effluent will flow toward proximal production wells and to determine whether recharge facilities would be located within a two year travel time of the production wells.

Depth to water measurements and the calculated groundwater elevations indicate a groundwater flow direction consistent with the regional mapping, toward the southeast. This would indicate flow toward the Barnstable Water Company Maher wells. The Maher wells are located approximately 2,250 feet from candidate area A, 5,000 feet from candidate area B and 6,250 from candidate area C.

Although they are not directly downgradient , the Mary Dunn Wells and the Barnstable Water Company Airport Well No. 1 may be closer to the candidate areas. Water could potentially be drawn to those wells also, as a result of their cones of depression.

Using a water table gradient of .0014 feet/foot, (based on the gradient determined to exist between candidate area C and candidate area A), a hydraulic conductivity of 200 feet per day and an estimated aquifer porosity of 20%, a groundwater flow rate of 1.4 feet per day has been calculated. Travel time from each candidate site to proximal production wells is summarized on Table 1.

Pumping from the wells likely results in a cone of depression around the wells, increasing the gradient. However, that impact either (1) does not reach the candidate sites and therefore there is a several year travel time between the candidate sites and the cone of depression, or (2) the resultant gradient is that which was observed and was used in the calculation. Either way, travel time to the production wells can be concluded to be in excess of two years.

f. Potential Mounding. Because the depth to groundwater is approximately 15 feet below grade at the Airport, a preliminary mounding analysis was completed to verify that

discharge at the Airport was feasible with respect to mounding. Using an analytical mounding calculator (the Hantaxis program, used by MADEP to calculate mounding impacts), a variety of discharge scenarios were run. The various scenarios tested different flow rates applied to the appropriate area (based on a discharge rate of 5 gpd/sq ft). A hydraulic conductivity value of 200 feet per day was used in the simulations. The results of the preliminary mounding analysis are presented on Table 2.

The preliminary mounding analyses indicate that if the site has a hydraulic conductivity around 200 feet per day, and maximum high groundwater conditions are considered, that the each candidate site can handle a flow of up to approximately 1 mgd. At that application rate groundwater levels at the discharge site were calculated to be within 7 feet of the surface but the mounding drops off in close proximity to the discharge site.

leaching field only?

CONCLUSIONS

The Airport has a number of qualities making it suitable for wastewater recharge. These include:

1. The Airport is a Town owned facility consisting of approximately 418 acres in its main, developed sections. Large sections of the Airport are cleared, unused, and potentially available for the construction of recharge facilities that are at or below grade.

2. The subsurface material is comprised of clean, uniform, medium to fine grain sand, providing an ideal infiltration matrix.

3. High hydraulic conductivity values are indicated by the presence of several public supply wells in the area that can produce from 500 to 1,000 gallons per minute. A value of 200 to 250 feet per day is being used by the USGS to complete groundwater modeling in this area.

4. Groundwater travel time from candidate area A in the southern portion of the Airport to the nearest downgradient wells is greater than the 2 year time considered significant in the state's reuse policy.

5. The site has little to no relief (essentially flat) and is cleared, which would simplify the construction of facilities.

6. The site (candidate area A) is located 6,800 feet from the WPCF. The distance, in itself, is not an advantage or disadvantage, until compared to the distances of other candidate sites. This is the closest candidate remote site presently being considered.

7. Percolation rates of 2 minutes per inch were obtained, suggesting suitable soils for recharge near the surface.

8. There are also some potential limitations or restrictions to using the Airport property. These include:

9. Federal Aviation Administration (FAA) and Airport regulations will strictly limit construction activities, above grade structures, and locations of facilities. Discussions with Airport personnel suggest that proper design of new facilities that take these considerations into account could be allowed with FAA and Airport approval. Specific restrictions at this time include no construction of any kind within 150 feet of the center of the runways (the Buffer Zone). Beyond the Buffer Zone is the "Obstacle Free Zone" that extends 500 feet from the center of the runway. In this zone there can be no vertical obstructions (such as berms). The Obstacle Free Zone extends 1,000 feet off the ends of the runways.

10. No construction can be planned or undertaken until the Airport completes its plans for redesigning the layout of the Airport, which is a project currently underway by the Airport. The design is expected to be finished near the end of 2003.

11. Although there do not appear to be any conditions that specifically exclude the construction of recharge facilities, there are a number of sensitive environmental issues that would most likely have to be considered during the MEPA review and permitting process including:

    - proximity of water supplies;
    - proximity of groundwater contamination that could be impacted by mounding; and
    - proximity of a Natural Heritage Priority Site which is designated because of the pond habitats located in the central portion of the Airport. Impacts to water levels in those ponds could impact the protected species.

12. Groundwater is relatively close to the surface (15 to 20 feet), which could limit discharge rates.

To summarize, the Airport has the potential to be an ideal site to discharge treated effluent. There would be restrictions related to location and construction activities but it

appears those could be managed. Soil type, topography, distance from sensitive receiving waters, and proximity to the WPCF all contribute to this conclusion.

If the Town elects to pursue the Airport as a remote discharge site, Stearns & Wheler recommends the following course of action.

- Develop a conceptual design of a disposal facility in terms of type and size.
- Meet with FAA and Airport to discuss the feasibility of constructing such facilities and what restrictions or limitations would have to be considered, and to discuss incorporating the Town's plans into the Airport's redevelopment plans.
- Based on further discussions with USGS, consider obtaining refined hydraulic conductivity data by completing a pumping test at the site.
- Refine the facility design based on flow rates and Airport and FAA limitations.
- Incorporate the Airport site into the Facilities Plan MEPA/EIR process concurrently with pursuing a Groundwater Discharge Permit for the site.

Please call with any questions or comments.

Very truly yours,

STEARNS & WHELER, LLC

T. Lawrence Hineline, CPG
Associate

J. Gage Muckleroy, P.E.
Associate

/tlh

Attachments

cc: Robert Butterworth, P.E., DEE

Tables

Table 1
Groundwater Travel Time From Discharge Sites to Supply Wells
Airport Evaluation - Effluent Mitigation Investigation Project
Town of Barnstable, Massachusetts

Public Supply Well	Area A		Area B		Area C	
	Distance (ft)	Travel time in years	Distance (ft)	Travel time in years	Distance (ft)	Travel time in years
BW Air 1	1750	3	2750	5	3375	7
Mary Dunn 1	3125	6	3125	6	3875	8
Maher 1	2250	4	5000	10	6250	12

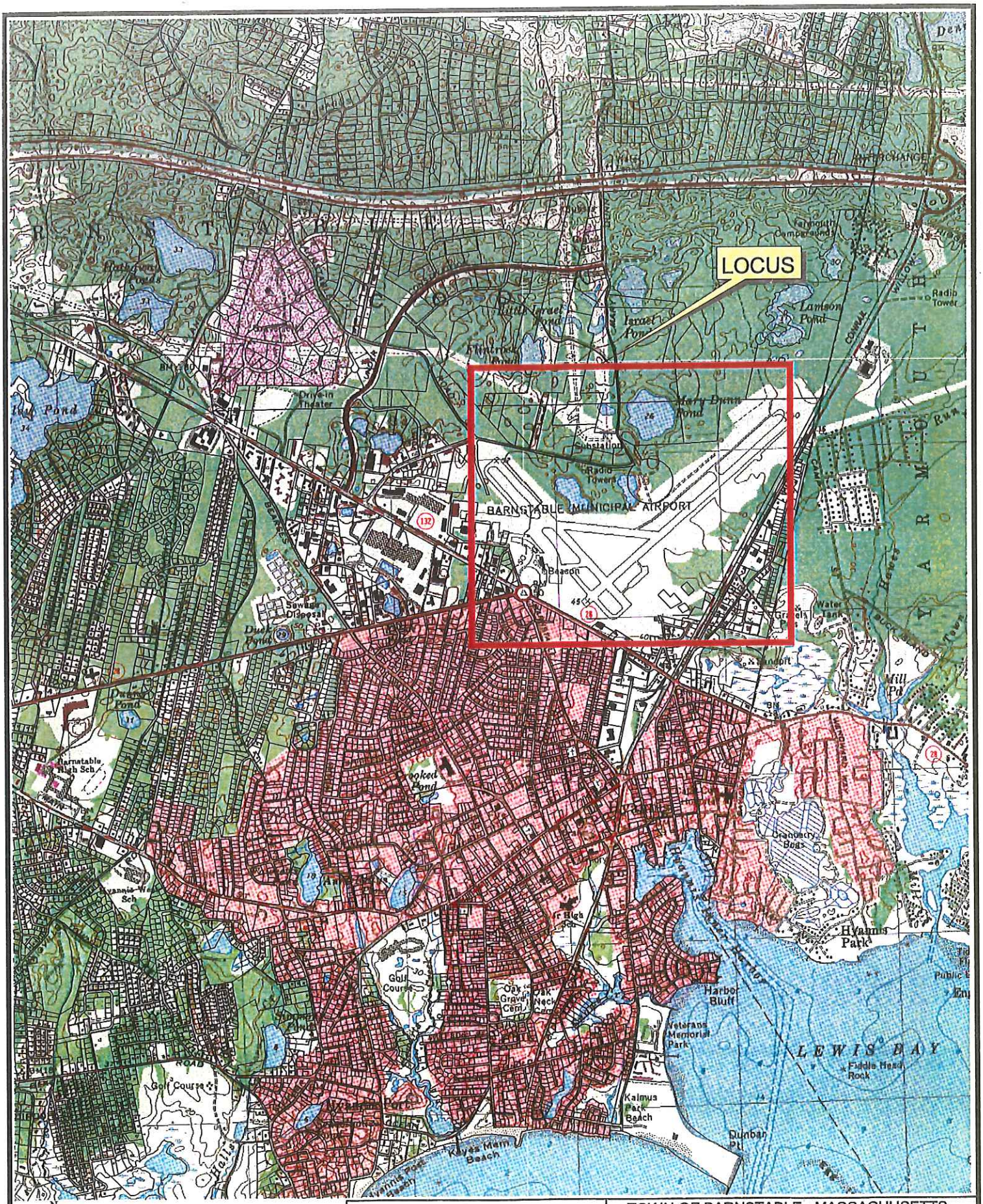
(*Hydraulic Conductivity is 200 feet /day)

Table 2
Mounding Impacts of Groundwater Recharge
Airport Evaluation - Effluent Mitigation Project
Town of Barnstable, Massachusetts

Run	Flow (MGD)	Area (1) (acres)	Hydraulic Conductivity (ft/day)	Mound (ft)	Resultant Depth to Water (2)	Resultant Depth to Water Inc. Max High Factor (3)
1	0.5	2	200	2.0	13.00	9.00
2	1	5	200	4.0	11.00	7.00
3	2	9	200	7.0	8.00	4.00

(1) Area based on discharge of 5 gpd per square foot
(2) Based on background depth to water of 15 feet
(3) Based on 4 foot Frimpter-Belfit adjustment

Figures


LOCUS
BARNSTABLE MUNICIPAL AIRPORT
Drive-In Theater
Mary Dunn Pond
Lamson Pond
Israel Pond
Little Israel Pond
Hathaway Ponds
Duck Pond
Dowse Pond
Hooked Pond
Cranberry Bogs
Hyannis Park
Harbor Bluff
Veterans Memorial Park
LEWIS BAY
Fiddle Head Rock
Kalmus Park Beach
Dunbar Pt
Keyes Main Beach
Hyannis Port Beach
Golf Course
Oak Grove Cem
Oak Neck Cem
Barnstable High Sch
Hyannis West Sch
Jr High Sch
Sewage Disposal
Water Tank
Gravel Pits
Radio Tower
Substation
Beacon
Radio Tower
Falmouth Campground
Mill Pd
Mill Pond
Red Lily Pond
Middle Pond
Long Pond
Wequaquet Lake
Bumps River
Centerville River
Hayes Creek
Marstons Mills River
Santuit River
Seapit River
Bridge
Rotary
Public Landing
Public Boat Ramp
Enj
Tidal Flats
Tidal Flats
Tidal Flats

FLINT ROCK POND

BW MD#3

TP C-3

TP C-2

OW-C

AREA C

TP C-1

BW MD#2

BW MD#1

MARY DUNN POND

TP B-2

TP B-3

TP B-1

OW-B

AREA B

N

BW AIR#1

TP A-1

OW-A

TP A-3

TP A-2

AREA A

Barnstable Municipal Airport

Monitoring Well

Test Pit Location

Public Well Supply

49 Elevation Contour

Estimated Rare Species Habitat

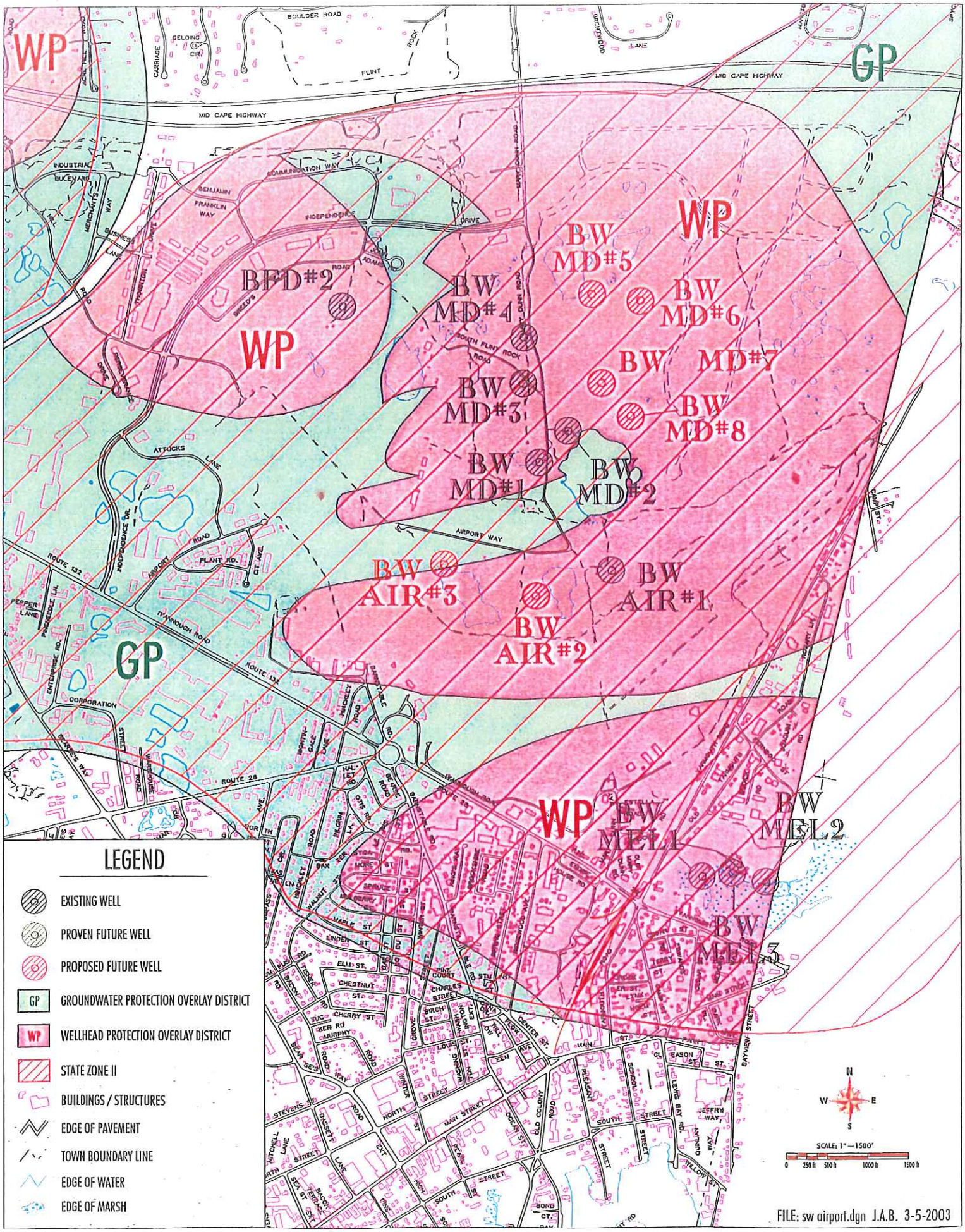
1000 0 1000 2000 Feet

Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS
JOB NO.: 20190 DATE: 4/01/03

TOWN OF BARNSTABLE, MASSACHUSETTS
EFFLUENT MITIGATION PROJECTS
FIGURE 2
AIRPORT SITE MAP

Attachment A

Groundwater Protection Areas


WP
GP
BFD#2
BW MD#1
BW MD#2
BW MD#3
BW MD#4
BW MD#5
BW MD#6
BW MD#7
BW MD#8
BW AIR#1
BW AIR#2
BW AIR#3
BW MEL1
BW MEL2
BW MEL3
BOULDER ROAD
FLINT ROCK
MID CAPE HIGHWAY
INDEPENDENCE DRIVE
ATTUCKS LANE
AIRPORT WAY
PLANT RD.
ROUTE 132
ROUTE 28
MAIN STREET
LEGEND
EXISTING WELL
PROVEN FUTURE WELL
PROPOSED FUTURE WELL
GROUNDWATER PROTECTION OVERLAY DISTRICT
WELLHEAD PROTECTION OVERLAY DISTRICT
STATE ZONE II
BUILDINGS / STRUCTURES
EDGE OF PAVEMENT
TOWN BOUNDARY LINE
EDGE OF WATER
EDGE OF MARSH
N
W
E
S
SCALE: 1" = 1500'
0 250 ft 500 ft 1000 ft 1500 ft
FILE: sw airport.dgn J.A.B. 3-5-2003

Attachment B

Sensitive Environments

MA DEP - Bureau of Waste Site Cleanup

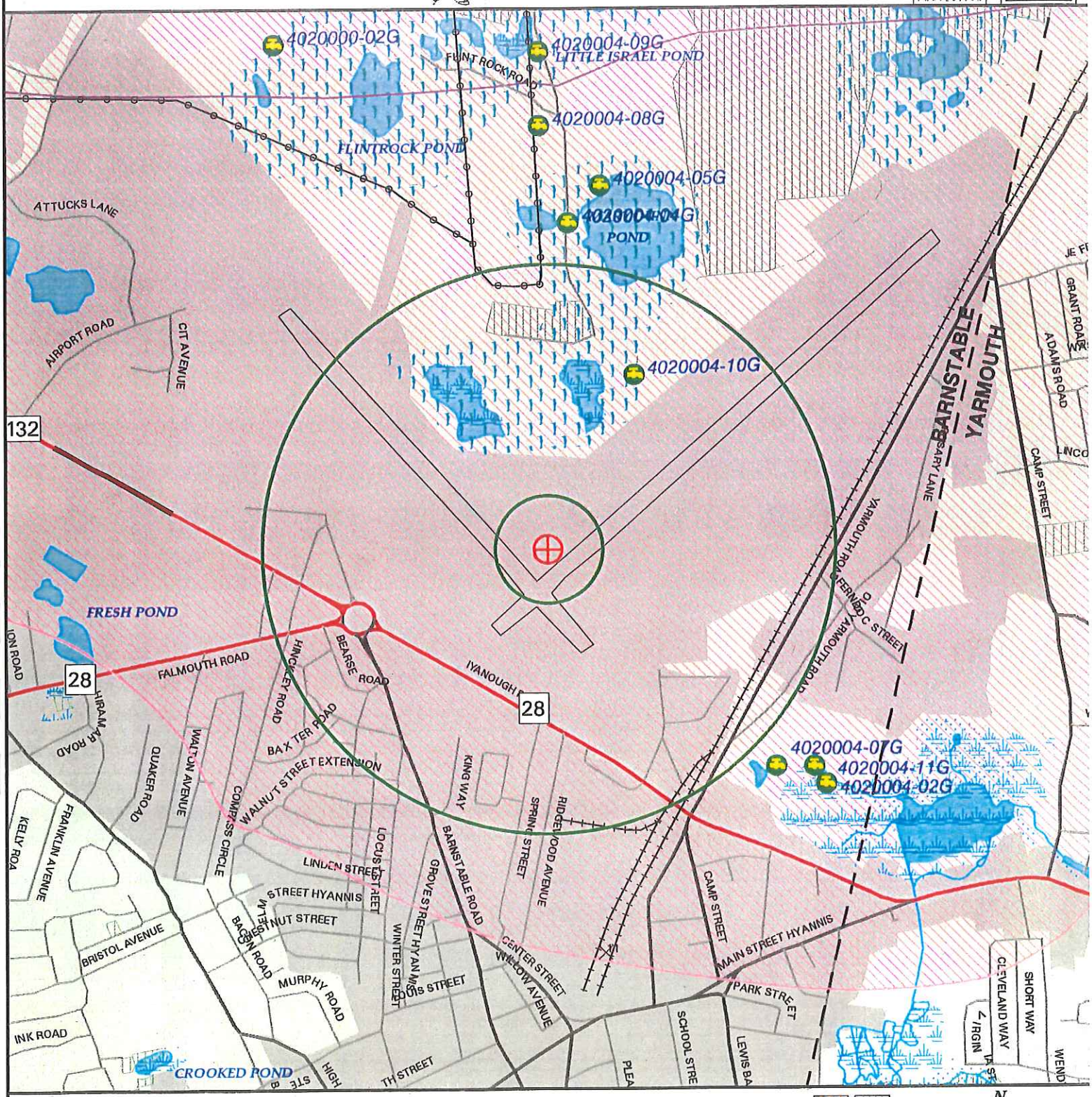
Site Scoring Map: 500 feet & 0.5 Mile Radii

SITE NAME:
Barnstable Municipal Airport
480 Barnstable Road
BARNSTABLE, MA 02601
414000n 701653ew

Site Location

The information shown on this map is the best available at the date of printing. Please refer to the data source descriptions document.

MASS GIS — Massachusetts Geographic Information System
Massachusetts Executive Office of Environmental Affairs - 2003



Roads: Limited Access, Divided, Major Road, Connector, Street, Track, Trail
Boundaries: Town, County, DEP Region; Train; Powerline; Pipeline; Aqueduct
Basins: Major, Sub; Streams: Perennial, Intermittent, Man Made Shore, Dams
Potentially Productive Aquifers: Medium,High Yield
Non-Potential Drinking Water Source Area: Medium,High Yield

EPA Sole Source Aquifer; FEMA 100-year floodplain
Public Water Supplies: Ground,Surface,Non Community
Approved Zone2; IWPA; Surface Water Supply Zone A
Hydrography: Water Features,Public Surface Water Supply
Wetlands: Fresh,Salt,NHESP Wetlands Habitat
Protected Open Space; ACEC
DEP Permitted Solid Waste Facilities; Certified Vernal Pools

N NE E SE S SW W NW

SCALE 1:15000

0 1/2 MILES
0 1/2 1 KILOMETERS

March 04, 2003

Attachment C

Excerpt From Interim Guidelines on Reclaimed Water

Type of Reuse - Indirect Aquifer Recharge - Discharges into aquifer recharge areas as defined by Zone II boundaries and groundwater discharges that will recharge reservoirs or tributaries to reservoirs. Required Treatment Level . secondary[4] . filtration (possibly)[5] . disinfection[6]	Discussion Attached
Required Reclaimed Water Quality[2] . pH 6 – 9 . BOD - ≤ 10 mg/l or ≤30 mg/l . ≤ 2 NTU or ≤ 5 NTU . fecal coliform – median of no detectable colonies/100 ml over continuous, running 7 day sampling periods, not to exceed 14/100 ml or 200 colonies/100 ml . TSS - 5 mg/l or 10 mg/l . Total Nitrogen - < 10 mg/l . Class I Groundwater Permit Standards (SDWA Drinking Water Standards)[10]	Required Reclaimed Water Monitoring . pH - weekly or daily . BOD - weekly . Turbidity - continuous . Fecal coliform - daily or 2/week • Metals -quarterly, TSS - weekly or 2/week . Nitrogen - 1 or 2/week • MS-2 phage - quarterly • Total culturable viruses - quarterly . Variable testing requirements 0 Disinfection UV intensity - daily or chlorine residual - daily
Comments New treatment plants located in approved Zone IIs with less than a two year groundwater travel time to the public water supply well must treat to the more rigorous of the two standards listed above. Existing treatment plants that can demonstrate the four or five feet of separation and where the well has not shown any evidence of water quality degradation, may maintain the lesser standard. Massachusetts Drinking Water Program waivers reducing the required sampling of Public Water Supply Wells will not be issued if there are permitted Groundwater Discharges in the Zone II. Treatment plants that meet the criteria listed above are considered to be improvements over unsewered Title 5 systems as it pertains to SDWA Susceptibility Assessments.	

Attachment D

Test Pit Logs

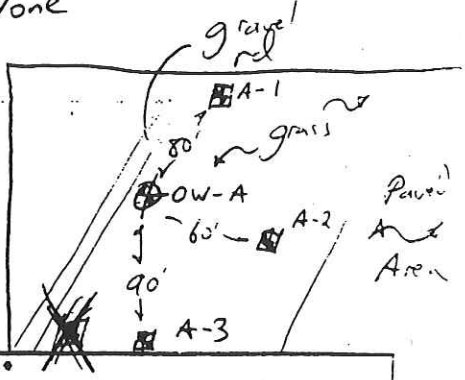
FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number A-1 Date: 1/10/03 Time: 1:30PM Weather 30s, Sunny
Location (identify on site plan) See attached
Land Use Commercial Slope (%) 0-1% Surface Stones None
Vegetation low grass, spyic
Landform Outwash plain
Position on landscape (sketch on the back)
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	



DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
1"-0"	O	—	10YR 3/3	None	Fim, 40% gravel
0"-3"	A	loamy Sand	10YR 6/4	None	Several 1"-3" ø stones throughout layers A, C_2
3"-12"	B	loamy Sand	10YR 5/4	None	
12"-26"	C_1	medium to coarse Sand	10YR 5/6	None	
26"-104"	C_2	Medium Sand	2.5Y 7/4	None	15% gravel, some stones, loose

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial outwash Depth to Bedrock: >104"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: >104"

DEP APPROVED FORM - 12/07/95

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number A-2 Date: 1/10/93 Time: 2:20PM Weather 30s, cloudy
Location (identify on site plan) See attached
Land Use Commercial Carport Slope (%) 0-1% Surface Stones None
Vegetation Lawngrass
Landform Outwash plain
Position on landscape (sketch on the back) See attached
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
1"-0"	O	—	—	None	Some small stones & gravel (~25%)
0"-4"	A	loamy Sand	10YR 6/4		
4"-8"	B	loamy Sand	10YR 5/4		~5% of 1/2" ϕ stones
8"-46"	C_1	Medium Sand	10YR 5/6		loose
46"-106"	C_2	Coarse Sand	2.5Y 7/4	↓	Loose, 20% gravel, "Beach Sand"

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial outwash Depth to Bedrock: >106"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: >106"

O I P

DEP APPROVED FORM - 12/07/95

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number A-3 Date: 1/10/03 Time: 2:45PM Weather 30s, cloudy
Location (identify on site plan) See attached
Land Use Commercial (airport) Slope (%) 1-3% Surface Stones None
Vegetation Low grass, sparse
Landform Outwash plain
Position on landscape (sketch on the back) See attached.
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
6"-0"	(Fill)	—	—	None	Looks like fill - bottom of horizon marked by dense dark black line
0"-8"	B	Loamy Sand	10YR 6/4	None	25% stones, 1"-2" ø
8"-24"	C_1	Medium Sand	10YR 5/6	None	30% gravel (fine gravel)
24"-100"	C_2	Coarse Sand	2.5Y 7/4	(?) Large pocket of black matter at 80" with 5% mottles below	No stones or gravel, loose

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial Outwash Depth to Bedrock: >100"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: >100"

DEP APPROVED FORM - 12/07/95

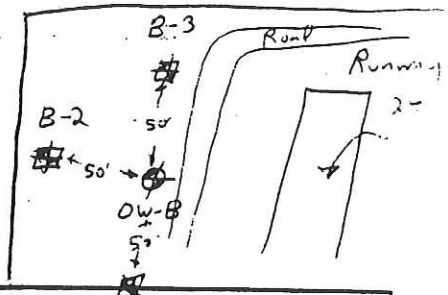
FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number B-1 Date: 1/10/03 Time: 11:35AM Weather 40s, prtly cldy
Location (identify on site plan) see attached
Land Use Commercial (Airport) Slope (%) 0-2 Surface Stones None
Vegetation low grass, peat moss
Landform Outwash plain
Position on landscape (sketch on the back)
Distances from:

Open Water Body ~~300~~	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	



DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
2"-0"	O	Sandy Loam	10YR 3/6	None	Roots, no gravel or stones
0"-4"	A	Sandy Loam	10YR 4/6	None	0-5% gravel, some loose 1/2" stone
4"-8"	B	Medium to Coarse sand	7.5YR 4/6	~~common~~ None	5%-10% gravel, 1/4" ϕ Loose
8"-46"	C_1	Medium Sand	2.5Y 6/4	14"-16" (5%-10%) 5YR 4/6	5% stones ~1" ϕ Loose
46"-120"	C_2	Coarse Sand	10YR 5/6	None	0-2% gravel, 0-2% 1/2" ϕ stone, no large stones
For 120"-122"	C_3	Coarse Sand	2.5Y 6/4	None	No gravel, stones, Loose

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial outwash Depth to Bedrock: >122"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: >122"

DEP

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number B-2 Date: 1/10/03 Time: 12:30PM Weather 40s, partly cldy
Location (identify on site plan) See attached
Land Use Commercial Slope (%) 0-2% Surface Stones None
Vegetation Lowgrass, moss
Landform Outwash plain
Position on landscape (sketch on the back)
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
2"-0"	O	Sandy Loam	10YR 4/6	None	No gravel, no stones, root system
0"-2"	A	Sandy loam	10YR 4/6	None	0-5% gravel, loose 1/2" ϕ stone
2"-8"	B	Medium Sand	7.5YR 4/6	None	loose 1/2"-1/4" ϕ gravel 5%-10%
8"-72"	C_1	Medium to Coarse Sand	10YR 5/6	48" (20%) 62" (5%) 5YR 4/6	10%-20% gravel, several 1/2" stones
72"-108"	C_2	Medium to Coarse Sand	2.5Y 7/6	None	5% gravel, some 1/2" stones loose

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial outwash Depth to Bedrock: >108"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: >108"

DEP APPROVED FORM - 12/07/95

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number B-3 Date: 1/10/03 Time: 12:45PM Weather 40s, partly cldy
Location (identify on site plan) See attached
Land Use Commercial Slope (%) 0-2% Surface Stones None
Vegetation low grass
Landform Outwash plain
Position on landscape (sketch on the back) See attached
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
0"-2"	A	Sandy Loam	10YR 4/6	None	Some small gravel loose.
2"-14"	B	Medium Sand	7.5YR 4/6	None	5% gravel
14"-54"	C_1	Coarse Sand	10YR 5/6	None	Several small, 1/2" stones (10%), loose
54"-120"	C_2	Medium & Coarse Sand	2.5Y 7/6	60" (10%) 5YR 4/6	Loox, (5%) 1/2" stones, minim. gravel.

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial Outwash Depth to Bedrock: >120"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: >120"

DEP APPROVED FORM - 12/07/95

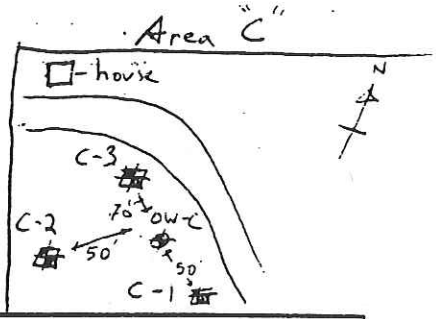
FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number C-1 Date: 1/10/03 Time: 8:45 AM Weather 40s, cloudy
Location (identify on site plan) (See attached)
Land Use Commercial (Airport) Slope (%) 0-2 Surface Stones None
Vegetation Low sparse grass, peat
Landform Outwash plain
Position on landscape (sketch on the back) ~~N/A~~ (See attached)
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	



DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
0"-4"	A_p	Sandy Loam	10YR 3/3	None	Loose, 0% gravel or stones
4"-28"	B*	Medium Sand	10YR 5/4	None	Loose, 0% gravel
28"-100"	C_1	Medium and coarse Sand	10YR 5/6	(28"-32" 80%) (33"-100" 0-2%) 5YR 4/6	20% gravel, some stones 1/4", 2% stones 4"-6" ø
100"-104"	C_2	Medium and coarse Sand	2.5Y 7/4	None	No stones or gravel, loose sand

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial Outwash Depth to Bedrock: ~~>104"~~ >104"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: None
Estimated Seasonal High Ground Water: ~~>104"~~ >104"

DEP APPROVED FORM - 12/07/95

*Note: A thin (2") band of dark material resembling buried material observed in "B" horizon. Possible indication of former grade, and possible that A and B were fill on top during airport construction.

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number C-2 Date: 1/10/03 Time: 9:45 AM Weather 40s, cloudy
Location (identify on site plan) See attached
Land Use Commercial Slope (%) 0-4 Surface Stones Minimal
Vegetation Low grass (thin), moss
Landform Outwash plain
Position on landscape (sketch on the back) See attached
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
1"-0"	O	Loam	10YR 3/3	None	Firm, no stones
0"-2"	A or Ap	Loam	10YR 3/3	None	Firm, no stones
2"-28"	B	Sandy Loam	10YR 6/4	24"-26" (10%) 5YR 4/6	~20% gravel with 1/2" ϕ Some 4"-6" stones (0-2%)
28"-112"	C_1	Medium Sand	7.5YR 5/8	28"-34" 60% 5YR 4/6	Band of very dark material @ 5'-7' depth. Several 1/8" ϕ gravel, minimal 4" stone
112"-114"	C_2	Coarse Sand	7.5Y 7/4	None	Minimal stones & gravel, loose

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial outwash Depth to Bedrock: >114"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: 25"-28"
Estimated Seasonal High Ground Water: >114"

Note: Upper levels of ground were saturated from recent rainfall. Seepage occured at top of dark material layer between Band C

DEP APPROVED FORM - 12/07/95

Note: No Perc test conducted at C-3

FORM 11 - SOIL EVALUATOR FORM

Location Address or Lot No. Barnstable Municipal Airport

On-site Review

Deep Hole Number C-3 Date: 1/10/03 Time: 10:05AM Weather 40s, cloudy
Location (identify on site plan) See attached
Land Use Commercial Slope (%) 0-4% Surface Stones Minimal — None
Vegetation Short grass, sparse, with peat
Landform Outwash plain
Position on landscape (sketch on the back) See attached
Distances from:

Open Water Body	feet	Drainage way	feet
Possible Wet Area	feet	Property Line	feet
Drinking Water Well	feet	Other	

DEEP OBSERVATION HOLE LOG*

Depth from Surface (Inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other (Structure, Stones, Boulders, Consistency, % Gravel)
0-3"	Ap	Sandy Loam	10YR 3/3	None	Gravel and stones
3"-24"	B	Medium Sand	10YR 6/4	None	" " "
24"-30"	O	Loam	10YR 2/1	None	Dense roots, very firm and compact
30"-36"	A	Loam	10YR 7/1	30"-32" (20%) 5YR 4/6	No stones or gravel
36"-48"	B	Fine and Med. Sand	10YR 5/6	None	5-20% stones & gravel, stones = 2'-6' ϕ
48"-106"	C	Medium to Coarse Sand	2.5Y 7/4	None	10% stones, 2"-4" ϕ

* MINIMUM OF 2 HOLES REQUIRED AT EVERY PROPOSED DISPOSAL AREA

Parent Material (geologic) Proglacial Outwash Depth to Bedrock: >106"
Depth to Groundwater: Standing Water in the Hole: None Weeping from Pit Face: Minimal, at 24"
Estimated Seasonal High Ground Water: >106"

DEP APPROVED FORM - 12/07/95

* Note: It is very likely as with TP-C2, that this site was used for depositing fill during cut and fill operations during airport construction (or other construction activity). The layer at 24"-30" appeared to be an old compacted organic layer.

Attachment E

Percolation Test Logs

FORM 12 - PERCOLATION TEST

Location Address or Lot No. Barnstable Municipal Airport

COMMONWEALTH OF MASSACHUSETTS

, Massachusetts

Percolation Test*		
Date: 1/10/03	Time: See below	
Observation Hole #	A-1	
Depth of Perc	32"	
Start Pre-soak	1:50 PM	
End Pre-soak	1:55 PM	
Time at 12"	—	
Time at 9"	—	
Time at 6"	—	
Time (9"-6")	—	
Rate Min./Inch	2 min/inch	

* Minimum of 1 percolation test must be performed in both the primary area AND reserve area.

Site Passed ☑ Site Failed ☐

Performed By: Drew Gronewold

Witnessed By: None

Comments: Preliminary Test - 25 gallons of water was added to hole in presoak, a depth of 9 inches could not be maintained.

DEP

DEP APPROVED FORM - 12/07/95

FORM 12 - PERCOLATION TEST

Location Address or Lot No. Barnstable Municipal Airport

COMMONWEALTH OF MASSACHUSETTS

, Massachusetts

Percolation Test*		
Date: 1/10/03	Time: (see below)	
Observation Hole #	C-3	B-1
Depth of Perc	48"	40"
Start Pre-soak	10:26 AM	12:10 PM
End Pre-soak	10:33 AM	12:22 PM
Time at 12"	—	—
Time at 9"	—	—
Time at 6"	—	—
Time (9"-6")	—	—
Rate Min./Inch	2 min/inch	2 min/inch

* Minimum of 1 percolation test must be performed in both the primary area AND reserve area.

Site Passed ☑ Site Failed ☐

Performed By: Drew Gronewold

Witnessed By: None

Comments: Preliminary Test - ✱ For both sites, 25 gallons of water was added during pre-soak, and a liquid depth of 9" could not be maintained

DEP

DEP APPROVED FORM - 12/07/95

Attachment F

Soil Boring Logs

Boring/Well ID:	OW-A SE Hyannis Airport

Project Name:	Barnstable Effluent Mitigation
Job. No.	20190
Start Date & Time:	1-8-03; 7:30AM
Finish Date & Time:	1-8-03; 3:00PM
Drilling Co.:	GeoLogic
Driller:	Tim (Foreman); John (laborer)
S&W Inspector:	DTP
Rig Type:	Mobile B-90
Drilling Method:	Split Spoons/ High Pressure Water
Weather:	low 30's; overcast; some flurries

Groundwater Observations	
Time:	10:00AM
Casing Depth:	
Boring Depth:	
Depth to Water:	~18-19 ft
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Two inch PVC well installed from surface to 51 feet. 10 foot, .010 slot screen from 41 to

Depth (ft)	Blow Counts (every 6")	PID (PPM)	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Groundwater
							Sample Description
0	4,5			13			Fine SAND, some SILT, trace GRAVEL; moist; yellow orange to brown color; compact
1	6,10						
2							
3							
4	24,38			14			
5	31,28						
6							
7							
8							
9	6,9			9			Medium SAND; yellowish white to tan; moist and loose
10	9,11						
11							
12							
13							
14	23,21			9			
15	24,29						
16							
17							
18					▼		
19	16,14			8			
20	11,11						
21							
22							

23							
24	14,11			8			
25	12,15						
26							
27							
28							
29	10,13			4			Fine to medium SAND; yellowish brown to tan; loose; saturated.
30	16,12						
31							
32							
33							
34	10,8			8			Medium SAND; some fine SAND; whitish to tan; saturated.
35	13,13						
36							
37							
38							
39	11,16			8			
40	15,15						
41							
42							
43							
44	12,13			15			Top 7" - Compact, orangish-brown SILT. Bottom 8" Pure light gray
45	12,10						
46							
47							
48							Medium SAND; light brown; loose; saturated. Top 1/2" gray clay (may have dropped down from above clay layer).
49	13,12			10			
50	24,29						
51							

Boring/Well ID:	OW-B NE Hyannis Airport

Project Name:	Barnstable Effluent Mitigation
Job. No.	20190
Start Date & Time:	1/9/03; 7:30AM
Finish Date & Time:	1/9/03; 2:15PM
Drilling Co.:	GeoLogic
Driller:	Tim (Foreman); John (laborer)
S&W Inspector:	DTP
Rig Type:	Mobile B-90
Drilling Method:	Split Spoons/ High Pressure Water
Weather:	lower 40's - partly cloudy

Groundwater Observations	
Time:	9:20AM
Casing Depth:	
Boring Depth:	
Depth to Water:	~19 feet
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Two inch PVC well installed from surface to 51 feet. 10 foot, .010 slot screen from 41 to

Depth (ft)	Blow Counts (every 6")	PID (PPM)	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Groundwater
							Sample Description
0	3,4			10			Medium SAND; yellowish-orange; dry; loosely compacted.
1	14,18						
2							
3							
4	12,25			14			
5	33,30						
6							
7							
8							
9	9,11			8			
10	21,19						
11							
12							
13							
14	10,12			7			Fine to medium SAND; whitish to tan in color; tightly packed; wet
15	19,29						
16							
17							
18					▼		
19	14,21			10			
20	18,22						
21							
22							

23							
24	10,15			9			Top 6" - med SAND; saturated; very tightly compacted; whitish to tan. Bottom 3" - Fine SAND; saturated; tight; whitish to tan color.
25	18,18						
26							
27							
28							
29	9,8			8			Fine SAND; saturated; loose; tan color.
30	8,8						
31							
32							
33							
34	7,8			9			
35	8,12						
36							
37							
38							
39	10,10			15			Fine SAND w/ some SILT; saturated; grayish-brown.
40	11,13						
41							
42							
43							
44	3,4			24			Soft CLAY; very wet; some SILT; light gray.
45	3,4						
46							
47							
48							
49	15,17			11			Fine SAND; little med SAND; little SILT; saturated; loose; light gray color.
50	21,21						
51							

Boring/Well ID:	OW-C NW Hyannis Airport

Project Name:	Barnstable Effluent Mitigation
Job. No.	20190
Start Date & Time:	1/6/03; 10AM
Finish Date & Time:	1/7/03; 11:30AM
Drilling Co.:	GeoLogic
Driller:	Tim (Foreman); John (laborer)
S&W Inspector:	DTP
Rig Type:	Mobile B-90
Drilling Method:	Split Spoons/ High Pressure Water
Weather:	1/6/03 - 30-deg F, overcast, snow 1/7/03 - 28-deg F, overcast, windy

Groundwater Observations	
Time:	
Casing Depth:	
Boring Depth:	
Depth to Water:	~18 feet
Below Surface:	
Below Meas. Point:	
Surface Elevation:	
Measuring Point El:	
GW Elevation:	

Two inch PVC well installed from surface to 51 feet. 10 foot, .010 slot screen from 41 to

Depth (ft)	Blow Counts (every 6")	PID (PPM)	Sample Log	Recovery (in)	Other Notes	Lithology	Other Notes Key: ▼ Depth to Groundwater
							Sample Description
0	2,9			13			
1	12,25						Medium to coarse SAND, w/ some GRAVEL; moist; loosely compacted; golden brown in color.
2							
3							
4							
5	9,22			12			
6	30,37						
7							
8							
9							
10	10,12			12			
11	11,23						
12							
13							
14							
15	13,19			16			White/yellow fine SAND; dry and loose.
16	22,19						
17					▼		
18					⏥		
19							
20	9,11			13			Medium to coarse SAND. Saturated with water; brown in color.
21	10,12						
22							

23							
24							
25	1,3			9			Fine to medium SAND; yellow/orange to tan in color; saturated and loosely compacted.
26	3,4						
27							
28							
29	8,8			8			
30	9,10						
31							
32							Fine SAND w/ bands of gravel and coarse SAND; saturated; densely packed; brown to tan in color.
33							
34	28,20			7			
35	21,25						
36							
37							
38							
39	13,14			7			Medium to coarse SAND; loosely compacted; yellowish to tan in color.
40	16,21						
41							
42							
43							
44	25,27			7			
45	25,23						
46							
47							
48							
49	24,36			4			
50	53,59						
51							

Appendix O

Benchmark Evaluation to Investigate Groundwater Mounding Downgradient of the Hyannis WPCF; February 2005

Stearns & Wheler, LLC
Environmental Engineers and Scientists

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Hyannis, MA 02601

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February 18, 2005

Mr. Mark Giordano, P.E.
Senior Project Manager
Department of Public Works
Town of Barnstable
367 Main Street
Hyannis, MA 02601

Re: Effluent Mitigation Investigation Project
Task 3 - Benchmark Evaluation
Final Letter Report

Dear Mr. Giordano:

This letter presents the findings of an evaluation to determine the next Benchmark Elevation at which potential impact due to groundwater mounding may occur at parcels in the vicinity of the Hyannis Water Pollution Control Facility (WPCF). This evaluation is a component of the Wastewater Facilities Planning (WWFP) and Environmental Impact Report (EIR) Project that the Town of Barnstable (Town) is currently completing. The primary objective of this evaluation is to determine the amount of wastewater that can be discharged at the Hyannis WPCF on a maximum monthly flow basis without causing potential flooding to structures or septic systems due to resultant groundwater mounding. In accordance with paragraph 2.2.5.2 of the Contract for Consultant Services, QA/QC procedures of the Scope of Work were adhered to in the completion of this project. In accordance with paragraph 2.2.5.4 of the Contract, Stearns & Wheler is providing five (5) bound copies, one (1) unbound copy, and one computer copy of this report.

EXECUTIVE SUMMARY

The need to evaluate effluent management alternatives in the WWFP became evident when work conducted by Geraghty & Miller (G&M) (1992, 1995) concluded that it was possible that mounding, in conjunction with naturally high groundwater occurrences,

could potentially increase groundwater in the vicinity of structures or septic systems at properties within a one-mile radius of the Hyannis WPCF. As a result of the G&M work, the first Benchmark Elevation was identified as the rising of groundwater to a depth less than eight feet below grade (G&M, April, 1995). However, our findings conclude that groundwater rising to that level did not necessarily result in the flooding of buildings nor did it produce evidence that septic systems would become inoperable. It is possible for groundwater to rise to a level less than eight feet from the surface without flooding structures or disrupting the operation of septic systems at the properties of concern.

The first Benchmark Elevation was identified in 1995 as 36.26 ft above mean sea level (msl) at a property located approximately 800 feet east of the Hyannis WPCF previously known as Nevada Bob's but now under new ownership. While under its previous ownership, the basement of Nevada Bob's was filled in with cement to mitigate flooding. Based upon the modeling work of G&M and actual observed evidence, the Town has further identified and mitigated parcels that had the potential of flooding from groundwater mounding resulting from effluent discharge at the Hyannis WPCF site. Other susceptible buildings have either been demolished or the owner's have negotiated with the Town for easements on the property to allow increased groundwater levels on the property.

The mitigated parcels include:

- Christian Center on Route 28 (easement)
- The Medieros property on Enterprise Road (easement)
- A residence on St. Francis Circle (purchase)

The goal of this evaluation was to identify the next Benchmark Elevation/Location and to identify the effluent discharge rate at the Hyannis WPCF that could substantially reduce the potential for flooding to structures or septic systems This evaluation is based on a monthly flow which is the average of daily flows during that month. The maximum month is the largest of the monthly averages for the period of record used. The maximum

monthly flow at the Hyannis WPCF usually occurs in July or August. Daily flows may be greater than the monthly flow.

It should be noted here that the discharge rate that would result in the Benchmark Elevation being exceeded is primarily based on the condition of groundwater being at its highest elevation naturally. The level of the groundwater, without any contribution from the plant flow, could result in the flooding of basements or first floors of buildings.

Previous evaluations by G&M were primarily based on theoretical modeling with limited verification based on historical groundwater elevation data. This evaluation builds upon the previous G&M work and has been further refined using groundwater elevation data that has been collected between 1992 and 2002. The historical data analysis has been used for comparison to the predictions used in the Benchmark Elevation determination process to evaluate:

- The accuracy of the Frimpter Belfit adjustment at this particular setting;
- The accuracy of the predictions made by the G&M modeling; and
- The precision of the predictions made by the G&M modeling.

The evaluation concluded that:

- An approximate 6.0 foot Frimpter Belfit adjustment is generally accurate however, this is a generalization of a range of values.
- The model is generally conservative, predicting higher groundwater elevations than actual observed conditions.
- The model is generally accurate in its predictions, with predicted water elevations generally being within 0.7 to 2.4 feet of actual conditions.



- The results of the model are not precise. The precision should be adjusted to be plus or minus six inches, therefore within a one foot range, rather than using exact values for elevation comparisons.

Although the model is reasonably accurate, many assumptions and generalizations are applied in its use. The model generally predicts the elevation of groundwater quite well. What the model cannot do is predict whether flooding of basements or first floor elevations are occurring. For example, based on the G&M model, there are several areas within a one-mile radius of the Hyannis WPCF that the model predicts flooding of basements at an effluent discharge rate of 1.0 MGD or less. However, operational history shows that during the spring of 1998, with a discharge of up to 2.0 MGD, and maximum high groundwater, that only isolated structures showed evidence of water seeping into basements. It is important to note that during this period in the area of St. Francis circle where one house had basement flooding, the Barnstable Water Company reported a water main break (north of the property) that was experiencing an estimated discharge of 0.5 MGD over an extended period of time.

Comparing observations of actual conditions during a high groundwater event to model predictions makes it reasonable to conclude that while being generally accurate, the G&M model should not be used to precisely predict when and where an impact will occur. It can be used as a predictive tool to identify potentially susceptible areas, but it cannot be used to predict the flooding of structures or causing disruptive operations of septic systems.

These conclusions lead to a recommendation that the Hyannis WPCF can continue to discharge on a maximum month basis between 2.3 and 2.5 MGD (the current maximum monthly flows). Due to natural fluctuations in the groundwater (similar to the elevations experienced in the spring of 1998), potential flooding of structures may occur. The discharge of flows greater than the current maximum monthly flows during periods of high groundwater may contribute to potential flooding of structures or septic systems. Based on historical observations and the previous mitigating efforts by the Town, this risk may be low, however, there is still a risk. The Town should develop a risk management strategy that would address potential flooding of structures during high groundwater

periods when concurrently the Hyannis WPCF is discharging greater than the current monthly maximum flows.

As a result, Stearns & Wheler recommends that the Town immediately begin the process of developing remote discharge sites to accommodate wastewater flows from: Areas of Concern identified in the WWFP (specifically Area H-1, Lake Wequaquet and the Cape Cod Community College); Chapter 40B Affordable Housing developments; and, infilling within the existing sewer service area. Based on an acceptable risk management strategy, the Town could move forward with these projects, but should not do so until a remote site (or sites) have been identified to be technically feasible and available to the Town.

It is also recommended that the Town use wells within its current groundwater monitoring program as part of an effluent discharge management system. Based on groundwater elevations, decisions could be made as to when it would be necessary to transfer flows to remote sites.

This letter report presents Stearns & Wheler's detailed evaluation and is comprised of the following sections:

- Benchmark Elevation Background
- Preliminary Evaluations
- Identification of Benchmark Elevation and Location
- Conclusions
- Recommendations
- Attachment – Detail Presentation of Project Scope – Preliminary Evaluations – Sensitivity Analysis

The information conveyed in this letter report will be integrated into the Final WWFP Report.

BENCHMARK EVALUATION BACKGROUND

Previously in the course of developing the Wastewater Facilities Plan, the Benchmark Elevation was defined as the water table elevation that could flood the basement of the former Nevada Bob's building located approximately 800 feet east of the Hyannis WPCF. The Benchmark Elevation was defined as 36.26 feet at that location, as measurable in well 92-16, located just outside of Nevada Bob's. Since that determination was made, that building's basement has been filled in. Other buildings, previously identified as potentially flooded along Enterprise Road, have been modified to mitigate this. In addition, the Town has negotiated a high water easement on the Medieros property on Corporation Road and on the Christian Center property on Route 28. The risk of flooding those properties near Enterprise Road has been eliminated through these recent effluent mitigation efforts. Therefore, other potentially flooded parcels and the maximum effluent discharge rate at the Hyannis WPCF that could contribute to the flooding during high groundwater periods needed to be identified. Susceptible areas identified are shown on Figure 1, a map of the study area.

Conclusions reached to date are based on work completed by G&M in January and April 1995. In two reports prepared at that time, G&M evaluated the aquifer capacity to accept treated effluent without bringing the water table to within 8 feet of the ground surface at the site of a basement or septic system (as located by the Town's GIS system). G&M based their conclusions on a groundwater model that was calibrated to June 1992 groundwater elevations and WPCF flow rate of 1.8 MGD.

The G&M modeling effort concluded that when groundwater was naturally at the highest elevation, the Benchmark Elevation at Nevada Bob's would be exceeded with a plant flow of 1.0 MGD. The evaluation used the Frimpter and Belfit (1992) correction to estimate maximum groundwater elevation. The Frimpter and Belfit correction was developed by the Cape Cod Commission and the USGS to assist the home building industry to determine the possible fluctuation of groundwater elevation to aid in the

design and construction of septic systems. The correction uses historical data from USGS index wells to determine the likely range of groundwater elevations. The historical data covers a range of highest to lowest historical levels. The water level of a well of interest (say well 92-16) is compared to the groundwater elevation of the nearest USGS index well on a date of interest (June 1992). We can determine where the well of concern is in its natural range of fluctuation by measuring the index well's level in its natural range of fluctuation. The G&M report concluded that from the groundwater levels at the time of model calibration, groundwater near the WPCF had the potential to rise 6.4 feet to achieve a maximum high groundwater condition.

Groundwater model runs that simulated various plant discharge rates led G&M to conclude that the Benchmark Elevation (36.26 feet at Nevada Bob's) would be exceeded at a flow rate above 1.0 MGD.

Original Benchmark Elevation calculations were based on the elevation of the former Nevada Bob's basement. The basement is no longer present, and other properties that could be potentially flooded in the Enterprise Road industrial area have been addressed. It therefore became necessary to define the next location most susceptible to flooding due to high groundwater.

The goals of the project were met through the following sequence of tasks:

A. **Determine Benchmark Location.** The properties that would be the first ones to potentially experience flooding (either in basement or first floor) or disrupting the operations of a septic system (if applicable) as groundwater elevations rise were identified.

B. **Determine Benchmark Elevation.** Once the properties were identified, the elevation at which flooding or disruption of the septic system was identified.

C. **Determine WPCF Effluent Discharge Rate at Maximum Groundwater Elevation Conditions.** Based on the G&M groundwater model maps, the maximum month flow rate at the WPCF that results in the Benchmark Elevation being exceeded was determined.

D. **Determine Critical Groundwater Elevation at WPCF.** Using existing mapping data, a critical groundwater elevation at a WPCF well, that would indicate that the Benchmark Elevation is potentially going to be exceeded, was determined.

PRELIMINARY EVALUATIONS

Prior to identifying the Benchmark Location and Elevation and the corresponding WPCF maximum monthly effluent discharge rate, a number of preliminary evaluations were conducted to verify the applicability of the methods and associated assumptions used. Detailed descriptions of the preliminary evaluations are provided as an attachment to this letter and are summarized below.The preliminary evaluations included:

- Confirming the accuracy of Frimpter adjustment – A comparison of actual high groundwater conditions (observed in 1998) to Frimpter predictions, and a statistical analysis of groundwater elevations using available historical data both demonstrated that a Frimpter adjustment to the 1992 water levels of approximately 6 feet was generally met.

- Confirming the accuracy of G&M predictions – G&M model projections were compared to actual groundwater levels at modeled conditions that were met in 2002. The comparison revealed that the predictive capabilities of the model are generally accurate but that the original calibration of the model was approximately one foot high so predicted levels are generally one foot high.

- Evaluating the precision of collected data – This evaluation concluded that the model is generally accurate but that it is not very precise. A number of generalizations and assumptions are inherent in modeling. Although the models are precise enough to be used as a general planning tool, they cannot be considered so precise that they can define a precise "Benchmark Elevation" upon which definitive engineering decisions can be made. Predicted elevations ranged from 0.4 to 2.7 feet above observed levels. Based on this conclusion the benchmark determination was to be conducted using groundwater elevations within a precision of +/- 0.5 feet.

- Completing a sensitivity analysis – This evaluation was completed using a representative number of potentially impacted locations to test various model scenarios including: (1) evaluating data precision and rounding, (2) refining the accuracy of the model by lowering the model predictions by one foot, (3) considering a reduced maximum high water level adjustment and changing depth of when a basement would flood from 8 feet to 7 feet. Based on the sensitivity analysis, a most likely scenario was defined for completing the benchmark identification effort.

After refining the evaluation criteria, as described above, Stearns & Wheler proceeded with a process for identifying the Benchmark Elevation.

IDENTIFICATION OF BENCHMARK ELEVATION AND LOCATION

Following the sensitivity analysis, Stearns & Wheler completed the evaluation by determining which property would be the first to be flooded or whose septic system operation may be disrupted as groundwater elevation increased. The evaluation was completed using the parameters defined in the proceeding section and the G&M modeling results presented in their April 1995 report. To complete the evaluation, the prior results from the 350 foot per day hydraulic conductivity runs were compared. The hydraulic conductivity of 350 feet per day was used because this value was verified by a pumping test completed at the Hyannis WPCF. Potential high groundwater impacts were defined as groundwater either (1) causing flooding, (2) flooding a basement or ground level floor (based on a basement floor being 8 feet below ground surface) or (3) coming within 8 feet

of ground surface at the site of a septic system leaching field (based on Title 5 criteria). Each of the 22 areas identified by the 1995 modeling were evaluated to determine which location would be impacted first as water levels increased as a result of modeled plant flow being added to a condition of maximum high groundwater.

The evaluation is summarized in tabular form on Table 1. The areas evaluated on Table 1 are shown on the attached Figure 1. Figure 1 shows the area in a one-mile radius around the WPCF. The drawing also shows the groundwater elevation contours for the modeled condition of the plant discharging 2.5 MGD during a maximum high groundwater condition. Also shown on the map are the 22 areas where increased groundwater elevation has the potential to exceed the bottom elevation of structures or septic systems as shown in varying shades of blue. Table 1 identifies these susceptible low areas. Each of the 22 areas were evaluated by determining the potential for groundwater to exceed the lowest elevation of a structure or septic system. On Table 1, there are two rows of data associated with each incremental plant flow rate. The upper row indicates resultant groundwater elevation at the indicated flow rate during low groundwater conditions as were observed in June 1992, the model calibration date. The lower row indicates resultant groundwater elevation at the indicated flow rate during a maximum high groundwater condition. The green cells indicate that the parcel would not have structures low enough to be effected at the stated flow rate. The yellow cell indicate if one of the three criteria used in defining impacts occurs at the given flow rate during low groundwater conditions. The orange cells indicate where impact occurs at the given flow rate during maximum high groundwater conditions.

The evaluation indicates that there are seven areas where predicted groundwater elevations exceed elevations that could result in either potential flooding or disrupting the operation of an existing septic system during the discharge of 1.0 MGD or less during maximum high groundwater conditions. These seven areas include:

Area G&M Study Designation	Description	No. of Potentially Impacted Parcels
2	Dunns Pond	20 houses
3	Lincoln & Arrowhead	10 houses
5	St Francis Circle	8 houses
7	Hampshire Avenue	2 houses
9	Crooked Pond	Schoolyard flooding
8	Hambden Circle	28 houses
12	Blanchard Liquors Area	Comm. property flooding

Because of the number of properties, a single benchmark location and elevation is not identified. Based on the model, potential flooding of buildings or disruption of septic system operations at these parcels may occur at a plant flow rate of 1.0 MGD or less during maximum high groundwater conditions.

Following the first Benchmark Location and Elevation Identification task, the task was repeated with a modified definition of when basements may flood or when a septic system's operation may be disrupted. In the second evaluation, the definition of impact included only surface flooding and impact to basements or first floors. Potential impacts to Title 5 compliance were not considered in this evaluation with the justification that the four or five foot separation criteria established by Title 5 is conservative and that short occurrences of groundwater being within that range will not adversely affect the performance of the system. Under this evaluation the number of sites potentially impacted at 1.0 MGD and maximum high groundwater conditions is reduced from seven to three, including Dunn's Pond, a depression at Lincoln and Arrowhead and basements along Route 28 east of the WPCF.

CONCLUSIONS

- This evaluation was originally undertaken to verify certain aspects of the methods used (Frimpter adjustment, model prediction capabilities) and to update the benchmark and plant flow rate identification efforts undertaken previously by the Town. The evaluation demonstrated that the model predicts groundwater elevation reasonably accurately but that it does not necessarily predict where and when impacts occur. The treatment plant has routinely discharged between 0.9 and 2.5 MGD on a monthly basis for a number of years with virtually no documented areas where groundwater has flooded structures or disrupted septic systems being reported. Only in the spring of 1998, when groundwater reached its maximum natural elevation and the plant was discharging from 1.8 to 2.0 MGD, were impacts identified. Some flooding was detected on Corporation Drive and on Route 28 just east of the facility. One basement at St. Francis Circle was reportedly flooded. Since the spring of 1998, the Town has undertaken a number of mitigation efforts. The house at St. Francis Circle was purchased and easements have been obtained from two businesses along Corporation Drive and Route 28. The basement of Nevada Bob's, the original Benchmark Location was filled in by its owner. Other commercial buildings on Enterprise Road have reportedly been demolished or modified. These actions by the Town and others should effectively eliminate the reoccurrence of flooding of structures or disruption to septic systems.

- There are several characteristics of the model that limit its utility to precisely predict when and where flooding of a structure of disruption of septic system operations will occur, therefore effluent management planning decisions can not be made solely on the model results. These limitations include:

  - The evaluation relies on a uniform hydraulic conductivity of 350 feet per day across the entire study area. Although this is a reasonable generalization, it is, in all likelihood, an oversimplification.

  - Although average predictions are generally accurate, the differences in actual from predicted groundwater levels ranged from 0.7 to 2.4 feet. In this evaluation, a one

foot adjustment was applied to the model results, but a residual difference of up to 1.4 must still be considered.

- The Frimpter adjustment of 6.0 was considered representative, but the actual range in groundwater elevation difference between June 1992 (the model calibration date) and May 1998 (a maximum high groundwater condition) ranged from 5.2 to 7.8 feet. Additionally, the Frimpter adjustment varies with distance from the index well and distance from the coastline, meaning that a single average number is not precise.

To summarize, although the model is a representative tool, it cannot be considered so precise that major engineering and planning decisions can reasonably be made on the prediction of potential flooding of structures or disruption to septic systems. Impacts have been defined based on water level fluctuations of no more than a foot or two, but fluctuations of that magnitude are well within the inherent errors in the model.

- The Hyannis WPCF has operated at rates ranging from 0 to 0.9 to approximately 2.5 MGD on a monthly flow basis over the past 15 years. Only once in that time period (spring 1998) was there documented flooding of structures or disruption to septic systems resulting from high groundwater. Actual groundwater level data and the statistical evaluation conducted corroborate the conclusion that maximum high groundwater reoccurs every 20 to 25 years. The infrequency of the potential impacts should be regarded when considering effluent management planning.

RECOMMENDATIONS

Stearns & Wheler recommends that the Town base its effluent management plans on criteria other than a specific defined Benchmark Elevation and the resultant limited flow rate. Specifically, observed historical conditions should be regarded in establishing the Town's effluent management strategies.

Stearns & Wheler recommends that the Town of Barnstable pursue remote discharge sites for monthly flows greater than 2.5 MGD during periods of high groundwater to



accommodate needed additional capacity. As described above, the structures that had flooding in basements in the spring of 1998 have been addressed through demolition, basement filling, direct purchase or acquisition of easements. These actions have reduced the potential for flooding to occur or have eliminated the Town's liability for flooding that might occur at these properties. Given the limitations of the model discussed above, it is not feasible to exactly predict at what discharge rate and at what location additional flooding might occur. The recommended monthly flow rate of 2.5 MGD is an estimate based on an understanding of the mounding and natural groundwater elevation fluctuations and the mitigation efforts taken so far by the Town. If necessary, to accommodate additional flows from: Areas of Concern identified in the WWFP; Chapter 40B Affordable Housing Developments; and infilling with the existing sewer service area, the Town may proceed to add these flows, with the understanding that the risk of property flooding is increased during high groundwater periods. The Town should implement a risk management strategy that would address potential flooding of structures during high groundwater periods when the Hyannis WPCF is discharging flows greater than the current maximum monthly flows. Stearns & Wheler recommends that the Town immediately begin the process of developing remote discharge sites based on an acceptable risk management strategy. The Town could move forward with currently planned sewer extension projects, but should not initiate construction of these extensions until a remote site has been identified to be technically feasible and is available for use by the Town.

The Town should continue its groundwater elevation monitoring program and supplement it with a monthly evaluation of depth to water in potentially impacted areas so that potential impacts can be predicted.

The Town should establish a "Sentinel Well" at the WPCF. Because of the number of properties that could potentially be impacted, identifying a single benchmark location and elevation is not appropriate. Rather than establishing impact at one of these locations as the benchmark, a groundwater elevation of 36.5 at the WPCF, in monitoring well PT-300SE, feet has been determined to correlate to potential impacts at any of these properties. This elevation is presently an approximation based on the well's proximity to one of the modeled areas, Area 22, the lower parking lot at the WPCF. Well PT-300SE

would reflect a similar groundwater elevation as modeled for Area 22. Closer inspection of the area and a determination of the measuring point elevation of well PT-300SE will allow the "Critical Groundwater Elevation" at well PT-300SE to be better defined.

Upon the Town's review and approval and any subsequent revisions, the content of this letter report will be integrated into the Wastewater Facilities Plan. If you have any questions regarding the content of this letter, please call.

Very truly yours,

STEARNS & WHELER, LLC

T. Lawrence Hineline, LSP
Associate

J. Gage Muckleroy, P.E.
Associate

TLH/JGM/tac

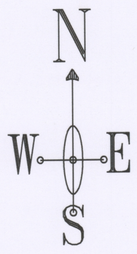
Attachments

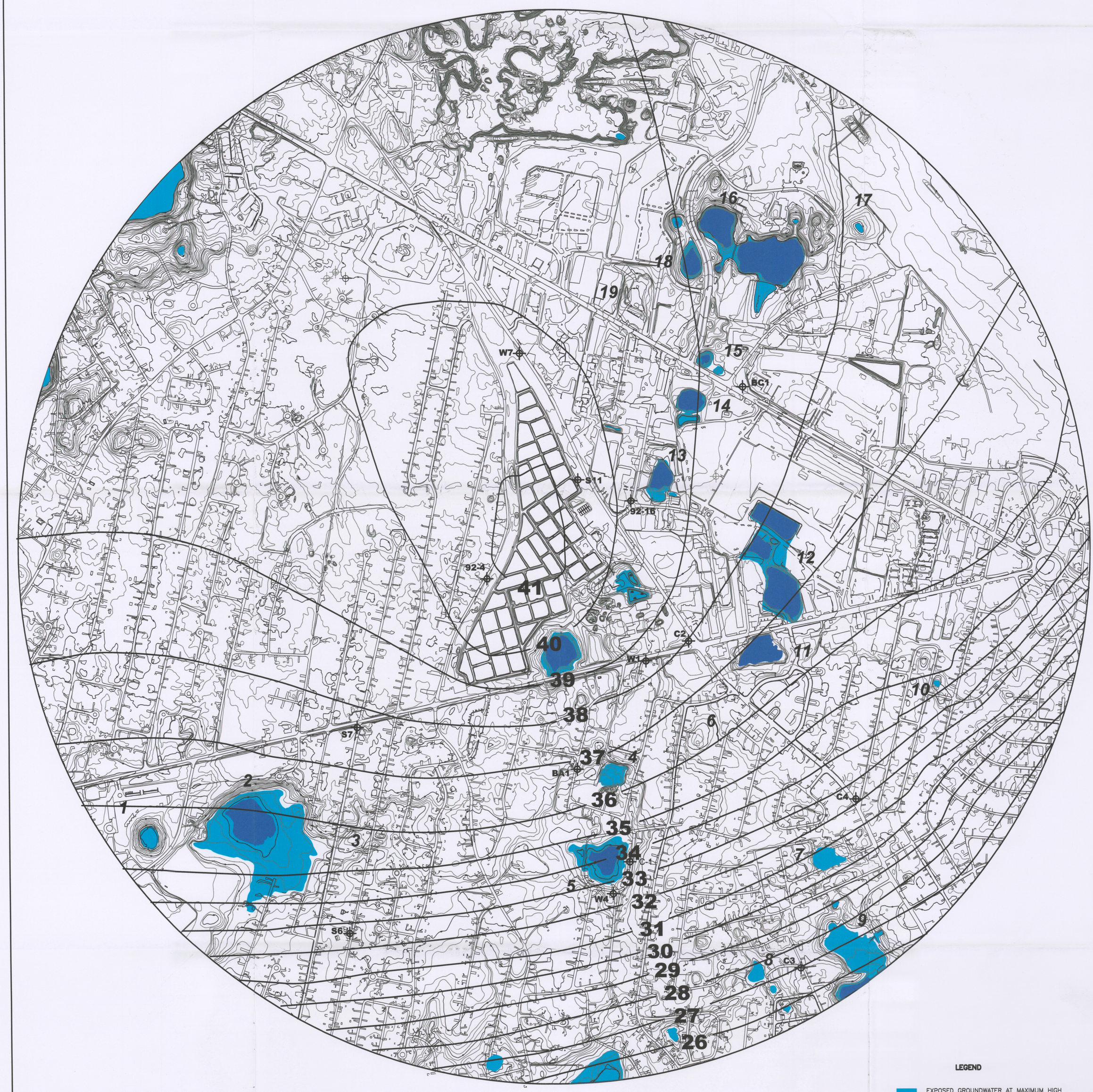
cc: Robert Butterworth, P.E., DEE

Figure 1

Areas of Potential Impact

ONE MILE RADIUS STUDY AREA AROUND BARNSTABLE WASTE WATER TREATMENT PLANT





1" = 500'

250 0 500

LEGEND

- EXPOSED GROUNDWATER AT MAXIMUM HIGH GROUNDWATER CONDITIONS AT 2.5 MGD
- EXPOSED GROUNDWATER AT 1992 CONDITIONS
- GROUNDWATER CONTOURS (2.5 MGD AND MAXIMUM HIGH GROUNDWATER CONDITIONS ASSUMED)
- 8 AREA OF POTENTIAL IMPACT
- C3 WPCF MONITORING WELLS

NOTE:
BASE MAP AND GROUNDWATER CONTOUR DATA PROVIDED BY BARNSTABLE GIS UNIT 4/14/03

Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS

DATE: 4/14/03 JOB No. 20190

TOWN OF BARNSTABLE, MASSACHUSETTS
EFFLUENT MITIGATION INVESTIGATION
BENCHMARK EVALUATION

FIGURE 1
AREAS OF POTENTIAL IMPACT

Table 1

Benchmark Identification with Basements/Surface Flooding/ Septic Systems

Table 1
Benchmark Identification
with Basements/Surface Flooding/Septic Systems
Effluent Mitigation Investigation Project
Benchmark Elevation Evaluation

Susceptible Area	G&M # 1 Small Pond West of Dunns	G&M #2 Dunns Pond	G&M #3 Depression between Lincoln and Arrowhead	G&M # 4 Alicia Road Circle	G&M # 5 Francis Circle	G&M #6 Depression Between Megan and Kelly Rd	G&M #7 Vineyard and Hampshire	G&M #8 Hambden Circle Depression - A	G&M #8 Hambden Circle Depression - B	G&M #8 Hambden Circle Depression - C	G&M #9 Crooked Pond - A	G&M #9 Crooked Pond - B	G&M #10 Depression North of Pilgrim Lane	G&M #11 Pond at Bearses and Falmouth	G&M #12 Fresh Pond, between Falmouth and Iyanough	G&M #13 Pond off Enterprise Road	G&M #14 Pond SW of Iyanough and Airport Road	G&M #15 Pond North of Iyanough and Airport Road	G&M #16 Pond between Airport Road and Independence Drive	G&M #17 Depression east of Airport (Attuck's?) Road	G&M #18 Small Pond West of Independence Drive	G&M #19 Depression North of Pineedle and Iyanough	G&M #20 Eastern shore of Lake Wequaquet	G&M #21 Pond at WPCF	G&M #22 Parking Lot at WPCF	Corresponding Elevation at WPCF Well PT-300SE
Trigger Elevation	56.0	25.0	30.0	32.2	28.0	35.0	25.0	28.0	23.7	22.1	27.0	34.0	38.5	39.0	28.0	40.0	41.3	41.3	40.1	50.2	44.3	40.0	44.0	45.1	37.1	
Sewered Site?	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	
Residential Site?	TBD	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No, school	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	
Trigger Elevation Description	Estimated floor of commercial building	Basement elevation of houses adjacent to Pond where surface elevation is 33'	Basement elevation of nearest house where ground surface elevation is 38'	Basement elevation of nearest house where ground surface elevation is 40.2	Ground surface elevation in front of houses (36') minus 8-foot reduction for septic allowance	Ground surface elevation in front of houses (43') minus 8-foot reduction for septic allowance	Ground surface elevation in front of houses (33') minus 8-foot reduction for septic allowance	Ground surface elevation in front of houses (36') minus 8-foot reduction for septic allowance	Ground surface elevation in front of houses (31.7') minus 8-foot reduction for septic allowance	Ground surface elevation in front of houses (30.1') minus 8-foot reduction for septic allowance	Flood elevation of school playing field	Ground surface elevation at houses to west of pond minus 8-foot reduction for septic allowance	Ground surface elevation in back of house (38.5') corresponds to floor of walk out basements	*Assuming a condominium, this is elevation of surface*	Ground surface elevation at houses (36') minus 8-foot reduction for septic allowance	Ground surface elevation of parking lot and building to west of pond	Low point of road (Route 132) adjacent to pond	Low point of road (Route 132) adjacent to pond	Flood elevation of parking area to south of pond	Low point on Attuck's lane adjacent to pond	Low point on Independence drive adjacent to Pond	Slab elevation of building to south of depression	Slab elevation of building on eastern shore of lake minus 8 feet for septic system	Low point in road (Route 28) to the south of pond	Elevation of low point in paved parking area at WPCF	
TOP VALUE = 6/92 conditions																										
BOTTOM VALUE = Maximum Height Groundwater conditions (including mounding from WPCF effluent)																										
1.0 MGD	26.8	26.9	26.4	26.5	24.5	26.3	21.5	19.3	18.5	17.8	19.3	17.3	24.8	26.8	28.0	29.5	29.5	29.5	29.5	28.8	29.8	30.2	32.3	29.3	29.3	-
	32.8	32.9	32.4	32.5	30.5	32.3	27.5	25.3	24.5	23.8	25.3	23.3	30.8	32.8	34.0	35.5	35.5	35.5	35.5	34.8	35.9	36.2	38.3	35.3	35.3	35.3
1.5 MGD	27.3	27.5	27.1	27.5	25.3	27.3	22.3	19.8	19.0	18.3	19.8	17.8	25.5	27.8	29.0	30.7	30.5	30.4	30.5	29.5	30.6	31.1	32.6	30.5	30.6	-
	33.3	33.5	33.1	33.5	31.3	33.3	28.3	25.8	25.0	24.3	25.8	23.8	31.5	33.8	35.0	36.7	36.5	36.4	36.5	35.5	36.6	37.1	38.6	36.5	36.6	36.6
1.8 MGD	27.5	27.8	27.5	28.0	25.5	27.8	22.5	20.0	19.3	18.5	20.0	17.8	25.8	28.5	29.8	31.4	31.2	31.0	30.9	30.0	31.2	31.6	32.8	31.5	31.5	-
	33.5	33.8	33.5	34.0	31.5	33.8	28.5	26.0	25.3	24.5	26.0	23.8	31.8	34.5	35.8	37.4	37.2	37.0	36.9	36.0	37.2	37.6	38.8	37.5	37.5	37.5
2.0 MGD	27.6	28.0	27.8	28.4	25.8	28.0	22.8	20.0	19.3	18.4	20.0	17.8	26.0	28.8	30.0	31.8	31.5	31.4	31.3	30.3	31.5	31.9	32.9	31.9	32.0	-
	33.6	34.0	33.8	34.4	31.8	34.0	28.8	26.0	25.3	24.4	26.0	23.8	32.0	34.8	36.0	37.6	37.5	37.4	37.3	36.3	37.5	37.9	38.9	37.9	38.0	38.0
2.5 MGD	28.3	28.6	28.5	29.5	26.3	29.2	23.5	20.6	19.8	19.0	20.8	18.5	27.0	29.8	31.0	32.9	32.5	32.3	32.0	31.0	32.3	32.8	33.1	33.4	33.4	-
	34.3	34.6	34.5	35.5	32.3	35.2	29.5	26.6	25.8	25.0	26.8	24.5	33.0	35.8	37.0	38.9	38.5	38.3	38.0	37.0	38.3	38.8	39.1	39.4	39.4	39.4
3.0 MGD	28.8	29.4	29.3	30.5	27.8	30.1	24.3	21.3	20.3	19.3	21.3	18.8	27.8	30.8	32.0	34.0	33.5	33.1	32.8	31.7	33.1	33.7	33.3	34.6	34.6	-
	34.8	35.4	35.3	36.5	33.8	36.1	30.3	27.3	26.3	25.3	27.3	24.8	33.8	36.8	38.0	40.0	39.5	39.1	38.8	37.7	39.1	39.7	39.3	40.6	40.6	40.6
3.5 MGD	29.3	30.0	29.9	31.4	28.3	31.0	24.6	21.5	20.5	19.5	21.8	19.0	28.5	31.8	33.0	35.2	34.4	34.1	33.5	32.4	33.8	34.6	33.6	36.0	36.0	-
	35.3	36.0	35.9	37.4	34.3	37.0	30.6	27.5	26.5	25.5	27.8	25.0	34.5	37.8	39.0	41.2	40.4	40.1	39.5	38.4	39.8	40.6	39.6	42.0	42.0	42.0
4.0 MGD	29.6	30.5	30.5	32.3	28.8	31.9	25.3	22.0	21.0	20.0	22.0	19.3	29.1	32.5	33.8	36.3	35.3	34.9	34.3	33.1	34.7	35.4	34.0	37.3	37.3	-
	35.6	36.5	36.5	38.3	34.8	37.9	31.3	28.0	27.0	26.0	28.0	25.3	35.1	38.5	39.8	42.3	41.3	40.9	40.3	39.1	40.7	41.4	40.0	43.3	43.3	43.3
4.2 MGD	29.9	30.8	30.9	32.8	29.3	32.3	25.5	22.0	21.0	20.0	22.3	19.8	29.5	33.0	34.3	36.6	35.8	35.3	34.6	33.4	35.0	35.8	34.0	37.8	37.8	-
	35.9	36.8	36.9	38.8	35.3	38.3	31.5	28.0	27.0	26.0	28.3	25.8	35.5	39.0	40.3	42.6	41.8	41.3	40.6	39.4	41.0	41.8	40.0	43.8	43.8	43.8
5.0 MGD	30.6	31.6	32.0	34.3	30.5	33.8	26.5	23.0	22.0	20.8	23.0	20.3	30.6	34.5	35.8	38.3	37.3	36.7	35.8	34.5	36.3	37.0	34.5	39.8	39.8	-
	36.6	37.6	38.0	40.3	36.5	39.8	32.5	29.0	28.0	26.8	29.0	26.3	36.6	40.5	41.8	44.3	43.3	42.7	41.8	40.5	42.3	43.0	40.5	45.8	45.8	45.8

Trigger elevation not exceeded

Trigger elevation exceeded at designated flow rate, based on June 92 GW elevation

Trigger elevation exceeded at designated flow rate, based on Projected high groundwater level

Because data is considered accurate to +/- 0.5 feet, impact is considered to occur when trigger elevation is exceeded by one foot.

Table 2

Benchmark Identification with Basements/Surface Flooding/ Septic Systems

Table 2
Benchmark Identification with Surface Flooding/Basements
Benchmark Elevation Evaluation

Susceptible Area	G&M # 1	G&M #2	G&M #3	G&M # 4	G&M # 5	G&M #6	G&M #7	G&M #8	G&M #8	G&M #8	G&M #9	G&M #9	G&M #10	G&M #11	G&M #12	G&M #13	G&M #14	G&M #15	G&M #16	G&M #17	G&M #18	G&M #19	G&M #20	G&M #21	G&M #22	Corresponding Elevation at WPCF Well PT-30OSE
	Small Pond West of Dunns	Dunns Pond	Depression between Lincoln and Arrowhead	Alicia Road Circle	Francis Circle	Depression Between Megan and Kelly Rd	Vineyard and Hampshire	Hambden Circle Depression - A	Hambden Circle Depression - B	Hambdn Circle Depression - C	Crooked Pond - A	Crooked Pond - B	Depression North of Pilgrim Lane	Pond at Bearses and Falmouth	Fresh Pond, between Falmouth and Iyanough	Pond off Enterprise Road	Pond SW of Iyanough and Airport Road	Pond North of Iyanough and Airport Road	Pond between Airport Road and Independence Drive	Depression east of Airport (Attuck's?) Road	Small Pond West of Independence Drive	Depression North of Pineedle and Iyanough	Eastern shore of Lake Wequaquet	Pond at WPCF	Parking Lot at WPCF	
Trigger Elevation	56.0	25.0	30.0	32.2	31.6	32.0	28.8	26.0	24.7	23.1	27.0	35.0	38.5	39.0	31.3	40.0	41.3	41.3	40.1	50.2	44.8	40.0	52.0	45.1	37.1	
Sewered Site?	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	
Residential Site?	TBD	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No, school	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	No	No	
Trigger Elevation Description	Estimated floor of commercial building	Basement elevation of houses adjacent to Pond where surface elevation is 33'	Basement elevation of nearest house where ground surface elevation is 38	Basement elevation of nearest house where ground surface elevation is 40.2	Surveyed basement level	Basement elevation of nearest house where ground surface elevation is 40	Surveyed basement level	Basement elevation of nearest house where ground surface elevation is 33	Basement elevation of nearest house where ground surface elevation is 31.7	Basement elevation of nearest house where ground surface elevation is 30.1	Flood elevation of school playing field	Basement elevation of nearest house where ground surface elevation is 42	Ground surface elevation in back of house (38.5') corresponds to floor of walk out basements	*Christian Center Bought access*	Basement elevation of nearest house where ground surface elevation is 38.3 (Commercial bldgs. S of 28)	Ground surface elevation of parking lot and building to west of pond (Medeiros-bought access)	Low point of road (Route 132) adjacent to pond	Low point of road (Route 132) adjacent to pond	Flood elevation of parking area to south of pond	Low point on Attuck's lane adjacent to pond	Low point on Independence drive adjacent to Pond	Slab elevation of building to south of depression	Slab elevation of building on eastern shore of lake	Low point in road (Route 28) to the south of pond	Elevation of low point in paved parking area at WPCF	
TOP VALUE = 6/92 conditions BOTTOM VALUE = Maximum Height Groundwater conditions (including mounding from WPCF effluent)																										
1.0 MGD	26.8 32.8	26.9 32.9	26.4 32.4	26.5 32.5	24.5 30.5	26.3 32.3	21.5 27.5	19.3 25.3	18.5 24.5	17.8 23.8	19.3 25.3	17.3 23.3	24.8 30.8	26.8 32.8	28.0 34.0	29.5 35.5	29.5 35.5	29.5 35.5	29.5 35.5	28.8 34.8	29.8 35.8	30.2 36.2	32.3 38.3	29.3 35.3	29.3 35.3	- 35.3
1.5 MGD	27.3 33.3	27.5 33.5	27.1 33.1	27.5 33.5	25.3 31.3	27.3 33.3	22.3 28.3	19.8 25.8	19.0 25.0	18.3 24.3	19.8 25.8	17.8 23.8	25.5 31.5	27.8 33.8	29.0 35.0	30.7 36.7	30.5 36.5	30.4 36.4	30.5 36.5	29.5 35.5	30.6 36.6	31.1 37.1	32.6 38.6	30.5 36.5	30.6 36.6	- 36.6
1.8 MGD	27.5 33.5	27.8 33.8	27.5 33.5	28.0 34.0	25.5 31.5	27.8 33.8	22.5 28.5	20.0 26.0	19.3 25.3	18.5 24.5	20.0 26.0	17.8 23.8	25.8 31.8	28.5 34.5	29.8 35.8	31.4 37.4	31.2 37.2	31.0 37.0	30.9 36.9	30.0 36.0	31.2 37.2	31.6 37.6	32.8 38.8	31.5 37.5	31.5 37.5	- 37.5
2.0 MGD	27.6 33.6	28.0 34.0	27.8 33.8	28.4 34.4	25.8 31.8	28.0 34.0	22.8 28.8	20.0 26.0	19.3 25.3	18.4 24.4	20.0 26.0	17.8 23.8	25.9 32.0	28.8 34.8	30.0 36.0	31.8 37.8	31.5 37.5	31.4 37.4	31.3 37.3	30.3 36.3	31.5 37.5	31.9 37.9	32.9 38.9	31.9 37.9	32.0 38.0	- 38.0
2.5 MGD	28.3 34.3	28.6 34.6	28.5 34.5	29.5 35.5	26.3 32.3	29.2 35.2	23.5 29.5	20.6 26.6	19.8 25.8	19.0 25.0	20.8 26.8	18.5 24.5	27.0 33.0	29.8 35.8	31.0 37.0	32.9 38.9	32.5 38.5	32.3 38.3	32.0 38.0	31.0 37.0	32.3 38.3	32.8 38.8	33.1 39.1	33.4 39.4	33.4 39.4	- 39.4
3.0 MGD	28.8 34.8	29.4 35.4	29.3 35.3	30.5 36.5	27.8 33.8	30.1 36.1	24.3 30.3	21.3 27.3	20.3 26.3	19.3 25.3	21.3 27.3	18.8 24.8	27.8 33.8	30.8 36.8	32.0 38.0	34.0 40.0	33.5 39.5	33.1 39.1	32.8 38.8	31.7 37.7	33.1 39.1	33.7 39.7	33.3 39.3	34.6 40.6	34.6 40.6	- 40.6
3.5 MGD	29.3 35.3	30.0 36.0	29.9 35.9	31.4 37.4	28.3 34.3	31.0 37.0	24.8 30.8	21.5 27.5	20.5 26.5	19.5 25.5	21.8 27.8	19.0 25.0	28.5 34.5	31.8 37.8	33.0 39.0	35.2 41.2	34.4 40.4	34.1 40.1	33.5 39.5	32.4 38.4	33.8 39.8	34.6 40.6	33.6 39.6	36.0 42.0	36.0 42.0	- 42.0
4.0 MGD	29.6 35.6	30.5 36.5	30.5 36.5	32.3 38.3	28.8 34.8	31.9 37.9	25.3 31.3	22.0 28.0	21.0 27.0	20.0 26.0	22.0 28.0	19.3 25.3	29.1 35.1	32.5 38.5	33.8 39.8	36.3 42.3	35.3 41.3	34.9 40.9	34.3 40.3	33.1 39.1	34.7 40.7	35.4 41.4	34.0 40.0	37.3 43.3	37.3 43.3	- 43.3
4.2 MGD	29.9 35.9	30.8 36.8	30.9 36.9	32.8 38.8	29.3 35.3	32.3 38.3	25.5 31.5	22.0 28.0	21.0 27.0	20.0 26.0	22.3 28.3	19.8 25.8	29.5 35.5	33.0 39.0	34.3 40.3	36.6 42.6	35.8 41.8	35.3 41.3	34.6 40.6	33.4 39.4	35.0 41.0	35.8 41.8	34.0 40.0	37.8 43.8	37.8 43.8	- 43.8
5.0 MGD	30.6 36.6	31.6 37.6	32.0 38.0	34.3 40.3	30.5 36.5	33.8 39.8	26.5 32.5	23.0 29.0	22.0 28.0	20.8 26.8	23.0 29.0	20.3 26.3	30.6 36.6	34.5 40.5	35.8 41.8	38.3 44.3	37.3 43.3	36.7 42.7	35.8 41.8	34.5 40.5	36.3 42.3	37.0 43.0	34.5 40.5	39.8 45.8	39.8 45.8	- 45.8

Trigger elevation not exceeded

Trigger elevation exceeded at designated flow rate, based on June 92 GW elevation

Trigger elevation exceeded at designated flow rate, based on Projected high groundwater level

Because data is considered accurate to +/- 0.5 feet, impact is considered to occur when trigger elevation is exceeded by one foot.

Attachment

Project Scope
Preliminary Evaluations
Sensitivity Analysis

ATTACHMENT

PROJECT SCOPE – PRELIMINARY EVALUATIONS – SENSITIVITY ANALYSIS

1.0 PROJECT SCOPE

The scope of work for this evaluation, as developed in the contract for services is presented below:

Task No.	Task Description
1.	Compile, review, and interpret existing data related to the Benchmark Elevation Evaluation. This task includes reviewing model calibration and comparing theoretical high groundwater levels with measured high groundwater levels. Additionally, this task will include compiling existing groundwater elevation data maintained by the Water Pollution Control Department (WPCD, and developing groundwater elevation contour maps on two historical dates and comparing actual conditions of water level and Water Pollution Control Facility (WPCF) flow with the modeled results. The purpose of this effort is to further validate the groundwater model upon which the benchmark evaluation is based. Meet with Town to summarize existing status of evaluation.
2.	Request Town GIS Department to create map revisions of 2.5, 2.8 and 4.0 mgd scenarios by changing the Frimpter adjustment to 6.4 feet rather than the 6 foot adjustment used previously. (Note: Groundwater elevation maps exist that show modeled water table contours based on discharge rates of 2.5, 2.8, and 4.0 mgd. Those maps also show potentially impacted parcels if a Frimpter maximum water table elevation factor is considered.) Modifications of those maps are required to continue the Benchmark Elevation Evaluation. Provide direction to GIS Department as to what changes are needed and what the final maps should show. (Revised contours, revised definition of impacted areas).

3. Identify areas where groundwater comes to within 8 feet of the surface using the revised maps and the 2.5 mgd scenario. If impact is observed at 2.5 mgd, evaluation will continue as described in Task No. 4. If no impact is observed at 2.5 mgd, other flows (2.8 and 4.0 mgd) will be evaluated until a flow rate causing impact is identified. Once the flow rate that could potentially cause impact is identified, the impacted parcels will be identified as described below.

4. Request Town GIS Department to determine whether basements or septic systems are present in the potentially impacted areas by reviewing the existing database. If septic systems are the item of concern, the likelihood and effect of sewering will be considered.

5. Identify the first parcel(s) where a basement or septic system could potentially be impacted by a rising water table.

6. Request that the Town survey the potentially impacted parcels to determine actual elevation of parcel and of impacted structure (based on known, assumed or measured depth below grade). Review survey information; determine critical groundwater elevations based on actual surveyed elevations of potentially impacted parcels.

7. Identify the following, based on results of the evaluation:

   a. Potentially impacted parcel(s)
   b. Benchmark Elevation (elevation of groundwater at the potentially impacted parcel at which point impact could occur)
   c. Plant flow rate that results in adverse impact
   d. Maximum allowable discharge from WPCF
   e. Groundwater elevation in a WPCF well that corresponds to off-site impact.

8. Prepare a draft letter report that summarizes the results of our evaluation including maps, tables, and calculations. Following review and comment by the Town, conclusions and recommendations will be integrated into the Facilities Plan.

2.0 PRELIMINARY EVALUATIONS

As part of Task 1, a number of evaluations were performed to check the accuracy of methods and assumptions used in prior benchmark evaluations. The check on accuracy was warranted at this time because several years of groundwater elevation data have been collected since G&M completed their modeling in 1992. The groundwater elevation records were used to characterize the accuracy of the model predictions as well as to verify that the Frimpter Belfit method, which was used to predict potential maximum high groundwater levels, is representative of actual groundwater elevation observations. The existing treatment plant records that were compiled, reviewed, plotted, and interpreted as part of the separate Effluent Mitigation Investigation Task 2, provided the basis for these evaluations. Reviewing this data allowed us to identify the fluctuations in groundwater elevation, observe trends, and draw conclusions related to relationships between groundwater elevation changes, precipitation and WPCF flow rates. Selected exhibits from that review are included with this report as Appendix A.

2.1 COMPLETED EVALUATIONS

A. Evaluation 1 – Confirm Accuracy of Frimpter Adjustment

The first evaluation entailed confirming the accuracy of the Frimpter adjustment that predicts maximum potential high groundwater elevation. Stearns & Wheler completed this evaluation using two methods:

- a comparison of actual high groundwater conditions (observed in 1998) to Frimpter predictions, and

- conducting a statistical analysis of groundwater elevations using available historical data from both WPCD and USGS

The first half of this evaluation was made by comparing actual high groundwater elevations to elevations that would have been predicted by adding the Frimpter-Belfit correction to June 1992 data. Groundwater elevations from June 1992 were those used by G&M to calibrate their groundwater model. Using the methods prescribed by the Frimpter Belfit method and the June 1992 data, G&M determined that the Maximum groundwater elevation would exist at an elevation 6.4 feet higher than the elevation measured in June 1992.

A review of groundwater elevation trends indicates an approximately 20 year high in May of 1998. Figure 1 shows the fluctuations in groundwater levels as recorded in USGS Index Well A1W-230 located near the Barnstable Municipal Airport (Airport). This plot shows the high water level that occurred in 1987 (approximately 20 years before the 1998 occurrence). In Index Well A1W-230, the water level in 1998 is slightly lower than in 1987, however, if index well A1W-247 is also considered, it can be seen that, at that well, the water level in 1998 was slightly higher than in 1987. The data from these two index wells and the data from the WPCD monitoring wells support the conclusion that May 1998 represents a maximum high groundwater condition. To verify the validity of the Frimpter adjustment, water levels in wells in June 1992 were compared to water elevations in wells in May 1998. There were five wells in the vicinity of the WPCF where data is available on both of those dates. The water levels from those two dates are summarized on Table A1. The average difference in water levels between the two dates is 6.04 feet. The range in difference was 5.25 feet to 7.8 feet.

This data supports the Frimpter-Belfit adjustment as an accurate predictor of what could be the maximum high groundwater elevation in the area of the WPCF. As stated above, G&M based their work on a 6.4 foot difference (although the report inexplicably references a 5.5 difference in one table). Because the available data suggests a correction of approximately 6 feet and for reasons related to precision in this evaluation (presented below) the remainder of the evaluation was completed using a Frimpter-Belfit adjustment of 6.0 feet.

The second half of this evaluation included a statistical evaluation of the Frimpter-Belfit adjustment. The water level histories for the USGS Index Wells and the WPCD monitoring wells were evaluated statistically to determine the frequency of the water levels reaching their maximum condition, as would be predicted by the Frimpter Belfit correction. The statistical evaluation culminated in assigning a water level to various return frequencies ranging from 1 year to 100 years. This evaluation is summarized on Table A2. On Table A2, each column represents one of the WPCD monitoring wells or one of the USGS Index wells. The right column indicates return frequencies and the values under each well heading are the groundwater elevations that are achieved at the frequency indicated. The blue colored cells indicate the groundwater elevations seen in May 1998, the likely maximum high groundwater elevation. The green cells represent the 25 year return frequency. The evaluation indicates that the Frimpter-Belfit adjustment roughly correlates to a 25 year high water event this is generally consistent with the observation made in this study that high groundwater events occurred about 20 years apart.

B. Evaluation 2 – Confirm Accuracy of Geraghty & Miller Predictions

The second evaluation entailed an evaluation of the accuracy of the predictions of the G&M model. This evaluation could not be made at the time the model was developed, because there was no future data to which the model predictions could be compared. The model had been calibrated to a single point in time, June 1992. The accuracy of its predictions could not be evaluated until future data was accumulated. There is approximately 10 years of data available since the model was calibrated.

To complete this evaluation Stearns & Wheler compared a predicted scenario of the model (WPCF flow of 2.5 mgd during a low groundwater period comparable to that present when the model was calibrated in 1992.) That situation was found to exist in July 2002. In July 2002, background groundwater elevations were comparable to those in June 1992. Also in June 2002 the WPCF was operating at a rate of approximately 2.5 mgd, a condition predicted by the model.

Table A3 compares modeled groundwater elevations for a low groundwater-2.5 mgd condition to actual low groundwater-2.5 mgd conditions experienced in July 2002. On this table the third column represents the difference between the modeled water level and the measured water level. The difference ranged from plus 0.7 feet to 1.78 feet. The average difference was 1.21 feet. In accordance with the conclusions reached while evaluating the precision of the data in the study (as discussed in the next evaluation) the difference between actual and modeled conditions is rounded to 1.0 feet. The one foot difference is not attributed to the model not predicting accurately but is attributed to the fact that the model was one foot high when calibrated. The actual predictive capabilities of the model are quite accurate when that one foot correction is considered. Based on this evaluation and a review of the G&M process and mapping in general, Stearns & Wheler concluded that the G&M results are consistently, approximately 1 foot high. It was acknowledged by G&M in their original report that their calibration was completed with modeled groundwater elevation approximately 1 foot above the measured levels at the time of calibration. G&M proceeded with their modeling at this point and indicated that the 1 foot difference would make their predictions conservative, building in a margin of safety. Our benchmark evaluation proceeded incorporating a 1 foot adjustment to the modeled results obtained by G&M.

C. Evaluation 3 –Precision of Evaluation data

The third evaluation entailed looking at the precision of data. Historically the benchmark evaluation had been conducted looking at water levels within 0.01 feet to make decisions. A look at the origins of the data and the assumptions that were necessary indicated that the evaluation should not rely on data any more accurate than +/- 0.5 feet. This generalization was made after considering the following:

- The Frimpter-Belfit adjustment varies with distance from the coast. Although the method establishes broad areas where a single adjustment is prescribed, in reality the adjustment varies across those areas.

- The modeling is based on a constant hydraulic conductivity of 350 feet per day. This number is only an estimate and would vary across the model area.

- The model results can only be considered to be estimates given the inherent assumptions used in the modeling process. The precision of the model itself cannot be considered to be any more accurate that plus or minus 0.5 feet.

- There is some variability in elevation data. When comparing well elevations to surface elevation data derived from either MassGIS or Barnstable GIS, there is not always a match. In some cases the differences are several feet.

For all of these reasons, the evaluation proceeded using the premise that all predictions of groundwater elevations could be considered to be accurate within the range of plus or minus 0.5 feet.

D. **Summary**

The three preliminary evaluations culminated in the following conclusions:

- The Frimpter-Belfit adjustment of approximately 6 feet accurately predicts the potential maximum high groundwater elevation that might occur, based on June 1992 groundwater levels. *A Frimpter-Belfit adjustment of 6 feet is appropriate and was added to modeled June 1992 groundwater elevations to predict the maximum, natural, high groundwater elevation in the study area.*

- The model generally predicts groundwater elevations that are one foot higher than measured groundwater elevations. This is attributed to the fact that the model was considered calibrated when it matched measured groundwater elevations of June 1992 to within approximately one foot, being approximately one foot higher than measured values. This differential was accepted by G&M as a built in degree of conservatism. Other than this initial calibration difference, the model predicts future conditions with

an acceptable degree of accuracy. *This evaluation will incorporate the consistent one foot differential into future evaluations; that is, predictions of water elevations made in this investigation were determined to be one foot lower than the G&M model result.*

- Given the many inherent inaccuracies in modeling, application of the Frimpter-Belfit adjustment and in assigning a single hydraulic conductivity value over a large area and a thick vertical section of the aquifer, a reasonable level of precision must be used in this evaluation. *A degree of precision of plus or minus 0.5 feet is appropriate and was applied the interpretations.*

3.0 EVALUATION METHOD SENSITIVITY ANALYSIS

After refining the evaluation criteria, as described above, Stearns & Wheler proceeded with a process for identifying the Benchmark Elevation. The procedure identified the groundwater elevation at the parcel where rising groundwater would cause impact. The same methods were employed that were used in earlier iterations of the Benchmark Evaluation, that is, the results of the G&M model, coupled with the adjustments in procedure identified in the previous section were used to identify where impacts might occur.

To complete this evaluation, a number of sensitivity analysis runs were completed at a select number of likely locations to see first impact. These locations included Alicia Road (Area #4), St. Francis Circle (Area #5), Branchard Liquors (Area 12) and Corporation Drive (Area 13). In the sensitivity analysis Stearns & Wheler adjusted the following parameters to determine the extent to which the results were impacted. A change in results means that impact at a particular location, as determined by the modeling, would occur at a different flow rate at the WPCF than first concluded in the 1995 evaluation.

A. Run 1 - Baseline Run

This interpretation used the G&M data exactly as presented in their 1995 report. This run served as a basis of comparison for the other runs of the sensitivity analysis. This run allowed the

determination of a WPCF flow that resulted in impact as defined in this investigation.

B. **Run 2 - Change Accuracy to +/- 0.5 Feet**

All values used in the evaluation, including depth where impact could occur and model projections were rounded to the nearest one-half foot. This change had no impact on the results for the sites being evaluated in the sensitivity analysis.

C. **Run 3 - Lower Model Results of Water Table Elevation by One Foot**

In this run, the elevation of the modeled water table was lowered one foot based in the conclusion stated above the G&M model appeared to be approximately one foot high. This change increased allowable flow from 1 mgd to 1.5 mgd before impacts occurred at St Francis Circle.

D. **Run 4 - Change Depth of Impact From 8 Feet Below Ground Surface to 7 Feet Below Ground Surface (in combination with Run 3 adjustment)**

Because the definition of impact occurring at 8 feet is a policy decision by the Town, it is possible to vary this parameter to evaluate the affects of changing it. With this change, impact at St Francis Circle occurred at an increased flow rate 2 mgd. Hampshire Ave impact occurred at a flow rate that increased from 1 mgd to 1.5 mgd.

E. **Run 5 - Change Maximum High Groundwater Adjustment (Frimpter-Belfit Adjustment) From 6 Feet to 5 Feet. (In Combination with Run 3 and Run 4 Adjustments)**

This change was based on the decision that wastewater management would not be restricted by the maximum groundwater elevation but by a more frequently occurring, but lower groundwater condition. In this run St. Francis circle impact occurred at an increased flow rate of 3 mgd, Hampshire Ave impact occurred at an increased flow rate of 2 mgd.

The results of the five sensitivity analysis runs are summarized on Table A4 and suggests that:

- Rounding the values did not change the results in these particular analyses. However, the final evaluation will be conducted using the rounded number because they are more technically defensible than using water level information accurate to 0.01 feet as was done historically.

- Lowering the water table elevations predicted by the model adds approximately 0.5 mgd to the plant flow limit before impact occurs.

- Changing the depth of impact from 8 feet to 7 feet adds approximately 0.5 mgd to the plant flow limit before impact occurs.

- Using a high groundwater level that is one foot lower than predicted by the Frimpter-Belfit method adds approximately 0.5 mgd to the plant flow limit before impact occurs.

Based on the sensitivity analysis, a most likely set of the sensitivity analysis parameters for completing the evaluation was identified. These included:

- All analysis values would be rounded to the nearest half foot

- A Frimpter-Belfit adjustment of 6 feet was applied to June 1992 groundwater elevations to define maximum high groundwater.

- Impact was defined to occur as surface flooding or reaching a depth of 8 feet below grade where either basements or septic systems are present.

Table A1
Difference Between 6/92 and 5/98 Measured Groundwater Levels
Effluent Mitigation Investigation Project
Benchmark Evaluation

Well	Measured Elevation May 1998(1)	Measured Elevation June 1992(2)	Difference
C-2	37.57	29.77	-7.8
W-1	35.95	29.15	-6.8
W-4	31.54	25.56	-5.98
A1W-230	21.6	17.21	-4.39
AIW-247	23.75	18.5	-5.25
Average Difference			-6.04

(1) Probable Maximum High Groundwater Event
(2) G&M Model Calibration Date

Table A2
Statistical Evaluation of Frimpter-Belfit Correction
Effluent Mitigation Investigation Project
Benchmark Evaluation

Return Interval (Years)	A1W-230	A1W-247	C-2	92-16	W-1	W-4	S-11	BC-1	92-4
	Airport & Mary Dunn Road		Bearses Way	Enterprise Road	Route 28	St. Francis Circle	Bearse's Way	K-Mart Mall	Pitcher's Way
100	22.73	26.94	40.62	41.39	38.81	33.48	42.09	42.39	43.86
75	22.62	26.80	40.41	41.21	38.62	33.30	41.89	42.12	43.63
50	22.47	26.61	40.10	40.95	38.33	33.05	41.60	41.73	43.30
33	22.31	26.40	39.76	40.67	38.03	32.79	41.30	41.32	42.94
25	22.20	26.26	39.53	40.47	37.82	32.60	41.09	41.03	42.70
15	21.98	25.98	39.09	40.11	37.42	32.25	40.68	40.49	42.23
10	21.81	25.75	38.72	39.80	37.08	31.96	40.35	40.03	41.84
5	21.48	25.33	38.05	39.23	36.47	31.42	39.73	39.20	41.13
2	20.99	24.71	37.04	38.39	35.56	30.62	38.81	37.96	40.06
1	20.56	24.16	36.16	37.66	34.75	29.92	38.00	36.86	39.13
June 92 Elevation	17.21	20.48	29.77		29.15	25.56			
Frimpter Adjustment (6 ft)	23.21	26.48	35.77		35.15	31.56			
Frequency	never	33 years	always		2 years	10 years			
25 year adjustment	4.99		9.76		8.67	7.04			
10 year adjustment	4.60		8.95		7.93	6.40			
100 year adjustment	5.52		10.85		9.66	7.92			
5 year adjustment	4.27		8.28		7.32	5.86			

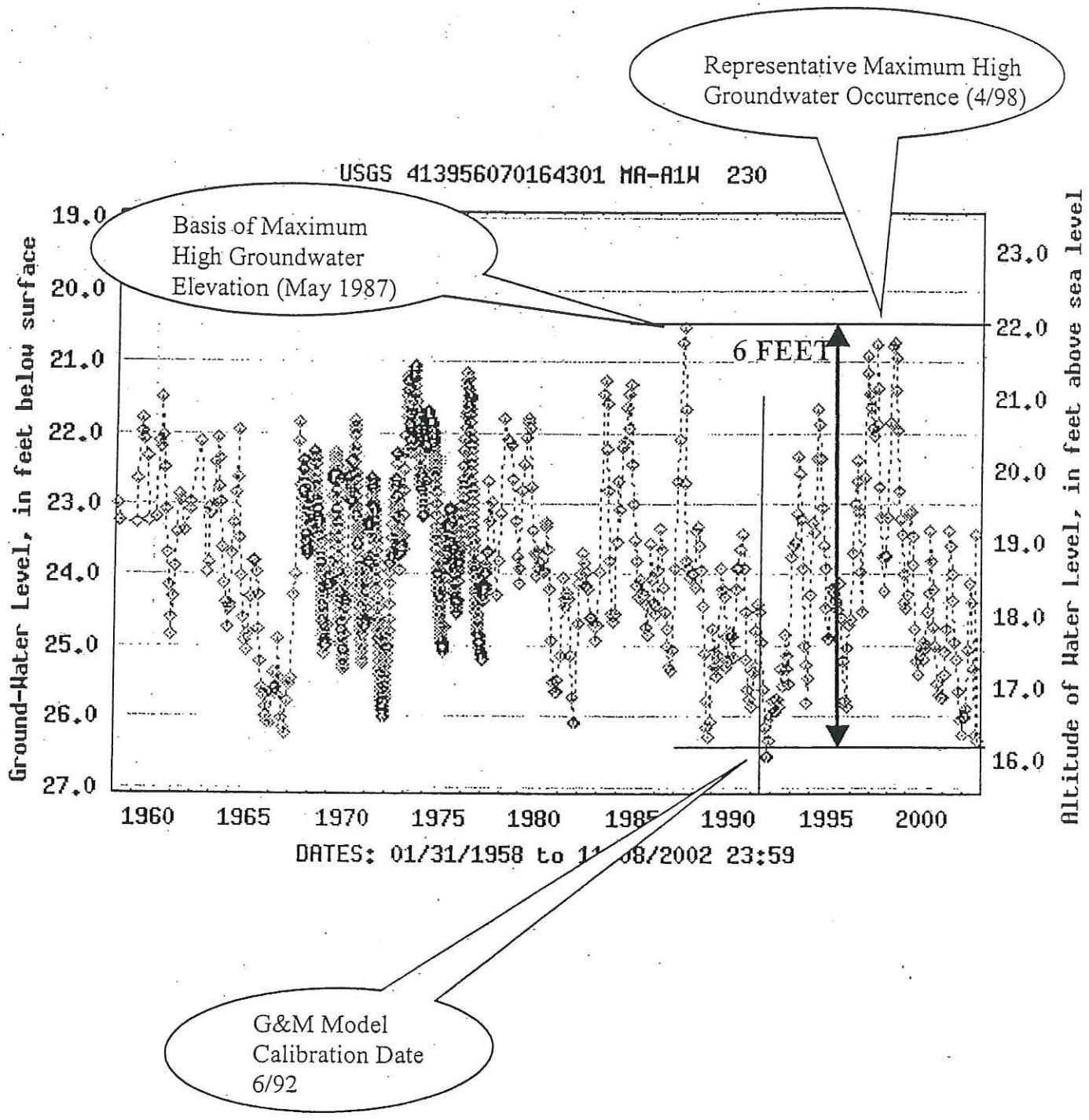
Return Interval (Years)	92-4	C-3	S-7	C-4	BA-1	BD	W-7	BB-1	BE	
	Pitcher's Way	Crooked Pond Rd.	Lincoln Rd.	Bearse's Way @ Walton Ave.	Delta Street	Pine Grove Street	Bearse's Way @ Elks	Pitcher's Way	LaFrance Avenue	
100	43.86	25.65	38.90	28.92	38.80	18.13	39.52	20.96	25.11	
75	43.63	25.53	38.77	28.79	38.44	18.04	39.39	20.88	24.95	
50	43.30	25.35	38.59	28.61	37.92	17.90	39.22	20.75	24.72	
33	42.94	25.16	38.39	28.42	37.37	17.75	39.03	20.61	24.47	
25	42.70	25.03	38.26	28.29	36.99	17.65	38.90	20.52	24.29	
15	42.23	24.79	38.00	28.03	36.27	17.45	38.65	20.34	23.96	
10	41.84	24.58	37.78	27.82	35.66	17.29	38.44	20.19	23.69	
5	41.13	24.20	37.39	27.43	34.54	16.99	38.06	19.91	23.18	
2	40.06	23.63	36.80	26.85	32.89	16.54	37.49	19.50	22.43	
1	39.13	23.14	36.28	26.34	31.43	16.15	36.99	19.14	21.76	
June 92 Elevation				23.74	20.41	14.41		17.48	18.56	
Frimpter Adjustment (6 ft)				29.74	26.41	20.41		23.48	24.56	Average
Frequency				never	always	never		never	33 years	Adjustment
25 year adjustment				4.55		3.24		3.04	5.73	5.88
10 year adjustment				4.08		2.88		2.71	5.13	5.33
100 year adjustment				5.18		3.72		3.48	6.55	6.61
5 year adjustment				3.69		2.58		2.43	4.62	4.88

Table A3
Comparison of Model to Actual Elevations
1.8 mgd to 2.5 mgd
Effluent Mitigation Investigation Project
Benchmark Evaluation

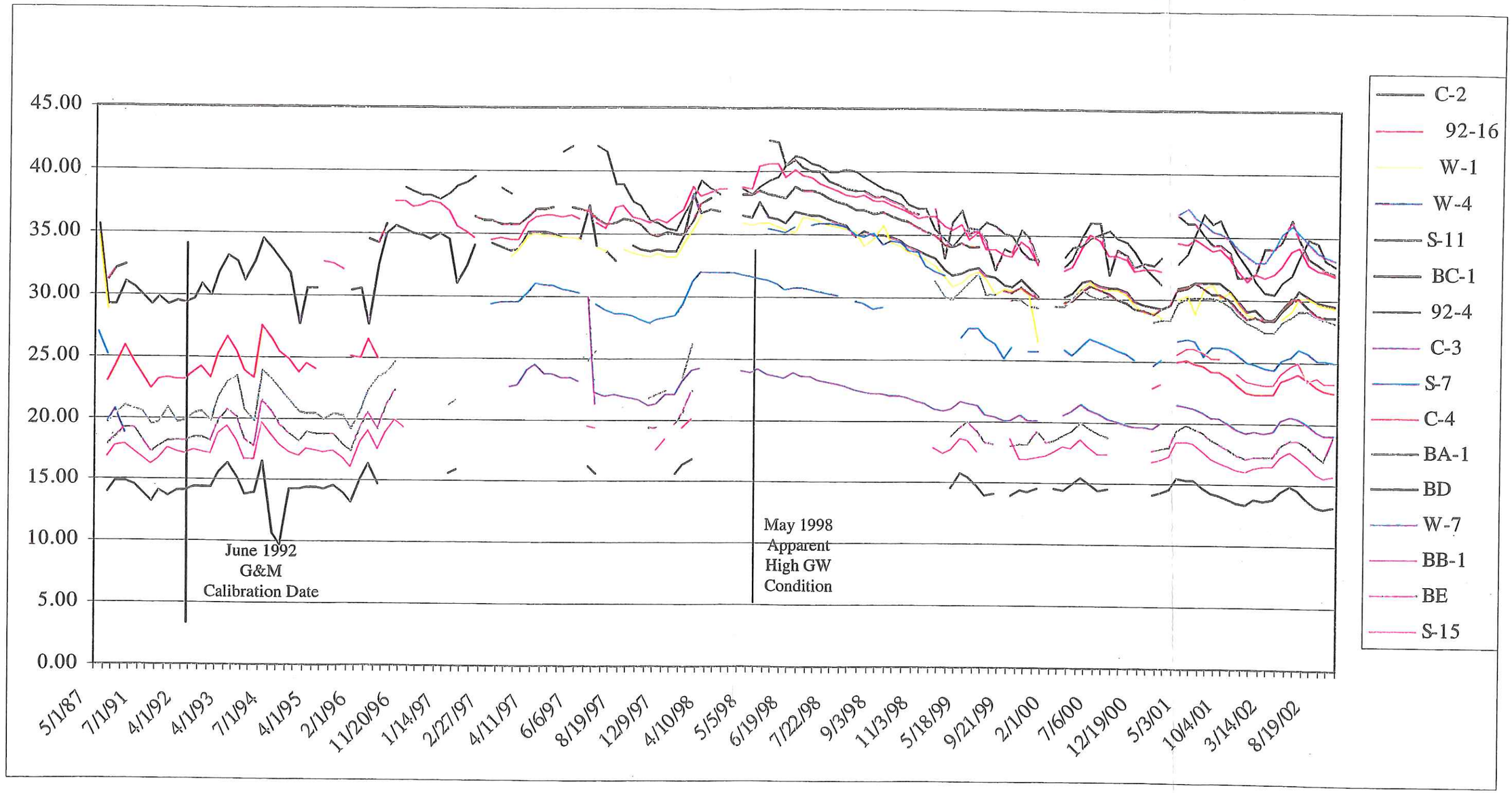
Well	Modeled Elevation 2.5 mgd	Actual Elevation 2.5 mgd	Difference
BA-1	30.9	29.12	1.78
W-4	26.5	25.8	0.7
C-4	26	23.57	2.43
C-2	32.1	30.27	1.83
92-4	35.5	34.82	0.68
92-16	34.5	32.89	1.61
Average Difference			1.51

Table A4
Flow Rate at Which Impact Occurs
Under Different Evaluation Scenarios

EVALUATION SCENARIO	Alicia Road Circle	St. Francis Circle	Vineyard/ Hampshire	Blanchard Liquors	Corporation Drive
1. ORIGINAL GM EVALUATION	NI	1	1	3.5	5
2. CHANGE ACCURACY TO +/- 6 INCHES	NI	1	1	3.5	5
3. LOWER MODEL RESULTS BY 1 FOOT	NI	1.5	1	3.5	NI
4. CHANGE DEPTH OF INFLUENCE TO 7 FT	NI	2	1.5	3.5	NI
5. CHANGE MAX HI GW CORRECTION TO 5 FT	NI	3	2	5	NI
6. MOST LIKELY (6' FRIMPTER, 8' bgs IMPACT, MODEL -1'	NI	1.5	1	4	NI



Stearns & Wheler, LLC Environmental Engineers and Scientists CAZENOVIA, NEW YORK DATE: 4/03 JOB No: 20190	TOWN OF BARNSTABLE EFFLUENT MITIGATION **FIGURE A1** **USGS INDEX WELL AIW230**

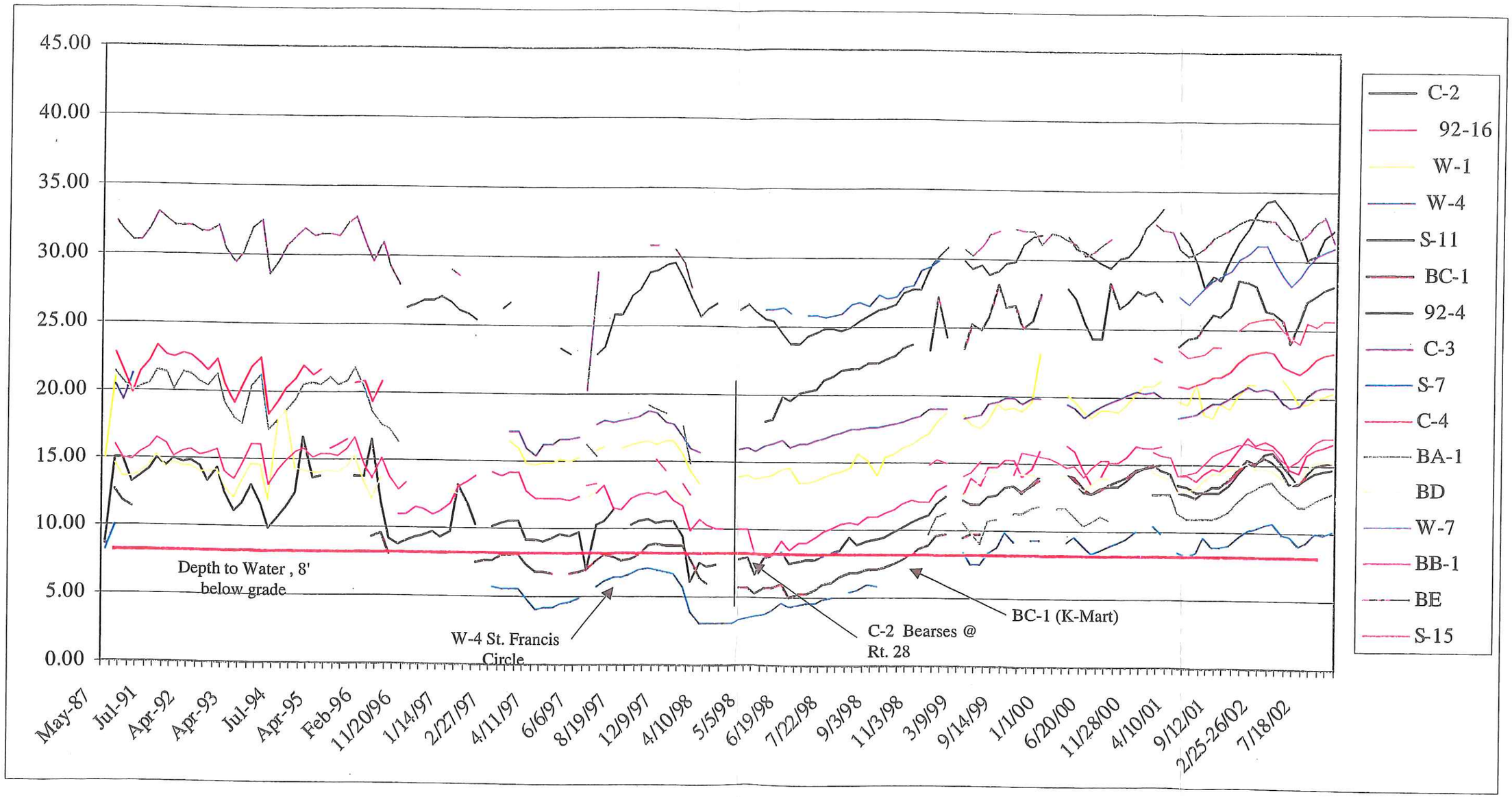


Stearns & Wheler, LLC
ENVIRONMENTAL ENGINEERS & SCIENTISTS
HYANNIS MASSACHUSETTS

DATE: 2/03 JOB No: 20190

TOWN OF BARNSTABLE
EFFLUENT MITIGATION PROJECTS

FIGURE 2
WPCD MONITORING WELL HISTORY - ELEVATION

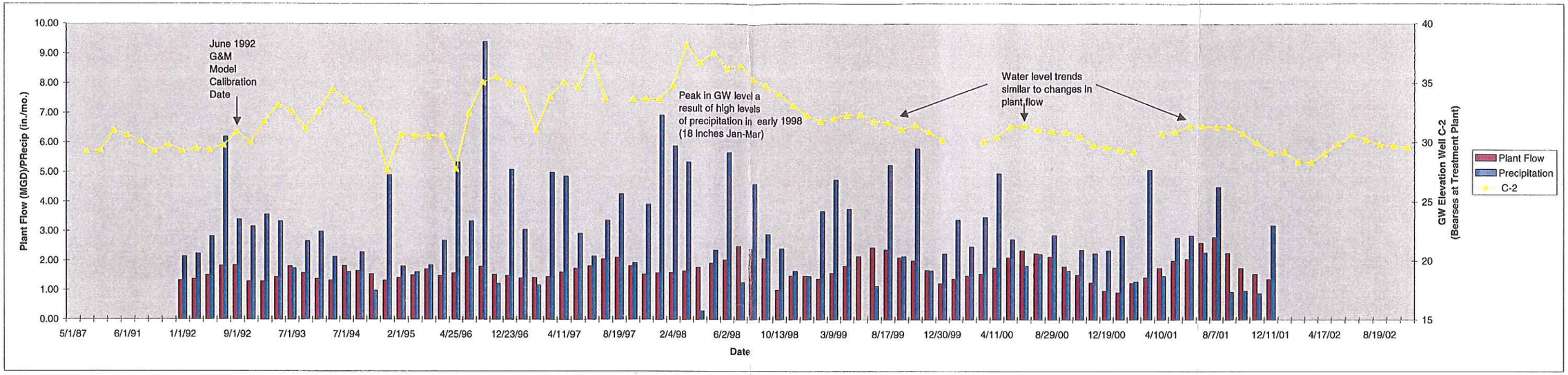


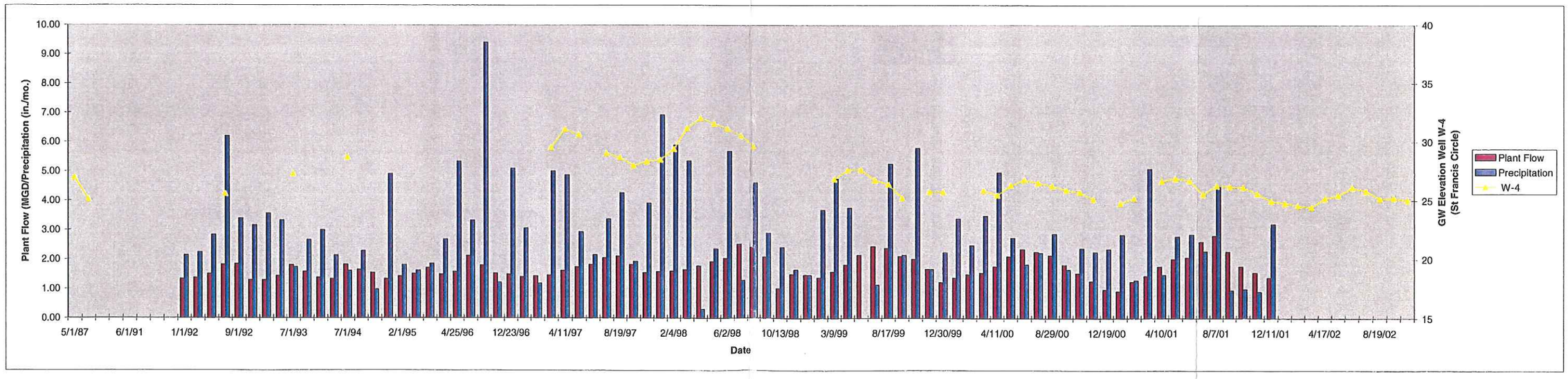
Stearns & Wheler, LLC
ENVIRONMENTAL ENGINEERS & SCIENTISTS
HYANNIS MASSACHUSETTS

DATE: 2/03 JOB No: 20190

TOWN OF BARNSTABLE
EFFLUENT MITIGATION PROJECTS

FIGURE 3
WPCD MONITORING WELL HISTORY – DEPTH TO WATER





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DATE: 2/03 JOB No: 20190

TOWN OF BARNSTABLE
EFFLUENT MITIGATION PROJECTS

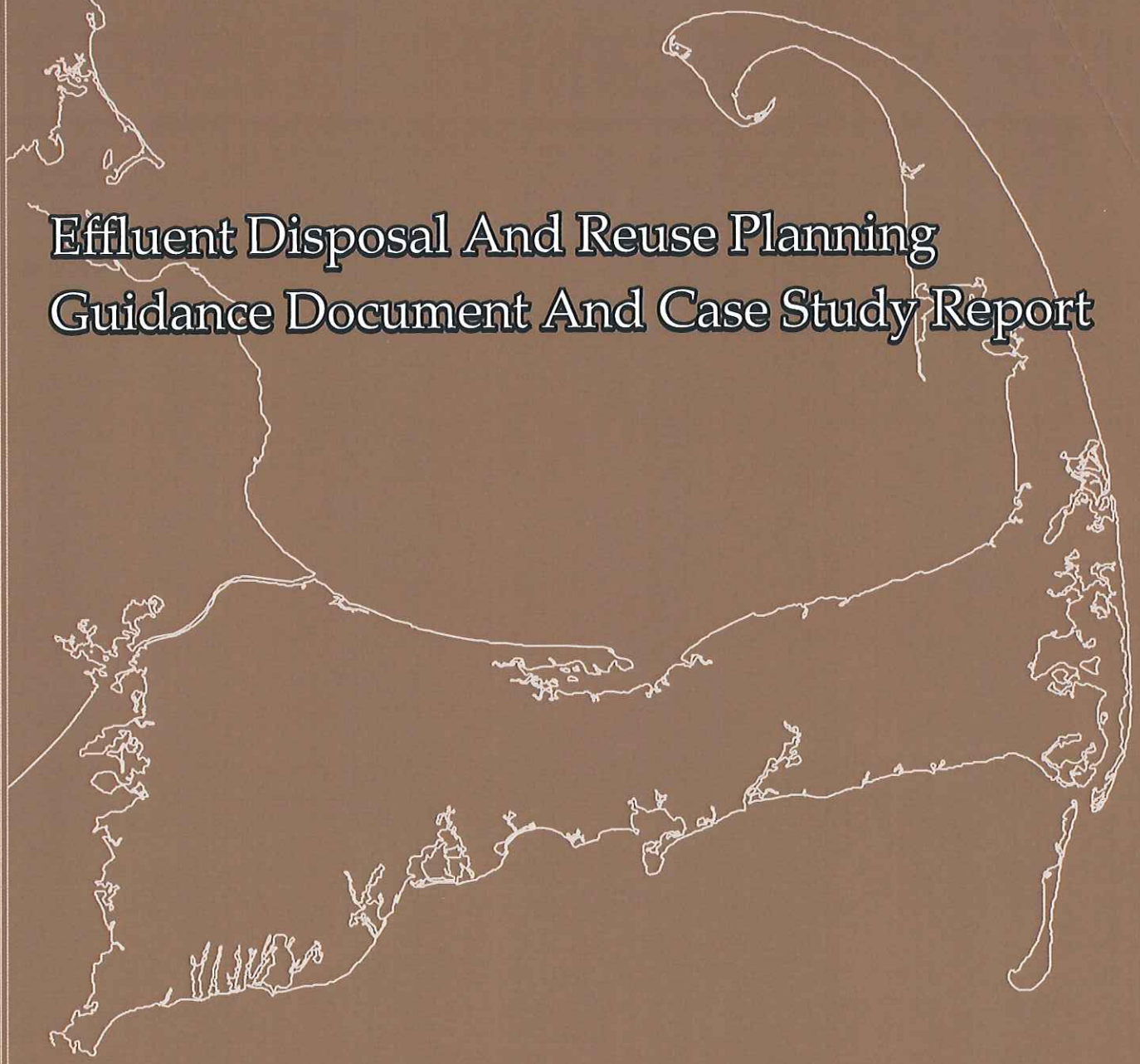
FIGURE 4 GROUNDWATER ELEVATION VS PLANT FLOW AND PRECIPITATION

Appendix P

Effluent Disposal and Reuse Planning Guidance Document and Case Study Report; February 2005

DRAFT

Effluent Disposal And Reuse Planning Guidance Document And Case Study Report



Prepared for
Barnstable County, MA
Town of Barnstable, MA

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FEB 23 2005

TOWN OF BARNSTABLE
DEPARTMENT OF PUBLIC WORKS

February 21, 2005

Mr. Mark J. Giordano, P. E.
DPW Senior Project Manager
Town of Barnstable
367 Main Street
Hyannis, MA 02601

RE: Wastewater Implementation Committee – Grant Project
Draft Report – Effluent Disposal and Reuse Planning:
Guidance Document and Case Study Report
Stearns & Wheler Job No. 40198.0

Dear Mr. Giordano:

Enclosed please find fifteen copies of the Draft Report: Effluent Disposal and Reuse Planning: Guidance Document and Case Study Report. The submittal of this draft document constitutes completion of Tasks 1-5 as described in the Town's Memorandum of Agreement with Barnstable County and the Town's Agreement with Stearns & Wheler. The copies of the draft report are provided for review by the Town and the Wastewater Implementation Committee.

If you have any questions regarding this submittal, please call.

Very truly yours,

STEARNS & WHELER

Gage Muckleroy /TAM

J. Gage Muckleroy, P.E., DEE
Associate

JGM/tam

Enclosures

cc: Robert Butterworth, P.E., DEE, S&W

cc: Mark Ells
Bud Breault
Bob Burgmann
Peter Doyle

Effluent Disposal And Reuse Planning Guidance Document And Case Study Report

Prepared for
Barnstable County, MA
Town of Barnstable, MA

Prepared by
Stearns & Wheler, LLC
255 Stevens Street
Hyannis, MA 02675

February 2005

PART 1 - IDENTIFICATION AND CHARACTERIZATION

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PART 1 - IDENTIFICATION AND CHARACTERIZATION

SECTION 1 - INTRODUCTION

1.1 BACKGROUND

This document has been prepared to assist communities in Cape Cod, coastal Massachusetts, and other coastal communities with similar wastewater management concerns, to identify land-based wastewater disposal technologies that are cost effective and protective of the environment. The procedures presented in this document are an integral part of wastewater management planning efforts on Cape Cod and elsewhere.

Cape Cod is an area that has experienced significant population growth in recent decades. The area is also home to a number of sensitive ocean, estuarine, and freshwater ecosystems. A consequence of the increasing population is the impact to the environment as a result of wastewater discharge. For approximately two decades, communities on Cape Cod have been studying their wastewater management programs in a comprehensive manner to evaluate existing practices, potential impacts of those practices, future needs, and potential solutions to mitigate these impacts. Through the years, the Massachusetts Department of Environmental Protection (MADEP) has worked to formalize the evaluation process. In January 1996, MADEP issued the *Guide to Comprehensive Waste Water Management Planning*, which described the multi-phase procedure for completing wastewater planning efforts. In March 2002, MADEP drafted an update to the 1996 document and titled it *Guide to Integrated Water Resource Management Planning*. This updated document recognizes the connection that modern wastewater management has with the management and protection of all water resources. The guidance document has not yet been finalized, but is expected to be released in the near future.

More recently, one of the most significant developments in the wastewater planning process was the inception of the Massachusetts Estuaries Project (MEP). Nutrient enrichment of estuaries along the Massachusetts coastline has become the greatest consequence of wastewater discharge. Elevated levels of nutrients (nitrogen, in particular) are adversely impacting recreational opportunities, shellfish and sea grass habitats, and breeding grounds for marine fisheries (see Figure 1).

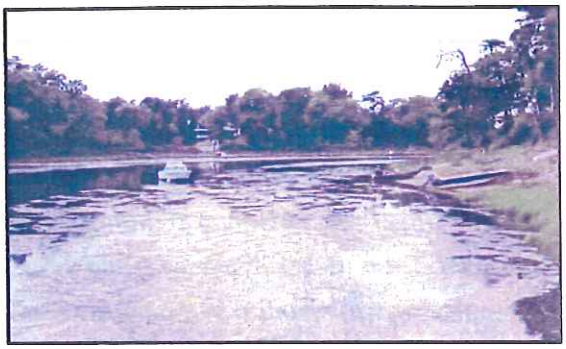

Figure 1 - Some coastal waters have become choked with weeds as a result of nutrient loading.

The MEP is a collaborative effort among coastal communities, MADEP, the University of Massachusetts in Dartmouth, the U.S. Geological Survey (USGS), the Cape Cod Commission (CCC), School for Marine Science and Technology (SMAST), the U.S. Environmental Protection Agency (USEPA), and the Executive Office of Environmental Affairs. The objective of the program is to develop total maximum daily load values for watershed nitrogen loadings to the estuaries. The program entails detailed evaluations of watershed areas, nitrogen loading from all nitrogen sources, tidal flushing rates, and water quality modeling to establish the nitrogen limits. This program is having a significant impact on comprehensive wastewater management planning on Cape Cod and has prompted communities to proactively advance their planning efforts (see Figure 2).



Figure 2 - Estuaries on the Cape Cod coast. The Three Bays area in the Town of Barnstable.

An integral aspect of wastewater management planning is the disposal of treated wastewater. As more towns evaluate their options, centralized treatment plants are being upgraded, expanded, or constructed. In each case, facilities for treated wastewater disposal are required.

Cape Cod and all of coastal Massachusetts is under the jurisdiction of the Ocean Sanctuaries Act, which, by prohibiting "activities that may significantly alter or endanger the ecology or appearance of the ocean, seabed or subsoil of sanctuaries," effectively eliminates ocean outfalls as a viable alternative for disposal of treated wastewater. As a result, Cape Cod

communities must rely on some form of land disposal for treated wastewater.

Another symptom of a growing population is the increased demand on water supplies. Public water suppliers have had to be more aware of groundwater levels in times of drought and high use. Seasonal shortages, coupled with the concept of deriving beneficial uses from treated municipal or industrial wastewater, have prompted the emergence of wastewater reclamation, recycling, and reuse as an integral component of water resource planning, even in the historically water-rich Northeast. As such, beneficial reuse of treated wastewater has become a major consideration related to wastewater management on Cape Cod.

1.2 PURPOSE OF DOCUMENT

Land disposal of treated wastewater represents many challenges for communities. In seeking locations for land disposal, communities must consider the following:

- Is there sufficient land available?
- Will the soil and groundwater conditions at the available land be suitable?
- Are there sensitive ecological systems in the vicinity of the available land that could be impacted by discharge?
- Is wastewater disposal a land use that is consistent with the surrounding land use?
- Is the available land close enough to the treatment plant to minimize transmission costs and address issues of bacterial regrowth in the transmission system?
- What disposal technology is the most appropriate?
- Is there a viable reuse component to our wastewater management planning?

The objective of this document is to assist communities in completing the process of finding suitable land for discharging treated wastewater and to determine which of the many disposal technologies best meet the community's needs. This document presents a procedure for identifying and characterizing candidate sites and provides guidance in selecting appropriate discharge technologies.

In addition to providing a description of general procedures, this document will also provide a Case History of the process employed by the Town of Barnstable, MA (Town) during their Comprehensive

Wastewater Management Planning project (CWMP) to identify candidate disposal sites. The Town has been involved in CWMP for a number of years. The planning process has resulted in a number of improvements to the existing wastewater treatment plant, construction of sewers, and plans for additional sewers. Although the Town has significant capacity for disposal at the existing treatment plant, plans for future expansion of the plant have led the Town to identify new, remote sites for additional capacity. The Town's application of the general procedures described in Part I of this document are presented in Part 2.

This document focuses on environmental conditions and wastewater management concerns found on Cape Cod. However, the procedures and technologies presented herein are applicable to communities across Massachusetts as well as in other states, especially coastal communities.

SECTION 2 - AVAILABLE DISCHARGE TECHNOLOGIES

2.1 INTRODUCTION

There are a number of technologies available for land disposal or recharge for beneficial reuse of treated wastewater. Some of these technologies are commonly used on Cape Cod and in the region. Others are used in other regions of the United States, but have little or no history of use in this area. And finally, some can be considered innovative technologies.

The most common means of treated wastewater disposal in the area, especially for larger municipal treatment plants, is rapid infiltration beds (RIBs). This disposal technology utilizes open sand beds into which treated wastewater is discharged. The treated water infiltrates through the sand, into the subsurface soils, and ultimately into the groundwater.

The second most used technology is subsurface infiltration. These systems are typically used for smaller municipal treatment plants or for smaller package plants for neighborhoods, institutions, or commercial facilities. Leaching of treated wastewater is accomplished through the use of subsurface chambers, pits, or trenches.

Spray irrigation is a common land disposal alternative in southern climates, but because its effectiveness is limited in areas where freezing occurs, it is not frequently

used in a northern climate. Cape Cod has two spray irrigation installations.

Drip irrigation is another proven technology for wastewater disposal with a beneficial reuse component; however, no drip systems are known of in the area.

Injection wells are utilized primarily in Florida and southern California to accomplish both disposal and beneficial reuse. The use of injection wells, although a proven technology in those regions, is regarded as an innovative technology in the Northeast.

Wick wells are modified injection wells that rely on gravity flow rather than pumping water under pressure. There are currently two wick well installations in the southeastern Massachusetts region.

Wetland restoration is another innovative disposal/wastewater management method being considered. This technology/ management concept utilizes effluent recharge upgradient of a previously disturbed wetland (such as abandoned cranberry bogs). It also includes the restoration of the wetland to produce a more varied and natural wetland setting that can assist with natural nitrogen attenuation in the wetland. There are several wetland restorations currently being considered on Cape Cod.

Each of the technologies introduced above will be discussed in greater detail in the following section in terms of operating principle, design considerations, and suitability in given conditions. A consolidated summary of these technologies is presented in Table 2-1.

2.2 Technology Evaluation

A. **Rapid Infiltration Beds.** RIBs are open basins designed to allow treated effluent to flow across the bottom of the basin and percolate through the sand bed, through the unsaturated zone, and then to the groundwater (see Figure 3).

TABLE 2-1

SUMMARY OF EFFLUENT DISCHARGE TECHNOLOGIES
Effluent Discharge and Reuse
Guidance Document and Case Study Project
Barnstable County Wastewater Implementation Committee and Town of Barnstable, MA

ALTERNATIVE	REGULATORY REQUIREMENTS	EFFLUENT QUALITY	MAINTENANCE REQUIREMENTS AND COMPLEXITY OF OPERATION	FLEXIBILITY	ENERGY USE
Rapid Infiltration Beds	Permitting and monitoring of effluent discharges and design requirements. Disinfection may be required by MADEP.	Effluent is already treated and sand beds provide some additional treatment.	Effluent discharge is reliable throughout the year and easy to maintain.	Flexibility is possible with multiple beds.	Lowest energy requirements due to no need to repump the effluent at the sand beds.
Subsurface Infiltration	Disinfection is not required prior to discharge, unless required to meet the Interim Guidelines for Reclaimed Water Use.	Effluent is already treated and infiltration facilities provide additional treatment. Effluent should be filtered before discharge.	Repair of the beds would be difficult because they are subsurface	Moderate depending on construction of dosing equipment and distribution piping.	Moderate due to effluent dosing pumps.
Spray Irrigation	Permitting and monitoring of effluent discharges and design requirements. Disinfection may be required by MADEP.	Spray irrigation provides further uptake of nitrogen in the effluent.	Moderate maintenance to maintain piping. Spray irrigation cannot be used in freezing weather.	Must have redundant back-up facilities for winter discharge.	Moderate due to repumping requirements.
Ocean Outfall	The Massachusetts Ocean Sanctuaries Act prohibits discharge of municipal wastewater into an ocean sanctuary. An NPDES permit required.	Disinfection may be required for the outfall.	Maintenance similar to a large force main	Minimal, unless land disposal remains for some backup discharge.	Moderate due to pumping requirements
Deep Well Injection	Permitting and monitoring of effluent discharges and design requirements. MADEP is not supportive of this technology.	Effluent must be well treated (filtered and chlorinated) before discharge.	Uncertain reliability due to few operating installations and increased maintenance due to the potential of plugging of injection point with solids.	Installation of multiple wells would allow individual wells to rest or be repaired.	Moderate due to repumping requirements.

TABLE 2-1 (continued)

ALTERNATIVE	REGULATORY REQUIREMENTS	EFFLUENT QUALITY	MAINTENANCE REQUIREMENTS AND COMPLEXITY OF OPERATION	FLEXIBILITY	ENERGY USE
Wick Wells	Permitting and monitoring of effluent discharges and design requirements. MADEP regards this as an innovative technology.	Effluent must be well treated (filtered and chlorinated) before discharge.	Uncertain reliability due to few operating installations and increased maintenance due to the potential of plugging of injection point with solids.	Installation of multiple wells would allow individual wells to rest or be repaired.	Moderate due to repumping requirements.
Wetland Restoration	Possible extensive wetland permitting depending on the type of restoration. Permitting and monitoring of effluent discharges and design requirements. MADEP regards this as an innovative technology.	Effluent must be well treated (phosphorus removal in addition to standard nitrogen removal, and disinfected before discharge)	Very low maintenance requirements and low operations complexity.	Minimal operations control. Flexibility would be provided with variable surface water level controls in the abandoned bog.	Moderate due to repumping requirements.

ALTERNATIVE	LAND REQUIREMENTS	POTENTIAL FOR AIR EMISSIONS	PUBLIC ACCEPTANCE	RELATIVE CAPITAL COSTS	RELATIVE O&M COSTS	SELECTED FOR DETAILED EVALUATION
Rapid Infiltration Beds	Moderate at large wastewater flows when compared to subsurface leaching.	Effluent is treated to a high level and odors would be minimal.	Potential for low acceptance from residents who are impacted by bed siting and construction.	Relatively low due low land area and easier construction.	Low due to low energy requirements and minimal maintenance.	Yes; the technology is simple and reliable. O&M requirements are minimal.
Subsurface Infiltration	Relatively high. Land surface above the infiltration system can be used for other purposes	Minimal.	Acceptance should be high due to minimal visual impacts and potential reuse of land area.	Relatively high due to highest land area and extensive piping.	High due to pumping requirements and potential high repair/cleaning costs.	Yes; technology is reliable and provides secondary use of discharge area.

TABLE 2-1 (continued)

ALTERNATIVE	LAND REQUIREMENTS	POTENTIAL FOR AIR EMISSIONS	PUBLIC ACCEPTANCE	RELATIVE CAPITAL COSTS	RELATIVE O&M COSTS	SELECTED FOR DETAILED EVALUATION
Spray Irrigation	Relatively high. Land above system can be can be used for other purposes when spray irrigation is turned off.	Minimal.	The public will want to see recycling of the effluent though they may be concerned about possible health threats.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to maintenance and pumping requirements.	Yes; it provides additional nitrogen uptake and reuse of the effluent.
Ocean Outfall	Minimal.	Minimal.	Low. Based on the opposition to the Deer Island outfall and the Ocean Sanctuaries Act.	Relatively high due to land area, extensive permitting pumping requirements.	Moderate due to pumping requirements	Yes, as a last alternative if all other land disposal alternatives are not sufficient to meet the Town's need.
Deep Well Injection	Relatively low compared to sand infiltration beds and subsurface leaching.	Minimal.	Land area requirements and visual impacts are minimal.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to pumping requirements. And maintenance needs.	No; MADEP is resistant to support the technology due to the need to chlorinate the effluent
Wick Wells	Relatively low compared to sand infiltration beds and subsurface leaching.	Minimal.	Land area requirements and visual impacts are minimal.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to pumping requirements. And maintenance needs.	Yes, MADEP has recently permitted a wick facility. Low land area is a benefit, however, MADEP is currently requiring 100% capacity reserve area for conventional system.
Wetland Restoration	Would make use of an existing extensive land area. The restoration efforts would occur in specific flow control and infiltration areas.	Minimal.	Could be favorable due to understanding that the technology/ concept is a restoration effort and the project could restore proper hydraulic balance to the watershed.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to pumping requirements. And maintenance needs.	Yes. There is much interest at MADEP with this concept to take an integrated approach to watershed management. This could be cost effective and provide secondary benefits.

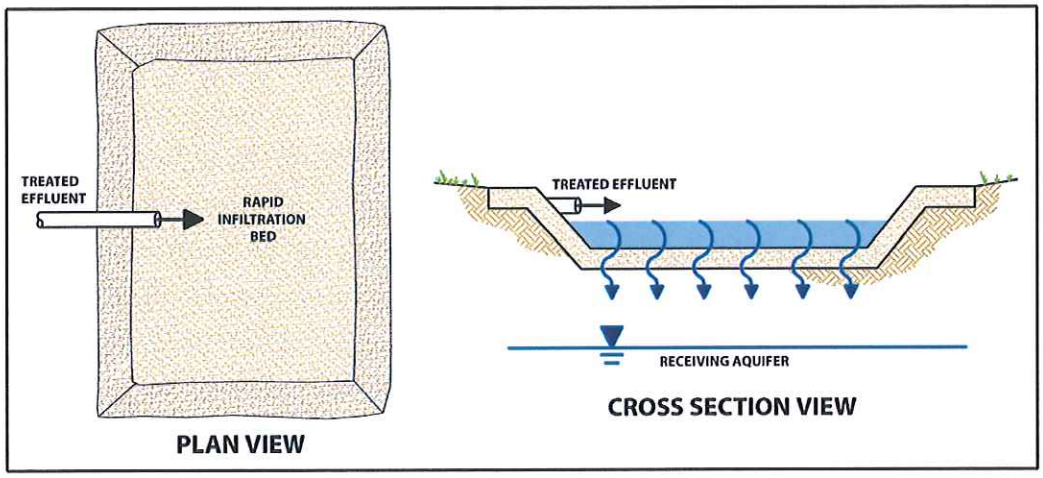

Figure 3 - Schematic of rapid infiltration beds

Bed maintenance is relatively easy because the bed is exposed at the surface and the sand surface can be raked or replaced if the sand becomes plugged with effluent solids. MADEP specifies loading rates for sand beds based on hydraulic conductivity rates of the underlying soils. Loading rates ranging from 2 to 5 gallons per day per square foot (gpd/sq ft) of sand area are suggested for percolation rates that range from 10 to 20 minutes per inch to less than 5 minutes per inch. Cape Cod towns currently utilizing sand infiltration beds as part of their wastewater treatment and discharge facilities include Barnstable, Falmouth, Chatham, and Orleans (Tri-Town) (see Figure 4).

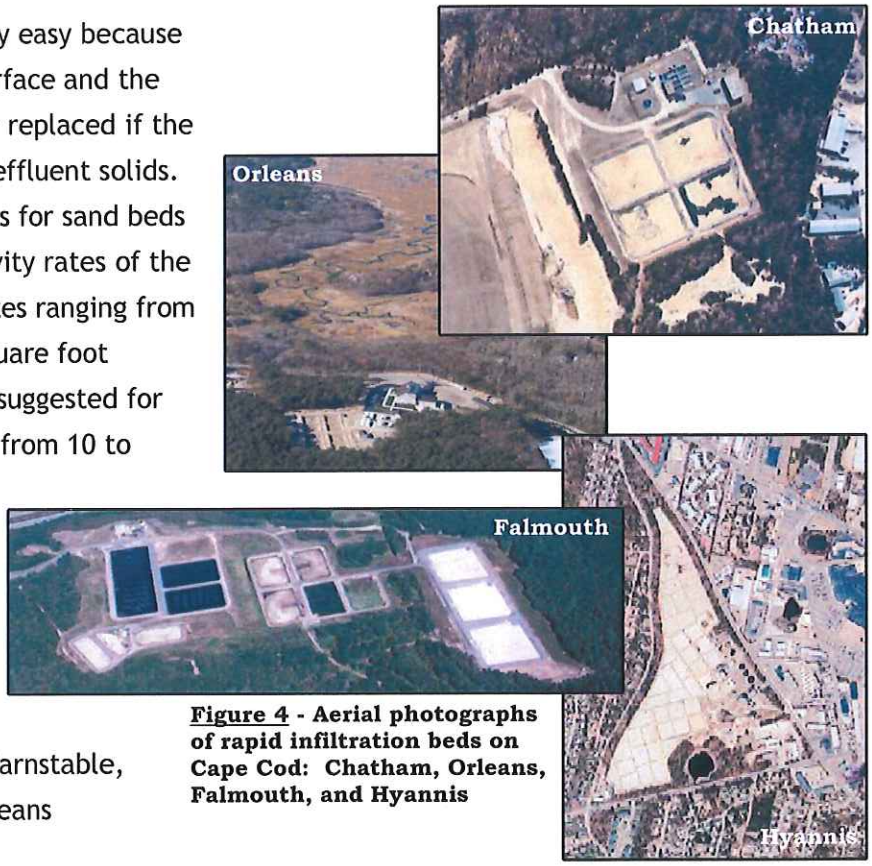

Figure 4 - Aerial photographs of rapid infiltration beds on Cape Cod: Chatham, Orleans, Falmouth, and Hyannis

Effluent disposal in rapid infiltration beds has the following advantages:

- Bed construction is relatively simple (however, it can be complicated by unfavorable subsurface conditions such as presence of boulders)
- Operation and maintenance (O&M) is relatively easy and O&M costs are lowest.
- Hydraulic loading rates are typically higher than other disposal methods, which allow the beds to take up less area.

Effluent disposal in rapid infiltration beds has the following disadvantages:

- Construction of new beds requires the clearing of large areas of land, which may have a visual impact.
- Infiltration beds do not have secondary uses, such as parking lots and recreational areas (as subsurface leaching or spray irrigation facilities might have).
- Low public acceptance.
- Disinfection is typically required.

Although infiltration beds have advantages with respect to cost of construction and ease of O&M, the most significant disadvantage is the area required. A facility with a 1 million gallon per day (mgd) discharge could require approximately 10 acres (see Figure 5) based on current MADEP recommended design criteria (*Guidelines for the Design, Construction, Operation and Maintenance of Small Sewage Treatment Facilities with Land Disposal*, MADEP, 1988).

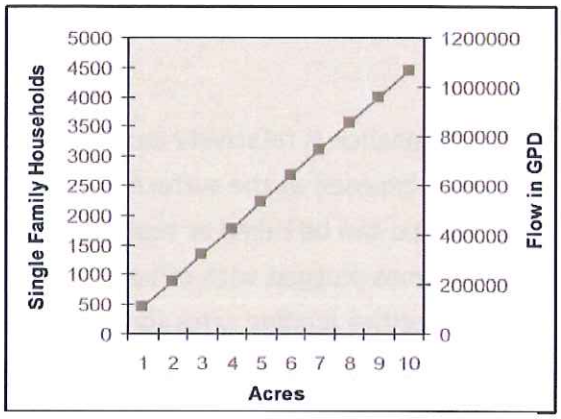

Figure 5 - Land area requirements for rapid infiltration beds

The following must be considered when determining the land area required for RIBs:

- Sufficient area to accommodate the required flow at 5 gpd/sq ft loading rate.
- Approximately 25 to 50 percent additional capacity to allow flow to be rotated between at least two to three

beds to allow beds to "rest" (i.e., dry out or be serviced).

- Approximately 20 percent additional area for berms and service roads between beds.
- A buffer of approximately 50 to 100 feet wide around the boundaries of the site, depending on the surrounding land use.
- A reserve area of approximately 50 percent total site capacity that is set aside and available, but not necessarily constructed, if the original site loses capacity or needs to be repaired over time.

These requirements are open to some degree of interpretation and negotiation with MADEP during the planning and permitting process and depend on the discharge site specifics.

B. **Subsurface Infiltration.** Large-scale subsurface infiltration facilities typically utilize pump and piping systems to pressure dose infiltration areas (trenches, beds, or galleries) where the effluent percolates to the groundwater (see Figure 6).

Maintenance and cleaning of these systems is more difficult because the infiltration area is not exposed to the surface and effluent solids that may accumulate cannot be easily removed. Subsurface infiltration beds can have secondary uses, such as parking lots, lawns, playing fields, and recreational areas. Hydraulic loading rates of 2.5 gpd/sf (of the trench or gallery base and side walls) are typical. Towns currently utilizing subsurface systems include Oak Bluffs and Provincetown (see Figure 7).

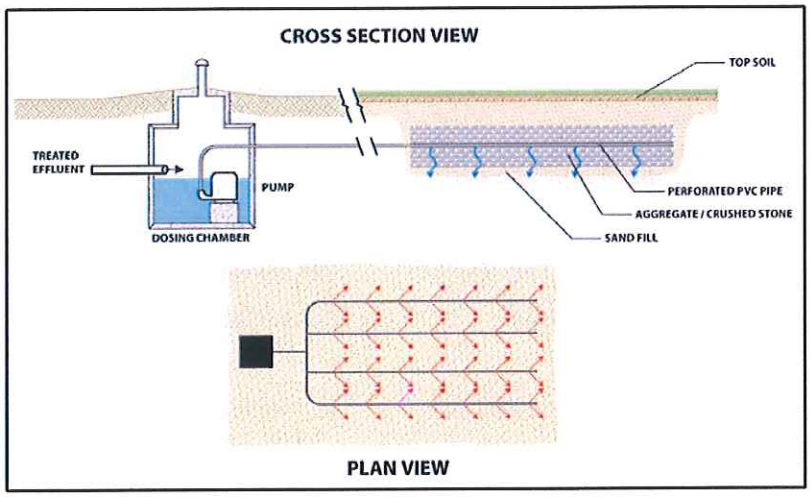

Figure 6 - Schematic of subsurface infiltration system



Figure 7 - Surface at site of Provincetown, MA subsurface infiltration system

Subsurface infiltration facilities have the following advantages:

- Disinfection is typically not required prior to discharge unless it is in a water supply recharge area or upgradient of a sensitive resource.
- Facilities are contained underground and can have a secondary use, such as parking lots and recreational areas.
- High public acceptance.

They have the following disadvantages:

- Large land areas may be required (larger than RIBs) due to lower hydraulic application rates.
- Pressure dosing is typically required for large systems, which increases capital and O&M costs.
- Extensive site work may be required for construction, particularly if the site is forested or there are adverse subsurface conditions
- Due to the limited access for cleaning and maintenance, the facilities may have to be reconstructed if they lose infiltration capacity.

A facility for a 1 mgd discharge could require as much as 18 acres based on current MADEP recommended design criteria (see Figure 8).

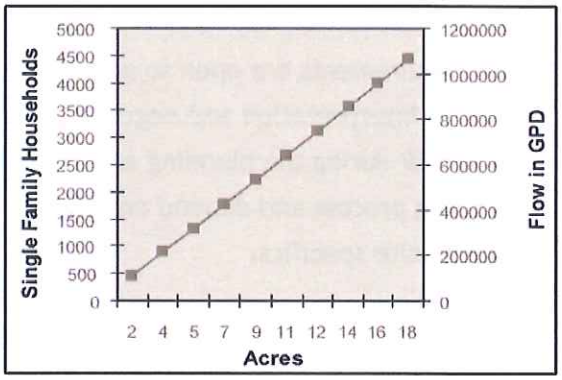

Figure 8 - Land area requirements for subsurface infiltration trench system

The following must be considered when determining the land area required for subsurface infiltration:

- Including a safety factor in the design by designing for 125 percent of the flow (as recently permitted in Provincetown).

- A layout that accommodates 100 percent reserve capacity by leaving space for replacement trenches between the constructed trenches. Trenches must be spaced a distance of three times the trench width (a Title 5 requirement that is considered applicable to larger leaching systems).
- Limit laterals to 100 feet in length (a Title 5 requirement that is considered applicable to larger leaching systems).
- A buffer approximately 50 feet wide around the boundaries of the site, depending on the surrounding land use.

Similar to the sizing requirements for RIBs, the sizing requirements for subsurface infiltration facilities are open to some degree of interpretation and negotiation with MADEP and depend on the discharge site specifics.

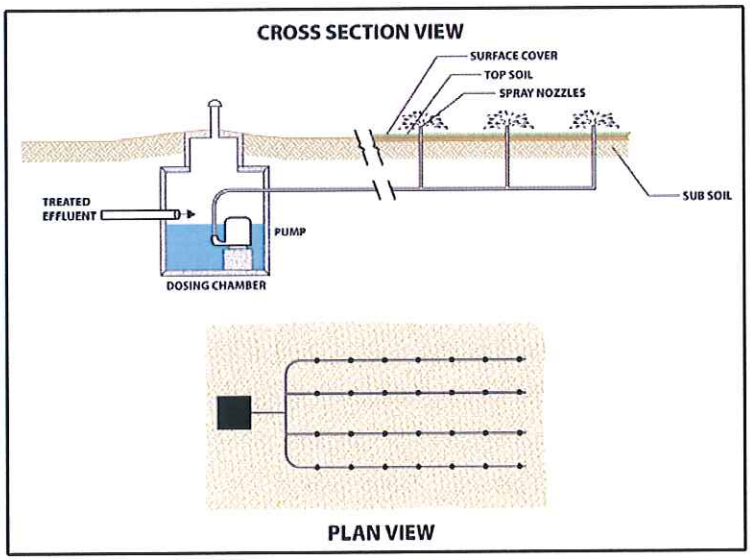

Figure 9 - Schematic of spray irrigation system

C. **Spray Irrigation.** Spray irrigation facilities are typically comprised of effluent pumps, distribution piping, and a spraying system consisting of risers and spray nozzles (see Figure 9). Treated effluent is pumped through various distribution lines and discharged via spray nozzles to the surrounding area. Spray irrigation systems have often been used at golf courses and in large remote fields. Application rates for non-golf course areas are typically 2 inches per acre per week. Application rates for golf courses are typically based on turf management needs. Spray irrigation is currently utilized at a golf course in Yarmouth and at the municipal treatment facility in Falmouth.

The goal of spray irrigation systems is to apply water at a rate that allows the site vegetation to uptake the nitrogen in the water at a rate that will limit the leaching of nitrogen into the groundwater. In some regulatory environments, the nitrogen

uptake capacity of the discharge site vegetation can be the limiting factor in loading rates (see Figure 10).



Figure 10 - Spray irrigation system in use at a golf course

Effluent disposal using spray irrigation has the following advantages:

- Allows for secondary use of land (i.e., golf courses) as regulated by MADEP.
- Provides an inexpensive means of irrigation, reducing clean water demands.
- Provides nitrogen uptake by plant life and also reduced nitrogen application at golf courses.

Effluent disposal using spray irrigation has the following disadvantages:

- Limited cold weather use due to potential freezing problems.
- Spray nozzles may be subject to clogging.
- Requires secondary means of effluent disposal or storage during wet periods, times when the land is being otherwise used (such as golf) and winter months.
- Must meet more stringent MADEP requirements for reclaimed water use, including disinfection.
- Often has low public acceptance due to health risk concerns associated with exposure to pathogens in the effluent.
- Large areas are needed.

A facility for a 1 mgd discharge could require as much as 130 acres, based on a loading rate of 2 inches per week as suggested above (see Figure 11).

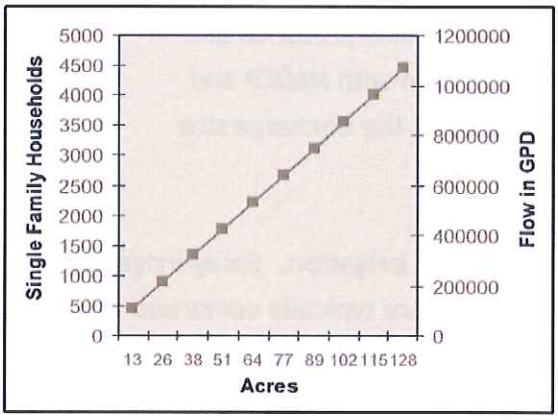

Figure 11 - Land area requirements for a spray irrigation system

D. **Drip Irrigation.** Drip irrigation is a subsurface version of spray irrigation. Treated wastewater is used to irrigate agricultural land (see Figure 12). Subsurface piping is laid out approximately 6 to 12 inches below the surface in areas to be irrigated. Discharge of wastewater is through emitters spaced 12 to 24 inches apart and laterals spaced at 12- to 24-inch intervals. Water is pumped through the lines under pressure but is discharged slowly through the emitters. The intent of the system is to discharge the water into the root zones of the plants, where the nutrients can be utilized by the plants and where increased evapotranspiration may be facilitated.

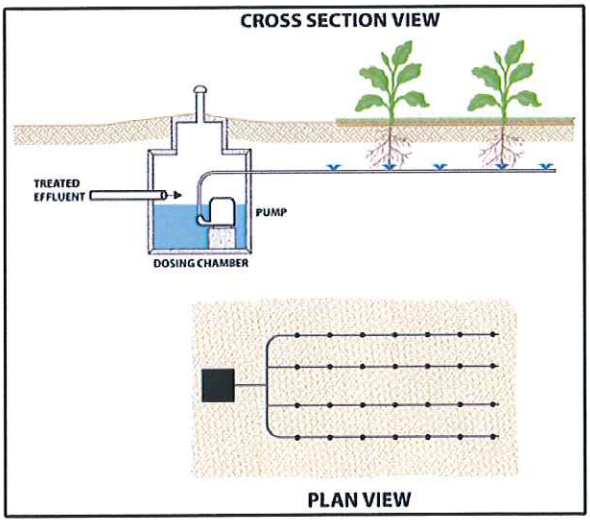

Figure 12 - Schematic of a drip irrigation system

Advantages include:

- Can be used in adverse terrain conditions.
- Is associated with water reuse because water is discharged into root zone of plants or crops.
- Ease of construction.
- Low human exposure to wastewater.
- Low delivery rate to minimize water table impacts.
- High public acceptance.

Disadvantages include:

- Effluent must be highly treated to minimize plugging.
- Difficult to monitor emitter performance.
- Periodic backflushing is required.
- May not operate in very cold conditions.
- Piping must be protected from heavy loads, such as car and truck traffic on the site.

If a system is designed to operate at 0.5 gallons per hour (gph) per emitter, and emitters and lines are at 2-foot spacing, a 1 mgd facility, including 20 percent redundant area, would require approximately 11 acres of land (see Figure 13).

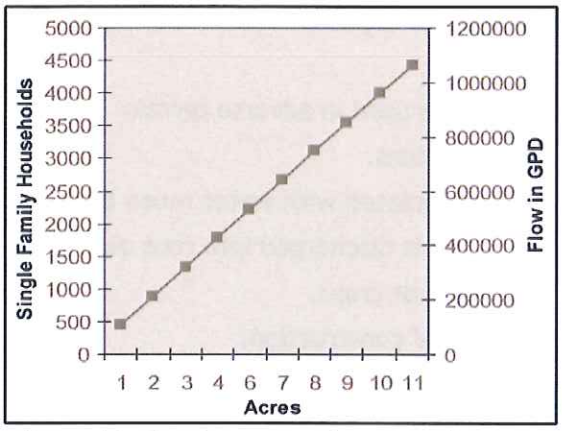

Figure 13 - Land area requirements for a drip irrigation system

treated wastewater has been practiced in Florida for 25 years. There are currently, approximately 47 injection wells in southern Florida. Wastewater injection in Florida differs from wastewater injection envisioned on Cape Cod because injection in Florida is typically at a depth of approximately 3,000 feet, whereas on Cape Cod, the objective of using well injection is to recharge the groundwater system. Therefore, shallow injection into the aquifer would be the likely approach.

E. **Well Injection.** Well injection involves the discharge of treated effluent to groundwater below the land surface. The discharge is accomplished by pumping the effluent through wells that extend into permeable, saturated geologic strata. This type of discharge can be compared to the reverse of extracting water from a well (see Figure 14).

Injection of treated wastewater occurs primarily in Florida and California. Deep well injection of

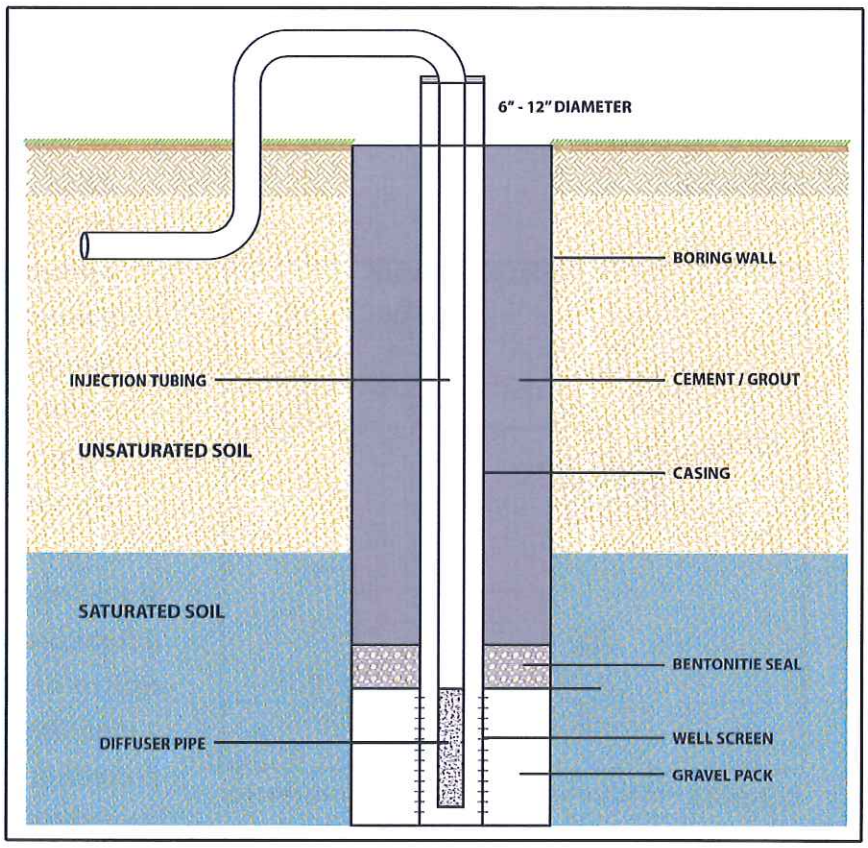

Figure 14 - Schematic of an injection well

In California, excessive pumping of groundwater resources has resulted in a lowering of the water table in coastal areas and subsequent saltwater intrusion. In a project referred to as Water Factory 21, approximately 22.6 mgd is injected into the ground. The California project injects the treated effluent into an aquifer utilized as a water source.

In 1999, the Town of Barnstable conducted an injection well pilot test. Treated effluent and potable water flows of 70,000 to 200,000 gpd, were injected into a 10-inch, 30-foot deep well. The well experienced plugging that was attributed to biological growth in the sand pack or at the boring wall. The test concluded that chlorine disinfection and effluent filtration would be required for injection to be technically viable. MADEP presently prohibits chlorination of injected wastewater due to concerns related to the formation of disinfection byproducts; therefore, injection wells have not been pursued further at this time. MADEP has indicated that as more municipalities seek innovative disposal technologies, the issue may be revisited.

Effluent disposal with well injection has the following advantages:

- Lowest land area requirements.
- Discharge is below grade so visual and odor impacts are low.
- Discharge points (wells) could be spread over a large area to minimize groundwater mounding.

It has the following disadvantages:

- Effluent filtration is needed to provide a high level of nutrient and solids removal to minimize plugging in the wells.
- Relatively unproven technology in Massachusetts, with recent testing at the Hyannis WPCF.
- Chlorination is needed, which conflicts with guidance from MADEP.

E. **Ocean Outfall.** This alternative would involve the siting, construction, and operation of an ocean outfall for effluent disposal into the Atlantic Ocean, Cape Cod Bay, or Nantucket Sound. Unfortunately, the Massachusetts Ocean Sanctuaries Act prohibits the discharge of any municipal wastewater into an ocean sanctuary, and Cape Cod is surrounded by ocean sanctuaries defined in the legislation. The legislation is strictly imposed and a variance is only available to communities that have an existing municipal wastewater discharge to an ocean sanctuary.

Effluent disposal using an ocean outfall has the following advantages:

- No large land area requirements.
- Protects the groundwater and coastal estuaries.

It has the following disadvantages:

- Special legislation, possibly at the federal level, would be required to obtain permits.
- Extensive design and permitting requirements, depending on the location of the discharge.
- Possible high public opposition due to perception that the ocean was being polluted.
- Potential reduction in aquifer recharge, which can lead to saltwater intrusion to wells.

F. **Wick Well Technology.** Wick technology is a relatively new and innovative approach to treated wastewater disposal. Wick technology entails the use of larger (3- to 6-foot diameter) wells dug to the water table aquifer (see Figure 15). The wells are filled with stone, and treated wastewater is discharged over the stone to infiltrate under gravity flow into the underlying aquifer.

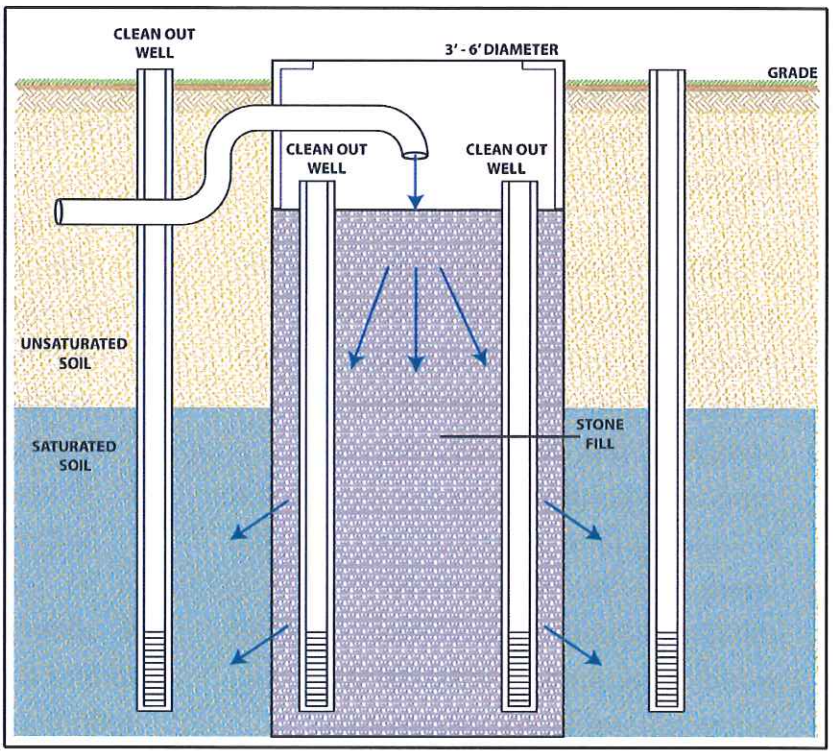

Figure 15 - Schematic of a wick well

There are two wick well installations in southeastern Massachusetts as described in detail below.

In 1997, the Town of Fair Haven, MA installed four disposal wells at their West Island facility. The West Island facility is a small neighborhood plant that serves about

380 homes. Daily flows range between 15,000 and 25,000 gpd. Three of the wells are open, gravity drained wells. The fourth well is referred to as a wick well. The only difference between the open wells and the wick well is that the wick well is filled with stone. At the time of installation, MADEP required Fair Haven to place the stone in the well. The regulatory rationale is uncertain; however, it has been attributed to MADEP being reluctant to permit an "injection well," and the stone fill may have made the disposal system a "wick well" and hence more acceptable. MADEP has since been more receptive to injection wells.

The Fair Haven wells are approximately 23 feet deep, 12 inches in diameter, and set in gravel caissons approximately 4 feet in diameter. The well screens are 1-1/2 to 2 feet long and are set in a favorable sand and gravel layer that is approximately 3 feet thick.

Flow into the Fair Haven wells ranges from 15,000 gpd in the off-season to a seasonal peak of about 25,000 gpd in the summer. The maximum flow to the wells on any given day has been 40,000 gpd. Typically, all of the flow goes into one well at a time. Those three daily flow rates represent 10 gpm, 17 gpm and 27 gpm average daily flow rates, respectively. However, Fair Haven reported wastewater is discharged to the wells in batches rather than flowing at a uniform rate all the time. So while the wells are actually operating, they are flowing at a rate of about 70 gpm for short periods of time (a few hours).

The wick well underwent a long-term clear water test when it was constructed. A flow of 100,000 gpd was pumped into the well for a period of 30 days, or an average rate of 70 gpm.

As stated above, all of the wells are used intermittently. The wick well has not been in service for about two years. After the wick well had been turned off for a period of time, it became plugged, apparently due to non-use, and has not been used since. The well has not been reconditioned, although reconditioning is planned for the future. The open wells (non-stone-filled) continue to operate as designed.

A second wick system was recently installed by a private developer of a small development in Hingham, MA. The system has just become operational at very low rates (a few thousand gpd based on the most recent information received from

MADEP) and therefore there is currently little operating history.

This system currently has three wick wells, and the engineering report claims that each well has a 300,000 gpd capacity, which is consistent with the test rate reported. MADEP approvals documented the understanding that the system may foul in the future and required that well rehabilitation needed to be addressed in the O&M plan. MADEP encouraged the installation of multiple cleanout/treatment wells.

Additionally, because it is an unproven technology, MADEP required an area be set aside for a conventional backup system (beds or leachfields) with a capacity equal to the permitted flow. It was not necessary to actually build the backup system; however, the developer chose to build it at that time so as to not damage the overlying golf course sometime in the future.

The Hingham treatment plant has an ultraviolet (UV) disinfection system as required by MADEP for pathogen/risk assessment concerns. It was recognized that the UV treatment does not leave a residual to mitigate biologically sourced plugging.

Effluent disposal with wick wells has similar advantages and disadvantages to injection wells. Advantages include:

- The land area required would be much less than the area required for infiltration beds, subsurface infiltration, and spray irrigation. The effluent discharge would occur below the surface, and the surface would have minimal disruption.
- Discharge points (wells) could be spread over a large area to minimize groundwater mounding.
- High public acceptance.

Disadvantages include:

- Effluent filtration is needed to provide a high level of nutrient and solids removal to minimize plugging in the wells.
- Relatively unproven technology in Massachusetts. Limited performance data is available.

G. **Wetland Restoration.** In recent years a new innovative technology/management concept has been considered. It is the conversion of abandoned cranberry bogs or previously modified wetlands to more diverse wetland settings that can accommodate and benefit from increased

hydrologic flow. Its primary purposes are to improve water quality of the groundwater flowing through the wetland and restore hydrologic balance to areas that have been impacted by drinking water withdrawals. It can provide natural nitrogen attenuation and thereby protect downgradient marine waters. It can also provide improved wildlife habitat and open space and recreational areas.

This concept has significant regulatory permitting challenges due to national, state, regional, and local wetland protection regulations that have been written to prevent any modifications to wetlands. Many regulators, municipalities, and citizen groups now recognize the water quality and wildlife habitat benefits of converting previously disturbed monoculture cranberry bogs to more diverse wetland settings and are working to overcome the regulatory constraints. The concept has been developed and promoted by the MEP as a way to increase natural nitrogen attenuation in the watershed. It is also being considered as a way to reintroduce highly treated wastewater into watersheds that have been impacted by water withdrawals.

Several wetland restoration projects are envisioned or underway on Cape Cod as briefly summarized below.

The 2003 Technical Report by the Massachusetts Estuaries Project for the Town of Chatham Embayment System (MEP, 2003) summarized MEP's evaluation of several alternatives to improve tidal flushing and/or provide wetland restoration to the Muddy Creek/Monomoy River. This water body and wetland system runs along the Chatham and Harwich boundary and empties into Pleasant Bay on the eastern end of Cape Cod (see Figure 16).



Figure 16 - Aerial photograph of the Muddy Creek area, Chatham, MA, showing location of proposed dike

The MEP found that reconstruction of a historic dike in the upper portion of the creek (and other improvements to re-establish a herring run) could reduce nitrogen to Pleasant Bay from this watershed by 40 percent, or approximately 2,800 kg/year. This same level of nitrogen removal by conventional wastewater treatment techniques would cost significantly more, would have environmental impacts during construction, and could (depending on the wastewater management strategy used) relocate water out of the watershed. The Chatham Health and Environment Department has initiated discussions to determine the regulatory feasibility of reconstructing the dike with a fish ladder; to date, many regulatory agencies are interested and are investigating ways to find an acceptable solution.

The 2004 Technical Report by the MEP for the Popponesset Bay watershed (MEP, 2004) discussed possible nitrogen attenuation through wetland restoration efforts in the Popponesset Bay watershed. These concepts are being pursued through a USEPA-funded project coordinated by MADEP. To date, various abandoned cranberry bogs and other disturbed wetlands have been identified and potential restoration concepts are being developed (i.e., construction of ponds and more varied wetland settings).

The Towns of Barnstable and Yarmouth are currently investigating a potential reuse concept to recharge the groundwater upgradient of an abandoned cranberry bog in the Lewis Bay watershed (see Figure 17).



Figure 17 - Aerial photograph of the Lewis Bay area, Hyannis, MA, showing abandoned cranberry bog being considered for restoration

This wetland system is currently impacted by a drinking water withdrawal of approximately 1 mgd upgradient of the abandoned bog. The withdrawal is affecting base flow through the watershed and

wetlands. The Towns' evaluation will consider the advanced treatment needed for regulatory approval as well as wetland restoration effort to restore the wetland to a more natural setting and provide natural nitrogen attenuation.

H. **Technology Summary.** Rapid infiltration beds are a simple and reliable effluent discharge technology with relatively low operating costs. With the exception of the well technologies, sand infiltration beds have the lowest land requirement.

Subsurface infiltration facilities are simple and reliable. These facilities are constructed below ground and therefore have minimal visual impacts, reduced potential for odors, and allow secondary use of the land. Effluent discharge in subsurface infiltration facilities has higher land area requirements. Subsurface infiltration facilities are not easily cleaned; therefore, the life of the facilities will be dependent on the quality of the effluent.

Spray irrigation (conventional and drip) is a simple and reliable effluent discharge technology with relatively low construction costs. It can provide additional nitrogen uptake and removal. Large areas of land are required and irrigation time is limited by wet and freezing weather.

Effluent discharge through well injection has relatively low land requirements and relatively low construction costs. Injection wells have the potential of plugging at the injection point due to biofouling and buildup of fine solids, and treated wastewater would likely require chlorination. This method does provide a means of effluent disposal at multiple potential sites with minimal land requirements; however, MADEP's resistance to support and permit this technology at this time is an obstacle.

Effluent discharge through wick well is a variation of well injection and has similar advantages and disadvantages. It is attaining limited regulatory acceptance, and more complete acceptance is contingent on long-term demonstration of effectiveness.

Wetland restoration effluent discharge and nitrogen attenuation concepts are being evaluated on Cape Cod and include evaluation and modeling of very site-specific considerations. If they prove to be feasible and acceptable to the regulatory community, they could be low cost methods

to discharge highly treated effluent, recharge impacted portions of the watershed, and attenuate nitrogen in the groundwater.

In summary, there is no universally defined best technology. The best technology is a function of the priorities of the municipality selecting the system, the land available for disposal, and very site-specific constraints and opportunities of the potential discharge/reuse sites.

2.3 Reuse Of Reclaimed Wastewater

As discussed previously through the identification of alternative technologies, municipalities should consider whether there are any viable reuse opportunities when evaluating methods of disposal of treated wastewater

Reuse, reclamation and recycling are often used interchangeably in discussions on water reuse, and sometimes there is little consistency in the use of the terminology from one agency or region to another. For the sake of consistency of understanding, definitions provided by Takashi Asano, a leader in reuse studies, will be utilized in this discussion.

A. **Wastewater Reclamation.** The treatment or processing of wastewater to make it usable.

B. **Water Reuse.** The use of treated wastewater for beneficial purposes such as agricultural irrigation and industrial cooling.

1. **Direct Reuse.** Implies the existence of pipes or other conveyance facilities to deliver reclaimed water

2. **Indirect Reuse.** Discharge of an effluent to receiving water (surface or ground) for assimilation and withdrawal downstream, which is recognized to be important but does not constitute planned direct reuse.

C. **Reclaimed Water.** Treated effluent suitable for an intended water reuse application.

D. **Recycled Water.** Normally involves one use or user, with the effluent from the user being captured and redirected back into that use scheme, typically an industrial practice. The relevance of reuse to Massachusetts was articulated by MADEP in May 1999 in their *Interim Guidelines on Reclaimed Water*. In this document, MADEP acknowledges that:

> "despite our relatively wet climate, many parts of Massachusetts are suffering the impacts of over-stressed, over-utilized water resources....One of our state's approaches to addressing water resource deficits is to promote and encourage the innovative reuse of treated wastewater while continuing to consider the public's health as the controlling factor."
> "We embrace the concept of reclaimed water use and recognize the fiscal, environmental and social benefits of doing so. Development patterns in Massachusetts and specific hydrogeologic setting that are not suitable for water withdrawals or wastewater disposal make the use of reclaimed water an attractive and necessary option."

Evidence that reuse is applicable to Cape Cod and eastern Massachusetts exists. Two examples include: (1) One town has had to abandon a production well because of saltwater intrusion; and (2) Several water purveyors have groundwater supplies that are stressed in dry times, especially during high summer usage.

These purveyors reportedly support the discharge of treated wastewater in a manner that would recharge the aquifers they withdraw from as long as sufficient quality measures are in place.

MADEP's *Interim Guidelines on Reclaimed Water* defines three types of reuse, each of which has particular treatment and quality requirements.

1. **Urban Reuse - Irrigation.** This refers to the use of treated wastewater for irrigation for golf courses or general landscaping.

2. **Urban Reuse - Toilet Flushing.** This refers to treating water to a level that makes it acceptable for toilet flushing. This is allowed in commercial establishments only.

3. **Discharge Into Zone IIs.** MADEP considers groundwater recharge that occurs in the Zone II of a community water system as reuse. As such, MADEP has treatment and quality guidelines for water that is recharged into Zone IIs. Additionally, MADEP discriminates between recharge that is within versus beyond a two-year groundwater travel time of public supply wells. Discharge within the two-year travel time is discouraged by MADEP, but can be permitted under special circumstances and has higher quality requirements.

Reuse for irrigation should be considered when feasible, although weather in Massachusetts is a significant constraint. Storage or alternative discharge methods must be available for winter and wet weather. An appropriate location for application of spray irrigation is in the resort areas of Cape Cod, where population and water use increase considerably in the summer months. The excess flow can be reused through spray irrigation. In the winter, when spray irrigation is not practical, that excess capacity is not required and another conventional treatment system can be used.

When new commercial developments are being planned, reclaimed water systems for flushing should be considered.

A form of indirect reuse has been implemented at one southeast Massachusetts development and is being considered for a northeast Massachusetts industry. This entails recharging groundwater upgradient from irrigation wells. As irrigation water is needed, it can be pumped from the recharged aquifer, thus having less impact on other municipal water supplies or aquifer water levels. In terms of regulatory framework, this is not defined as reuse and therefore quality requirements are not as stringent.

When siting treated wastewater discharge sites, consideration should be given to locating sites upgradient from and in the Zone IIs of municipal supply wells. This practice helps to replenish aquifers that supply water to the municipal wells. Many of the candidate locations for wastewater discharge in Cape Cod towns lie in Zone IIs. Development of these sites should be encouraged by regulators and the municipalities, rather than promoting discharge at sites that results in nearly direct subsurface flow and discharge to coastal waters. This has the combined benefits of replenishing the water supply and reducing nutrient migration to coastal estuaries.

SECTION 3 - THE PROCESS OF SITE SCREENING, IDENTIFICATION AND SELECTION

3.1 INTRODUCTION

Finding a suitable site for the disposal of treated wastewater is a complex process and a number of factors must be considered. A number of criteria must be considered when identifying a site. It is

appropriate to involve all stakeholders in the process, including the lead municipality; the Cape Cod Commission (on Cape Cod); the MADEP (in Massachusetts); and very importantly, the citizens of the community, both through public information programs and formal citizens advisory committees that can represent the interests and concerns of the residents in the formal selection process. Increasing the challenge is the fact that there is progressively less land available and, as more communities seek to improve their wastewater management programs through centralized neighborhood or cluster plants, more land will be needed for disposal. Associated with that challenge is the fact that land costs are steadily increasing.

The following sections provide a guide for identifying and selecting wastewater discharge sites. The process is summarized in the outline below.

Phase I - Preliminary Screening
- a. Site Identification
- b. Site Comparison and Ranking
- c. USGS or ModFlow® modeling

Phase II - Site Characterization and Selection
- a. Planning and Work Plan Development
- b. Field Investigation Tasks
- c. Data Interpretation
- d. Subsequent Testing
- e. Conceptual Design
- f. Public Participation
- f. Final Selection

This process is often not a linear step-by-step process. Often, two or more of these steps will be completed at the same time to meet project timelines.

Detailed descriptions of each task follow.

3.2 Phase I - Preliminary Screening

A. **Site Identification.** The preliminary screening phase is the first step in identifying suitable sites for wastewater disposal. Depending on each town's individual circumstances, this process may take one of two forms: (1) area-wide characterization; or (2) individual site identification.

Both methods have been successfully used to identify candidate sites for Cape Cod towns. The first method, area-wide characterization, is suitable for large towns with many potential suitable areas. The focus of the preliminary evaluation is to apply exclusion criteria to eliminate areas

of town that are not suitable, and then identify and characterize the available sites in the areas that remain. The second method (individual site identification) is more suitable to smaller towns or towns with a minimal number of available parcels of sufficient size to meet the town's wastewater discharge needs. In this approach, the limited number of available sites are identified and then screened with a number of evaluation criteria to determine which are acceptable, and of those, which are preferable.

1. **Area-wide Characterization.** As will be described in greater detail in the Case History section of this report, the Town of Barnstable completed an area-wide characterization. The area-wide characterization is very much simplified if a Geographic Information System (GIS) and associated database is available. If the town does not have a significant GIS database, a great deal of information can be obtained from the MASSGIS database available on the internet. The specific details of this project will be described in the Case History section, but the general process is described below.

Potential evaluation criteria are identified. Evaluation criteria may be exclusionary or may just be criteria for determining or ranking suitability. Examples of evaluation criteria include, but are not limited to, determining the proximity of:

- Wellhead or groundwater protection areas (as defined and determined by the municipality) or Zone Is or Zone IIs as defined by documentation submitted to MADEP. Recharge is not allowed in Zone Is. Recharge is allowed into Zone IIs, but entails greater regulatory scrutiny and additional monitoring requirements.

- **Areas of Critical Environmental Concern (ACECs).** ACECs have development and alteration limitations that would be applicable to wastewater discharge facilities.

- **Surface Water**. Surface water can be impacted by recharged wastewater, particularly with respect to nutrient impacts.

- **Vernal Pools.** Water levels in vernal pools can be affected by recharge. Hence, the sensitive ecology of the systems can be impacted.

- **Wetlands.** Hydraulic as well as chemical effects of groundwater recharge can impact sensitive wetland environments.

- **Areas of Rare and Endangered Plant and Wildlife Species.** These areas have building, development and alteration limitations that would be applicable to wastewater discharge facilities.

- **Conservation Areas.** Conservation areas are set aside to limit development. Some types of wastewater facilities would likely not be consistent with that land use.

- **Flood Hazard Zones.** Wastewater discharge facilities can not be located in flood zones due to potential facility damage during floods.

- **Shallow Groundwater.** Sufficient depth to groundwater must be maintained so the functioning of the discharge system is not jeopardized; flooding and runoff do not occur; and subsurface structures on proximal properties, such as basements or septic systems, are not impacted.

- **Groundwater Impacted by Oil or Hazardous Waste Releases.** Mounding resulting from recharge can alter groundwater flow paths and subsequently the migration of existing groundwater contamination.

- **Areas of Low Hydraulic Conductivity.** Areas of low hydraulic conductivity must be avoided to assure proper dispersion of recharged water.

- **Existing Treatment Plant.** Proximity of the treatment plant is a factor when considering pipeline costs.

The special consideration areas related to the above criteria are typically plotted on town maps through a GIS system, the MASSGIS database, or manual plotting. Some of the criteria listed above are considered exclusion criteria; that is, it is very unlikely that a discharge facility could be permitted in the area. Other criteria are more for evaluation, such as the location of Zone IIs or distance from the treatment plant (see Figure 18).

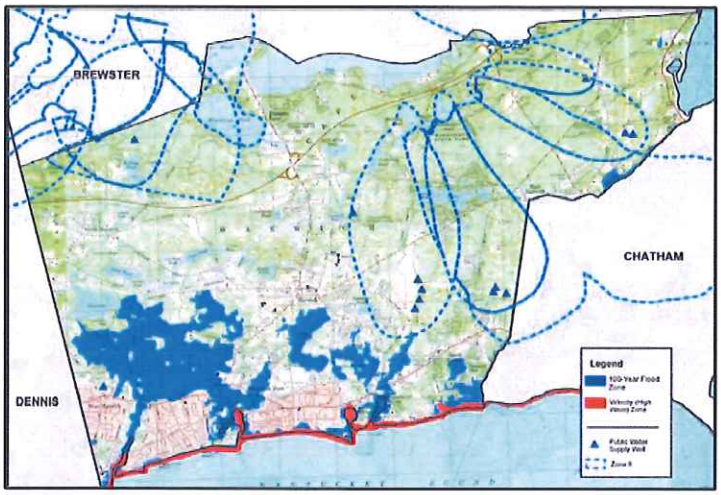

Figure 18 - MASSGIS map showing selected evaluation criteria

Locations within exclusion criteria areas should be eliminated from further consideration. Available areas for candidate sites can then be identified as those outside the exclusion areas.

Through the use of either a GIS database or available town mapping, specific sites can be identified using parcel maps. Undeveloped, town-owned, or potentially available parcels or groupings of parcels of sufficient size should be identified at this time.

2. **Individual Site Identification.** There is an alternative approach to conducting the town-wide characterization, which may be more suitable for smaller towns where the locations of likely available parcels is already known or easily determined by knowledgeable individuals or professional town staff (Town Planner, Health Agent, DPW Director, Water Superintendent, etc.). This type of site selection approach was used by the Towns of Chatham, Mashpee, and Falmouth.

In using the approach, potentially available parcels are identified as a first step using existing town mapping, a GIS database, or general knowledge of the town properties. Screening and characterization of the sites is completed in a subsequent step.

Whichever preliminary approach is used, this step culminates in a listing of candidate sites that are potentially suitable for discharge.

B. **Site Comparison and Ranking.** In either case, a useful tool at this point is the preparation of a matrix that will facilitate evaluation and comparison of sites. Although a number of sites may be acceptable, some may have features that make them more suitable than others. As a result, sites are ranked with respect to suitability. Characteristics that make one acceptable site more suitable than another

acceptable site include distance from the treatment plant (i.e., required force main length), compatibility with surrounding land use, watershed and nutrient loading impacts, reuse potential, and soil characteristics.

Tables 3-1 and 3-2 are examples of matrices that were developed by a Cape Cod town to characterize and rank sites identified through the Individual Site Identification approach. Table 3-1 serves as a qualitative review of site characteristics, and on Table 3-2, site characteristics are quantified and scored. The scoring serves to eliminate sites and to rank the remaining sites. To aid in ranking the sites, the scores may be weighted. The weighting scale is subjective and each town should develop their own scale based on their priorities. Examples of weighting are that the distance from the treatment plant may have minimal impact, so it has a weighting of 10 percent, while abutting land use may have a higher weighting of 25 percent. At the end of this step, a listing of potential available sites is developed.

An important task at this point, or at a previous point in the evaluation, is to conduct site visits. It is easy to think that mapping data provides all of the needed information. However, a site visit to observe, for example, actual topographic features, abutting land use, and presence of surface water is important and can exclude sites that, on paper, may seem suitable.

Based on the financial resources of the town and the expected land area requirements, the town now determines how many sites should have detailed characterizations completed. This is a discretionary decision reached by the town, potentially in conjunction with its consultant and its citizen advisory group. If there is one site that is clearly superior to others with sufficient area to meet the town's discharge needs, it may be necessary to evaluate only that single site. If there are multiple sites that could meet the needs of the town, or if more than one site is needed to provide the necessary capacity, multiple sites may undergo a detailed characterization. At the end of this step, the town will have decided which site(s) will have detailed characterizations completed.

C. **USGS Modeling.** Comprehensive wastewater management planning studies currently underway on Cape Cod have utilized groundwater modeling performed by the USGS to assess candidate discharge sites. USGS modeling has been a service

TABLE 3-1

RECOMMENDED SITE AND TECHNOLOGY MATRIX
Effluent Discharge and Reuse
Guidance Document and Case Study Project
Barnstable County Wastewater Implementation Committee and Town of Barnstable, MA

EFFLUENT DISPOSAL OPTION	DESCRIPTION	INFILTRATION LOADING AREA (ACRES)	ESTIMATED FACILITY CAPACITY (MGD)	DISTANCE FROM WPCF (LF)	SITE TOPOGRAPHY	SOIL PERMEABILITY (PERCOLATION RATE)
A	Site 1 - New Sand Beds	5.2	1.1	0.2	Mostly flat, wooded	Less than 5 minutes/inch
B	Site 1 - New Subsurface Leaching Facilities	6.3	0.7	0.2	Mostly flat, wooded	Less than 5 minutes/inch
C	Site 2 - Subsurface Leaching Facilities	8.0	0.9	0.7	Mostly flat, athletic field area and wooded	Less than 5 minutes/inch
D	Site 4 - Subsurface Leaching Facilities	6.4	0.7	1.3	Mostly flat, clear open areas, grass/underbrush	Less than 5 minutes/inch
E	Site 4 - Sand Infiltration Beds and Subsurface Leaching Facilities	6.9	1.2	1.3	Mostly flat, clear open areas, grass/underbrush	Less than 5 minutes/inch
F	Site 7 - Subsurface Leaching Facilities	2.8	0.3	2.5	Flat, athletic field	Less than 5 minutes/inch
G	Site 9 - Subsurface Leaching Facilities	2.3	0.3	3.3	Flat to slightly rolling, fairway -grass	Less than 5 minutes/inch
H	Site 9 - Subsurface Leaching Facilities with Spray Irrigation	2.3	0.3	3.3	Flat to slightly rolling, fairway -grass	Less than 5 minutes/inch
I	Site 10 - Subsurface Leaching Facilities	2.3	0.3	3.6	Irregular and undulating topography: tree vegetation and underbrush	Less than 5 minutes/inch

TABLE 3-1 (continued)

ALTER-NATIVE NO.	ALTERNATIVE NAME	AESTHETIC IMPACTS	PROXIMITY TO SENSITIVE RECEPTORS	CAPITAL COSTS	CAPITAL COST PER MGD ($/MGD)	ESTIMATED ANNUAL O&M COSTS	PRESENT-WORTH COSTS	PRESENT-WORTH COST PER MGD ($/MGD)
B1	McManus site with sand beds	Moderate due to deforestation and image of sand beds	2,700 feet to public water supply wells	$6,200,000	$3,900,000	$180,000	$8,100,000	$5,100,000
B2	McManus site with subsurface infiltration	Minimal after construction	2,700 feet to public water supply wells	$13,000,000	$14,000,000	$180,000	$15,000,000	$17,000,000
C2	Airport site with subsurface infiltration	Minimal after construction	1,100 feet to public water supply wells	$21,000,000	$9,100,000	$530,000	$27,000,000	$12,000,000
D1	Cape Cod Community College site with sand beds	Moderate due to deforestation and image of sand beds	4,100 feet to public water supply wells	$7,000,000	$4,100,000	$190,000	$9,000,000	$5,300,000
D2	Cape Cod Community College site with subsurface infiltration	Minimal after construction	4,100 feet to public water supply wells	$16,000,000	$15,000,000	$220,000	$19,000,000	$17,000,000
E1	Lorusso site with sand beds	Moderate due to deforestation and image of sand beds	2,300 feet to public water supply wells	$3,600,000	$7,200,000	$80,000	$4,500,000	$9,000,000
E3	Lorusso site with spray irrigation	Moderate due to perception of sprayed wastewater	2,300 feet to public water supply wells	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow

Table from Task 8 Report, *"Candidate Site Evaluation and Comparison, Stearns & Wheler, 2004."*
Capital costs are based on an Engineering News-Record (ENR) Index of 6,800 for 2003 costs.
Present-worth cost based on n = 20, I = 7.625%, P/A = 10.1.
All costs rounded to two significant digits.

TABLE 3-2

SITE IDENTIFICATION RANKING MATRIX
Effluent Discharge and Reuse
Guidance Document and Case Study Project
Barnstable County Wastewater Implementation Committee and Town of Barnstable, MA

Site ID	Description	Map-Block-Lot	Owner Type	Availability of Land	Soil Type	Site Access	Abutting land Use	Sensitive Receptors				Force Main Length (Approximate Distance From WPCF in ft)[2]	Watershed			Potential Aesthetic Impacts (Visual, Noise, Odors) Low; Medium; High	Historic Significance	Total	RANK
								In ACEC	Contains Estimated and Priority Habitats	Contains Wetlands	In Water Protection District		Name	MEP Nitrogen Removal Requirement (%)	Attenuation				
7	Site A		0	0	0	0	5	0	0	0	10	5	Watershed A	5%	0	1	0	15	1
9	Site B		0	0	0	0	5	0	0	10	0	5	Watershed B	0%	10	2	0	15	2
10	Site C		0	0	0	0	5	10	0	0	0	5	Watershed C	10%	10	3	0	15	3
1	Site D		0	0	0	0	5	0	0	0	10	1	Watershed C	10%	10	1	5	15	4
2	Site E		0	0	0	0	10	0	0	0	10	1	Watershed C	10%	10	2	0	20	5
11	Site F		5	5	0	5	10	10	0	0	0	5	Watershed A	20%	0	3	0	35	6
13	Site G		5	5	0	0	10	0	0	0	0	5	Watershed D	10%	0	3	0	20	7
1A	Site H		0	0	0	5	10	0	0	10	10	1	Watershed C	10%	0	1	0	35	8
5	Site I		0	10	0	0	5	0	10	0	10	5	Watershed C	20%	0	1	0	35	9
8	Site J		0	5	0	0	5	0	0	0	0	5	Watershed D	20%	10	2	5	10	10
4	Site K		0	0	0	0	5	0	10	0	10	5	Watershed E	5%	0	1	5	25	11
3	Site L		0	10	5	0	10	0	10	10	0	5	Watershed F	10%	10	2	0	45	12
12	Site M		5	5	0	5	5	0	10	0	10	5	Watershed H	20%	0	2	0	40	13
7A	Site N		5	5	10	5	5	10	0	10	10	5	Watershed I	5%	0	1	0	60	14
6	Site O		0	5	0	0	5	10	10	10	10	5	Watershed J	10%	0	2	10	50	15

(continued)

TABLE 3-2 (continued)

Ratings Legend	(The lower the number, the more favorable the rating)
Owner Type and Land Availability	Town = 0 Conservation = 5 Private = 10
Estimated Soil Type	Good = 0 Moderate = 5 Poor = 10
Site Access	Available = 0 Limited = 5 None = 10
Abutting Land Use	All Town = 0 Multiple Use = 5 All residential = 10
In ACEC	Yes = 0; No = 10
Priority Habitats	Yes = 0; No = 10
Wetlands	Yes = 0; No = 10
Water Protection District (WPD)	Yes = 0; No = 10
FM Length (from WWTF or Augusta property)	<1 miles= 1 1 to 5 miles = 5 >5 miles = 10
MEP Nitrogen Removal Requirement	0% = 0 1%-49% = 5 50%-89% = 10 >90% = 20
Attenuation	Yes = 0; No = 10
Potential Aesthetic Impacts	Low = 1 Medium = 2 High = 3
Historic Significance	Outside = 0 Adjacent = 5 Inside =10

provided by Barnstable County to assess groundwater and nutrient flow impacts that would result from the proposed recharge scenarios. USGS modeling as a county service is only available for a limited time (planned completion in October 2005); however, the model is in the public domain and can be used by towns in the future for their individual studies. The USGS model was previously developed for other water supply and water resource protection studies on Cape Cod. For the CWMP studies, the existing model was adjusted on a case-by-case basis for the towns. Although modeling by the USGS may not be available in the future, or not available at all to municipalities in other states, groundwater modeling at this step in the process can be a valuable assessment tool and should be considered, independent of access to the USGS program.

To use the model to assist in site evaluations, a projected flow is modeled at a candidate discharge site. The USGS model simulates the degree of mounding that would occur and uses ModFlow's® particle tracking function to simulate the flow direction of groundwater and associated nutrients in the subsurface. The model output is exported to GIS mapping to facilitate review of the results. The particle tracking shows the fate of recharged water and where recharged water intercepts surface water bodies, coastal waters, Zone IIs, and public supply wells for these flows. This information is valuable for site screening or subsequent environmental impact analysis. The model can account for the flows (measured in gpd) that recharge these various sensitive receptors and calculates a travel time estimate. The modeling provides significant insight into the potential impacts of recharge at the candidate sites and is a valuable characterization tool that is best incorporated prior to the investment in field investigations (see Figure 19).

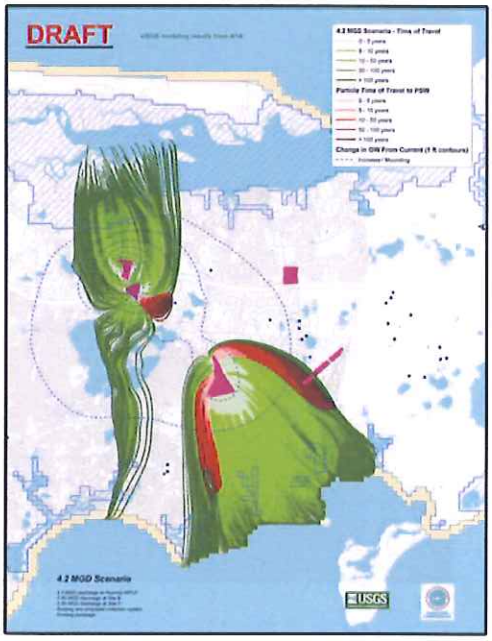

Figure 19 - USGS model output showing site of proposed recharge and fate of recharge water

3.3 Phase II - Site Characterization And Selection

A. **Planning and Work Plan Development.** At the end of Phase I, one or more sites will have been selected for further characterization to verify suitability. Information gathered to date on the site is typically from generalized sources such as town-wide mapping, U.S. Department of Agriculture (USDA) soils mapping, and other sub-regional mapping or data. The purpose of the site characterization step is to obtain very site-specific information related to soil types, depth to groundwater, and hydraulic conductivity. These site characteristics are typically defined with a subsurface investigation program using test borings, observation wells, and test pits.

The first step in the planning and work plan task is to define the specific objectives of the testing. The second step is a site visit to assess topography, physical access, and locations for testing. If the property is not owned by the town, arrangements must be made with the landowner for accessing the site. Provisions may need to be made to clear a temporary road into the site that will allow entrance of backhoes and other equipment.

A work plan should be developed that describes the proposed work. At this point, the town should seek feedback from MADEP regarding plans to evaluate sites. This is not a regulatory requirement and is not always done, but if the town desires a level of comfort that MADEP concurs the site warrants further investigation, this step can be taken.

B. **Field Investigation Tasks.**

1. **Borings.** One to three soil borings should be completed to characterize soil types and determine depth to water. Borings should be advanced at least 10 feet into groundwater. If regional data or literature indicates an aquitard (low permeability layer) or bedrock is potentially present at a depth that could impact system performance, the borings should extend to that depth.

2. **Wells.** If soil conditions revealed by the borings do not rule out the site being used, one or more of the borings should be completed as observation wells. If groundwater flow direction is an important consideration and not yet clearly defined, at least three wells should be installed to allow a

determination of flow direction (see Figure 20).



Figure 20 - Completing soil borings to characterize deep soils and aquifer characteristics

After wells are completed, they can be used to estimate hydraulic conductivity of the receiving aquifer through the use of slug tests. These are relatively simple in situ hydraulic conductivity tests that remove small quantities of water from the wells(s) and then measure the time for the well to return to its original water elevation. Due to the uncertainties inherent with slug tests, multiple tests should be completed in each of the wells present. Often, slug tests are very localized and may yield data that is not representative of the soil types present. In this case, it may be more appropriate to estimate hydraulic conductivity based on soil types or obtain estimates from regional studies completed by the USGS.

The USGS has completed groundwater modeling across Cape Cod and has assigned hydraulic conductivity values to the aquifers. Although their information may not be as site specific as on-site testing, it may provide reliable data. If there is not yet sufficient data to be certain that the hydraulic conductivity is adequate for the proposed flow, large volume pumping tests can be completed which can yield much more accurate hydraulic conductivity data. During these pumping tests, large quantities are pumped from a large diameter well (4 to 6 inches). The water table drawdown in a nearby observation well is measured and used to calculate hydraulic conductivity.

3. **Test Pits and Percolation Tests.** If RIBs or a subsurface leaching system is the likely technology choice, test pits and percolation tests should be completed to characterize shallow soils. Test pits should be completed by a certified soil evaluator so that the records are suitable for permitting purposes. Percolation test data should be used to determine whether infiltration rates will be sufficient for the proposed facility (see Figure 21).

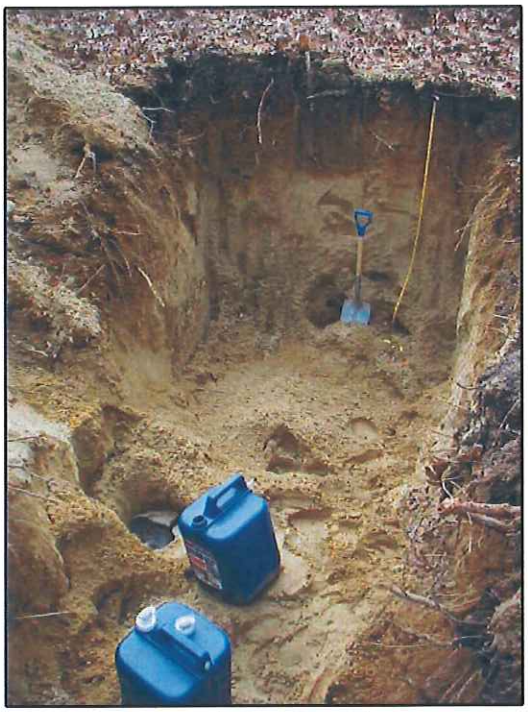

Figure 21 - Completing test pits and percolation tests

Eventually, if the site is selected for use, a groundwater discharge permit will be required. A significant amount of site testing is required to obtain a such a permit, including multiple wells, water quality testing, multiple test pits and percolation tests, along with additional evaluations using the obtained data. The site characterization tasks described above may contribute to the permit requirements, but may not meet them all. Therefore, it is important to have all investigations and analyses performed as part of the characterization to meet the permit process quality requirements. That way, the data can be used for (and in conjunction with additional data) MADEP permitting. Prior to completing the investigation, the town should determine whether it wants to invest in all the permit requirements at this early stage and avoid returning to the site again, or to defer some of the requirements until a later date, and complete the site characterization for a lesser investment.

C. **Data Interpretation.** Data from the field work is interpreted to make a determination regarding the suitability of the site. Factors to be considered include depth to seasonal high groundwater; deep hydraulic conductivity; and the resultant mounding analysis, percolation rate, and groundwater flow rate and direction. Each is discussed below.

1. **Depth to Seasonal High Groundwater.** Depth to groundwater and depth to seasonal high groundwater are determined with the wells and/or test pits. Standing water in either the well or test pit is the current groundwater level. Care must be taken to determine if perched groundwater is present. Seasonal high groundwater may be much higher than the measured groundwater level and soil

mottling (discolored soil above the current groundwater level) in either the test pit or the soil samples from the boring often represents the level of seasonal high groundwater. Seasonal high groundwater elevations can also be estimated through a calculation methodology described in a CCC and USGS guidance document (Frimpter, Belfit, 1992). This methodology utilizes historic groundwater data in a series of Cape Cod index wells to estimate seasonal high groundwater at most locations on Cape Cod. Depth to seasonal high groundwater is important because MADEP requires that groundwater remain 4 feet below the bottom of sand beds or leaching facilities in its highest level, including mounding impacts.

2. **Deep Hydraulic Conductivity and Mounding.** Deep hydraulic conductivity controls how efficiently the underlying aquifer will drain the recharged effluent effluent and what the mounding effects will be. The hydraulic conductivity data is used to calculate the potential mounding that will occur.

Multiple methods of calculating mounding are available in hydrogeology textbooks. Another option which MADEP uses is a relatively simple, commercially available, analytical calculator, referred to as the Hantaxis model, to calculate mounding. Model input includes recharge rate, recharge area, hydraulic conductivity, depth to water, and porosity, and creates a table and graphic of the mounding impacts (see Figure 22).

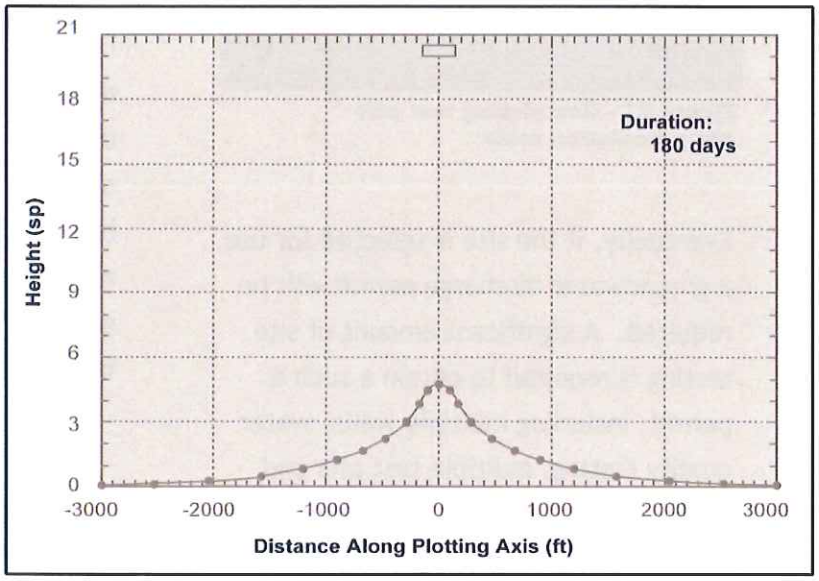

Figure 22 - Output from analytical calculator

An alternative is to complete a relatively simple numerical model using such commercially available software as ModFlow. Although there is generally insufficient data to develop a comprehensive groundwater flow model, a tool such as ModFlow can serve to develop a mounding estimate.

A number of Towns on Cape Cod have integrated regional groundwater modeling performed by the USGS into their site evaluation programs. The integration of USGS modeling was described in Section 3.2.

3. **Percolation Rates.** MADEP defines loading rates for RIBs and subsurface infiltration systems, measured in gpd/sf based on recorded percolation rate ranges. Table 3-3 summarizes MADEP guidance for determining acceptable loading rates. This calculation is important because it ultimately defines the capacity of a given area of land.

4. **Groundwater Flow Rate and Direction.** Groundwater flow rate and direction can be determined from sub-regional data or from data obtained during the investigation. Groundwater flow direction is determined from the relative water levels in at least three on-site or proximal wells. Groundwater flow rate is a function of hydraulic conductivity and water table gradient. Flow direction is important to identify environmental or human health receptors of the treated effluent. Flow rate is important when proposed facilities are in a Zone II to determine if the site lies within a two-year travel time of public supply wells and therefore if higher levels of treatment are required.

Again, regional modeling performed by USGS may be used to aid in determining the potential impacts of the proposed recharge facility, particularly with respect to the fate and migration of nutrients.

TABLE 3-3

MADEP GUIDANCE FOR DETERMINING HYDRAULIC LOADING RATES

INFILTRATION FACILITY TYPE	RECOMMENDED HYDRAULIC LOADING RATE (GPD/SF) FOR THREE RANGES OF PERCOLATION RATES		
	LESS THAN 5 MIN/INCH	5 TO 10 MIN/INCH	10 TO 20 MIN/INCH
Open sand beds	5.0	4.0	2.0
Leaching pits	3.0	2.5	1.5
Leaching chambers	3.0	2.5	1.5
Leaching trenches	2.5	1.5	1.0

From "*Guidelines for the Design, Construction, Operation, and Maintenance of Small Sewage Treatment Facilities with Land Disposal,*" MADEP, 1988.

D. **Subsequent Testing.** At the completion of the data interpretation, subsequent testing may be warranted. After the initial characterization, a site may seem suitable, but additional hydraulic characterization is needed to verify the site's capacity to accept the quantity of water proposed for the site. This is typically needed for sites located in the moraine areas of Cape Cod where soils are denser and highly variable.

A suitable test for this phase of evaluation, applicable to RIBs or subsurface infiltration systems, is a hydraulic loading test. Guidance for conducting loading tests is provided in the USEPA *Process Design Manual - Land Treatment of Municipal Wastewater* (1981). Loading tests entail constructing pilot-scale loading basins, a minimum of 10 feet in diameter. Larger diameter basins up to actual proposed size can be constructed, but USEPA recommends a minimum diameter of 10 feet. Loading tests are performed by saturating the soils at the basin and conducting a number of constant head and falling head evaluations to determine the soil's capacity in gpd/sf. USEPA guidance (USEPA, *Process Design Manual - Land Treatment of Municipal Wastewater*, 1981) suggests that a design infiltration rate for recharge facilities be 4 to 15 percent of the measured maximum infiltration rate as determined in loading tests. The range is a function of physical soil properties, and generally an average design factor of 10 percent is suitable. Given the generally innovative nature of

injection wells or wick wells, pilot testing is warranted for the technologies before designing and constructing full-scale systems.

E. **Conceptual Design.** Once sites are characterized in terms of available area, topography, and application capacity, discharge technologies should be matched to the sites. It is likely that early in the investigation, based primarily on the size of the site or the neighboring land use, it was known whether a site was most suitable for subsurface leaching, rapid infiltration beds, spray irrigation, or injection and/or wick wells,

Spray irrigation is viable where large tracts of open fields or woodlots are available, but again, in the Northeast, spray irrigation alone is not a viable alternative. It can be used in conjunction with other methods at other locations.

It is likely that if wick wells or injection wells have been selected, and the operational and regulatory hurdles of those technologies are understood and accepted, that smaller parcels have been identified for siting those particular technologies. It must be remembered that MADEP requires a reserve area for a conventional technology at wick well installations, and it is likely a similar requirement would be made for injection wells.

Wetland restoration would obviously be a predetermined alternative at a site selected specifically for that purpose.

Rapid infiltration beds or subsurface infiltration may be used interchangeably at a site, so a determination would be made at this point as to which alternative best meets the objectives of the town. As discussed in the technology review, RIBs are easier to maintain and may be more reliable over a long period of time. However, they are intrusive on the landscape. Subsurface leaching trenches have operational disadvantages but allow alternative use of the surface and are not as visually intrusive. The decision between the two technologies should be made based on the town's priorities and objectives for the site.

Once a technology is selected, it should be laid out conceptually, keeping in mind the need for perimeter buffers, reserve area, access roads, berms, parking, and ancillary facilities. After the facility is laid out and actual discharge area is determined, the capacity of the site can be defined. The capacity of the site will be one of the

criteria used in the final characterization, ranking, and selection of sites.

F. **Public and Regulatory Participation.** As discussed in Section 3.1, citizen and regulatory participation is a critical component of all aspects of comprehensive wastewater management planning, but especially with the potentially controversial topics of selecting a treated wastewater discharge site. Typically, the initial public perception of a large discharge site is unfavorable, especially to the proximal landowners. Keeping the citizenry involved throughout the process is important so they understand the need for a site, the likely candidate sites, and the rationale for selecting the favored site.

Citizen concerns will need to be addressed through design features that mitigate environmental impacts. Ultimately, the acceptance of new effluent discharge facilities and all major components of a town's CWMP will be determined by the formal Massachusetts Environmental Policy Act (MEPA) and Cape Cod Commission Development of Regional Impact (DRI) environmental review process. The public education and participation process must start at the beginning of the CWMP and site screening process to be successful.

G. **Final Selection.** Following the data interpretation task and any supplemental investigations, the suitability of each tested site should be determined. Again, as at the end of the preliminary screening task, it may be appropriate to develop a matrix to compare and rank the tested sites. If one site is clearly the best choice, a matrix may not be warranted. If multiple sites were tested and all prove to be acceptable, a matrix may be warranted to assist the town in determining which site should be the priority for construction. An example matrix prepared for this phase of the site selection process is provided as Table 3-4.

When the final site selection is made, steps toward regulatory approval and implementation can be initiated. If the site is not town owned, discussions should have already taken place regarding acquisition. Final steps in purchasing the site can be taken.

Following MEPA and CCC approvals, a groundwater discharge permit will need to be obtained. Most information for the permit application can be derived from the work completed to date, but as described above, additional investigations may have to be conducted to meet all of the permit application requirements.

TABLE 3-4

SUMMARY OF SITE EVALUATION
Effluent Discharge and Reuse
Guidance Document and Case Study Project
Barnstable County Wastewater Implementation Committee and Town of Barnstable, MA

ALTER-NATIVE NO.	ALTERNATIVE NAME	INFILTRATION LAND AREA (ACRES)	ESTIMATED FACILITY CAPACITY (MGD)	DISTANCE FROM WPCF (LF)	SITE TOPOGRAPHY	SOIL PERMEABILITY (PERCOLATION RATE)	DEPTH TO GROUNDWATER	ABUTTING LAND USE
B1	McManus site with sand beds	7.5	1.6	12,600	Irregular and undulating topography: tree vegetation	Less than 5 minutes/inch	±58 feet	Undeveloped and road ROW
B2	McManus site with subsurface infiltration	11	0.9	12,600	Irregular and undulating topography: tree vegetation	Less than 5 minutes/inch	±85 feet	Undeveloped and road ROW
C2	Airport site with subsurface infiltration	28	2.3	8,600	Mostly flat with a slight slope from northwest to southeast, grassed	Less than 5 minutes/inch	±20 feet during drilling; 14 to 18 feet after	Commercial property, undeveloped property and road ROW
D1	Cape Cod Community College site with sand beds	8.1	1.7	15,500	Natural topography is irregular and undulating: tree vegetation	Less than 5 minutes/inch	±65 to 70 feet	Undeveloped, road ROW, and Community College
D2	Cape Cod Community College site with subsurface infiltration	14	1.1	15,500	Natural topography is irregular and undulating: tree vegetation	Less than 5 minutes/inch	±65 to 70 feet	Undeveloped and road ROW
E1	Lorusso site with sand beds	2.3	0.5	10,400	Lightly vegetated, rolling terrain, disturbed site with powerlines overhead	Less than 5 minutes/inch	±65 feet	State roadway and undeveloped
E3	Lorusso site with spray irrigation	5	0.04	10,400	Lightly vegetated, rolling terrain, disturbed site with powerlines overhead	Less than 5 minutes/inch	±65 feet	Undeveloped

TABLE 3-4 (continued)

ALTER-NATIVE NO.	ALTERNATIVE NAME	AESTHETIC IMPACTS	PROXIMITY TO SENSITIVE RECEPTORS	CAPITAL COSTS	CAPITAL COST PER MGD ($/MGD)	ESTIMATED ANNUAL O&M COSTS	PRESENT-WORTH COSTS	PRESENT-WORTH COST PER MGD ($/MGD)
B1	McManus site with sand beds	Moderate due to deforestation and image of sand beds	2,700 feet to public water supply wells	$6,200,000	$3,900,000	$180,000	$8,100,000	$5,100,000
B2	McManus site with subsurface infiltration	Minimal after construction	2,700 feet to public water supply wells	$13,000,000	$14,000,000	$180,000	$15,000,000	$17,000,000
C2	Airport site with subsurface infiltration	Minimal after construction	1,100 feet to public water supply wells	$21,000,000	$9,100,000	$530,000	$27,000,000	$12,000,000
D1	Cape Cod Community College site with sand beds	Moderate due to deforestation and image of sand beds	4,100 feet to public water supply wells	$7,000,000	$4,100,000	$190,000	$9,000,000	$5,300,000
D2	Cape Cod Community College site with subsurface infiltration	Minimal after construction	4,100 feet to public water supply wells	$16,000,000	$15,000,000	$220,000	$19,000,000	$17,000,000
E1	Lorusso site with sand beds	Moderate due to deforestation and image of sand beds	2,300 feet to public water supply wells	$3,600,000	$7,200,000	$80,000	$4,500,000	$9,000,000
E3	Lorusso site with spray irrigation	Moderate due to perception of sprayed wastewater	2,300 feet to public water supply wells	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow

The site(s) will need to gain MEPA and CCC DRI approvals. If the public and regulatory participation process was successful, all (or nearly all) concerned citizens and regulatory agencies should understand the selection process that has resulted in one or more sites and technologies being selected. They should agree that the selected sites are the bet and should support the decision.

PART 1 - IDENTIFICATION AND CHARACTERIZATION

REFERENCES

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PART 2 - TOWN OF BARNSTABLE SITING EVALUATION AND SELECTION: CASE HISTORY

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PART 2 - TOWN OF BARNSTABLE SITING EVALUATION AND SELECTION: CASE HISTORY

SECTION 1 - INTRODUCTION

1.1 Background And Purpose

In the mid-1990s, the Town of Barnstable (see Figure 1) initiated efforts to find additional effluent disposal sites. At that time, the Town had completed the Needs Assessment Report of their Comprehensive Wastewater Management Plan, which identified effluent discharge capacity limitations at the Hyannis WPCF site as well as the need to locate additional effluent discharge sites.

The Town has completed the following components of its Comprehensive Wastewater Management Plan (CWMP) as well as the following improvements to the Hyannis WPCF and sewer system extensions as part of ongoing implementation of the wastewater plan:

- CWMP Needs Assessment Report (December 1993).
- CWMP Alternatives Screening Analysis Report (February 1996).
- CWMP detailed evaluations of the alternative solutions (1997 to present).
- Construction of a new secondary clarifier at the Hyannis WPCF (1997).
- Construction of an improved nitrogen removal process at the Hyannis WPCF (2000).
- Construction of several sewer system extensions and improvements on Bearses Way, Route 28, Barnstable Road, Summerside Lane, Norris Street, Center Street, Old Colony Road, and Corporate Drive (1996 through 2004).
- Preliminary design of sewer system extensions around Wequaquet Lake, Long Pond, Stewarts Creek, and Cape Cod Community College areas (2002 to present).
- Groundwater modeling of various effluent discharge sites as part of a collaborative effort between the United States Geological Survey (USGS), Barnstable County, and the Cape Cod Commission (2004 to present).
- Subsurface and feasibility evaluations of several sites to locate additional effluent discharge/reuse capacity (2002 to present).

The Town needs to site additional effluent discharge and/or reuse facilities before additional sewer extensions can occur. The

purpose of this portion of the report (Part 2: Town of Barnstable Siting Evaluation and Selection: Case History) is to briefly present the site evaluation completed by the Town of Barnstable as part of their wastewater planning efforts. The Town presents this history as a case study to assist other towns with their wastewater planning efforts and efforts to site advanced treatment and effluent discharge/reuse systems.

The Town of Barnstable believes that all towns and communities need to work together if they are going to efficiently meet the wastewater treatment needs currently being faced by Cape Cod and other coastal communities.

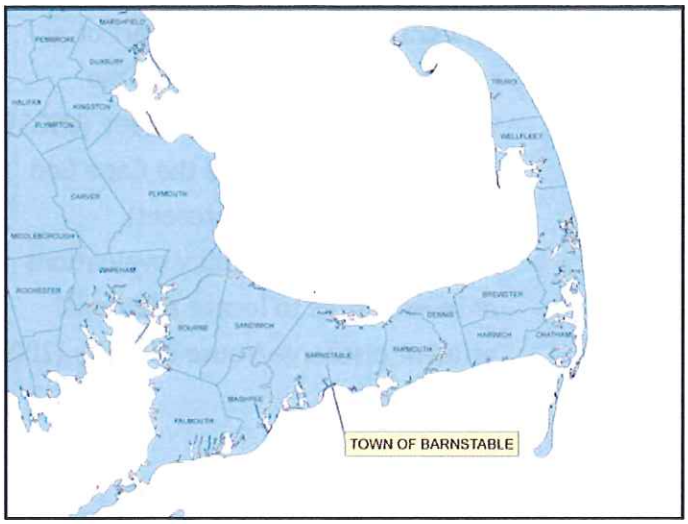


Figure 1 - : Location of Barnstable, MA on Cape Cod

SECTION 2 - IDENTIFICATION AND SCREENING OF NEW EFFLUENT DISCHARGE/REUSE SITES

2.1 First Round Of Screening

The site identification and preliminary screening was performed with the aid of the Town's computerized Geographic Information System (GIS). This system allows the integration of Town geographic information obtained from several aerial and land-based surveys with other databases of information relating to Town resources and activities. The integration of this information allows a Town-wide, multi-level evaluation of criteria. The evaluation utilized the graphical overlay of information to identify and screen sites on the selected criteria. The identification and preliminary screening was a multi-step process using the Town's GIS. The following steps summarize that process.

A. **Step 1.** The GIS was used to search the Town for undeveloped parcels that were 4 acres or greater. A total of 592 parcels were identified. The 4-acre area was used because it was determined to be the minimum area required to discharge a 0.5 mgd

flow, which was established as one of the criteria in the siting process

B. **Step 2.** The total number of identified parcels was reduced by screening out sites which were located in environmentally sensitive areas in which effluent discharge is not allowed. These areas were established by reviewing the recommendations made in the Needs Assessment and in consultation with the Town Department of Public Works, Conservation Department, Planning and Development Department, and Health Department. The following areas were identified:

1. Areas of Critical Environmental Concern (Sandy Neck ACEC).
2. Hyannis Coastal Plain Ponds Complex.
3. Vernal pools.
4. Atlantic White cedar swamps.
5. Rare and endangered wildlife habitat.
6. Rare and endangered plant habitat.
7. Coastal barrier beaches.
8. Coastal barrier beaches with dunes.
9. ZOCs.
10. Conservation areas.
11. Flood hazard zones (Velocity Zones and A Zones).

A base map was created by overlaying the Town boundaries, the location of the WPCF, radial distance in 1-mile increments from the WPCF, assessor's parcel information, and the areas identified above. The parcels identified in Step 1 which are located in the 11 areas were screened out, leaving 207 potential sites.

C. **Step 3.** The third analysis was performed to identify parcels in suitable soils for rapid infiltration beds (RIBs). The USGS surficial geology map was used to determine the general suitability of soils. Sand and gravel deposits and sandy to silty till were accepted, while impervious soils such as clay and silt deposits were not acceptable. Seventy-seven parcels greater than 4 acres, with generally suitable soils for rapid infiltration sand filter beds, were identified. Table 2-1 lists the 77 parcels identified in Step 3, as well as those parcels to be further screened in Steps 4 and 5. The information provided in Table 2-1 includes:

1. **Map, Parcel, and Extension Numbers.** These are assessor's numbers assigned to every property in the Town. The map and parcel numbers are the link used in the GIS for database analysis and graphic illustration.

TABLE 2-1

SUMMARY OF PARCELS ANALYZED FOR EFFLUENT DISPOSAL(1)
Effluent Discharge and Reuse
Guidance Document and Case Study Project
Barnstable County Wastewater Implementatoin Committee and Town of Barnstable, MA

Map No.	Parcel No.	Ext. No.	Owner Name	Parcel Area (acres)	Geologic Soil Class.	USGS Observation Well No.	Zone	Reference Water Level Jun-92	Water Table Adjustment Factor	Range in Depth to Groundwater (G&M 1992) Min.	Max.	Adjusted range in Depth to Groundwater Min.	Max.	Notes
10	43		FRAZIER, ROBERT	4.02	Qmp									(2)
17	25		HORWITZ, ROSE B	4.2	Qmp	MIW29	A	9.89	2.8	18	20	15.2	17.2	
18	97		DAVIS, SARAH B	4.69	Qmp									(2)
18	121		SCHEAR, SARAH D	4.68	Qmp	MIW29	A	9.89	2.8	10	26	7.2	23.2	(3)
40	3	C00	HAYDEN LAND DEVELCO INC	8.25	Qmp	SDW253	C	55.75	13.3	20	38	6.7	24.7	(3)
54	6	1	PARK, WILLIAM E	7.31	Qmp	SDW253	C	55.75	13.3	19	40	5.7	26.7	(3)
54	6	2	PARK, GEORGIA M	4	Qvf									(2)
54	10		KAUFMAN, SUMNER & CAROL A	5	Qmp									(2)
57	1	C00	SAVERY, CHARLES N	11.9	Qmp	SDW253	C	55.75	13.3	15	31	1.7	17.7	(3)
57	1	T00	SAVERY, CHARLES N	7.6	Qmp	SDW253	C	55.75	13.3	15	31	1.7	17.7	(3)
58	39	1	COTUIT LANDING JT VTRE ETAL	7.06	Qmp	SDW253	C	55.75	13.3	26	36	12.7	22.7	
77	37	4	CHAIKIN, RICHARD W	5.08	Qmp	SDW253	C	55.75	13.3	37	47	23.7	33.7	
78	120		DEROSIER, ROGER	4.29	Qmp	SDW253	C	55.75	13.3	30	40	16.7	26.7	
88	2		CARTER, JOHN R & JUDITH C	12.23	Qsm	SDW253	B	55.75	10	77	112	67	102	
88	6		PRINCI, MICHAEL J &	7.75	Qsm	SDW253	B	55.75	10	73	138	63	128	
88	7		SNOWDEN, LAURIE P TRS	15.15	Qsm	SDW253	B	55.75	10	66	134	56	124	
88	8	2	HILLS, FREDERICK L	10	Qsm	SDW253	B	55.75	10	60	140	50	130	
88	9		LEBEL, JOHN S	7.89	Qsm	SDW253	B	55.75	10	100	138	90	128	
108	5		UNKNOWN,	10.67	Qsm	SDW252	A	48.44	2.5	68	121	65.5	118.5	
108	8		CHAMBERS, ROGER A & JAN R	17.43	Qsm	SDW252	A	48.44	2.5	50	112	47.5	109.5	
108	12		MASSSACHUSETTS COMMWLTH OF	5.3	Qsm	SDW252	A	48.44	2.5	45	121	42.5	118.5	
110	2		AITTANIEMI, KARL W JR	4.3	Qsm	SDW252	A	48.44	2.5	91	102	88.5	99.5	
110	4	2	KELLY, JOHN M TRS	11.49	cb	SDW252	A	48.44	2.5	41	100	38.5	97.5	
110	7		LAMPI, CARL H	5.9	af	SDW252	A	48.44	2.5	22	84	19.5	81.5	
110	25	14	WEST PARRISH COMM ASSOC	15.23	cb	SDW252	A	48.44	2.5	57	140	54.5	137.5	(4)
111	69		WEEKES CROSSING COMM ASSOC	19.53	Qs	SDW252	A	48.44	2.5	10	60	7.5	57.5	(3)
126	69		CAPE COD CHURCH OF CHRIST	5.01	Qmp	SDW253	B	55.75	10	10	60	0	50	(3)
127	41		R H MCNEALY INVESTMENT CORP	13.24	Qsm	SDW253	B	55.75	10	42	84	32	74	
130	33		KENNEDY, JOSEPH E &	4.52	Qsm	SDW253	B	55.75	10	55	72	45	62	
131	4		PIERS, THEODORE L	12.69	Qsm	SDW253	B	55.75	10	58	90	48	80	
142	48		BARNSTABLE, TOWN OF (MUN)	57.18	Qk	SWD253	C	55.75	13.3	51	53	37.7	39.7	
150	12		FARRINGTON, EDNA M	11.94	Qsm	SDW253	B	55.75	10	32	51	22	41	
151	8	23	SOLLOWS, JEFFREY A TRS	14.23	Qsm	SDW253	B	55.75	10	50	138	40	128	(4)
151	47	T00	HUNTER HILL RESIDENT ASSOC	17.87	Qsm	SDW253	B	55.75	10	65	132	55	122	(4)
151	47	W00	HUNTER HILL RESIDENT ASSOC	14.94	Qsm	SDW253	B	55.75	10	83	134	73	124	(4)
152	5		STOUT, CHRISTOPHER D &	7.13	Qsm	SDW253	B	55.75	10	37	80	27	70	
155	32	1	BURKE, KATHLEEN H TRS	18.06	Qs									(2)
165	21		HALL, AGNES V	8.36	Qk	MIW29	C	9.89	5.6	43	50	37.4	44.4	
171	2		MASSACHUSETTS COMMWLTH OF	22	Qbo	SDW252	B	48.44	3.8	9	35	5.2	31.2	(3)
173	3	2	CHRIST CHAPEL INC	5.6	Qsm	SDW253	B	55.75	10	30	48	20	38	
173	5		EPSTEIN, LESTER S	16.36	Qsm	SDW253	B	55.75	10	36	52	26	42	
173	86	2	OJALA, RICHARD TRS &	6.83	cb	SDW253	B	55.75	10	18	22	8	12	(3)
174	1	1	BARNSTABLE, TOWN OF	26.7	Qsm	SDW252	B	48.44	3.8	32	84	28.2	80.2	(4)

Map No.	Parcel No.	Ext. No.	Owner Name	Parcel Area (acres)	Geologic Soil Class.	USGS Observation Well No.	Zone	Reference Water Level Jun-92	Water Table Adjustment Factor	Range in Depth to Groundwater (G&M 1992) Min.	Range in Depth to Groundwater (G&M 1992) Max.	Adjusted range in Depth to Groundwater Min.	Adjusted range in Depth to Groundwater Max.	Notes
174	1	X02	HUNTER HILL RESIDENT ASSOC	6.8	Qsm	SDW252	B	48.44	3.8	86	140	82.2	136.2	(4)
174	1	X03	HUNTER HILL RESIDENT ASSOC	9.48	af	SDW252	B	48.44	3.8	40	112	36.2	108.2	(4)
174	7	X01	RICCI, FRANCIS A	11.89	Qs	SDW252	B	48.44	3.8	24	73	20.2	69.2	(4)
174	7	X02	RICCI, FRANCIS A	4.62	Qsm	SDW252	B	48.44	3.8	54	92	50.2	88.2	(4)
174	8		HOLDER, NORMA I	6.39	cb	SDW252	B	48.44	3.8	24	30	20.2	26.2	
175	9		SMITH, ROBERT D	7.74	Qsm	SDW252	B	48.44	3.8	30	90	26.2	86.2	
175	13		SMITH, ROBERT D	6.56	Qsm	SDW252	B	48.44	3.8	60	129	56.2	125.2	
175	15		SMITH, ROBERT D	6.2	Qsm	SDW252	B	48.44	3.8	12	80	8.2	76.2	(5)
176	1	3	UNGERMANN, WALTER W	4.19	Qsm	SDW252	A	48.44	2.5	9	43	6.5	40.5	(3)
176	2	2	JENKINS, JAMES A	7.2	cb	SDW252	A	48.44	2.5	9	20	6.5	17.5	(3)
192	1		MEDEIROS, J CRAIG	5.82	Qbo	SDW252	B	48.44	3.8	24	42	20.2	38.2	
194	21		COMMONWEALTH ELECTRIC CO	5.32	Qsm	SDW252	B	48.44	3.8	100	100	96.2	96.2	
195	5		HORNICK, AVA	7.2	Qsm	SDW252	B	48.44	3.8	64	158	60.2	154.2	
195	6		DIRICO, FRANK	7.54	Qsm	SDW252	B	48.44	3.8	48	159	44.2	155.2	
195	8		WARREN, RICHARD R	4.2	Qsm	SDW252	B	48.44	3.8	58	136	54.2	132.2	
195	29		COMMONWEALTH ELECTRIC	8.5	Qsm	SDW252	B	48.44	3.8	100	135	96.2	131.2	
195	37		CONANT, FRED D	5.27	Qsm	SDW252	B	48.44	3.8	64	148	60.2	144.2	
214	11		CENTERVILLE/OST/MM FIRE DIS	12.5	Qsm	A1W247	C	28.02	9.7	65	110	55.3	100.3	
214	16		CAPPELLETTI, DOMINIC &	12.6	Qbo									(2)
215	20		CAPE COD YMCA INC	4.6	Qsm	A1W247	B	28.02	7.3	80	120	72.7	112.7	
215	23		BARNSTABLE, TOWN OF	8.25	Qsm	A1W247	B	28.02	7.3	71	107	63.7	99.7	
215	27	3	MASSACHUSETTS COMMWLTH OF	4.07	Qsm	A1W247	B	28.02	7.3	76	109	68.7	101.7	
215	28		BARNSTABLE, TOWN OF	5	Qsm	A1W247	B	28.02	7.3	75	120	67.7	112.7	
217	13		WRIGHT, EMILY M	4.14	Qsm	SWD252	A							(2)
234	18	W00	JENKINS, JAMES A	10.93	cb									(2)
234	58	B00	MASSACHUSETTS COMMWLTH OF	7.94	Qsm	A1W247	C	28.02	9.7	33	33	23.3	23.3	
234	60		MONAGHAN, LIAM P &	5.81	Qbo	A1W247	C	28.02	9.7	15	40	5.3	30.3	(3)
236	8		KNOTT, WILLIAM D	15.17	Qsm	A1W247	B	28.02	7.3	40	80	32.7	72.7	
236	11		BARNSTABLE, TOWN OF	8.67	Qsm	A1W247	B	28.02	7.3	40	95	32.7	87.7	
236	12		LOVEQUIST, A LAWRENCE	5.35	Qsm	A1W247	B	28.02	7.3	55	90	47.7	82.7	
236	13		HAYES, NORMAN W & SUSAN B	8.95	Qsm	A1W247	B	28.02	7.3	60	90	52.7	82.7	
256	6		FENNEY, WILLIAM N &	9	Qsm	A1W247	B	28.02	7.3	10	45	2.7	37.7	(3)
354	3		BARNSTABLE, TOWN OF	5.36	Qsm	A1W247	D	28.02	12.2	80	100	67.8	87.8	

Notes:

1. Column headings are described in detail in section 8.3.D of the text.
2. Parcel was screened out due to a minimum depth to groundwater of 8 ft. or less.
3. Parcel was screened out due to a minimum depth to maximum high groundwater of 8 ft. or less.
4. Parcel was screened out due the parcel being an open space for an existing subdivision.
5. Parcel was screened out due to the Adjusted Range in Depth to Groundwater rising to within 8 ft. of the ground surface for a modeled discharge of 0.5 mgd.

Table from Wastewater Facilities Plan - Phase II - Alternatives Screening Analysis, Town of Barnstable, MA Stearns & Wheler, 1996, 2004

2. **Owner's Name.** This is the name of the owner of the property from the assessor's records.

3. **Parcel Area.** This is the area of each parcel in acres from the GIS.

4. **Geologic Soil Classification.** This is the geological soil classification, as defined on the Sandwich, Cotuit, and Hyannis USGS Geologic Quadrangle maps, 1975 edition.

5. **USGS Observation Well Number.** The Cape Cod Commission, Water Resources Office (in cooperation with the USGS), maintains a network of 65 observation wells across the Cape. The water levels in these wells are measured monthly and the data is maintained in computer databases by both the Cape Cod Commission and the USGS.

6. **Zone.** This is the zone in which the parcel is located, and the zone is used to determine the annual water level range used to calculate the maximum high groundwater, as developed by Frimpter and Belfit (1992) and described in Section 8.1D.

7. **Reference Water Level June 1992.** This is the depth to groundwater for the USGS observation well in June 1992. This water level is used in combination with the zone to determine the water table adjustment factor.

8. **Water Table Adjustment Factor.** This is a factor used to adjust the groundwater elevation observed in 1992 to a maximum probable high groundwater level. The groundwater elevation observed in 1992 is presented as "Range in Depth to Groundwater," and the maximum probable high groundwater is presented as the "Adjusted Range in Depth to Groundwater."

9. **Range in Depth to Groundwater.** This is the range in depth to groundwater at each parcel as defined by comparing the observed 1992 water table (Geraghty & Miller) with the topography in the GIS. The range occurs because the topography of the site varies, while the water table is relatively flat.

10. **Adjusted Range in Depth to Groundwater.** The adjusted range in depth to groundwater at each parcel is

the range in depth to groundwater, based on the estimate of maximum high groundwater.

D. **Step 4.** A fourth analysis was performed to eliminate any parcels that have groundwater within 8 feet of the surface. The Geraghty & Miller 1992 Observed Groundwater Table Map, Figure 8 of the Groundwater Conditions Report (Geraghty & Miller, 1993), was used for this analysis.

E. **Step 5.** A fifth analysis was performed to review existing land use to determine if any of the remaining parcels were open space parcels for existing subdivisions.

F. **Step 6.** A sixth analysis was performed using hydraulic conductivities from the Groundwater Conditions Report (Geraghty & Miller, 1993) and the groundwater model (Geraghty & Miller, 1992) prepared during the Needs Assessment to establish the "mounded" groundwater level based on an effluent discharge of 0.5 mgd at each parcel. One parcel was eliminated as a result of this analysis.

G. **Step 7.** At this point, members of the Town met with MADEP to review the Town's progress in identifying and screening potential effluent discharge sites. At the request of MADEP, three sites that had been previously screened out were added to the list of sites to receive detailed evaluations.

H. **Step 8.** The eighth step involved consolidating the individual parcels into potential sites and the prioritization of the potential sites. The consolidation of parcels was accomplished by combining the 48 parcels into potential sites by grouping abutting parcels. Included in this effort are undeveloped parcels less than 4 acres that immediately abut the potential sites. Thirty potential sites were formed in anticipation of a more detailed screening in Phase III. The 30 sites were then prioritized to identify those most favorable for effluent discharge sites. The prioritization was based on five factors (listed below), for which various scoring scales were assigned. Additionally, each factor was given a weighting factor to give it a relative importance compared to the other factors. The scales and weighting factors are subjective and based on the priorities of the town completing the evaluation.

1. **Type of Owner.** This is the type of property owner based on assessor's

records. Ownership has been divided into three categories: town, public, and private. A prioritized ranking has been assigned to each of the three categories as follows: Town = 1; Public = 5; and Private = 10. Type of ownership carries a percentage weighting of 15 percent in the final prioritization.

2. **Hydraulic Conductivity.** The hydraulic conductivity values from the groundwater conditions report (Geraghty & Miller, 1993) and the groundwater model (Geraghty & Miller, 1993) prepared during Phase I were used to define hydraulic conductivity at each of the 30 sites. An incremental weighting was given to the hydraulic conductivities ranging from 1 for a site with a hydraulic conductivity of 200 ft/day to 9 for a site with a hydraulic conductivity of 0 ft/day. For each 25 ft/day change in hydraulic conductivity, one point change was reflected in the ranking. Hydraulic conductivity carried a percentage weighting of 20 percent in the final prioritization.

3. **Distance to the WPCF.** Sites closest to the WPCF were prioritized higher within that category than sites farthest away from the WPCF. The ranking for distance to the WPCF is the actual miles recorded from the GIS system. Distance to the WPCF carried a percentage weighting of 40 percent in the final prioritization.

4. **Abutting Land Use.** Each site was evaluated for compatible abutting land use. The Town zoning map and GIS were used to identify abutting land use. Residential land use was considered the least desirable abutting use.

Abutting land use was divided into two categories: (a) residential with a ranking of 10; and (b) non-residential with a ranking of 5. Abutting land use carried a percentage weighting of 5 percent in the final prioritization.

5. **Slope Ratio for Site Topography.** The GIS was used to define the range in distance to groundwater and area of each use. This data was put into an equation to relate the change in distance to groundwater on a site to the overall area of a site. The ranking for the slope ratio was the actual value calculated for each site. Slope ratio for site topography carried a percentage weighting of 20 percent in the final prioritization.

The final prioritization of each site was calculated by multiplying the prioritized ranking by the percent weighting for each of the five categories described above. This resulted in a final prioritized rating for each site ranging from 3 (most preferable) to 7 (least preferable). The prioritized rating was grouped into the following categories for further evaluation of Phase III: primary sites for evaluation (rating of 3); secondary sites for evaluation (rating of 4); and alternative sites for evaluation (rating of greater than 4). There were 2 primary sites, 8 secondary sites, and 20 alternative sites.

2.2 Second Round Of Screening

The results of the first round of screening were reviewed through the public participation process. After receiving all comments, the Town conducted a revised screening. In the second round of screening, a process similar to the first round was utilized. A nine-step screening process was used and, as in the first round, was based primarily on data available in the Town's GIS database. The screening was started using the assumption that the entire Town was available for land disposal. The screening process excluded or prioritized candidate sites by evaluating areas with respect to the criteria described for the first round. The second round entailed the following steps:

A. **Step 1**. The GIS database was used to map Zone IIs, groundwater protection areas and wellhead protection areas. In the time between the first and second screening efforts, MADEP became more receptive to treated wastewater discharge in Zone IIs. Although MADEP strongly discouraged recharge in Zone IIs in the early stages of the facilities planning process, the agency began considering the value of discharge in Zone IIs as a form of reuse. Recharge into a Zone II was no longer an exclusion criteria, but Zone II locations and distance from production wells were still significant criteria in siting (see Appendix A, Map 1).

B. **Step 2**. Step 2 identified areas that were restricted due to their environmental significance and mapped locations of ACECs, the Coastal Plain Complex, vernal pools wetlands, flood zones, and areas of rare and endangered habitats (see Appendix A, Map 2).

C. **Step 3.** Step 3 mapped areas where groundwater was at depths less than 10 feet (see Appendix A, Map 3).

D. **Step 4.** Step 4 mapped hydraulic conductivity boundaries as defined in the 1992 Geraghty & Miller evaluation (see Appendix A, Map 4).

E. **Step 5.** In Step 5, areas within 1/2 mile of those areas identified in Step 3 that are mapped as having groundwater within 10 feet of the surface were identified. This criteria was established to address concerns related to groundwater mounding as a result of recharge and the potential impacts the mounding could have on structures such as basements, leachfields, and septic tanks.

At the end of Step 5, the process resulted in the identifications of three areas of Town that were most favorable for wastewater recharge. The three areas were designated as Area A, located south of the Mid-Cape Highway on the western side of Town; Area B, located along the Mid-Cape Highway in the vicinity of Cape Cod Community College; and Area C, north of the Mid-Cape Highway on the eastern boundary of the Town (see Appendix A, Map 5).

F. **Step 6.** In Step 6, coastal recharge areas were added to the mapping to determine which embayment would be the ultimate receiving water for the discharged effluent (see Appendix A, Map 6).

G. **Step 7.** In Step 7, distance from the existing wastewater treatment plant was indicated on the project mapping. Areas A, B, and C were prioritized with respect to their distance from the treatment plant. Area B was the top priority area, as it was closest to the treatment plant (see Appendix A, Map 7).

H. **Steps 8, 9, and 10.** In Steps 8, 9, and 10, Areas B, C, and A respectively, were evaluated in a more detailed manner. The sites were evaluated with respect to:

1. Parcel sizes.
2. Degree of existing development.
3. Location with respect to Zone IIs.
4. Type of ownership (public or private).
5. Soil characteristics.
6. Depth to groundwater.
7. Abutting land use.
8. Accessibility of site.
9. Proximity to pubic water supplies.
10. Proximity to conservation lands.
11. Which coastal recharge area.
12. Site topography.

The second round of screening concluded that Area B represented the most favorable area in Town for recharging treated wastewater (see Appendix A, Map 8). The area had the advantage of having minimal environmental concerns, appeared to have available sites, and was closest to the wastewater treatment plant. A possible disadvantage was the fact that the area was located on the Sandwich Moraine, where soil conditions are not as favorable for recharge than the outwash plain. This had to be accepted, however, in that the outwash plain is generally too densely developed for siting recharge facilities. Subsequent site-specific testing in Phase III would be employed to determine the suitability of the soils for recharge. A second possible disadvantage was that drainage was potentially to the north, which was considered to be less desirable than drainage to the south.

The Town concluded that detailed evaluations would be conducted at yet-to-be-identified candidate sites in the vicinity of Area B.

2.3 Candidate Site Selection

The next step in the site identification and screening task entailed identifying specific sites and parcels at which recharge was considered feasible, and assessing the availability of parcels. This step included selecting specific parcels, contacting owners, and establishing availability. At the end of this process, seven sites were identified as potential candidate sites. The sites and their initial evaluation are described below.

A. **Cape Cod Community College.** The college has a significant amount of undeveloped acreage available for use. The college is interested in being connected to the treatment plant, which could facilitate a cooperative venture between the Town and the college.

B. **McManus Site.** The McManus site is a Town-owned, 11-acre area southeast of the intersection of the Route 6 Mid-Cape Highway and Route 132. The site is advantageous because of the surrounding land use, but has the disadvantage of having rugged topography.

C. **Lorusso Property**. The Lorusso property is a privately owned 11-acre site that is a power line right-of-way, parallel to and just south of the Route 6 Mid-Cape Highway. The site had the advantages of compatible area land use, size, and a willing private owner; but the disadvantages of irregular topography and power lines and poles that limit development area.

D. **Cape Cod Aggregate Property**. The Cape Cod aggregate property had the benefit of size, availability, and proximity to an existing but unused force main. Initial inspection of the site revealed it was comprised largely of asphalt and stump fill material. As a result, the site was rejected from further consideration.

E. **Route 6 Corridor**. The median or edges of the Route 6 corridor in the Town of Barnstable were considered a possible candidate site. Early conversations with the Massachusetts Highway Department indicated reluctance on their part to allow discharge in the right-of-way. Provincetown had to purchase the right-of-way to use it for its effluent discharge facilities. Purchase of the long stretch of Route 6 in Barnstable was not regarded as a likely option, and consideration of use of the Route 6 corridor was suspended.

F. **Route 132 Corridor**. The Route 132 corridor between Route 6 and Hyannis was considered an option that was made more favorable by a planned reconstruction of that segment of road. However, because it was believed the road layout area did not represent a sufficient area for recharge, consideration was suspended.

G. **Barnstable Municipal Airport.** Although somewhat remote from Area B and previously removed from consideration because of some general environmental concerns, there was widespread belief within the regulatory community and the Town that the airport should still be considered for discharge. It has a large available area, early discussions with the airport indicated land could be made available, and it is in proximity to the treatment plant.

The initial screening of candidate sites resulted in the identification of four sites that would undergo a detailed site-specific characterization. Those remaining candidate sites included:

1. The McManus site.
2. Cape Cod Community College.
3. The Lorusso property.
4. The airport.

The locations of the sites are shown on Figure 2. The site characterization that was conducted at each of these sites is described in the next section.

SECTION 3 - SITE CHARACTERIZATION

3.1 Purpose Of Site Characterization

Although the candidate sites had been generally characterized through the screening and identification process, the hydrogeologic assessment had been based primarily on regional or sub-regional mapping. Soil types, stratigraphy, depth to water, and hydraulic properties can vary widely in a small area. Because of that, it was important to assess site-specific hydrogeologic properties of the site to verify that the site can accept the amount of water proposed for recharge at that site. There were two important parameters to evaluate to characterize the site: (1) the capacity of the site to allow vertical infiltration of water; and (2) the capacity of the aquifer beneath the site to convey water away from the recharge area. At sites where wick wells or injection wells are being considered, the vertical infiltration parameter is not a concern because effluent is conveyed directly into the aquifer. A related parameter is the depth to groundwater, which is important for determining the mounding impacts of a potential effluent discharge facility.

3.2 Field Investigation Tasks

Field investigation tasks at the four candidate sites included excavation of test pits, completion of percolation tests, completion of soil borings, installation of observation wells, completion of in-situ hydraulic conductivity tests (slug tests), and site surveys. In each case, each field investigation was preceded by a site reconnaissance trip and conversations with the landowners. The objectives of the site reconnaissance were to determine site conditions, determine possible discharge facility locations, identify areas for testing and assessing access to test locations by observing topography, presence of low wet areas, and density of trees on wooded land. At the meetings with site owners, the



Figure 2: Locations of candidate recharge sites in the Town of Barnstable

objectives of the study were reviewed and the proposed elements of the field work were discussed. Acceptable degrees of clearing or grading, if needed, were agreed upon.

Following site reconnaissance and meeting with the landowner, it was possible to develop a work plan for each investigation. In each case MADEP was informed of the identification of each site and that a field investigation was planned. MADEP was notified of the schedule in the event they wished to observe any of the proposed work.

The scope of work at each site was designed to be completed in an iterative fashion that would allow decision making as work progressed. If conditions suggested the site was not suitable at any point in the investigation, then subsequent tasks such as well installation in a boring would not be completed.

A. **McManus Site.** The McManus site has rugged topography that limited access and the owner did not permit any tree clearing. As a result of those limitations, one soil boring/observation well was installed. Six test pits were installed in accordance with MADEP protocols and were logged by a certified soil evaluator. Those test pit observations could subsequently be used for the groundwater discharge permit application, although it was known it would be necessary to complete additional test pits in the future, should a decision be made to permit the site.

The observation well revealed that the subsurface at the site was comprised of fairly uniform fine to medium sand with traces of silt and gravel. The sand was very tightly packed. Groundwater was encountered at a depth of 58 feet, and a low permeability layer was encountered at 84 feet.

Multiple slug tests were performed in the observation well to estimate hydraulic conductivity. The slug tests yielded a result of approximately 1 foot per day. This was a lower rate than anticipated based on USGS and other published regional information and the nature of the material penetrated. Municipal supply wells located approximately 3,000 feet southeast of the site yield approximately 700 gpm, suggesting a higher hydraulic conductivity. Also, the generally clean sands present in the well would suggest a higher hydraulic conductivity. USGS has mapped this area to have a hydraulic

conductivity of approximately 200 feet per day. The low results could be attributed to the tight nature of the sands observed or the inherent inaccuracies of slug tests.

Test pits were advanced to 7 or 8 feet and revealed sandy loam grading to fine to medium sand. Percolation test rates ranged from 1.3 to 4.3 minutes per inch, under the 5 minutes per inch specified by MADEP for a loading rate of 5.0 gpd/sq. ft.

The investigation concluded that the McManus site could be a potential discharge site. Advantages included proximity to the treatment plant; suitable surrounding land use; good percolation rates; uniform, clean sand; and deep groundwater. Disadvantages included irregular topography and a potentially low hydraulic conductivity. The potentially low hydraulic conductivity is not necessarily a deterrent to development because of the significant depth to groundwater, which would limit adverse impacts of mounding. Based on the available area, the capacity of the site was estimated at approximately 1,600,000 gpd. Based on the results of the site investigation, the Town retained the McManus site as a candidate location for discharge.

B. **Cape Cod Community College.** The investigation at the college focused on two separate areas -- an athletic field and a wooded area. One observation well and one test pit were used to characterize the athletic field, and two observation wells and two test pits were used to characterize the wooded area. Following the original site reconnaissance and meeting with college personnel, it was determined the characterization of the wooded area would be accomplished with wells and test pits along the edge of the wooded area in order to avoid clearing trees or grading a road to the interior of the site.

The athletic field is approximately 5 acres and the wooded area is approximately 17 acres. The advantages of the field are that it is graded flat and is already open. The disadvantage is that it is only suitable for a subsurface system, which has less capacity per available area. The advantage of the wooded area is its size, and the disadvantages are that it is wooded and has irregular topography that would require additional grading.

Both the test pit and soil boring in the field revealed there are a number of large boulders in the subsurface. The boring location had to be moved twice to find a

location suitable for drilling. The presence of the boulders would complicate construction and could potentially impact the effectiveness of the site for recharge, so further consideration of the field was deferred.

The observation wells and test pits adjacent to the wooded area provided results that indicated the area could be suitable for discharge. Fill material and boulders were present in one of the test pits near the woods, so a percolation test was only completed in one of the two test pits. A percolation rate of 0.67 minutes per inch indicated the suitability of the area. The observation wells adjacent to the wooded area were advanced to depths of 84 and 96 feet. Fine to coarse sand was observed in both wells over their entire depth, and groundwater was encountered between 65 and 70 feet.

Slug testing indicated a hydraulic conductivity of approximately 100 feet per day, a reasonable value for the aquifer materials observed. Based on an estimated recharge of 1 mgd, a mound of approximately 12 feet was calculated. With groundwater being 65 to 70 feet deep, that degree of mounding did not represent an adverse impact.

The wooded area of the college was retained as a viable discharge site. The site has the advantage of size, with approximately 8 acres of application area available, allowing for the discharge of approximately 1.7 mgd using sand beds. If subsurface trenches are utilized, the capacity is approximately 1 mgd. One disadvantage associated with the site is the rolling topography, which would require additional site preparation work.

C. **Lorusso Property.** The Lorusso property is owned by a local sand and gravel supplier. It is comprised of 11 acres in multiple parcels and is situated along a power line right-of-way immediately south of Route 6. The site had the advantage of size and suitable adjacent land use, but the disadvantages include irregular topography and power line poles that would limit the extent of discharge facilities.

The site was investigated with three observation wells, slug tests, five test pits, and four percolation tests. The observation wells indicated the subsurface is comprised primarily of fine sand. At a depth of approximately 40 feet in two of the borings and 70 feet in the third boring, the fine sands graded to silt. Groundwater was

encountered between 60 and 65 feet. Slug testing indicated a hydraulic conductivity of approximately 50 feet per day. Earlier modeling in this area had used a similar hydraulic conductivity, but more recent modeling efforts by the USGS assumed a higher rate (150 feet per day). For mounding calculations, a conservative conductivity of 50 feet per day was used. Based on a discharge rate of approximately one million gallons per day, a mound height of 12 feet was calculated.

Because of the site's location on the crest of the Sandwich Moraine, groundwater flow direction could conceivably be to the north or south especially after mounding effects are considered. The site is in the Zone II of a well located approximately 2,000 feet to the northwest, but travel time to that well was calculated to be approximately five years. Travel time is a function of hydraulic conductivity and hydraulic gradient.

The test pits revealed uniform fine sand in the subsurface across the site, with the exception of the northeastern test pit, which had a silt layer present at a depth of about 6 feet. A percolation test was not completed in that test pit. In the other test pits, percolation rates of under 2 minutes per inch to 4.6 minutes per inch were recorded, indicating the suitability of the site.

It was determined that the Lorusso property would remain under consideration for discharge.

D. **Airport.** The airport is a roughly triangular piece of property, opening up to the northwest and northeast. The airport property includes 418 acres with a large area of flat, open land bordering the runways. Advantages of the airport include the expanses of open, flat land and proximity to the treatment plant. Disadvantages include proximity to endangered wildlife, proximity of production wells, shallow groundwater (15 to 20 feet), and construction limitations resulting from being on airport property. Specifically, there can be no construction within 150 feet of the runways and no vertical obstructions within 500 feet of the runways, meaning that subsurface leaching systems would have to be utilized.

Three areas of the airport were investigated: the northwest corner, the northeast corner and the east side of the southern point of the airport. Each area was investigated with one observation well

and three test pits. One percolation test was completed in each area. Slug tests were attempted, but were determined to not be representative of the soil conditions present, so hydraulic conductivity values used in USGS mapping efforts were used for groundwater travel time and mounding calculations. Test pits and percolation tests revealed the presence of medium to coarse sand and percolation rates of approximately 2 minutes per inch, generally good conditions for recharge.

The soil borings revealed the subsurface was comprised of medium to coarse sand and groundwater was at a depth of approximately 20 feet. Being in the outwash plain, rather than on the moraine, the airport had the most favorable soil conditions; however, the location was also accompanied by shallower groundwater. Based on a discharge rate of 1 mgd, a mound of approximately 13 feet was calculated, which results in the water table potentially rising to within 7 feet of the surface. Mottling observed in test pits further suggested that seasonal high groundwater could be higher than levels observed during the field investigation, which could limit recharge rates. Buildings or septic systems proximal to the airport could potentially be impacted.

Groundwater flow rates were also considered, given the proximity of the candidate discharge sites to production wells. However, flow rate calculations indicated that discharge sites were probably beyond the two-year travel time from the production wells.

Although the airport had many advantages and was not removed from further consideration, its priority was lowered because of concerns related to water table elevation and groundwater mounding.

3.3 USGS Modeling

Concurrent with the Town completing its site investigations, Barnstable County, through the Cape Cod Commission, entered into an agreement with the USGS to provide groundwater modeling in support of the Town's wastewater planning efforts. The timing of the Barnstable project and the agreement with USGS allowed Barnstable to be the first town to take advantage of this service.

USGS has completed several versions of groundwater models across Cape Cod over the past several years. The models have recently been upgraded and revised

related to water supply evaluations and to support the Massachusetts Estuaries Project. Separate models have been completed for the following groundwater systems on the Cape:

1. The Sagamore Lens which extends from Falmouth to Barnstable.

2. The Monomoy Lens that extends eastward to Chatham.

3. The multiple smaller lenses on the Outer Cape extending from Eastham to Provincetown.

The Town of Barnstable falls into the Sagamore Lens model. The basic model reflects groundwater contours as a function of pumping from production wells and the recharge from the Barnstable treatment plant in addition to natural recharge and discharge and return flow from septic systems.

The existing model served as a useful tool for further evaluating the effects of recharge at the various candidate sites. The USGS was able to modify their model by adding the proposed recharge at the various candidate sites. After the proposed recharge was added, the simulations provided information related to mounding, flow direction, travel time, and discharge to surface waters. Numerous possible recharge scenarios were completed by USGS at request of the Town, including:

Scenario 1 - 1 mgd at WPCF; 0.5 mgd at the McManus site, 0.5 mgd at Cape Cod Community College

Scenario 2 - 1 mgd at WPCF; 1 mgd at the McManus site

Scenario 3 - 1 mgd at WPCF; 1 mgd at Cape Cod Community College

A number of other potential scenarios were also modeled. The output for the model runs (Appendix B) provided information related to flow rates and directions. Flow rate and direction was indicated through the use of particle track lines. A specific quantity of water was recharged at each recharge site and a specific number of "particles" was assigned to the recharge cells that represented the flow of water from that location. The number of particles can therefore represent the quantity of water flowing from the recharge site, and the track of the particles represents the flow direction. The particles can also be used to represent

mass of conservative solutes, such as nitrogen, that is flowing from the discharge sites. Additionally, the tracks of the particles are color coded to represent distance traveled after various time intervals (1 to 5 years, 5 to 10 years, 10 to 50 years, and 50 to 100 years).

Some of the general observations from the simulations include:

1. Groundwater elevation at the treatment plant lowered in response to distributing some of that flow to remote sites.

2. Groundwater mounds of 4 to 8 feet formed at the new remote discharge sites depending on the distribution of flow.

3. In Scenario A, all flow from the college was toward Barnstable Harbor.

4. In Scenario B, most of the flow from the remote sites was toward Barnstable Harbor, with minor flows to proximal public supply wells and some flow to the south toward Lake Wequaquet.

The modeling provided information that assisted in evaluating the various remote sites. Issues identified in reviewing the model outputs included nutrient flow to Barnstable Harbor and Lake Wequaquet, and treated effluent flow toward production wells. The general conclusion of the modeling effort was that issues warranting consideration were identified related to every scenario, but none were perceived as being so significant as to prevent further evaluation of any of the scenarios.

SECTION 4 - CONCEPTUAL DESIGN AND COST EVALUATIONS

4.1 DISCHARGE TECHNOLOGY SCREENING

After the four candidate sites were screened, evaluated, and determined to warrant final characterization, discharge technologies were evaluated for suitability at each site. The various technologies described in Part 1 of this document were evaluated for suitability at each of the four candidate sites. RIBs, subsurface leaching, and spray irrigation were considered. Injection wells and wick wells were rejected because they are generally unproven technologies in this area and because of regulatory resistance. Each of

the technologies was considered at each of the four sites. The results of that evaluation are summarized below.

A. **McManus Site (Site B).** At this site, RIBs and subsurface infiltration were identified as appropriate technologies. Spray irrigation was identified as not appropriate due to the visual and misting impacts adjacent to Route 6.

B. **Airport Site (Site C).** At this site, subsurface infiltration was identified as an appropriate technology. RIBs and spray irrigation were identified as inappropriate because they could produce areas of standing water which could attract birds and be a hazard to air traffic. Also, the sand bed technology would utilize aboveground structures (berms), which are not allowed in close proximity to the runway.

C. **Cape Cod Community College Site (Site D).** At this site, RIBs and subsurface infiltration were identified as appropriate technologies. Spray irrigation was identified as not appropriate due to the visual and misting impacts adjacent to Route 6, the college center, and the interchange.

D. **Lorusso Site (Site E).** At this site, RIBs and spray irrigation were identified as appropriate technologies. Subsurface infiltration was identified as not appropriate because its lower hydraulic application rate in combination with the small site would result in a small discharge capacity.

Based on this evaluation, the following seven scenarios were developed for further evaluation:

B1: McManus site with RIBs
B2: McManus site with subsurface infiltration
C2: Municipal Airport site with subsurface infiltration
D1: Cape Cod Community College site with RIBs
D2: Cape Cod Community College site with subsurface infiltration
E1: Lorusso site with RIBs
E3: Lorusso site with spray irrigation

4.2 Conceptual Design

After potential discharge technologies were identified for each site, a conceptual design was completed which included a layout defining the actual recharge area

and associated capacity of the site with each selected discharge technology. The resultant capacity was one of the final evaluation criteria for the site.

Each alternative conceptual design was developed as described below. Conceptual layout sketches are provided in Appendix C.

A. **B1 - The McManus Site with RIBs.** Approximately 8 acres would be available for effluent application and approximately 1.6 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include installation of primary and standby effluent pumps. Improvements along the route would include the installation of a 12-inch force main with associated structures. Improvements at the site would include grading, piping, and sand bed construction.

B. **B2 - The McManus Site with Subsurface Infiltration.** Approximately 9 acres would be available for effluent application and approximately 0.7 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include new filtration facilities and effluent pumps. Improvements along the route would include the installation of a 10-inch force main with associated structures. Improvements at the site would include a receiving wet well, dry well with pumps, grading, piping, valves, and infiltration trench construction.

C. **C2 - The Municipal Airport Site With Subsurface Infiltration.** Approximately 28 acres would be available for effluent application and approximately 2.3 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include new filtration facilities, phosphorus removal facilities, and effluent pumps. Improvements along the route would include the installation of a 14-inch force main with associated structures. Improvements at the site would include a receiving wet well, dry well with pumps, grading, piping, valves, and infiltration trench construction.

D. **D1 - The Cape Cod Community College Site With RIBs.** Approximately 8 acres would be available for effluent

application and approximately 1.7 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include installation of primary and standby effluent pumps. Improvements along the route would include the installation of a 10-inch force main with associated structures. Improvements at the site would include grading, piping, and sand bed construction.

E. **D2 - The Cape Cod Community College Site With Subsurface Infiltration.** Approximately 15 acres would be available for effluent application and approximately 1.1 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include new filtration facilities and effluent pumps. Improvements along the route would include the installation of a 10-inch force main with associated structures. Improvements at the site would include a receiving wet well, dry well with pumps, grading, piping, valves, and infiltration trench construction.

F. **E1 - The Lorusso Site with Site RIBs.** Approximately 2.3 acres would be available for effluent application and approximately 0.5 mgd could be applied. Development of this design would require infrastructure improvements at the WPCF, along the route, and at the site. Improvements at the WPCF would include installation of primary and standby effluent pumps. Improvements along the route would include the installation of a 8-inch force main with associated structures. Improvements at the site would include grading, piping, and sand bed construction.

G. **E3 - The Lorusso Site With Spray Irrigation.** Approximately 5.0 acres would be available for effluent application and approximately 0.04 mgd could be applied. Based on the limited application volumes, this scenario was not been developed.

Following the conceptual design and determination of the various engineering requirements for each site, costs were developed for each site. A final site ranking was developed that included such criteria as size, capacity, topography, depth to water, soil type, adjacent land use, proximity to sensitive receptors and cost. Tables 4-1 and 4-2 summarize these factors.

TABLE 4-1

SUMMARY OF EFFLUENT DISCHARGE TECHNOLOGIES
Effluent Discharge and Reuse
Guidance Document and Case Study Project
Barnstable County Wastewater Implementation Committee and Town of Barnstable, MA

ALTERNATIVE	REGULATORY REQUIREMENTS	EFFLUENT QUALITY	MAINTENANCE REQUIREMENTS AND COMPLEXITY OF OPERATION	FLEXIBILITY	ENERGY USE
Rapid Infiltration Beds	Permitting and monitoring of effluent discharges and design requirements. Disinfection may be required by MADEP.	Effluent is already treated and sand beds provide some additional treatment.	Effluent discharge is reliable throughout the year and easy to maintain.	Flexibility is possible with multiple beds.	Lowest energy requirements due to no need to repump the effluent at the sand beds.
Subsurface Infiltration	Disinfection is not required prior to discharge, unless required to meet the Interim Guidelines for Reclaimed Water Use.	Effluent is already treated and infiltration facilities provide additional treatment. Effluent should be filtered before discharge.	Repair of the beds would be difficult because they are subsurface	Moderate depending on construction of dosing equipment and distribution piping.	Moderate due to effluent dosing pumps.
Spray Irrigation	Permitting and monitoring of effluent discharges and design requirements. Disinfection may be required by MADEP.	Spray irrigation provides further uptake of nitrogen in the effluent.	Moderate maintenance to maintain piping. Spray irrigation cannot be used in freezing weather.	Must have redundant back-up facilities for winter discharge.	Moderate due to repumping requirements.
Ocean Outfall	The Massachusetts Ocean Sanctuaries Act prohibits discharge of municipal wastewater into an ocean sanctuary. An NPDES permit required.	Disinfection may be required for the outfall.	Maintenance similar to a large force main	Minimal, unless land disposal remains for some backup discharge.	Moderate due to pumping requirements
Deep Well Injection	Permitting and monitoring of effluent discharges and design requirements. MADEP is not supportive of this technology.	Effluent must be well treated (filtered and chlorinated) before discharge.	Uncertain reliability due to few operating installations and increased maintenance due to the potential of plugging of injection point with solids.	Installation of multiple wells would allow individual wells to rest or be repaired.	Moderate due to repumping requirements.

TABLE 4-1 (continued)

ALTERNATIVE	REGULATORY REQUIREMENTS	EFFLUENT QUALITY	MAINTENANCE REQUIREMENTS AND COMPLEXITY OF OPERATION	FLEXIBILITY	ENERGY USE
Wick Wells	Permitting and monitoring of effluent discharges and design requirements. MADEP regards this as an innovative technology.	Effluent must be well treated (filtered and chlorinated) before discharge.	Uncertain reliability due to few operating installations and increased maintenance due to the potential of plugging of injection point with solids.	Installation of multiple wells would allow individual wells to rest or be repaired.	Moderate due to repumping requirements.
Wetland Restoration	Possible extensive wetland permitting depending on the type of restoration. Permitting and monitoring of effluent discharges and design requirements. MADEP regards this as an innovative technology.	Effluent must be well treated (phosphorus removal in addition to standard nitrogen removal, and disinfected before discharge)	Very low maintenance requirements and low operations complexity.	Minimal operations control. Flexibility would be provided with variable surface water level controls in the abandoned bog.	Moderate due to repumping requirements.

ALTERNATIVE	LAND REQUIREMENTS	POTENTIAL FOR AIR EMISSIONS	PUBLIC ACCEPTANCE	RELATIVE CAPITAL COSTS	RELATIVE O&M COSTS	SELECTED FOR DETAILED EVALUATION
Rapid Infiltration Beds	Moderate at large wastewater flows when compared to subsurface leaching.	Effluent is treated to a high level and odors would be minimal.	Potential for low acceptance from residents who are impacted by bed siting and construction.	Relatively low due low land area and easier construction.	Low due to low energy requirements and minimal maintenance.	Yes; the technology is simple and reliable. O&M requirements are minimal.
Subsurface Infiltration	Relatively high. Land surface above the infiltration system can be used for other purposes	Minimal.	Acceptance should be high due to minimal visual impacts and potential reuse of land area.	Relatively high due to highest land area and extensive piping.	High due to pumping requirements and potential high repair/cleaning costs.	Yes; technology is reliable and provides secondary use of discharge area.

TABLE 4-1 (continued)

ALTERNATIVE	LAND REQUIREMENTS	POTENTIAL FOR AIR EMISSIONS	PUBLIC ACCEPTANCE	RELATIVE CAPITAL COSTS	RELATIVE O&M COSTS	SELECTED FOR DETAILED EVALUATION
Spray Irrigation	Relatively high. Land above system can be can be used for other purposes when spray irrigation is turned off.	Minimal.	The public will want to see recycling of the effluent though they may be concerned about possible health threats.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to maintenance and pumping requirements.	Yes; it provides additional nitrogen uptake and reuse of the effluent.
Ocean Outfall	Minimal.	Minimal.	Low. Based on the opposition to the Deer Island outfall and the Ocean Sanctuaries Act.	Relatively high due to land area, extensive permitting pumping requirements.	Moderate due to pumping requirements	Yes, as a last alternative if all other land disposal alternatives are not sufficient to meet the Town's need.
Deep Well Injection	Relatively low compared to sand infiltration beds and subsurface leaching.	Minimal.	Land area requirements and visual impacts are minimal.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to pumping requirements. And maintenance needs.	No; MADEP is resistant to support the technology due to the need to chlorinate the effluent
Wick Wells	Relatively low compared to sand infiltration beds and subsurface leaching.	Minimal.	Land area requirements and visual impacts are minimal.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to pumping requirements. And maintenance needs.	Yes, MADEP has recently permitted a wick facility. Low land area is a benefit, however, MADEP is currently requiring 100% capacity reserve area for conventional system.
Wetland Restoration	Would make use of an existing extensive land area. The restoration efforts would occur in specific flow control and infiltration areas.	Minimal.	Could be favorable due to understanding that the technology/ concept is a restoration effort and the project could restore proper hydraulic balance to the watershed.	Relatively low due to minimal excavation, and minimal need to reshape the land.	Moderate due to pumping requirements. And maintenance needs.	Yes. There is much interest at MADEP with this concept to take an integrated approach to watershed management. This could be cost effective and provide secondary benefits.

TABLE 4-2

SUMMARY OF SITE EVALUATION
Effluent Discharge and Reuse
Guidance Document and Case Study Project
Barnstable County Wastewater Implementation Committee and Town of Barnstable, MA

ALTER-NATIVE NO.	ALTERNATIVE NAME	INFILTRATION LAND AREA (ACRES)	ESTIMATED FACILITY CAPACITY (MGD)	DISTANCE FROM WPCF (LF)	SITE TOPOGRAPHY	SOIL PERMEABILITY (PERCOLATION RATE)	DEPTH TO GROUNDWATER	ABUTTING LAND USE
B1	McManus site with sand beds	7.5	1.6	12,600	Irregular and undulating topography: tree vegetation	Less than 5 minutes/inch	±58 feet	Undeveloped and road ROW
B2	McManus site with subsurface infiltration	11	0.9	12,600	Irregular and undulating topography: tree vegetation	Less than 5 minutes/inch	±85 feet	Undeveloped and road ROW
C2	Airport site with subsurface infiltration	28	2.3	8,600	Mostly flat with a slight slope from northwest to southeast, grassed	Less than 5 minutes/inch	±20 feet during drilling; 14 to 18 feet after	Commercial property, undeveloped property and road ROW
D1	Cape Cod Community College site with sand beds	8.1	1.7	15,500	Natural topography is irregular and undulating: tree vegetation	Less than 5 minutes/inch	±65 to 70 feet	Undeveloped, road ROW, and Community College
D2	Cape Cod Community College site with subsurface infiltration	14	1.1	15,500	Natural topography is irregular and undulating: tree vegetation	Less than 5 minutes/inch	±65 to 70 feet	Undeveloped and road ROW
E1	Lorusso site with sand beds	2.3	0.5	10,400	Lightly vegetated, rolling terrain, disturbed site with powerlines overhead	Less than 5 minutes/inch	±65 feet	State roadway and undeveloped
E3	Lorusso site with spray irrigation	5	0.04	10,400	Lightly vegetated, rolling terrain, disturbed site with powerlines overhead	Less than 5 minutes/inch	±65 feet	Undeveloped

TABLE 4-2 (continued)

ALTER-NATIVE NO.	ALTERNATIVE NAME	AESTHETIC IMPACTS	PROXIMITY TO SENSITIVE RECEPTORS	CAPITAL COSTS	CAPITAL COST PER MGD ($/MGD)	ESTIMATED ANNUAL O&M COSTS	PRESENT-WORTH COSTS	PRESENT-WORTH COST PER MGD ($/MGD)
B1	McManus site with sand beds	Moderate due to deforestation and image of sand beds	2,700 feet to public water supply wells	$6,200,000	$3,900,000	$180,000	$8,100,000	$5,100,000
B2	McManus site with subsurface infiltration	Minimal after construction	2,700 feet to public water supply wells	$13,000,000	$14,000,000	$180,000	$15,000,000	$17,000,000
C2	Airport site with subsurface infiltration	Minimal after construction	1,100 feet to public water supply wells	$21,000,000	$9,100,000	$530,000	$27,000,000	$12,000,000
D1	Cape Cod Community College site with sand beds	Moderate due to deforestation and image of sand beds	4,100 feet to public water supply wells	$7,000,000	$4,100,000	$190,000	$9,000,000	$5,300,000
D2	Cape Cod Community College site with subsurface infiltration	Minimal after construction	4,100 feet to public water supply wells	$16,000,000	$15,000,000	$220,000	$19,000,000	$17,000,000
E1	Lorusso site with sand beds	Moderate due to deforestation and image of sand beds	2,300 feet to public water supply wells	$3,600,000	$7,200,000	$80,000	$4,500,000	$9,000,000
E3	Lorusso site with spray irrigation	Moderate due to perception of sprayed wastewater	2,300 feet to public water supply wells	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow	Not considered due to low flow

Table from Task 8 Report, *"Candidate Site Evaluation and Comparison, Stearns & Wheler, 2004."*
Capital costs are based on an Engineering News-Record (ENR) Index of 6,800 for 2003 costs.
Present-worth cost based on n = 20, I = 7.625%, P/A = 10.1.
All costs rounded to two significant digits.

4.3 Next Steps And Ongoing Efforts

The Town is proceeding with the legal considerations and decision making needed to move forward with the two highest-ranked sites: the McManus site and Cape Cod Community College. These sites have constraints related to state ownership, conservation restrictions, and questions of infiltration capacity due to their location in a moraine area of Cape Cod. The Town has begun a hydraulic loading test at the McManus site to develop better infiltration capacity information. At the same time, the Town is exploring possible agreements with the involved state agencies.

As of early 2005, the Town is evaluating an additional effluent discharge/reuse concept that would utilize the following components:

1. Installation of an effluent supply pipe through the central portion of Hyannis that would facilitate lawn irrigation at Town properties.

2. Discharge upgradient of the abandoned cranberry bog located near the border of Barnstable and Yarmouth to remediate groundwater withdrawals in that area.

3. Additional treatment at the Hyannis WPCF to provide additional water purification and allow the effluent to be used for irrigation on public parks and discharge at the impacted wetland (abandoned cranberry bog).

This concept is very innovative and would be coupled with a wetland restoration at the cranberry bog. The feasilbity study for this scenario is planned to be completed in June 2005.

4.4 Conclusions

The siting of new effluent discharge and reuse facilities has been a long and detailed process in Barnstable. The Town has proceeded proactively and carefully to site these facilities in a cost-effective manner. We have worked closely with the regulatory agencies to consider innovative solutions and find a management scenario that is cost effective. The Town has considered all alternatives.

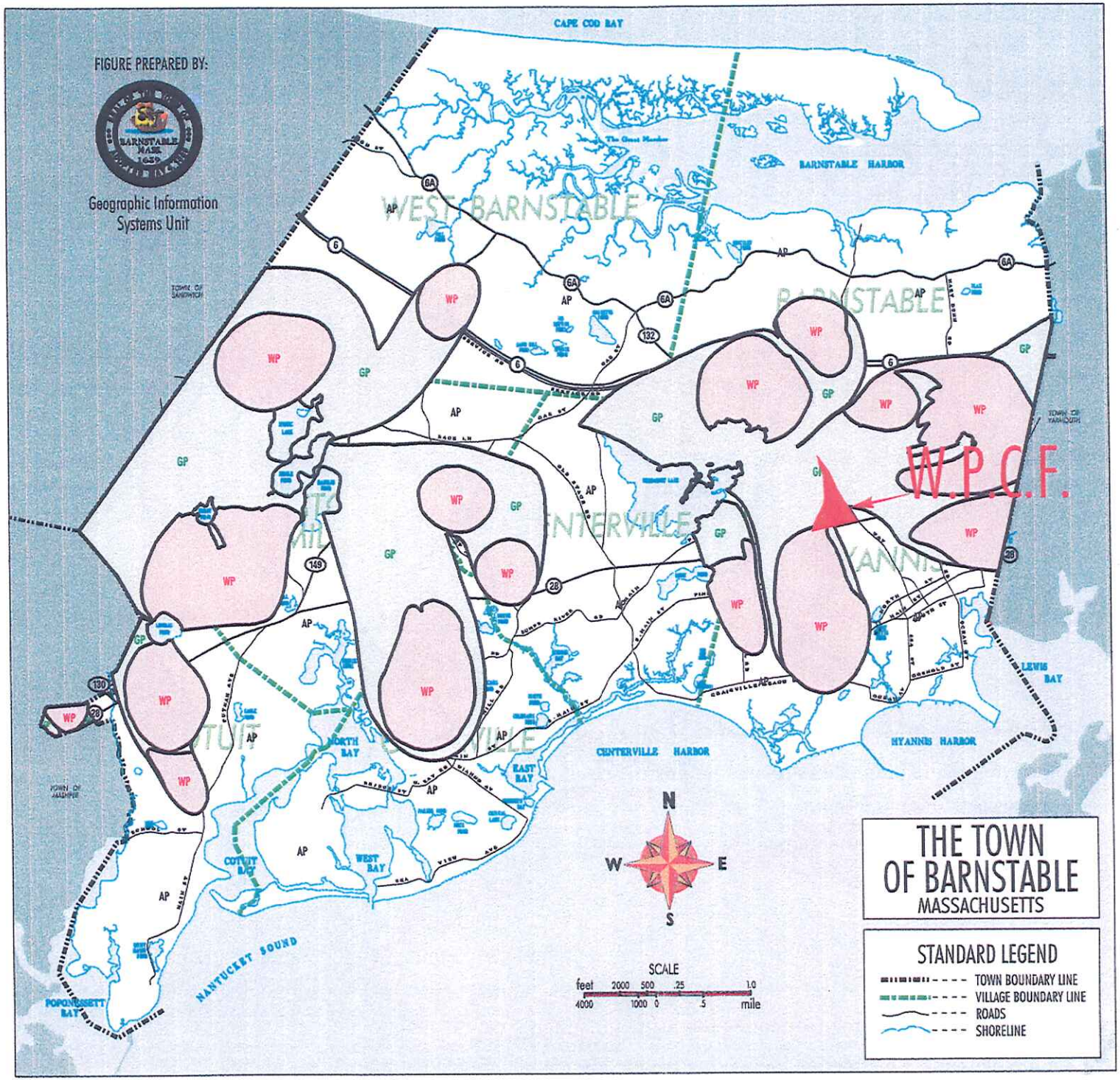
The final recommendations of this siting project have not yet been determined.

They must await the decision making process that has to weigh the politics with the solid science, engineering, and cost estimating we have completed to date.

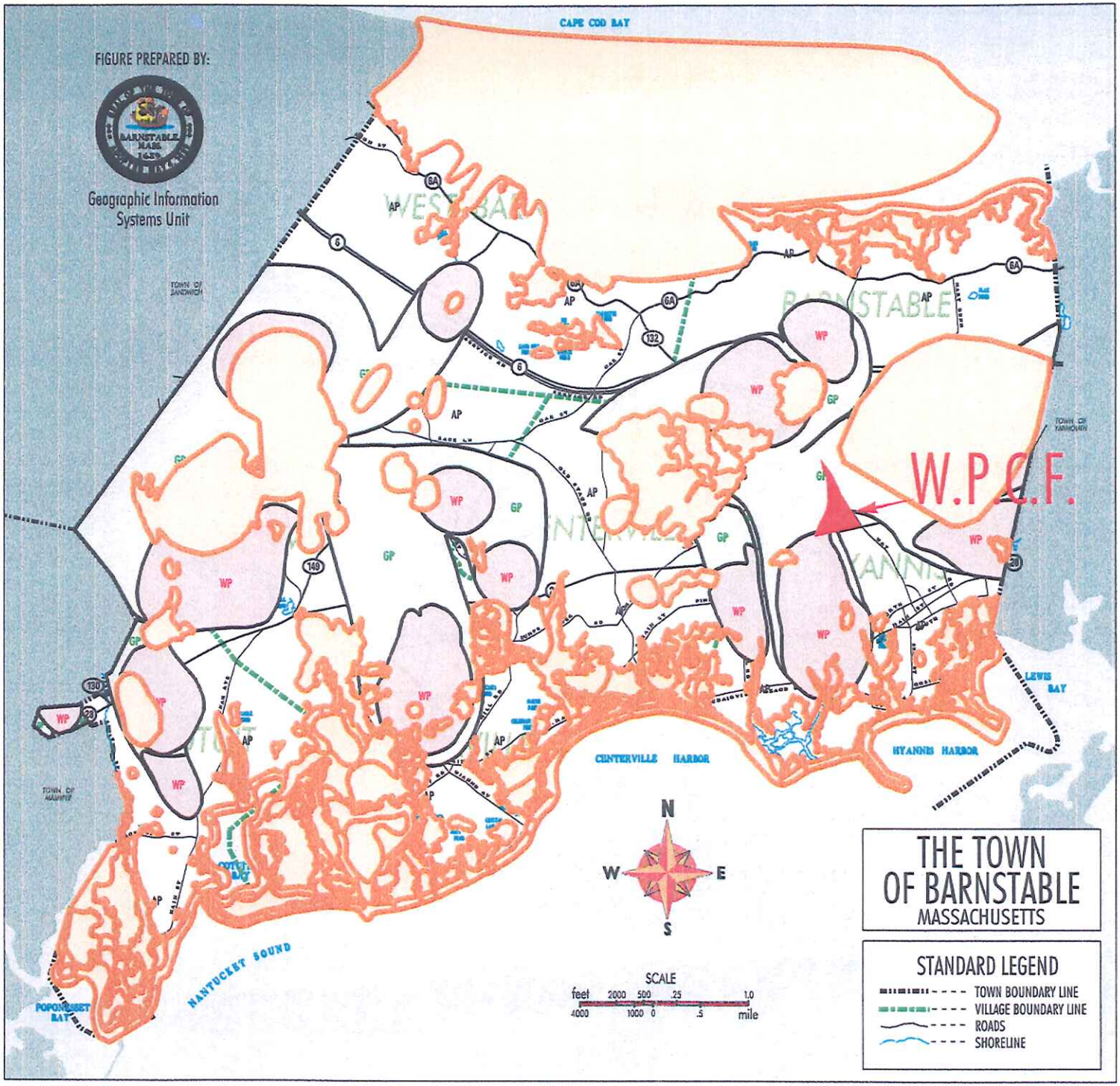
The Town appreciates the opportunity to share this experience with other towns on Cape Cod and with other municipalities off Cape. The Town plans to identify the final recommendations on the Town website as part of the Comprehensive Wastewater Management Plan.

Appendix A:
Barnstable Screening Process Maps

Map 1

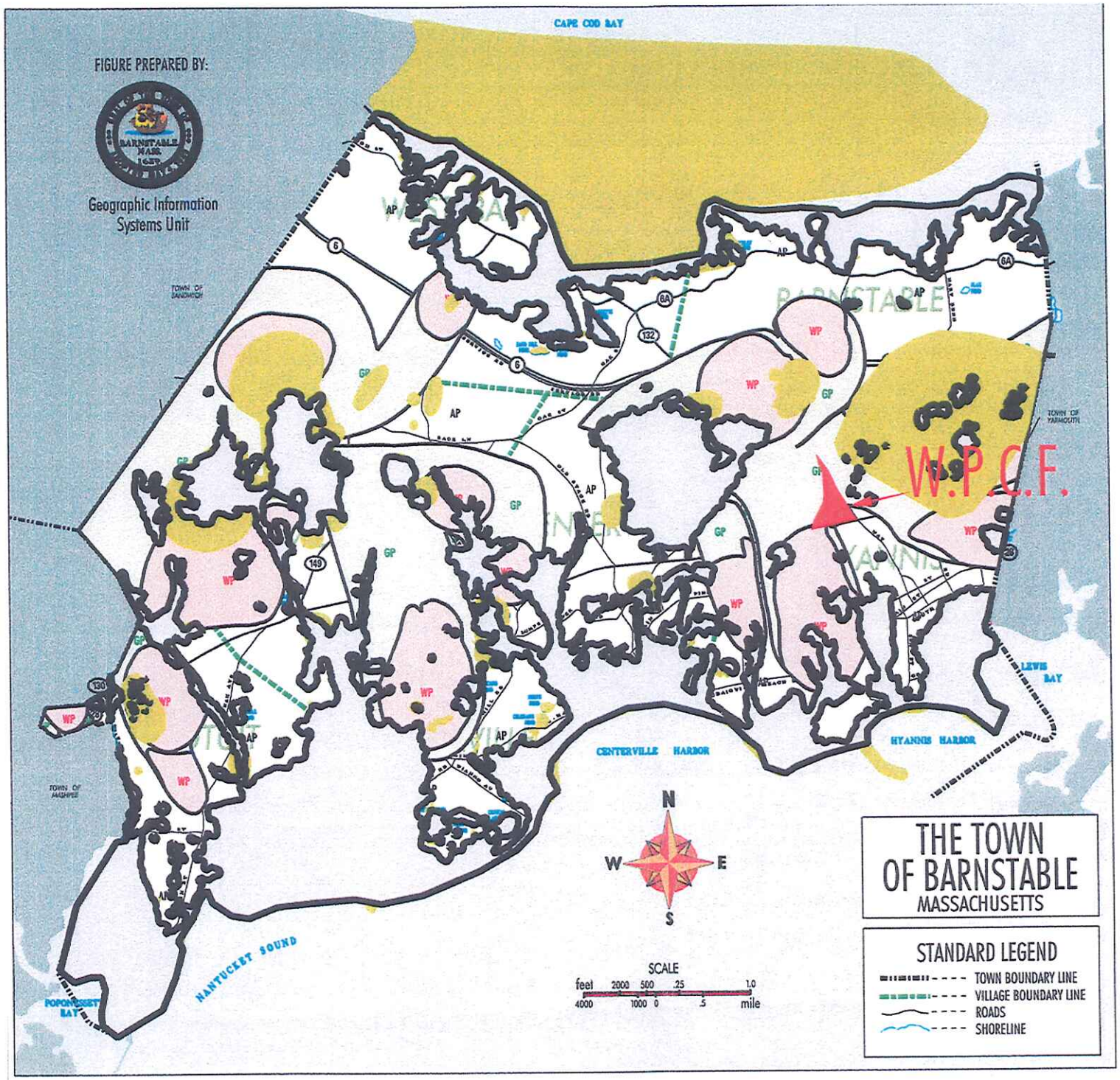


- WATER POLLUTION CONTROL FACILITY
- GROUND WATER PROTECTION AREA
- WELL HEAD PROTECTION AREA
- AREAS OF CRITICAL ENVIRONMENTAL CONCERN
- AREAS EXCLUDED FROM WASTE WATER DISCHARGE
- AREAS WITHIN 10 FEET OF GROUNDWATER
- HYDRAULIC CONDUCTIVITY BOUNDARY
- AREAS AT LEAST ONE HALF MILE FROM AREAS WITHIN 10' FROM GROUNDWATER
- AVAILABLE PARCELS
- AVAILABLE GOVERNMENTAL PARCELS
- PARCELS WITH PRIVATE WELLS
- COASTAL RECHARGE AREAS



Map 2

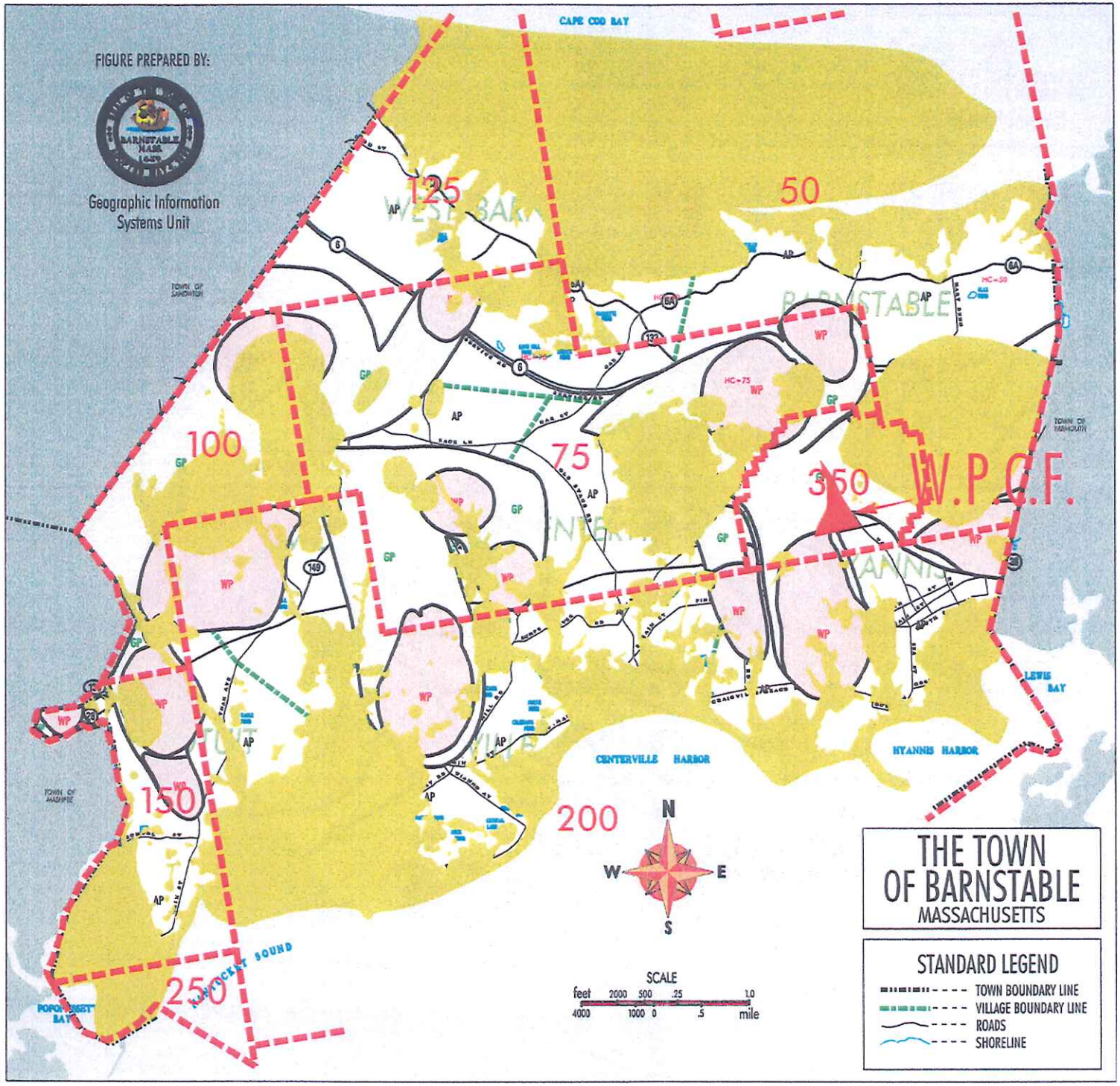
- WATER POLLUTION CONTROL FACILITY
- GROUND WATER PROTECTION AREA
- WELL HEAD PROTECTION AREA
- AREAS OF CRITICAL ENVIRONMENTAL CONCERN
- AREAS EXCLUDED FROM WASTE WATER DISCHARGE
- AREAS WITHIN 10 FEET OF GROUNDWATER
- HYDRAULIC CONDUCTIVITY BOUNDARY
- AREAS AT LEAST ONE HALF MILE FROM AREAS WITHIN 10' FROM GROUNDWATER
- AVAILABLE PARCELS
- AVAILABLE GOVERNMENTAL PARCELS
- PARCELS WITH PRIVATE WELLS
- COASTAL RECHARGE AREAS



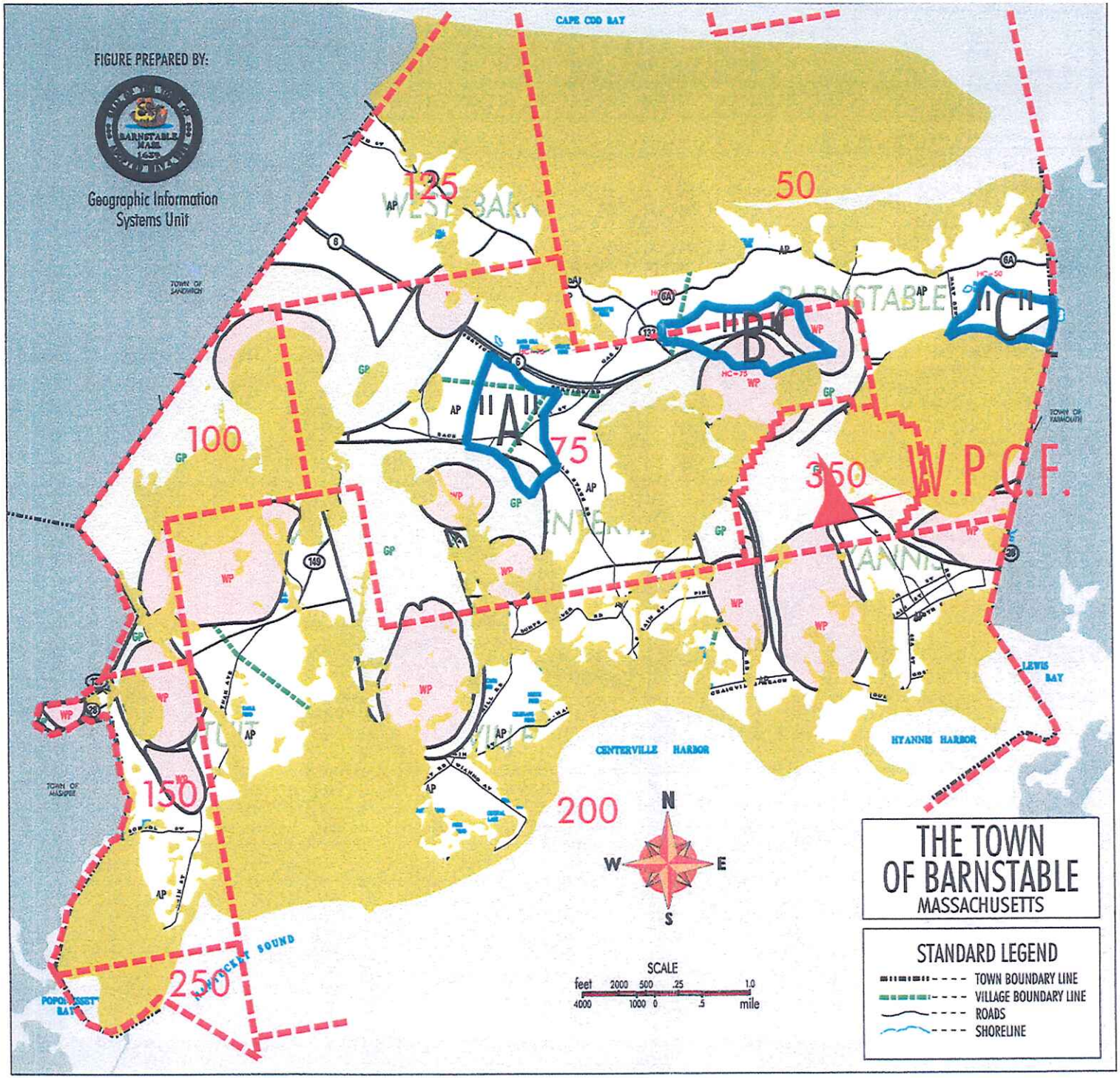
Map 3

- WATER POLLUTION CONTROL FACILITY
- GROUND WATER PROTECTION AREA
- WELL HEAD PROTECTION AREA
- AREAS OF CRITICAL ENVIRONMENTAL CONCERN
- AREAS EXCLUDED FROM WASTE WATER DISCHARGE
- AREAS WITHIN 10 FEET OF GROUNDWATER
- HYDRAULIC CONDUCTIVITY BOUNDARY
- AREAS AT LEAST ONE HALF MILE FROM AREAS WITHIN 10' FROM GROUNDWATER
- AVAILABLE PARCELS
- AVAILABLE GOVERNMENTAL PARCELS
- PARCELS WITH PRIVATE WELLS
- COASTAL RECHARGE AREAS

Map 4

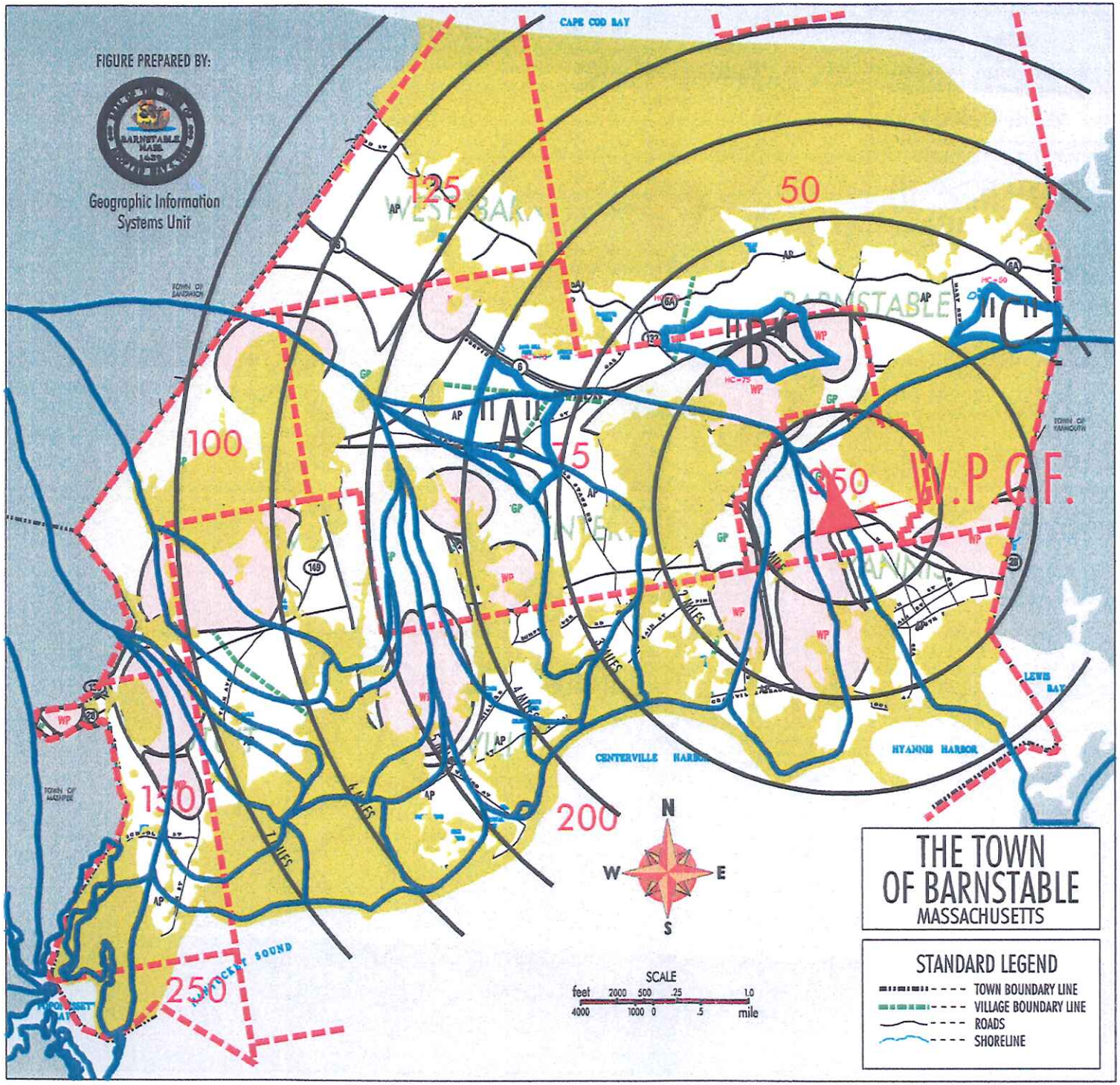


- WATER POLLUTION CONTROL FACILITY
- GROUND WATER PROTECTION AREA
- WELL HEAD PROTECTION AREA
- AREAS OF CRITICAL ENVIRONMENTAL CONCERN
- AREAS EXCLUDED FROM WASTE WATER DISCHARGE
- AREAS WITHIN 10 FEET OF GROUNDWATER
- HYDRAULIC CONDUCTIVITY BOUNDARY
- AREAS AT LEAST ONE HALF MILE FROM AREAS WITHIN 10' FROM GROUNDWATER
- AVAILABLE PARCELS
- AVAILABLE GOVERNMENTAL PARCELS
- PARCELS WITH PRIVATE WELLS
- COASTAL RECHARGE AREAS



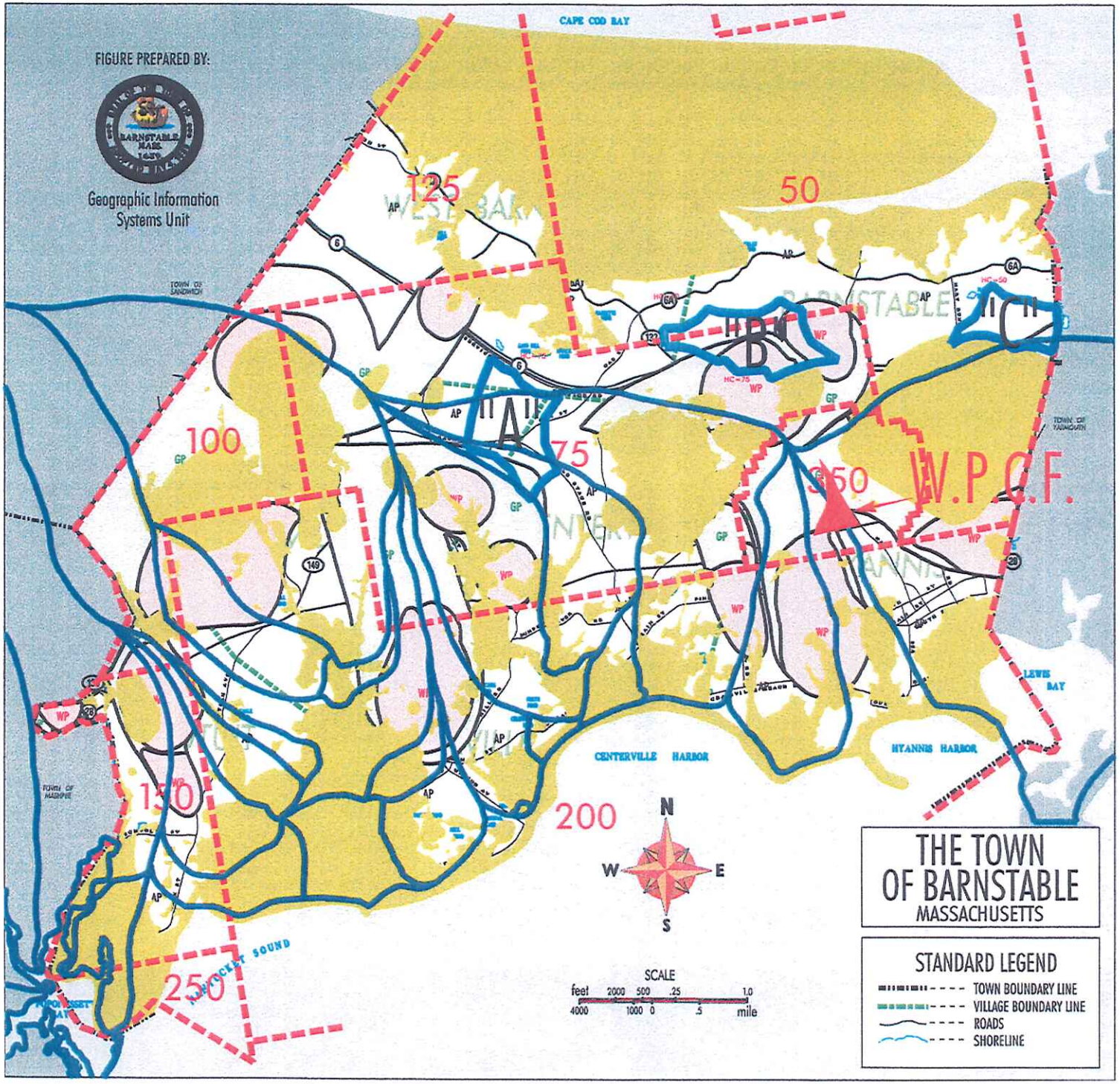
Map 5

- WATER POLLUTION CONTROL FACILITY
- GROUND WATER PROTECTION AREA
- WELL HEAD PROTECTION AREA
- AREAS OF CRITICAL ENVIRONMENTAL CONCERN
- AREAS EXCLUDED FROM WASTE WATER DISCHARGE
- AREAS WITHIN 10 FEET OF GROUNDWATER
- HYDRAULIC CONDUCTIVITY BOUNDARY
- AREAS AT LEAST ONE HALF MILE FROM AREAS WITHIN 10' FROM GROUNDWATER
- AVAILABLE PARCELS
- AVAILABLE GOVERNMENTAL PARCELS
- PARCELS WITH PRIVATE WELLS
- COASTAL RECHARGE AREAS



Map 6

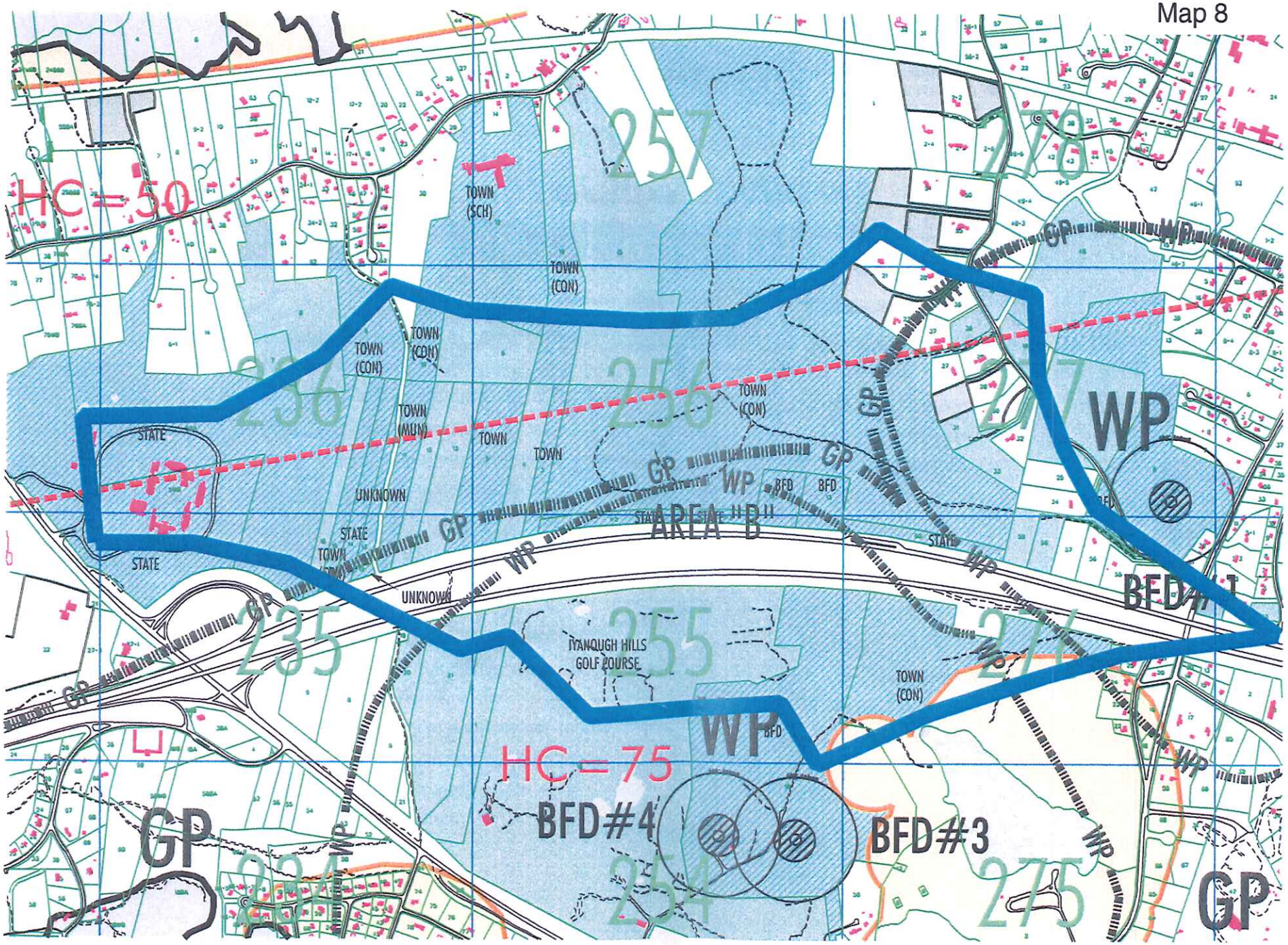
- WATER POLLUTION CONTROL FACILITY
- GROUND WATER PROTECTION AREA
- WELL HEAD PROTECTION AREA
- AREAS OF CRITICAL ENVIRONMENTAL CONCERN
- AREAS EXCLUDED FROM WASTE WATER DISCHARGE
- AREAS WITHIN 10 FEET OF GROUNDWATER
- HYDRAULIC CONDUCTIVITY BOUNDARY
- AREAS AT LEAST ONE HALF MILE FROM AREAS WITHIN 10' FROM GROUNDWATER
- AVAILABLE PARCELS
- AVAILABLE GOVERNMENTAL PARCELS
- PARCELS WITH PRIVATE WELLS
- COASTAL RECHARGE AREAS



Map 7

- WATER POLLUTION CONTROL FACILITY
- GROUND WATER PROTECTION AREA
- WELL HEAD PROTECTION AREA
- AREAS OF CRITICAL ENVIRONMENTAL CONCERN
- AREAS EXCLUDED FROM WASTE WATER DISCHARGE
- AREAS WITHIN 10 FEET OF GROUNDWATER
- HYDRAULIC CONDUCTIVITY BOUNDARY
- AREAS AT LEAST ONE HALF MILE FROM AREAS WITHIN 10' FROM GROUNDWATER
- AVAILABLE PARCELS
- AVAILABLE GOVERNMENTAL PARCELS
- PARCELS WITH PRIVATE WELLS
- COASTAL RECHARGE AREAS

Map 8



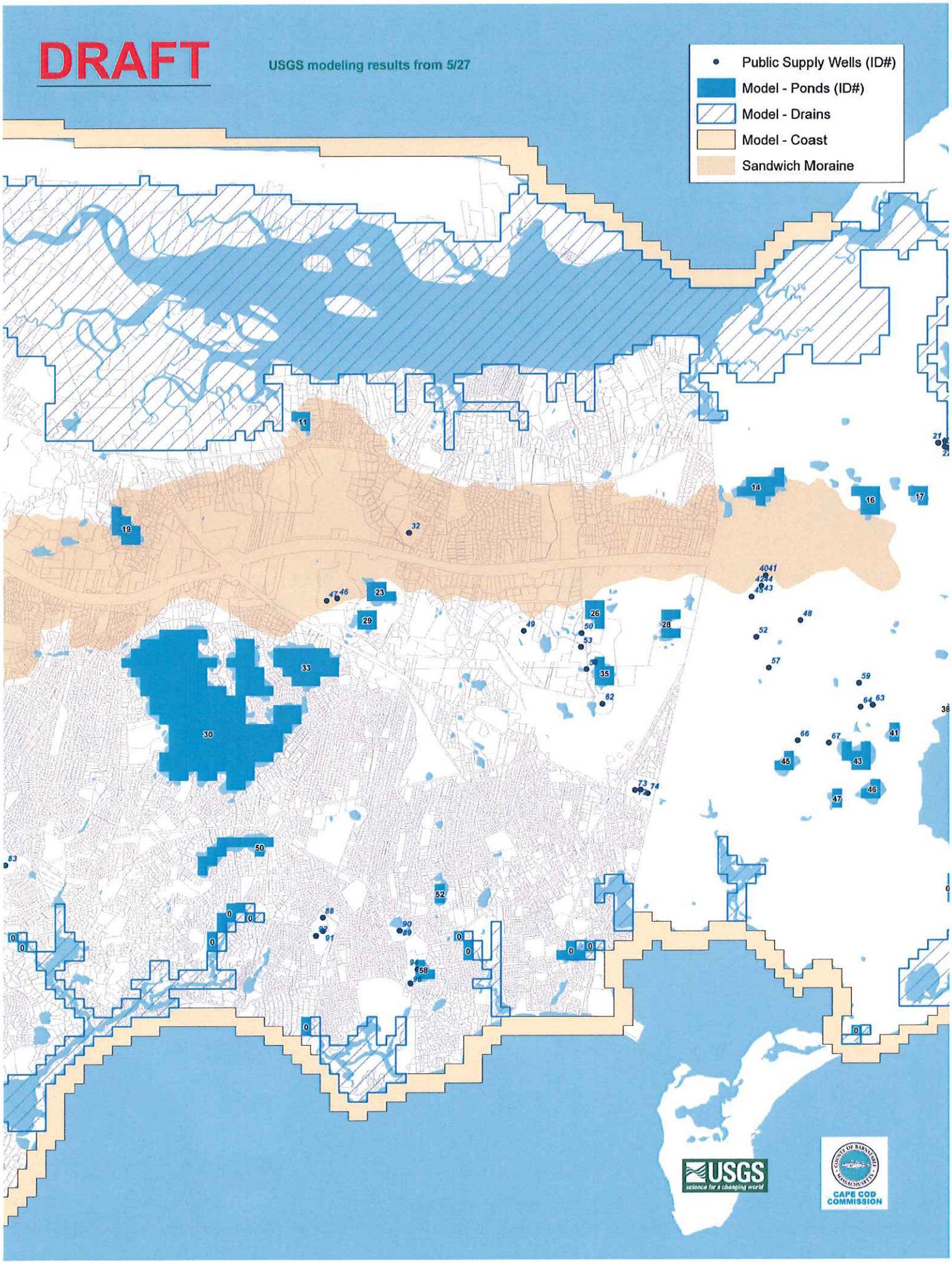
BARNSTABLE G.I.S. UNIT
G.M.C. 9/9/98

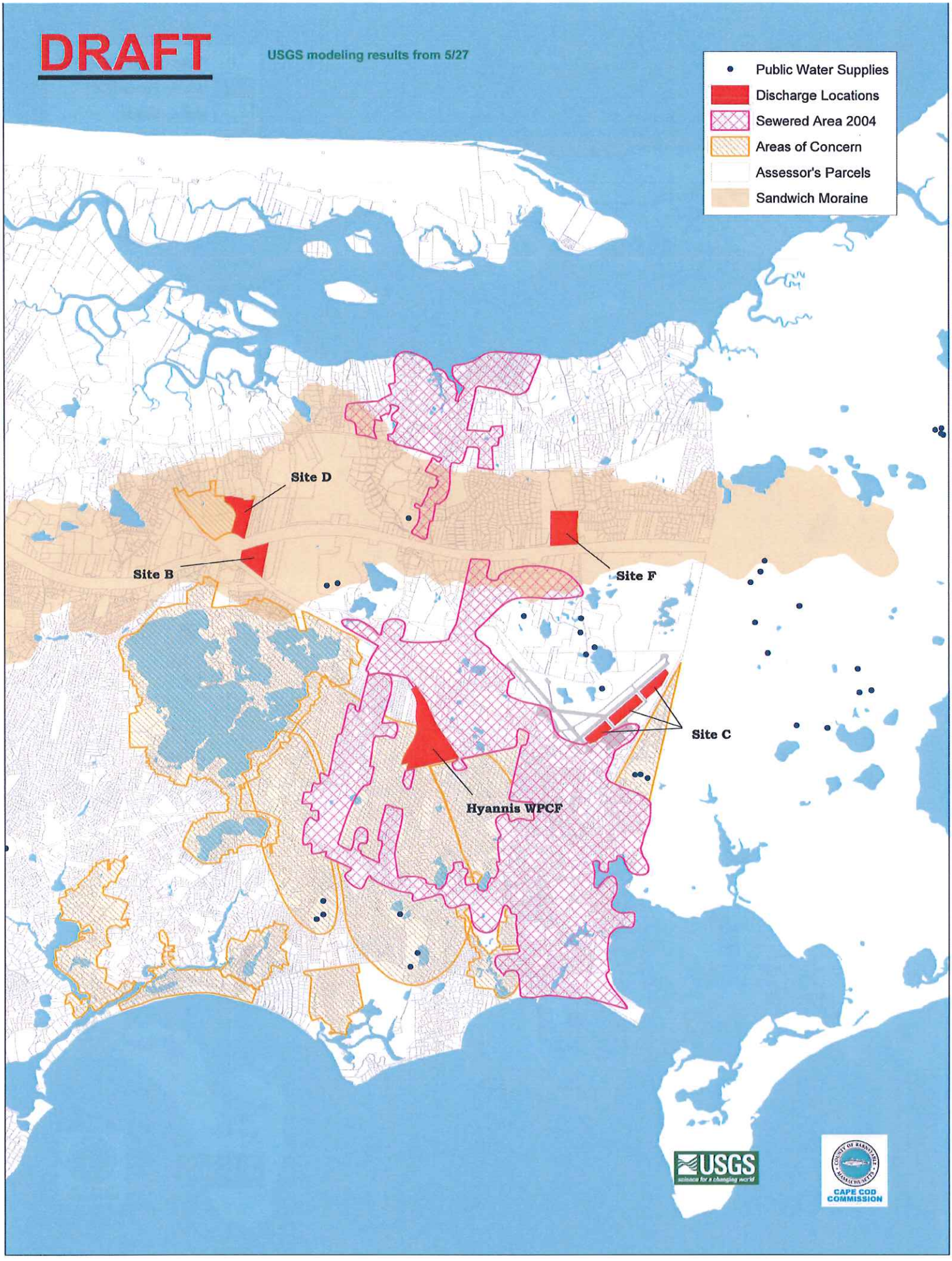
AREA "B"

AVAILABLE PARCELS
AVAILABLE GOVERNMENT PARCELS
PARCELS WITH PRIVATE WELLS
PARCELS WITHIN 10' OF GROUND WATER
AREAS OF ENVIRONMENTAL CONCERN
WP OR GP AREAS
AREA OVER 500' OF AREAS WITHIN 10' OF GROUND WATER

SCALE: 1"=800'
effmap9b.dgn

Appendix B:
USGS Model Output Maps


DRAFT
USGS modeling results from 5/27
Public Supply Wells (ID#)
Model - Ponds (ID#)
Model - Drains
Model - Coast
Sandwich Moraine
USGS
science for a changing world
CAPE COD COMMISSION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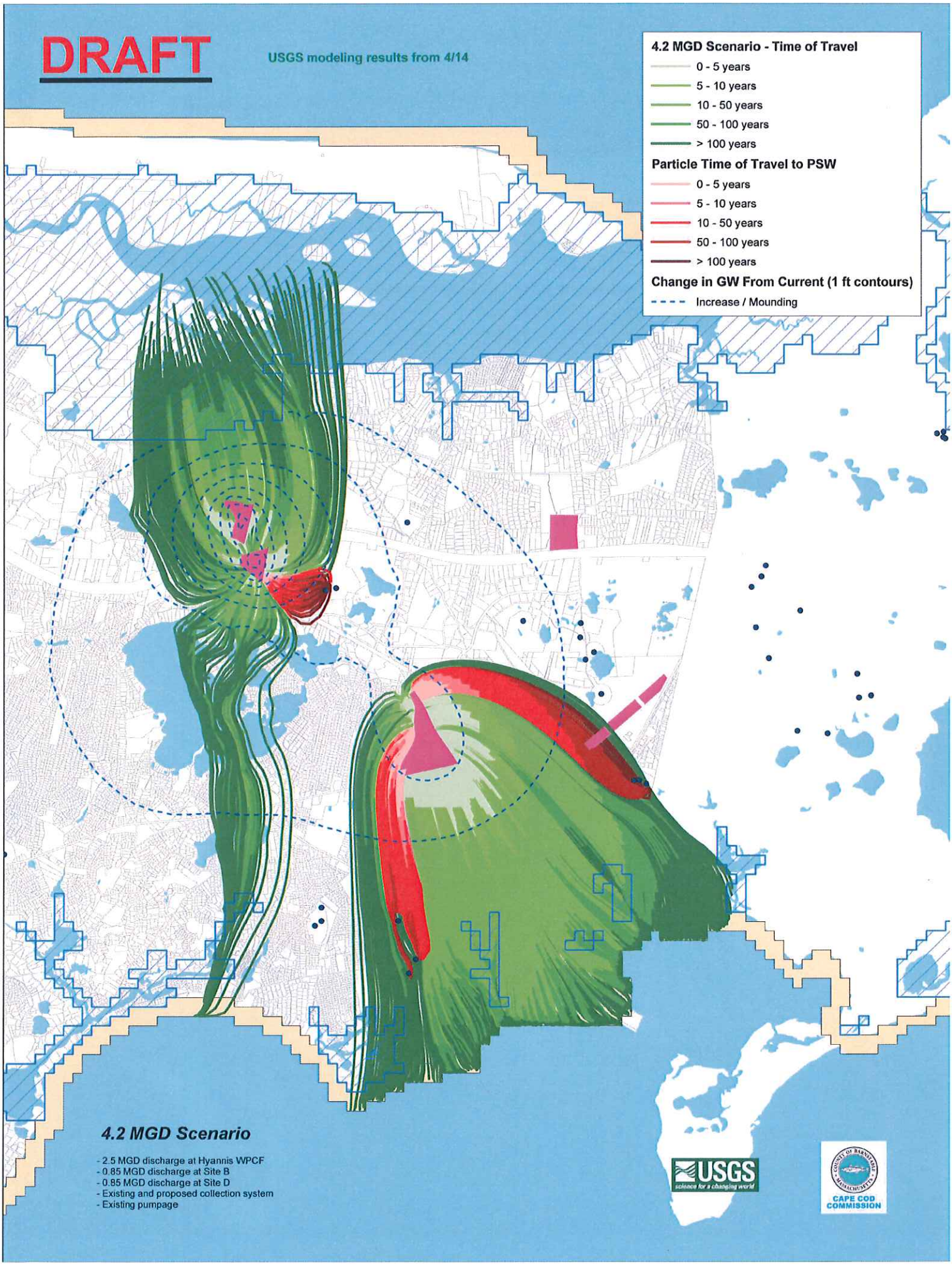
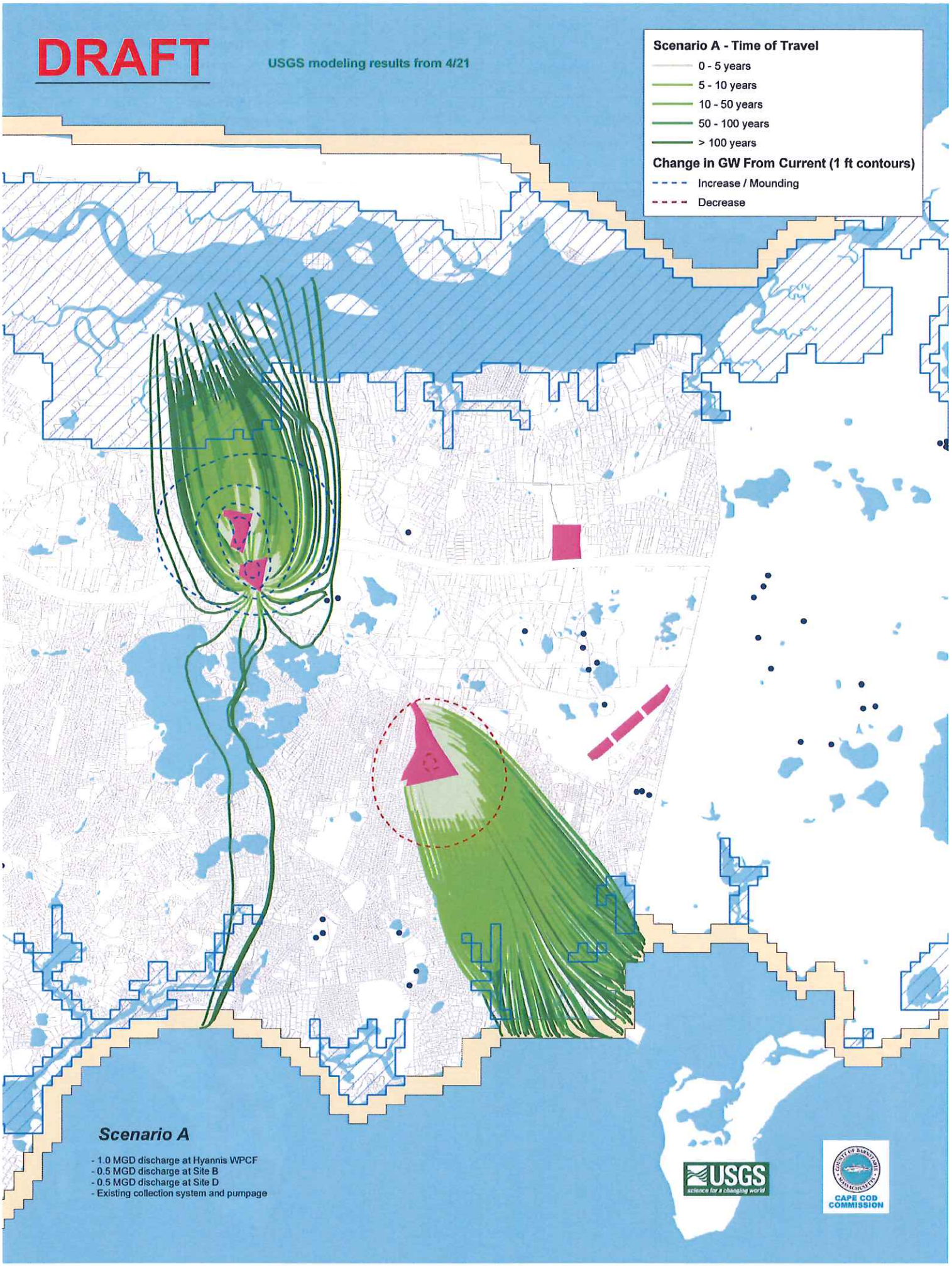
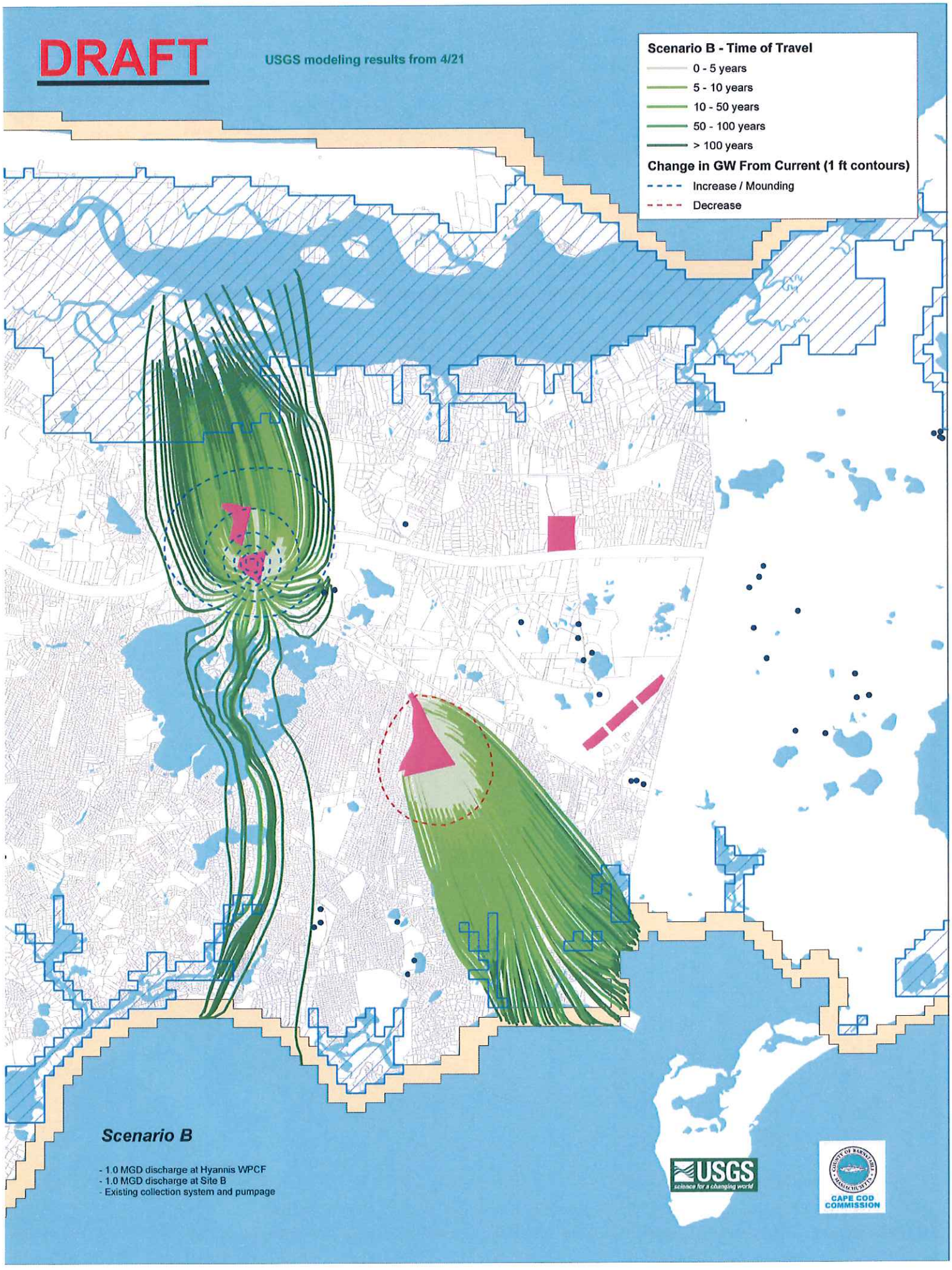
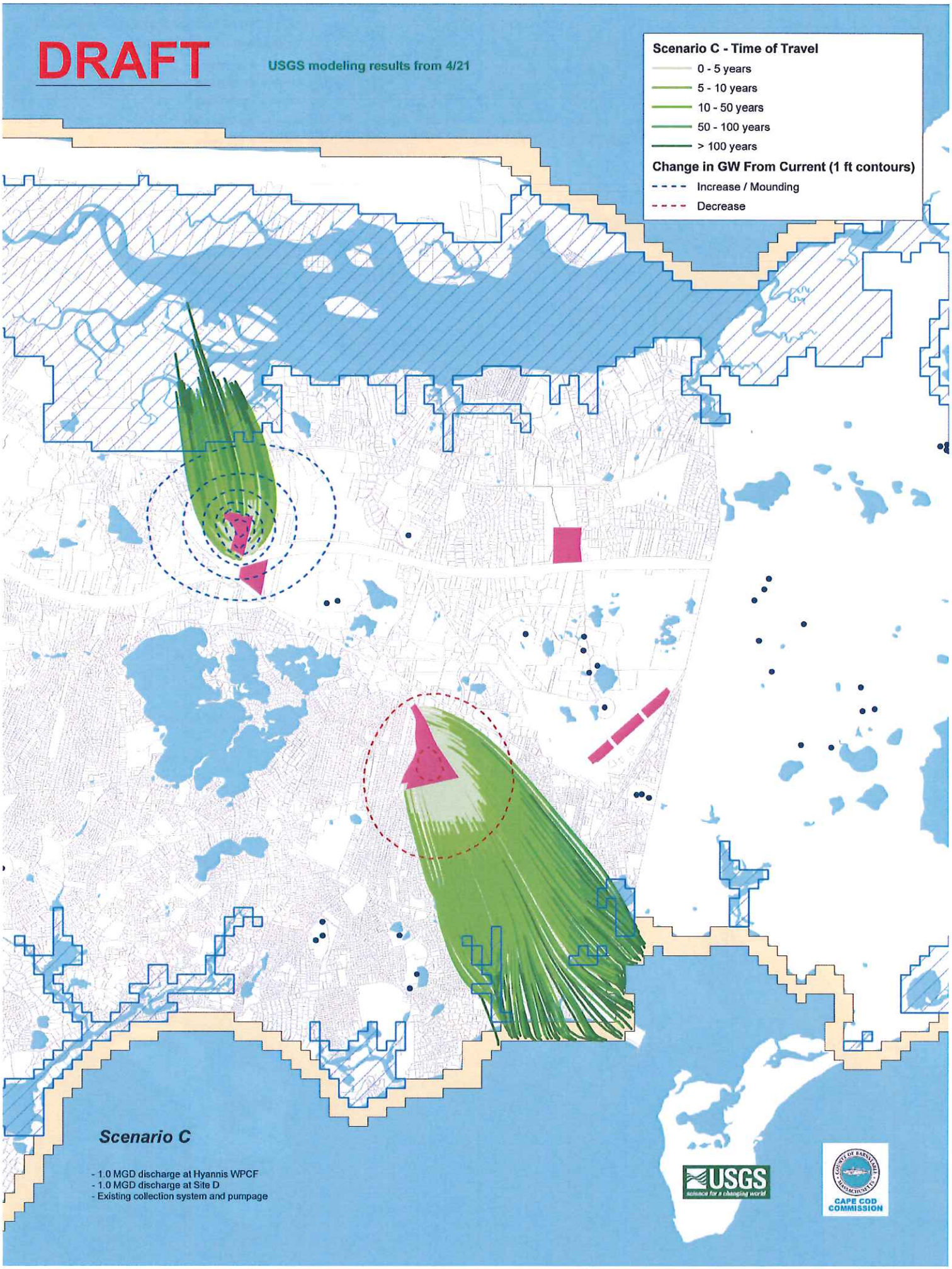
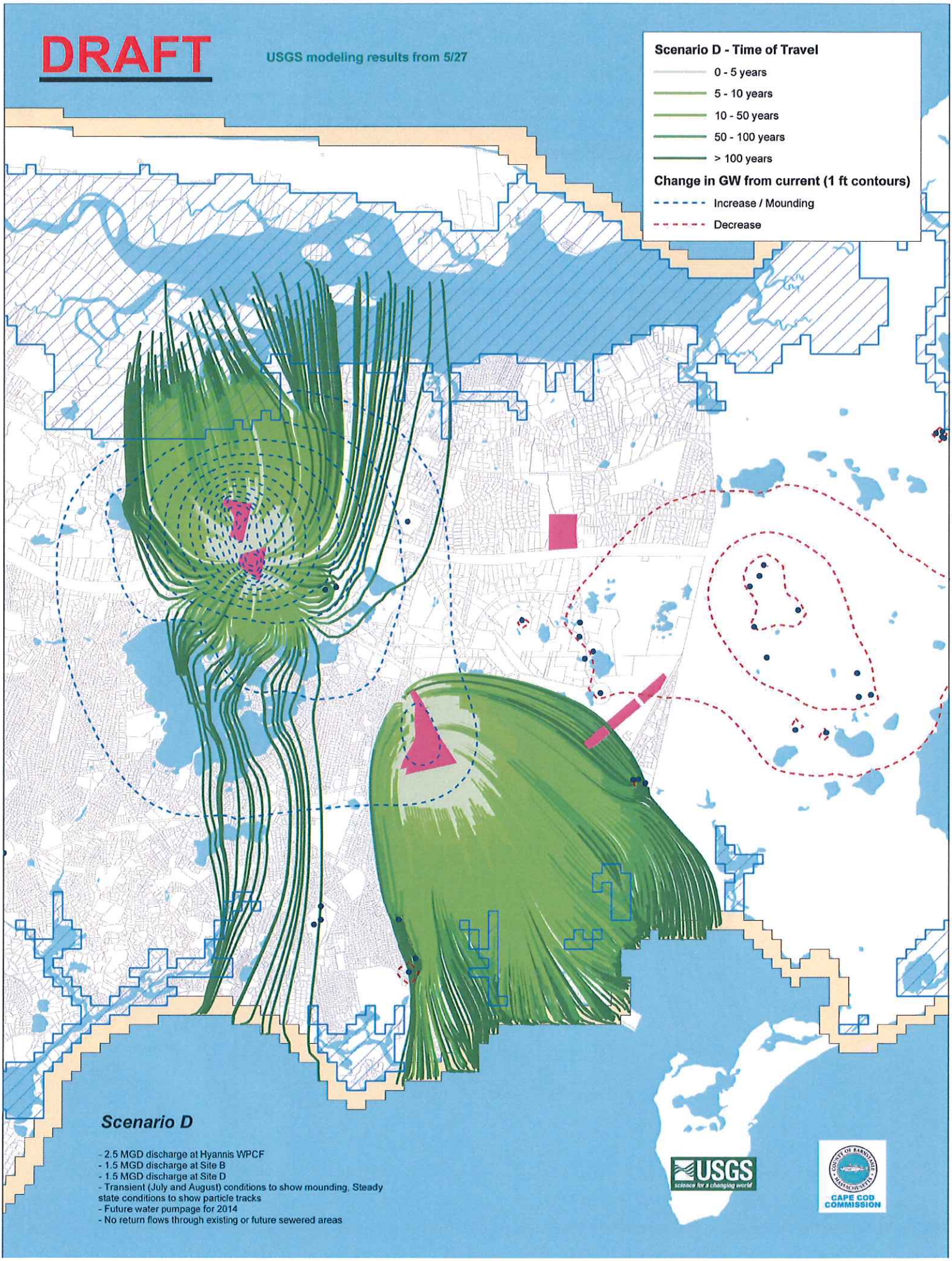
USGS modeling results from 5/27
Public Water Supplies
Discharge Locations
Sewered Area 2004
Areas of Concern
Assessor's Parcels
Sandwich Moraine
Site D
Site B
Site F
Site C
Hyannis WPCF
USGS
science for a changing world
CAPE COD COMMISSION


DRAFT
USGS modeling results from 4/14
4.2 MGD Scenario - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Particle Time of Travel to PSW
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW From Current (1 ft contours)
Increase / Mounding
4.2 MGD Scenario
- 2.5 MGD discharge at Hyannis WPCF
- 0.85 MGD discharge at Site B
- 0.85 MGD discharge at Site D
- Existing and proposed collection system
- Existing pumpage
USGS
science for a changing world
CAPE COD COMMISSION


DRAFT
USGS modeling results from 4/21
Scenario A - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW From Current (1 ft contours)
Increase / Mounding
Decrease
Scenario A
- 1.0 MGD discharge at Hyannis WPCF
- 0.5 MGD discharge at Site B
- 0.5 MGD discharge at Site D
- Existing collection system and pumpage
USGS
science for a changing world
CAPE COD COMMISSION


DRAFT
USGS modeling results from 4/21
Scenario B - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW From Current (1 ft contours)
Increase / Mounding
Decrease
Scenario B
- 1.0 MGD discharge at Hyannis WPCF
- 1.0 MGD discharge at Site B
- Existing collection system and pumpage
USGS
science for a changing world
CAPE COD COMMISSION


DRAFT
USGS modeling results from 4/21
Scenario C - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW From Current (1 ft contours)
Increase / Mounding
Decrease
Scenario C
- 1.0 MGD discharge at Hyannis WPCF
- 1.0 MGD discharge at Site D
- Existing collection system and pumpage
USGS
science for a changing world
CAPE COD COMMISSION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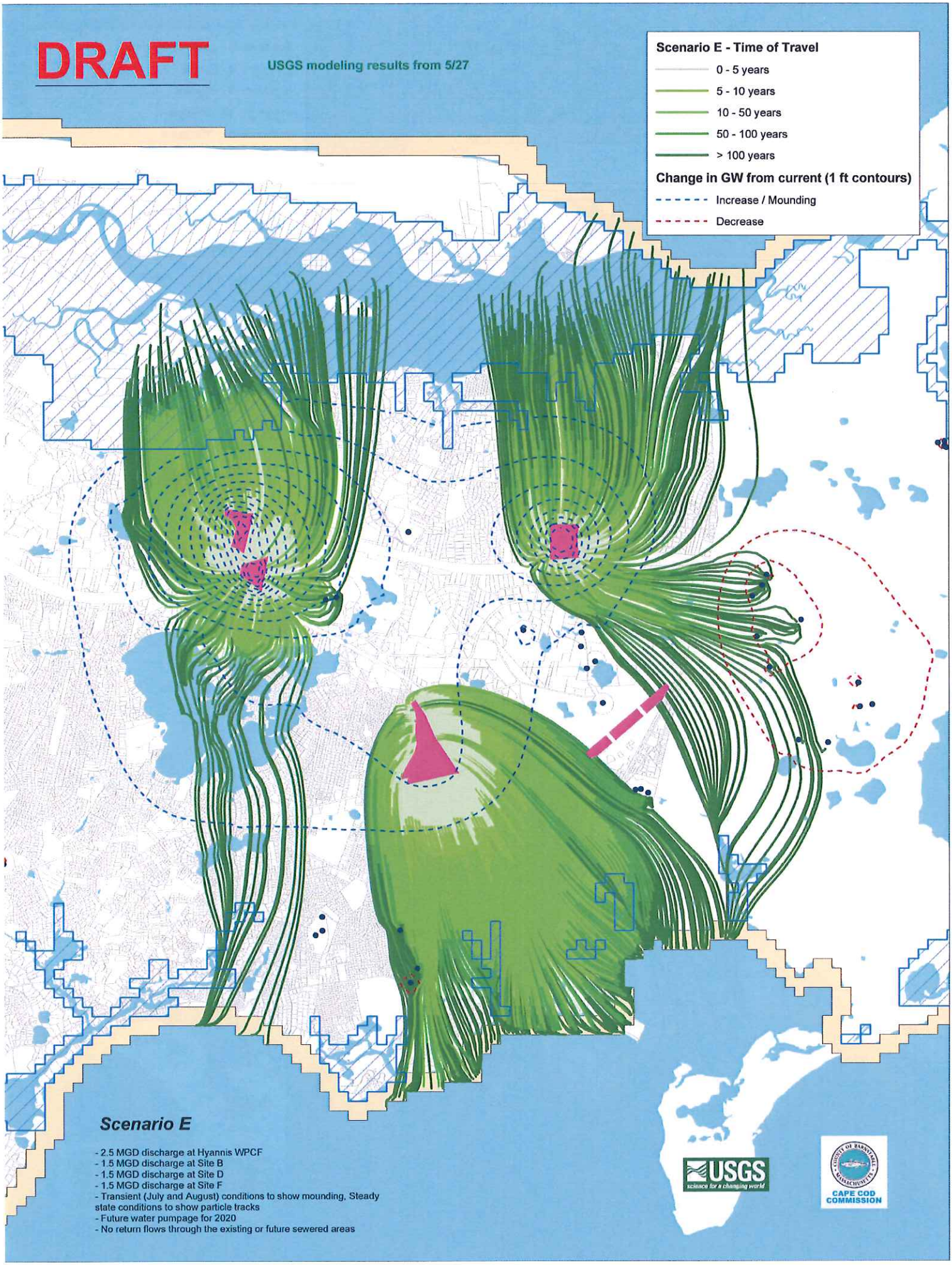
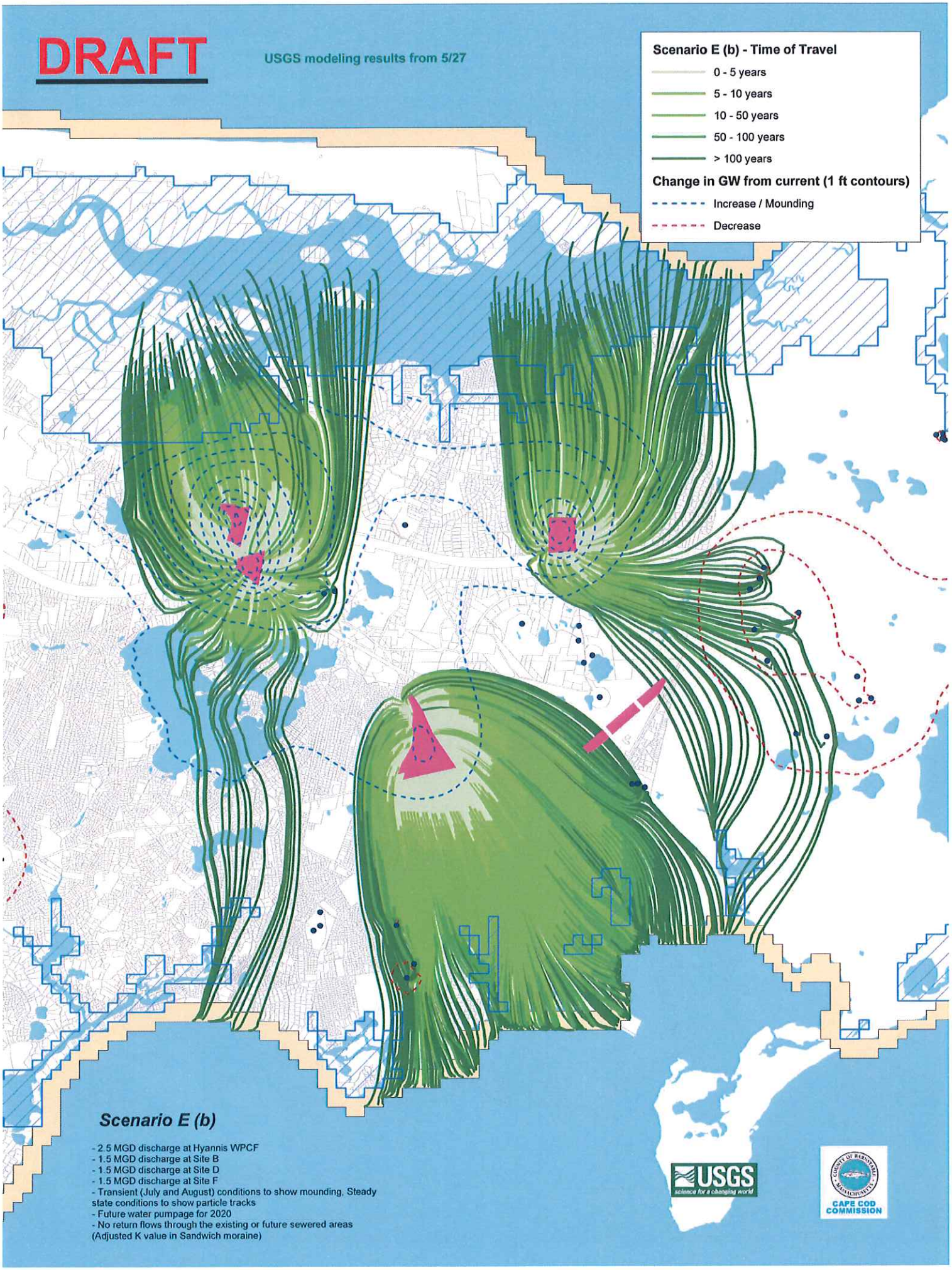
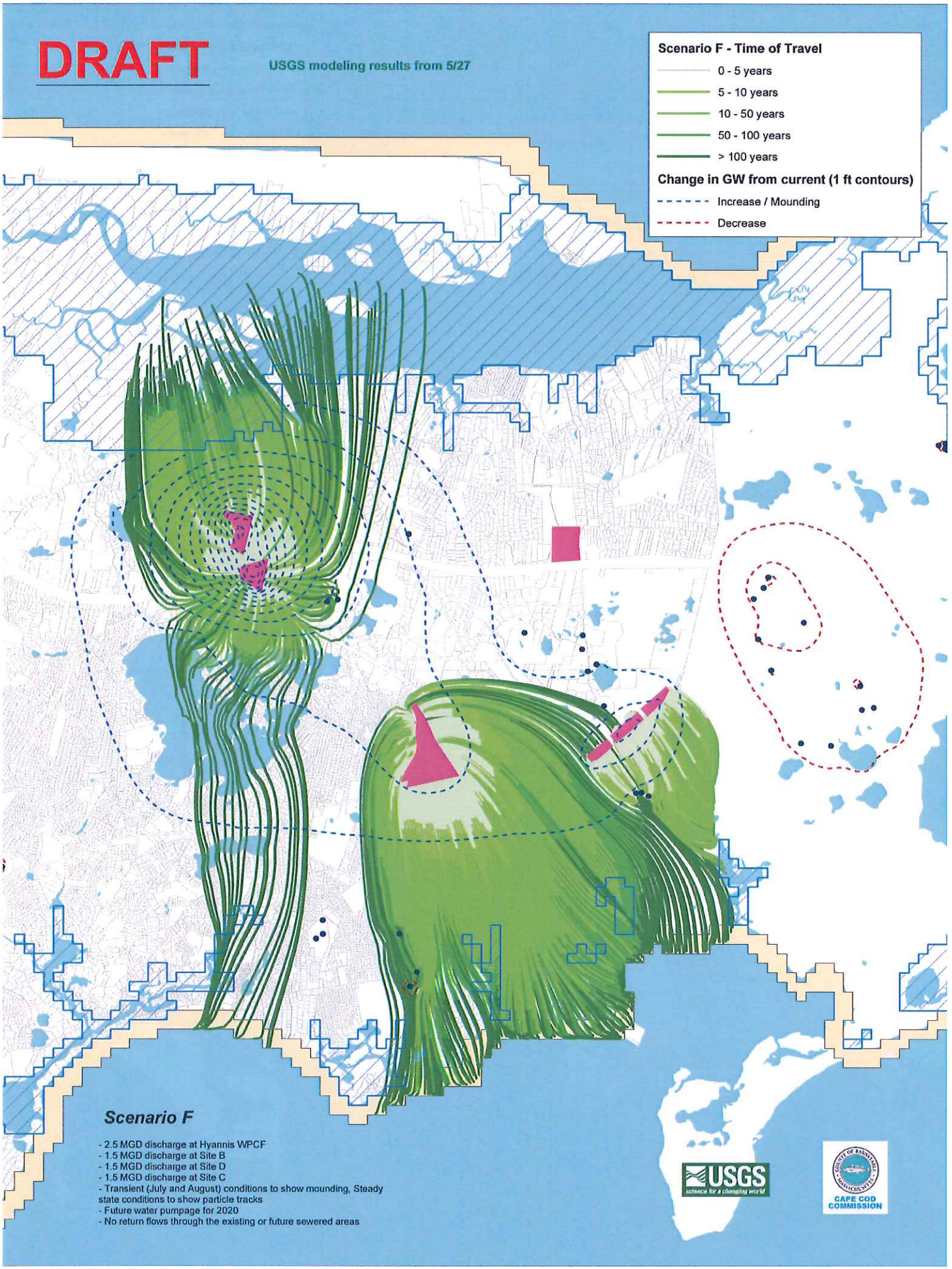
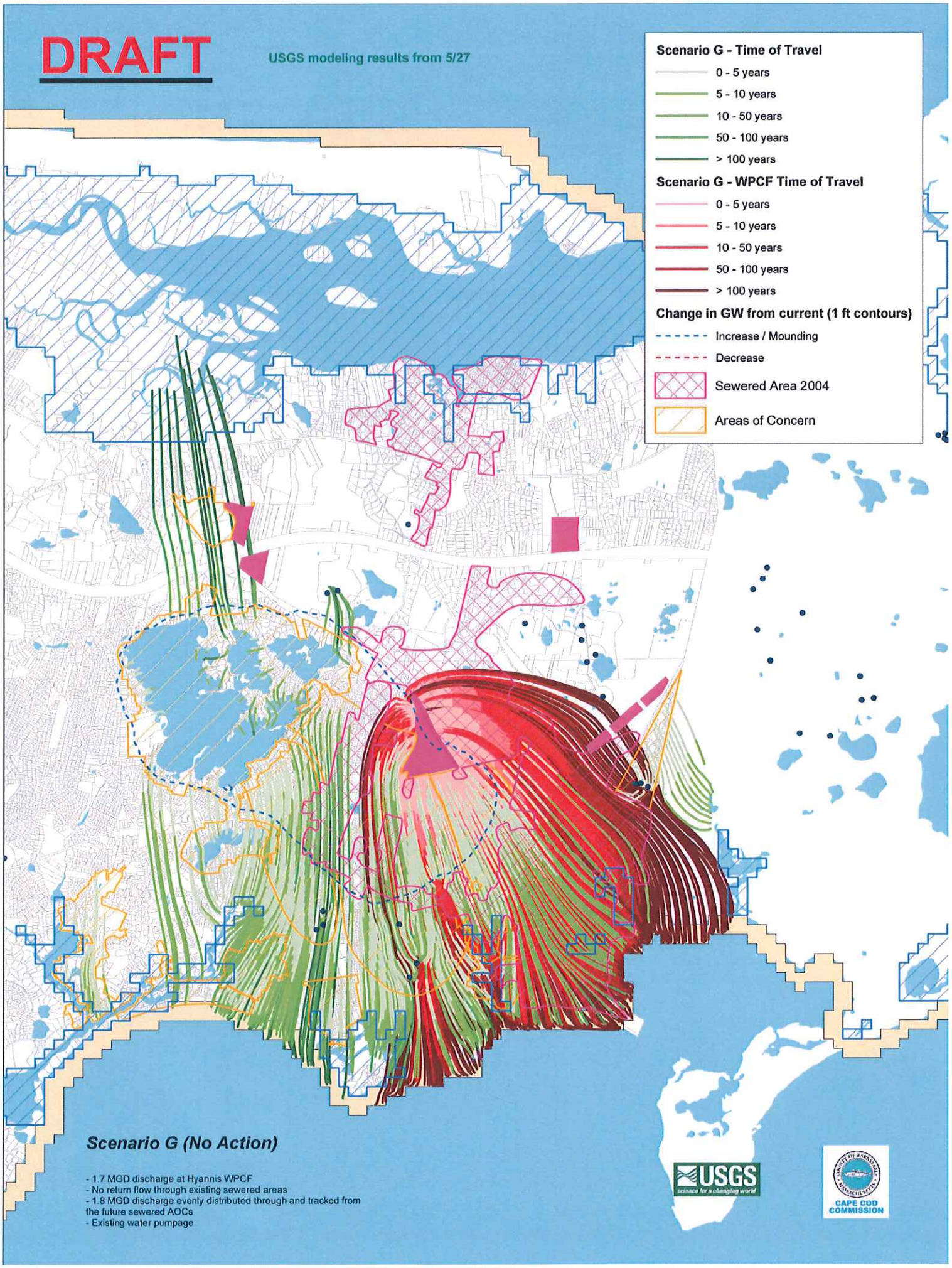
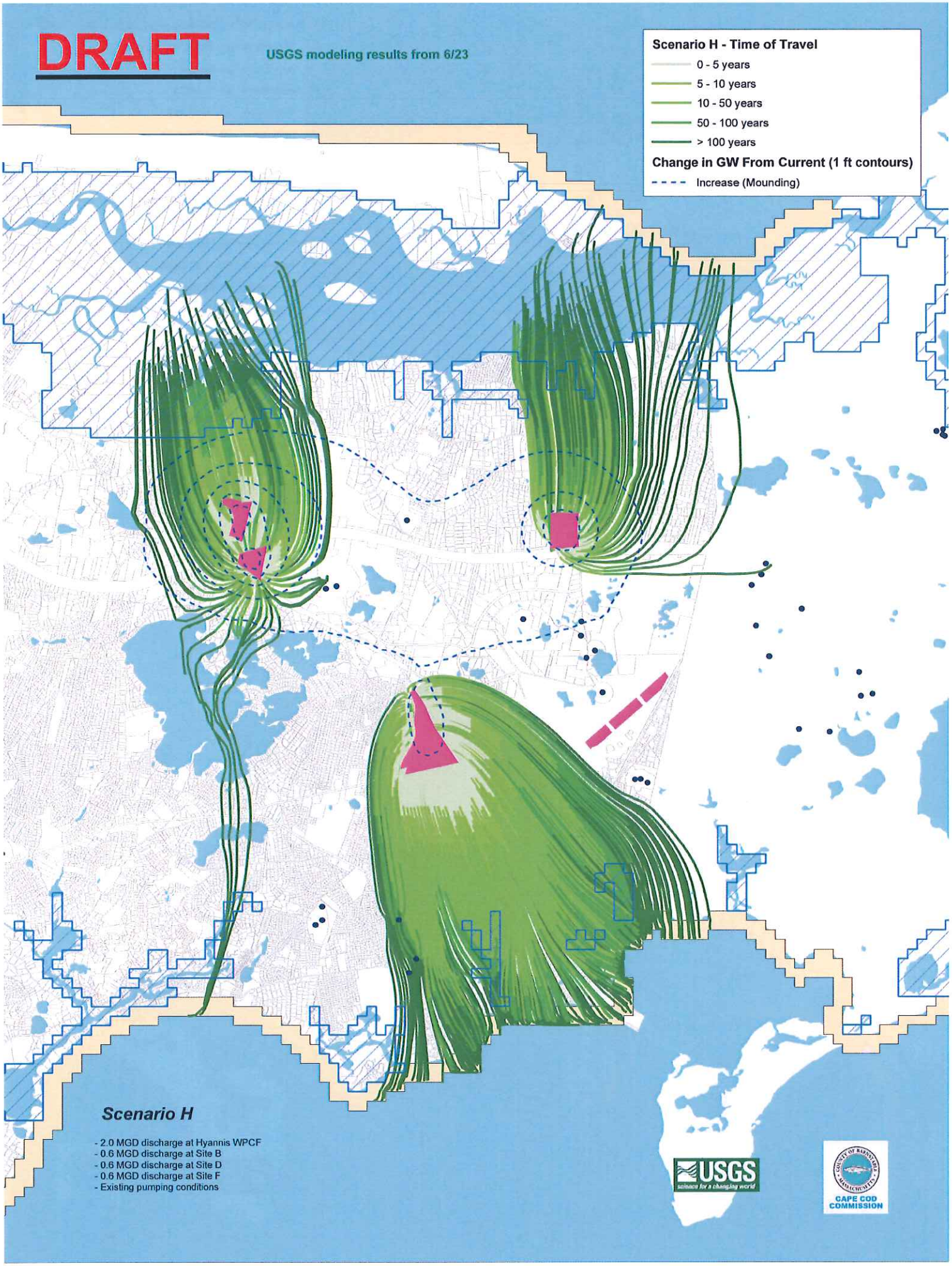
USGS modeling results from 5/27
Scenario D - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW from current (1 ft contours)
Increase / Mounding
Decrease
Scenario D
- 2.5 MGD discharge at Hyannis WPCF
- 1.5 MGD discharge at Site B
- 1.5 MGD discharge at Site D
- Transient (July and August) conditions to show mounding. Steady state conditions to show particle tracks
- Future water pumpage for 2014
- No return flows through existing or future sewered areas
USGS
science for a changing world
CAPE COD COMMISSION

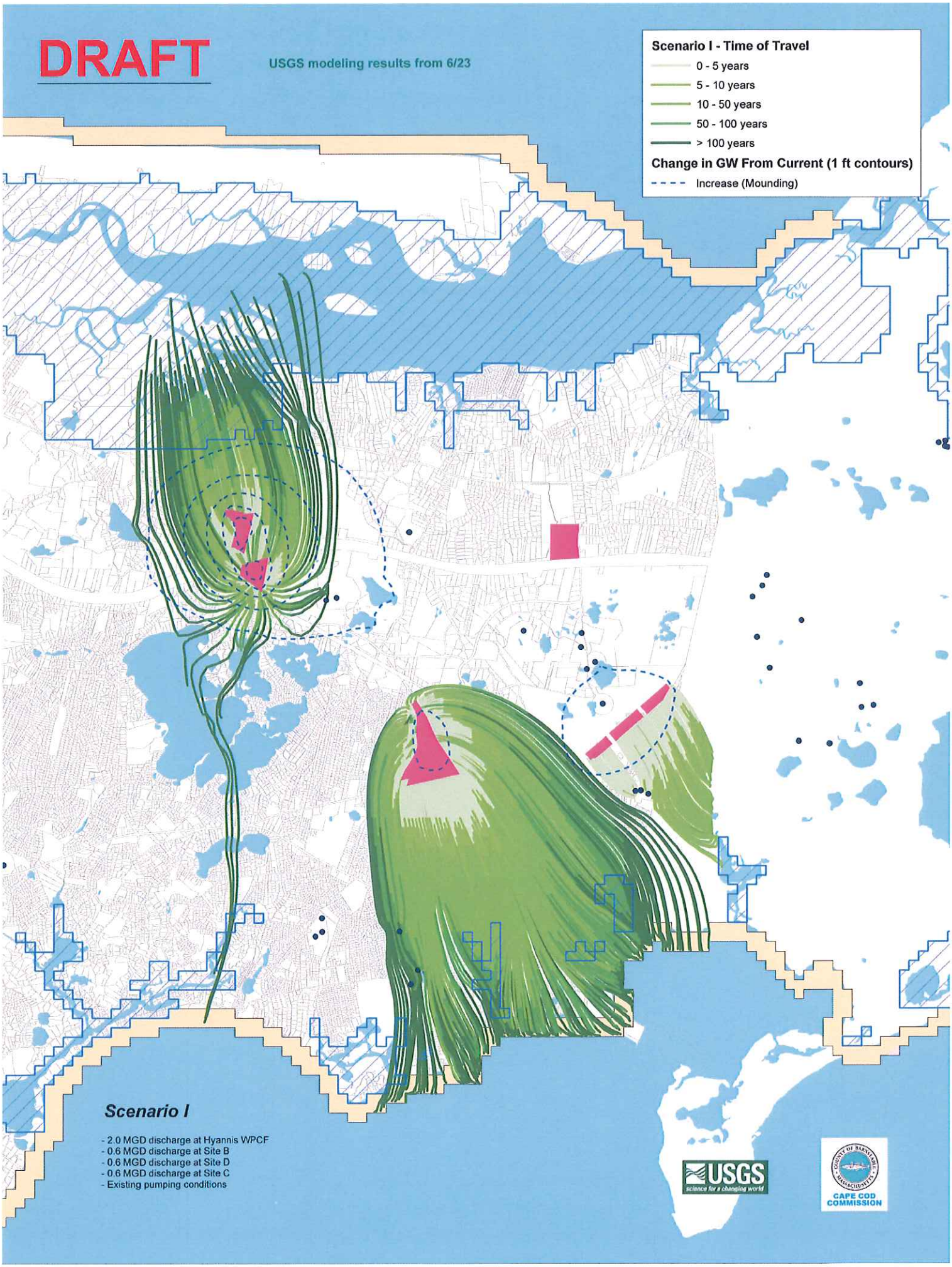

DRAFT
USGS modeling results from 5/27
Scenario E - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW from current (1 ft contours)
Increase / Mounding
Decrease
Scenario E
- 2.5 MGD discharge at Hyannis WPCF
- 1.5 MGD discharge at Site B
- 1.5 MGD discharge at Site D
- 1.5 MGD discharge at Site F
- Transient (July and August) conditions to show mounding, Steady state conditions to show particle tracks
- Future water pumpage for 2020
- No return flows through the existing or future sewered areas
USGS
science for a changing world
CAPE COD COMMISSION


DRAFT
USGS modeling results from 5/27
Scenario E (b) - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW from current (1 ft contours)
Increase / Mounding
Decrease
Scenario E (b)
- 2.5 MGD discharge at Hyannis WPCF
- 1.5 MGD discharge at Site B
- 1.5 MGD discharge at Site D
- 1.5 MGD discharge at Site F
- Transient (July and August) conditions to show mounding. Steady state conditions to show particle tracks
- Future water pumpage for 2020
- No return flows through the existing or future sewered areas (Adjusted K value in Sandwich moraine)
USGS
science for a changing world
CAPE COD COMMISSION

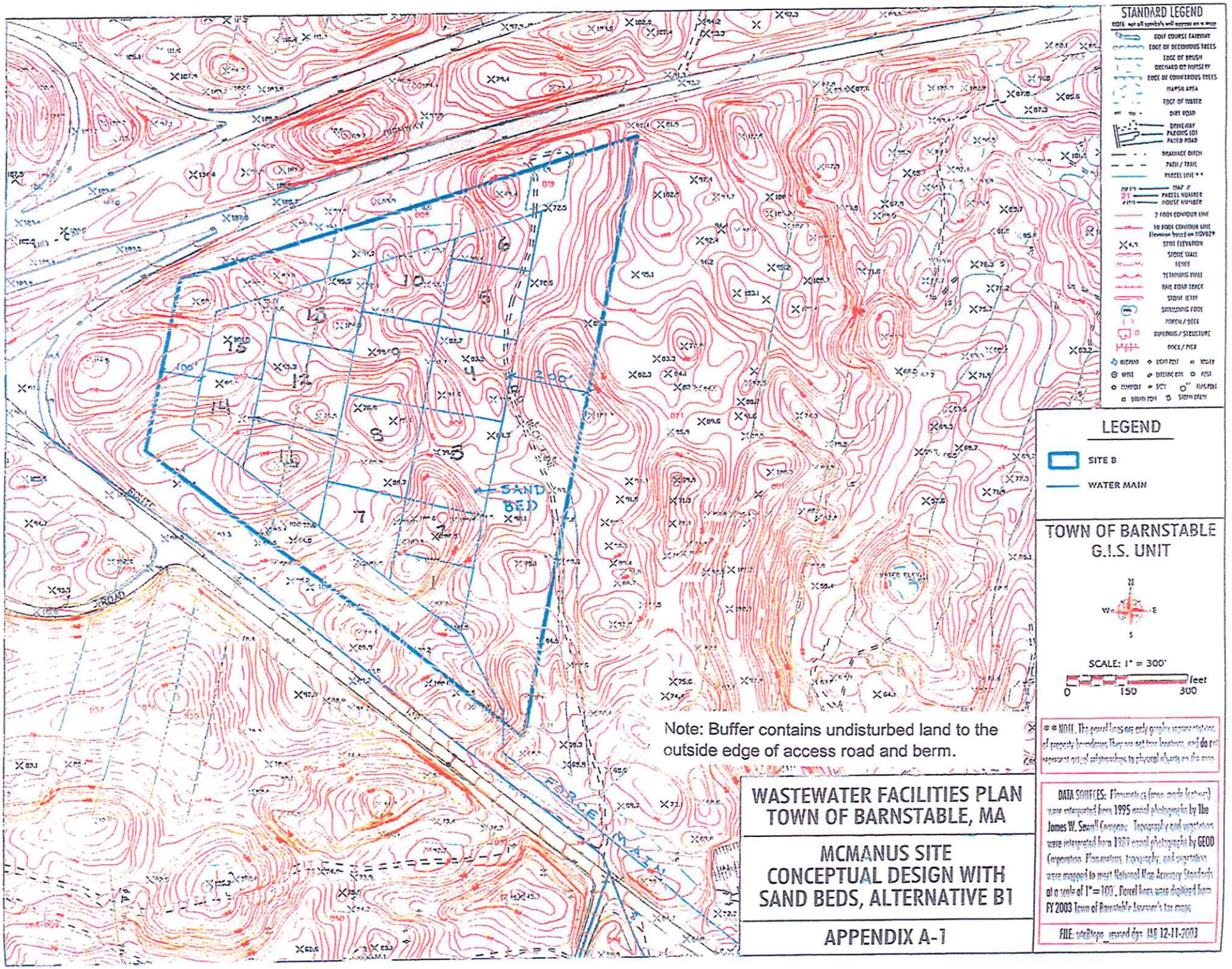

DRAFT
USGS modeling results from 5/27
Scenario F - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW from current (1 ft contours)
Increase / Mounding
Decrease
Scenario F
- 2.5 MGD discharge at Hyannis WPCF
- 1.5 MGD discharge at Site B
- 1.5 MGD discharge at Site D
- 1.5 MGD discharge at Site C
- Transient (July and August) conditions to show mounding, Steady state conditions to show particle tracks
- Future water pumpage for 2020
- No return flows through the existing or future sewered areas
USGS
science for a changing world
CAPE COD COMMISSION

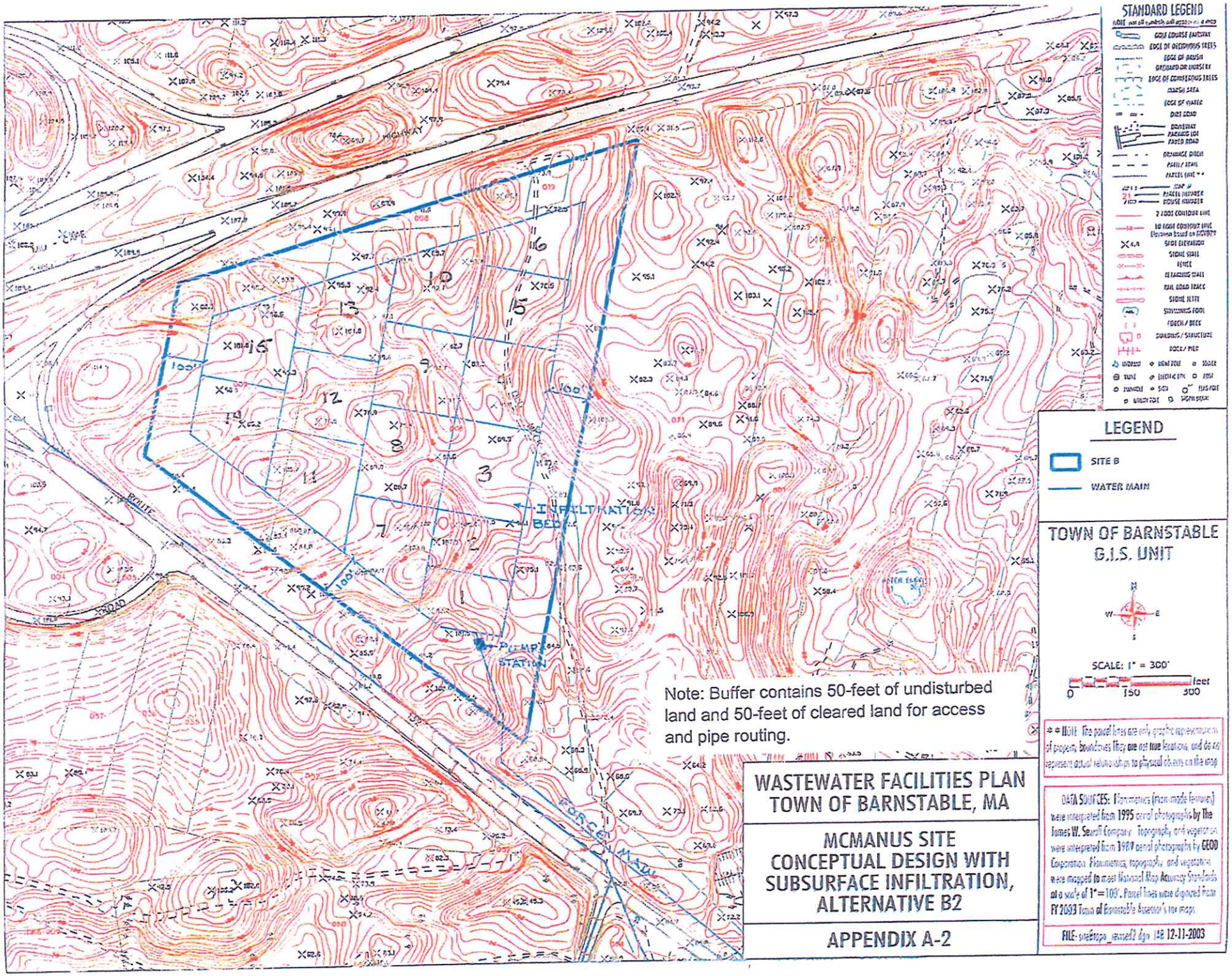

DRAFT
USGS modeling results from 5/27
Scenario G - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Scenario G - WPCF Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW from current (1 ft contours)
Increase / Mounding
Decrease
Sewered Area 2004
Areas of Concern
Scenario G (No Action)
- 1.7 MGD discharge at Hyannis WPCF
- No return flow through existing sewered areas
- 1.8 MGD discharge evenly distributed through and tracked from the future sewered AOCs
- Existing water pumpage
USGS
science for a changing world
CAPE COD COMMISSION

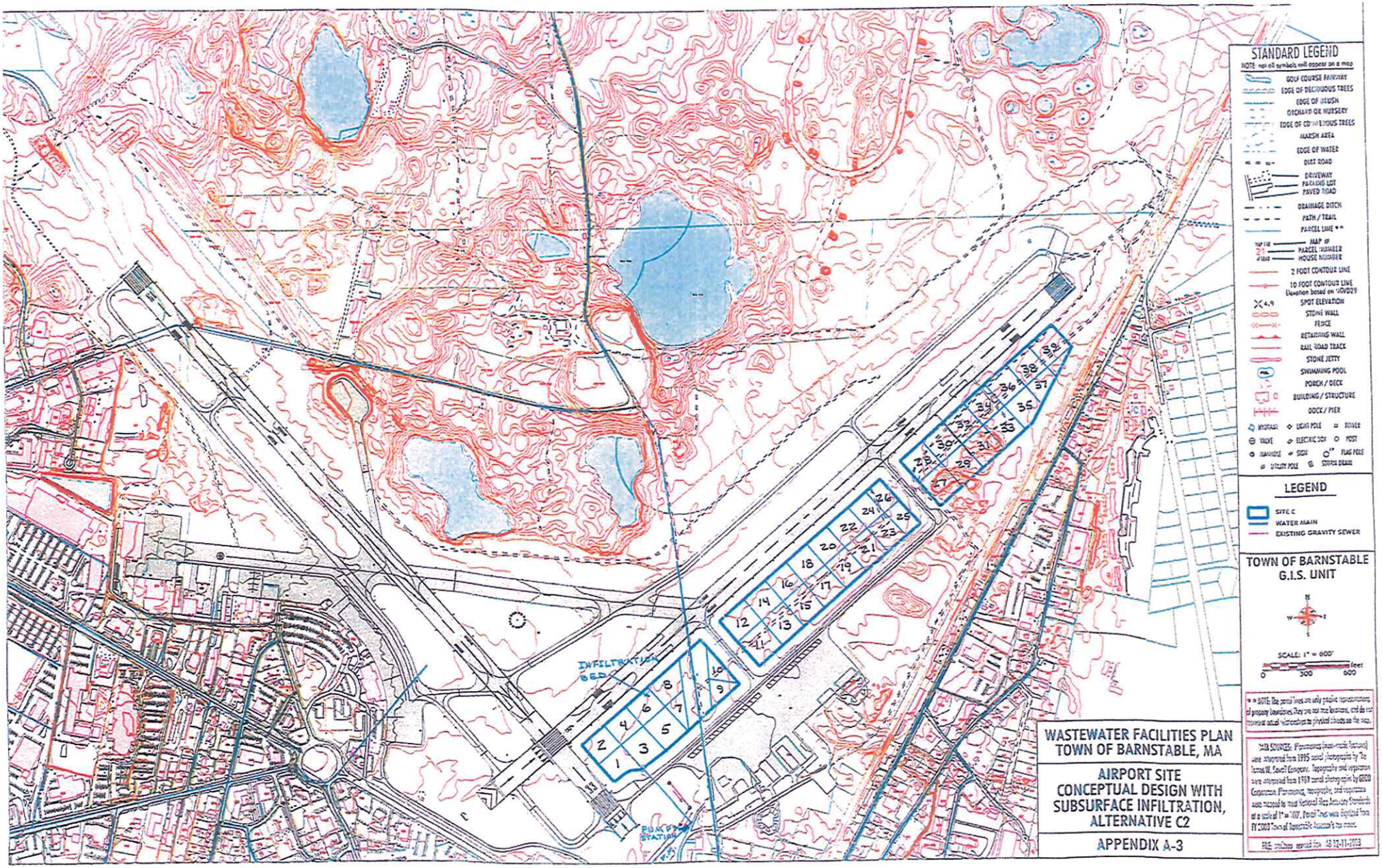

DRAFT
USGS modeling results from 6/23
Scenario H - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW From Current (1 ft contours)
Increase (Mounding)
Scenario H
- 2.0 MGD discharge at Hyannis WPCF
- 0.6 MGD discharge at Site B
- 0.6 MGD discharge at Site D
- 0.6 MGD discharge at Site F
- Existing pumping conditions
USGS
science for a changing world
CAPE COD COMMISSION

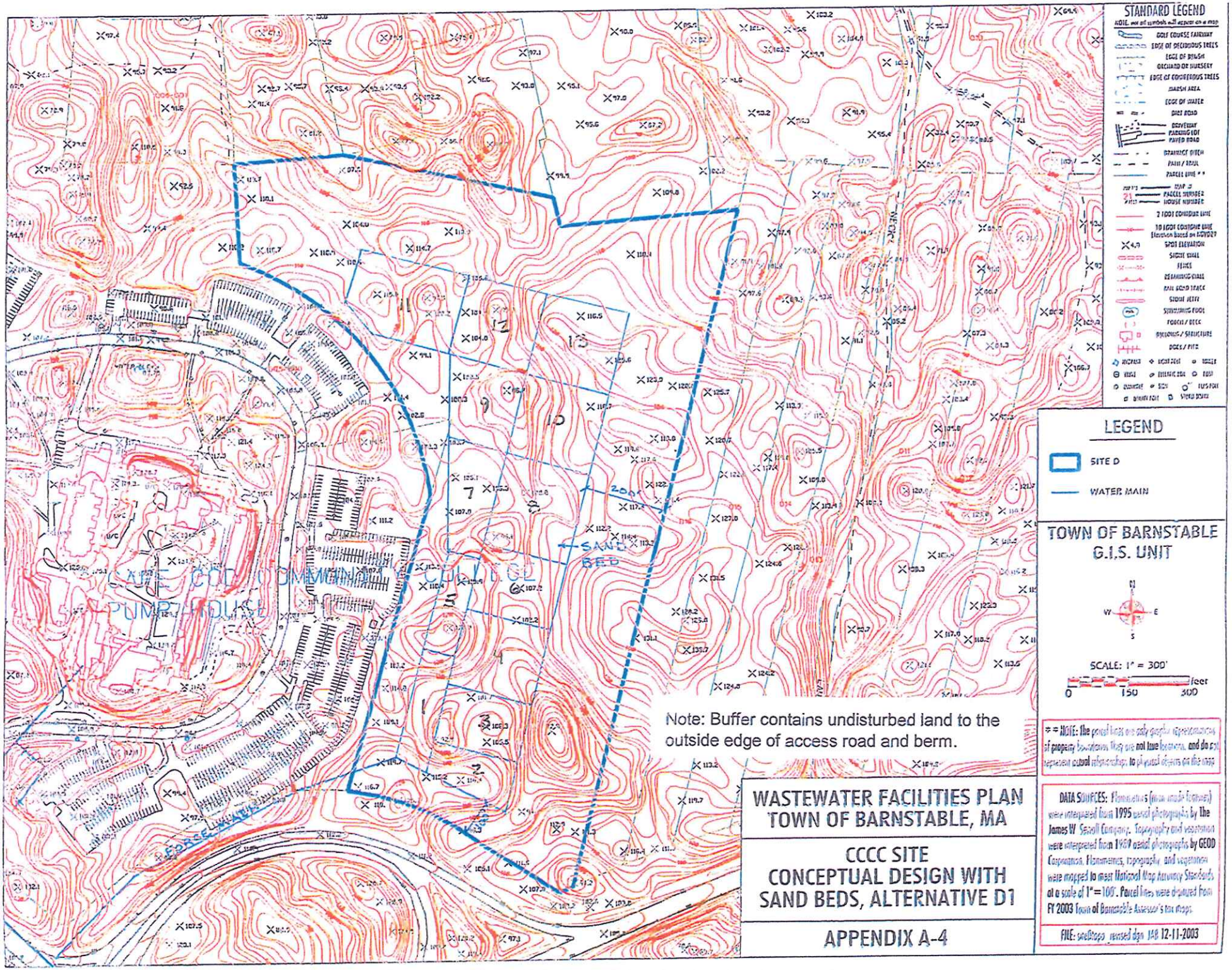

DRAFT
USGS modeling results from 6/23
Scenario I - Time of Travel
0 - 5 years
5 - 10 years
10 - 50 years
50 - 100 years
> 100 years
Change in GW From Current (1 ft contours)
Increase (Mounding)
Scenario I
- 2.0 MGD discharge at Hyannis WPCF
- 0.6 MGD discharge at Site B
- 0.6 MGD discharge at Site D
- 0.6 MGD discharge at Site C
- Existing pumping conditions
USGS
science for a changing world
CAPE COD COMMISSION

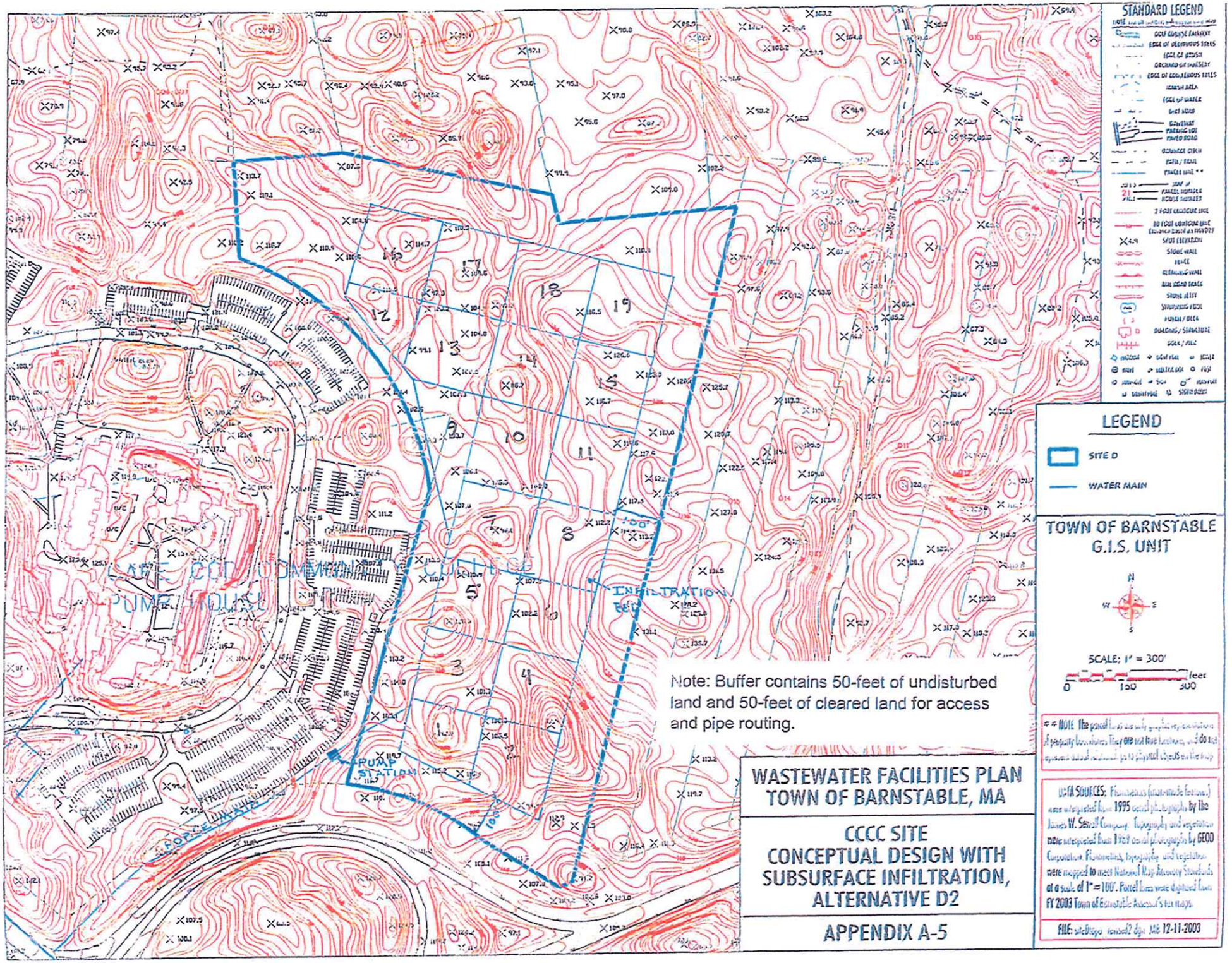
Appendix C:
Conceptual Layouts at Candidate Sites

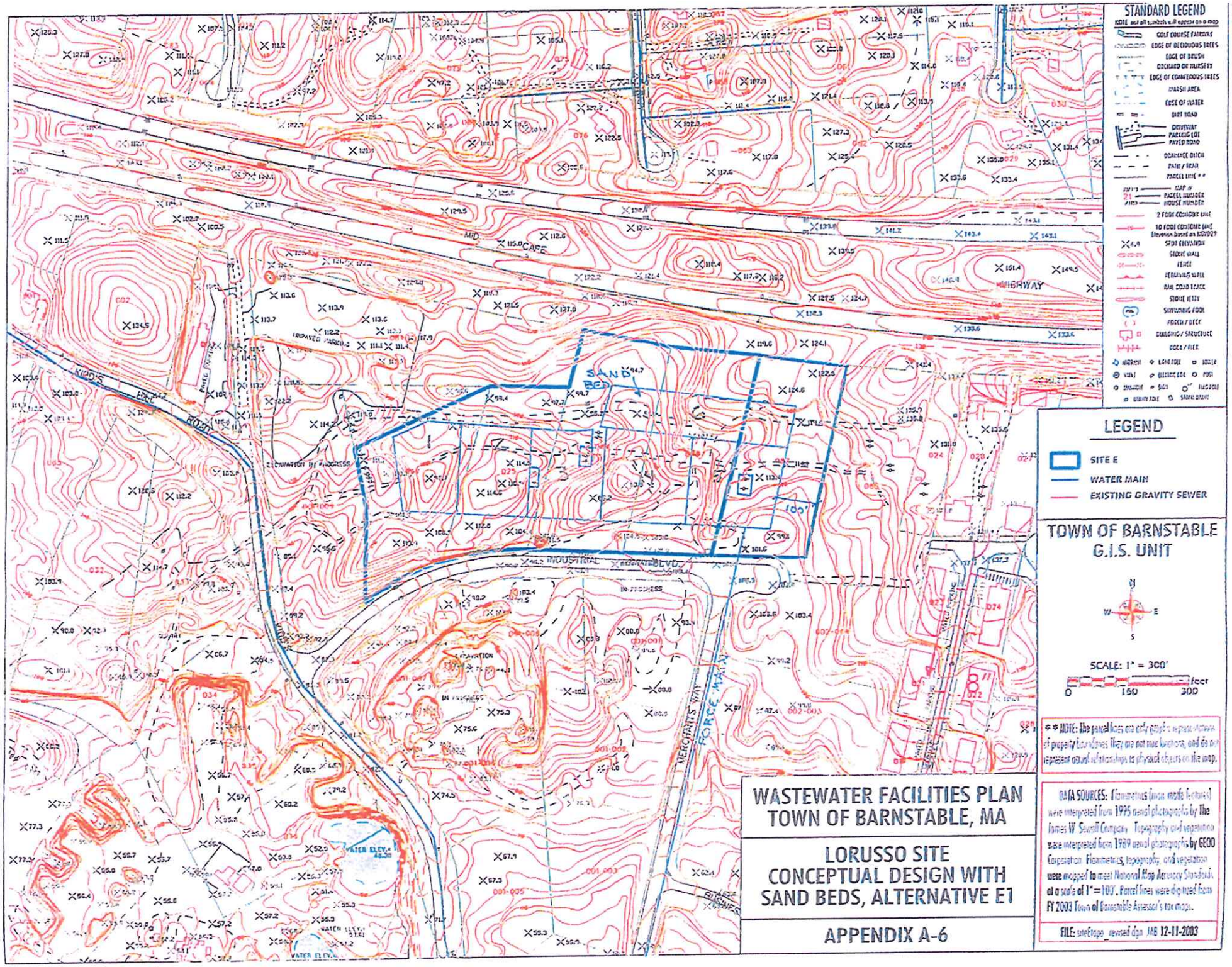

STANDARD LEGEND
LEGEND
SITE B
WATER MAIN
TOWN OF BARNSTABLE
G.I.S. UNIT
SCALE: 1" = 300'
0
150
300
feet
SAND BED
FORCE MAIN
Note: Buffer contains undisturbed land to the outside edge of access road and berm.
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
MCMANUS SITE
CONCEPTUAL DESIGN WITH
SAND BEDS, ALTERNATIVE B1
APPENDIX A-1


STANDARD LEGEND
LEGEND
SITE B
WATER MAIN
TOWN OF BARNSTABLE
G.I.S. UNIT
SCALE: 1" = 300'
feet
0
150
300
Note: Buffer contains 50-feet of undisturbed land and 50-feet of cleared land for access and pipe routing.
INFILTRATION BED
PUMP STATION
FORCE MAIN
ROUTE 132
ROAD
HIGHWAY
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
MCMANUS SITE
CONCEPTUAL DESIGN WITH
SUBSURFACE INFILTRATION,
ALTERNATIVE B2
APPENDIX A-2
DATA SOURCES: Planimetrics (man-made features) were interpreted from 1995 aerial photographs by The James W. Sewall Company. Topography and vegetation were interpreted from 1989 aerial photographs by GEOD Corporation. Planimetrics, topography, and vegetation were mapped to meet National Map Accuracy Standards at a scale of 1"=100'. Parcel lines were digitized from FY 2003 Town of Barnstable Assessor's tax maps.
FILE: siteBmap_revised2.dgn LAB 12-11-2003


STANDARD LEGEND
NOTE: not all symbols will appear on a map
GOLF COURSE FAIRWAY
EDGE OF DECIDUOUS TREES
EDGE OF BRUSH
ORCHARD OR NURSERY
EDGE OF CONIFEROUS TREES
MARSH AREA
EDGE OF WATER
DIRT ROAD
DRIVEWAY
PARKING LOT
PAVED ROAD
DRAINAGE DITCH
PATH / TRAIL
PARCEL LINE **
MAP #
PARCEL NUMBER
HOUSE NUMBER
2 FOOT CONTOUR LINE
10 FOOT CONTOUR LINE
Elevation based on NGVD29
SPOT ELEVATION
STONE WALL
FENCE
RETAINING WALL
RAIL ROAD TRACK
STONE JETTY
SWIMMING POOL
PORCH / DECK
BUILDING / STRUCTURE
DOCK / PIER
HYDRANT
LIGHT POLE
MANHOLE
SIGN
FLAG POLE
UTILITY POLE
CATCH BASIN
LEGEND
SITE C
WATER MAIN
EXISTING GRAVITY SEWER
TOWN OF BARNSTABLE
G.I.S. UNIT
SCALE: 1" = 600'
feet
0
300
600
** NOTE: The parcel lines are only graphic representations of property boundaries. They are not true boundaries, and do not represent actual relationships to physical objects on the map.
DATA SOURCES: (Planimetrics (base-mapic features)) were interpreted from 1995 aerial photographs by The James W. Sewall Company. Topography and vegetation were interpreted from 1969 aerial photographs by AERO Corporation. Planimetrics, topography, and vegetation were compiled to meet National Map Accuracy Standards at a scale of 1" = 100'. Parcel lines were digitized from FY 2003 Town of Barnstable Assessor's tax maps.
FILE: cmilnes (revised from AS-12-11-2003)
INFILTRATION BED
PUMP STATION
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
AIRPORT SITE
CONCEPTUAL DESIGN WITH
SUBSURFACE INFILTRATION,
ALTERNATIVE C2
APPENDIX A-3


STANDARD LEGEND
LEGEND
SITE D
WATER MAIN
TOWN OF BARNSTABLE
G.I.S. UNIT
SCALE: 1" = 300'
feet
0
150
300
Note: Buffer contains undisturbed land to the outside edge of access road and berm.
SAND BED
PUMP HOUSE
FORCE MAIN
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
CCCC SITE
CONCEPTUAL DESIGN WITH
SAND BEDS, ALTERNATIVE D1
APPENDIX A-4


STANDARD LEGEND
LEGEND
SITE D
WATER MAIN
TOWN OF BARNSTABLE
G.I.S. UNIT
SCALE: 1" = 300'
0
150
300
feet
INFILTRATION BED
PUMP STATION
POPCEL WAY
Note: Buffer contains 50-feet of undisturbed land and 50-feet of cleared land for access and pipe routing.
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
CCCC SITE
CONCEPTUAL DESIGN WITH
SUBSURFACE INFILTRATION,
ALTERNATIVE D2
APPENDIX A-5
FILE: siteDtopo revised2.dgn JAB 12-11-2003


STANDARD LEGEND
LEGEND
SITE E
WATER MAIN
EXISTING GRAVITY SEWER
TOWN OF BARNSTABLE
G.I.S. UNIT
SCALE: 1" = 300'
0
150
300
feet
SAND BED
INDUSTRIAL BLVD.
MERCHANTS WAY
FORCE MAIN
MID CAPE
HIGHWAY
ROAD
ELEVATION IN PROGRESS
IN PROGRESS
WATER ELEV.
8"
100'
WASTEWATER FACILITIES PLAN
TOWN OF BARNSTABLE, MA
LORUSSO SITE
CONCEPTUAL DESIGN WITH
SAND BEDS, ALTERNATIVE E1
APPENDIX A-6
DATA SOURCES: Planimetrics (man made features) were interpreted from 1995 aerial photographs by The James W. Sewall Company. Topography and vegetation were interpreted from 1989 aerial photographs by GEOD Corporation. Planimetrics, topography, and vegetation were mapped to meet National Map Accuracy Standards at a scale of 1" = 100'. Parcel lines were digitized from FY 2003 Town of Barnstable Assessor's tax maps.
FILE: siteEtopo_revised.dgn JAB 12-11-2003

Appendix Q

Infiltration Loading Tests, McManus Site; October 2005

Report

Infiltration Loading Tests
McManus Site
Town of Barnstable, MA

October 2005

Stearns & Wheler
Companies

INFILTRATION LOADING TESTS

McMANUS SITE

TOWN OF BARNSTABLE, MASSACHUSETTS

Prepared for

TOWN OF BARNSTABLE, MASSACHUSETTS

Prepared by

STEARNS & WHELER, LLC
Environmental Engineers and Scientists
255 Stevens Street
Hyannis, Massachusetts 02601

October 2005

Project No. 5007610

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INFILTRATION LOADING TESTS
McMANUS SITE
TOWN OF BARNSTABLE, MASSCHUSETTS

SECTION 1 – INTRODUCTION

1.1 PURPOSE OF REPORT

The Town of Barnstable is undertaking comprehensive Wastewater Management Planning to develop strategies for collecting, treating and disposing of wastewater. A key element of that planning process is identifying a site in the Town where treated wastewater can be applied to recharge groundwater. This report describes the testing that was completed at one candidate site to determine its suitability for receiving and infiltrating treated wastewater.

1.2 BACKGROUND

In the course of completing comprehensive wastewater management planning, the Town of Barnstable determined that additional wastewater collection and treatment at the existing water pollution control facility (WPCF) was an appropriate remedy to water quality concerns in the Town.

To accommodate an increase in treated effluent from the treatment plant, the Town has been seeking remote locations for the recharge of highly treated effluent. The Town undertook an extensive screening process to identify areas of Town that would be most suitable for wastewater recharge. They then identified four specific sites that were considered favorable for recharge. Preliminary investigations, including completion of soils borings, observation wells, test pits, and percolation tests, were completed at each of the four sites. At the culmination of that testing, the Town determined that the site referred to as the McManus site, located just southeast of Exit 6 on Route 6 (see Figure 1, Site Location Map) would be the Town's priority candidate site. This decision was based on a number of factors, including location, distance to the WPCF, surrounding land use, proximity of sensitive receptors, size, and hydrogeologic properties.

1.3 PRELIMINARY SITE CHARACTERIZATION

The McManus site is comprised of four separate parcels, all owned by the Town. The site is trapezoidal in shape, occupies approximately 28 acres, and is comprised of wooded, rolling terrain. The preliminary investigation completed in the spring of 2003 indicated generally favorable conditions for treated wastewater recharge. Test pits revealed the surficial material was comprised of fine to medium sand. Percolation test rates were all under 5 minutes per inch. The soil boring indicated fine to medium, tightly packed sands to a depth of 85 feet.

Because the site is located on the Sandwich Moraine, soil types can be quite variable and the presence of clay layers or boulders is a possibility, but the preliminary evaluation revealed conditions that suggested the site was generally acceptable.

1.4 RECOMMENDATIONS BASED ON PRELIMINARY SITE CHARACTERIZATION

After the initial screening process and the preliminary site evaluations, the Town selected the McManus site as the priority candidate site. However, because the site is on the moraine where geology can be variable, and because the subsurface, although comprised of fine to medium sand, was tightly compacted, the Town determined that additional testing was warranted to verify the site's hydrogeologic suitability. Larger-scale loading tests were proposed to further evaluate the infiltration capacity of the site soils. The proposed loading test would evaluate the site soils' infiltration capacity using thousands of gallons of water rather than a few gallons of water, as are used for percolation tests, plus the loading tests would allow an evaluation of potential water table mounding impacts.

SECTION 2 - FIELD INVESTIGATION

2.1 LOADING TESTS

Loading tests are essentially large-scale percolation tests. They are accomplished by applying large quantities of water to basins with a specific surface area to allow the calculation of an infiltration rate in minutes per inch and in gallons per day per square foot. The general protocol for completing loading tests is described in the USEPA *Process Design Manual–Land Treatment of Municipal Wastewater (1981)*. A work plan was developed describing the proposed loading test and was submitted to the Massachusetts Department of Environmental Protection (MADEP) for review and approval.

2.2 TEST PREPARATION

Six locations were chosen as test sites. The test sites were spaced throughout the entire McManus site to obtain a comprehensive idea of the site's potential for infiltrating treated effluent. Figure 2 is a site map showing the location of the test basins on the site. One 10-foot diameter basin and two observation wells were installed at each test site (except for Basin 2, where only one well was installed). The basins served as the infiltration sites for the loading tests and the observation wells were installed for monitoring the water table response to the infiltration tests.

Test site preparation included sufficient clearing and grading to allow access to drilling equipment and construction equipment to install the test basins. The drilling contractor and the excavation/construction contractor worked concurrently to construct the wells and basins. The driller installed two wells at each basin, one adjacent to the test basin and one 50 feet away from the basin. At Test Basin 1, the original well installed in the 2003 preliminary investigation served as one of the two wells. At Test Basin 2, a significant clay layer was encountered in the interval from 42 to 82 feet in one of the borings. No well was installed in that boring, and the test at Test Basin 2 was conducted with only the immediately adjacent observation well. The soil conditions were observed and noted during the drilling process. Boring logs are provided in Appendix A. Drilling continued until groundwater was reached and then continued approximately 10 feet below the water table. Once the final depth was reached, observation wells were installed in each boring. Wells were constructed with 2-inch PVC pipe, including 10 feet of

PVC screen at the bottom of the well. Wells were finished with a cast iron protective casing and a locking cap.

Basin installation was completed after the wells were installed. The basin sites were excavated to a depth sufficient to clear top soil and roots. The soils below the top soil were primarily medium and coarse sands. The contractor provided prefabricated 10-foot diameter, 30-inch tall, 3/16-inch thick, aluminum "rings" which served as the walls of the basin. The rings were put in place and pushed into the soils approximately 6 inches below the excavated depth. This served to seal the basin walls into the ground to promote the vertical flow of water out of the basins rather than lateral flow. The basin walls were secured in place by backfilling the outside of the walls up to the original grade. A schematic of a completed test basin is shown in Figure 3. Photographs of basin construction are provided in Appendix B.

A 21,000-gallon storage tank was brought to the site and was supplied by a Barnstable Fire District fire hydrant located a few hundred feet north of the storage tank. A pump and approximately 3,500 feet of pipe and hose were provided to supply water for the testing. A valve for controlling flow was located at each test basin.

Pressure transducers were placed in each of the wells located immediately adjacent to the basins four days before the testing began. The transducers were installed early to provide background water table levels before any loading took place. The transducers were left in place for the duration of the loading tests to observe any effects the loading tests had on the groundwater levels.

2.3 CONSTANT HEAD AND FALLING HEAD TESTS

A series of tests were conducted at the basins over an eight-day period. Appendix B includes selected photographs taken during the testing. There was adequate water supply to test two basins at a time and each round of tests took three days. The testing was completed on the schedule displayed on Table 1.

The basin testing included three phases, as indicated on the schedule: saturation, constant head testing, and falling head testing. Each phase is described below.

A. **Saturation.** The soils at each basin were saturated before testing began. This was done by supplying water to the basin for a 24-hour period. Flow into each basin was sustained at a rate that would keep a generally constant level of water in the test basin, although the exact level was not a factor. As saturation progressed, the infiltration rate of the underlying soils declined. By the end of the day, it was possible to adjust the flow into the basins to a rate that would keep water in the basins overnight without flooding them.

B. **Constant Head Test.** The constant head tests were started after the basins had been saturated for 24 hours. The constant head test was performed by noting the water level in the basin and supplying enough flow to maintain this level over the course of an eight hour test period. In the early stages of the test, the flow rate had to be adjusted periodically to keep the water level in the basin constant. The water level was noted, the flow rate was measured, and the observation well water levels were measured throughout the testing. In the constant head tests, the infiltration capacity is measured in gallons per minute (gpm) as water is added to the 10-foot infiltration basin at the same rate that the water infiltrates out of the basin. Flow rate was measured at the spigots using containers of known volume and a stop watch. By dividing the amount of flow in a day by the square foot area of the basin, an infiltration capacity in gallons per day per square foot is calculated.

At the end of the day of constant head testing, the basins were again supplied with a constant flow overnight to maintain saturated conditions.

C. **Falling Head Test.** The falling head tests were started the day after the constant head tests. These tests were performed by filling the basin to a specific level and then cutting off the water supply and observing the rate at which the water level in the basin dropped. The falling head tests were repeated three times by refilling the basin after the water level had dropped a minimum of 6 inches for each test. In the falling head tests, infiltration is measured in inches per hour. This result is converted to cubic feet per hour and subsequently to gallons per day per square foot. Water levels in the monitoring wells were observed throughout the falling head tests.

SECTION 3 - FINDINGS AND CONCLUSIONS

3.1 SUBSURFACE CONDITIONS

Additional information regarding subsurface conditions at the site was obtained through the installation of the 11 new soil borings. Conditions are generally homogeneous across the site. The entire section penetrated is comprised primarily of fine to coarse sand. A layer of gravel and evidence of cobbles were encountered in many of the borings at a depth of about 15 feet. Isolated silt layers were also encountered in some of the borings. In Boring 2B, a significant stiff gray silt layer was encountered at a depth of 42 feet. The silt layer was penetrated to a depth of 82 feet, but the bottom of the silt layer was never encountered. The silt layer was limited to the northeast corner of the site and was not encountered in the other borings, not even the other boring installed at Test Basin 2. Because the silt layer did not extend further into the McManus site, it was determined that it would not adversely impact the performance of the site, as a whole. A well was not installed in the 2B boring, but a well was installed in the 2A boring and a loading test was completed at Test Basin 2.

Also in the 2A boring, boulders or cobbles had a more significant presence in the 0-20 foot section than in other borings. In several other borings, cobbles were detected in the 15 to 20 foot interval, but did not appear to have a significant impact on the overall character of the stratigraphic profile. However, in boring 2A, in almost the entire section from the surface to 20 feet, boulders or cobbles were present. As part of final design of the site facility, this area of the site will be further characterized to verify suitability.

A silt layer was also encountered in Boring 5A in the interval between 51 and 60 feet below grade. Because a significant silt layer was not encountered in the other borings, it is unlikely that the silt layers encountered in Borings 2B and 5A were connected.

The surface elevations at the various test sites range from 61 to 90 feet. Depth to groundwater at the site ranges between 33 to 50 feet, depending on the surface elevation; and groundwater at the site is found in the elevation interval between 34.5 and 36 feet. Figure 4 illustrates two profiles across the site, based on surveyed elevations and groundwater depth measurements. Based on data obtained from the on-site wells, groundwater flows to the northeast. This conclusion is consistent with Town's town-wide water table mapping.

Overall, the subsurface conditions are generally homogeneous, comprised of fine to coarse sand with lenses of gravel or cobbles and silt. The predominance of the sand suggests suitable conditions for infiltration of treated wastewater.

3.2 CONSTANT HEAD TEST RESULTS

The first set of testing at each basin was constant head testing. As described above, the constant head testing entailed adding water to the basins at the same rate that water drained out of the basin. As expected, from the time saturation was initiated to the time the constant head tests were initiated, the infiltration rate decreased considerably as the soils became more saturated. However, during the constant head tests, the infiltration rates remained generally constant, with the exception of Basin 4, which had variable, but much faster infiltration rates. The infiltration rates for the six infiltration tests are illustrated on Figure 5.

The raw data from the constant head tests is presented on Table 2 and summarized on Table 3. With the exception of Basin 4, which accepted a flow rate of 10 to 17 gpm, the basins generally accepted a flow of approximately 5 gpm. Some were closer to 4 gpm and others were closer to 6 gpm, but for general discussion, a rate of 5 gpm is a reasonable generalization. Five gpm equates to 7,200 gallons per day (gpd). The discharge of 7,200 gpd in a 10-foot diameter basin (surface area 78 sq. ft.) equates to 92 gpd/sq ft. If, for the purposes of design, the most conservative recharge rate of 4 gpm is used to calculate infiltration rate, the calculated rate is 74 gpd/sq. ft.

USEPA protocols for conducting loading tests suggest that, although loading tests are probably the most accurate means of estimating loading rate, loading tests have a greater horizontal flow component than full-scale installations; therefore, loading tests overestimate full-scale capacity. Therefore, USEPA recommends design rates that are only 10 to 15 percent of observed rates in loading tests. The loading tests suggest an infiltration rate of approximately 74 gpd/sq ft, hence a design loading rate of up to 7 gpd/sq ft can be considered reasonable. MADEP establishes a maximum design loading rate of 5 gpd/sq ft, but allows proponents to make a demonstration for a greater loading rate, once full-scale facilities are constructed and operational.

Based on the results of the constant head testing, which indicated a infiltration rate of at least 74 gpd/sq ft, a design loading rate of up to 7 gpd/sq ft is reasonable. Hence, the MADEP-

recommended rate of 5 gpd/sq ft for rapid infiltration beds or 3.0 gpd/sq ft for leaching trenches is appropriate.

3.3 FALLING HEAD TEST RESULTS

To supplement the constant head test results, falling head tests were performed in each of the basins after the constant head tests were completed. Between the tests, water was continuously added to the basins to retain the saturated soil conditions.

To complete the falling head tests, basins were filled to a specific measured mark. The water supply was then turned off and the rate at which the water level in the basin dropped was recorded. The falling head tests were repeated three times in each basin, with the basin being refilled at the beginning of each test run. The results of the falling head tests are presented on Tables 4-1 through 4-6. Infiltration rate is presented in three different units on the tables: minutes per inch, inches per hour, and gallons per day per square foot (gpd/sq ft). Infiltration rates in minutes per inch (the units used in MADEP guidance) are illustrated on Figures 6 through 11. Infiltration rates in gpd/sq ft for all of the tests are summarized on Figure 12. The average infiltration rates in gpd/sq ft for each of the basins were 90 gpd/sq ft, 59 gpd/sq ft, 51 gpd/sq ft, 137gpd/sq ft 74 gpd/sq ft and 82 gpd/sq ft, respectively. The highest average was at Basin 4 (137 gpd/sq ft) and the lowest average was at Basin 3 (51 gpd/sq ft). The average result was 82 gpd/sq ft, but this average is affected by the results from Basin 4, which cannot be considered representative of site-wide conditions because of the anomalously high infiltration rates at that site. To be conservative, if the lowest average infiltration rate of 51 gpd/sq foot is used as the basis on design, and the EPA criteria of using 10 percent of the infiltration test rate is applied, a design loading rate of 5 gpd/sq ft is appropriate. This specified design loading rate is based on a number of conservative considerations. First, the USEPA's 10 percent factor has been applied, and second, it is based on the lowest average value across the site (51 gpd/sq ft) rather than the average rate (82 gpd/sq foot), which is more likely representative of overall site conditions.

3.4 MOUNDING IMPACTS

Two observation wells were installed at each basin with the exception of Basin 2, where subsurface conditions did not warrant the installation of a second well. Recording pressure transducers were placed in each of the "A" wells (i.e., the wells immediately adjacent to the

basins) four days prior to the startup of the testing to record background conditions. The transducers recorded water level in the wells every 15 minutes and were left in place throughout the tests and for a period of four days after testing was completed. Additionally, water levels were measured in the B wells during the course of the testing at the respective basin.

Water level data is depicted graphically on Figures 13 through 18. Figure 19 is a compilation of the six data sets so that the fluctuations in water levels in the six wells can be compared.

Although there are fluctuations in the water levels in the wells, they all track very similarly, independent of the fact that the testing took place in the wells during different times during the 10-day test period. The three-day period, during which the testing was undertaken at each well (one day saturation, one day constant head test, one day falling head test, with continuous saturation occurring during the night), is depicted on the graphs by the yellow block. The loading testing did not appear to have any noticeable impact on the water table at the site of each basin. The fluctuations observed on the graphs occurred at the same times in each of the six wells independent of whether the testing was occurring.

There was no precipitation during the testing or during the week prior to the testing, which was initiated on June 6. Between May 22 and May 29, there were eight days of rain. Daily totals ranged from 0.01 to 0.73 inches (May 24) for a total of 2.33 inches. Rainfall did not affect the interpretation of the loading test impacts, as variations from the common trend of all the wells would appear at the wells being tested. The one unexplained anomaly is the fact that the fluctuations in Well 5A, although similar to the other wells, are exaggerated.

Figure 20 is a graph of the Well B water levels as testing was completed at each well's respective basin (except Basin 2, which had no B well). No observable effects of the loading were seen, as would be expected, given the fact that there was no indication of impact in the more proximal A wells.

SECTION 4 - CONCLUSIONS

4.1 Test Conclusions

Loading tests were completed for treated wastewater recharge in the Town of Barnstable at a candidate site referred to as the McManus site. The McManus site is trapezoidal in shape and encompasses approximately 11 acres. The site is wooded, undeveloped, and has rolling topography. A preliminary site investigation was conducted in 2003, indicating general suitability for wastewater recharge.

Loading tests were completed between June 6 and June 15, 2005. Testing was performed at six 10-foot basins, distributed across the site. Testing was comprised of:

1. One day of saturating the soils beneath the basins for a 24-hour period by sustaining a water level in the basins as was infiltrating out of them.

2. One day of constant head testing, during which water was fed to the basin at the same rate that water drained from the basin, as indicated by a constant water level in the basin.

3. One day of falling head testing, recording the rate at which the water level in the basins dropped. This was repeated three times.

From the constant head and falling head tests, infiltration rate in gpd/sq ft was calculated. In the constant head testing, an average infiltration rate of 106 gpd/sq ft was calculated. If Basin 4 data is rejected as not being representative of the site because of its significantly higher rate, the average infiltration rate was 90 gpd/sq ft. Applying the USEPA design factor of 10 percent to that result, an appropriate design loading rate is 9 gpd/sq ft. MADEP limits initial design loading rate to 5 gpd/sq ft until the full-scale system can be used to demonstrate higher allowable rates.

In the falling head testing, an average infiltration rate of 82 gpd/sq ft was calculated. If Basin 4 data is rejected as not being representative of the site because of its significantly higher rate, the average infiltration rate was 72 gpd/sq ft. Applying the USEPA design factor of 10 percent to that result, an appropriate design loading rate is 7 gpd/sq ft.

4.2 Estimated Site Capacity

If the data from the slowest basin from either set of testing is used as the basis for design, that average infiltration rate was 59 gpd/sq ft. Again, applying the USEPA design factor of 10 percent to that result, an appropriate design loading rate is 6 gpd/sq ft. Even applying the most conservative interpretation, the design load rate is still above and supportive of the general MADEP policy maximum of 5 gpd/sq ft.

Because a significant factor of conservation is applied to the USEPA policy of a design rate of 10 percent of the test rate, because the testing provided significant demonstration through a number of tests at a number of locations across the site, and because the MADEP guidance is extremely conservative (5 gpd/sq ft equates to 181 min/inch), Stearns & Wheler concludes that the test results demonstrate the capability of the site to receive at least 5 gpd/sq ft via open sand beds or 3 gpd/sq ft using subsurface leaching trenches.

The Town of Barnstable is considering subsurface leaching trenches as a preferred recharge technology for this site. MADEP provides guidance on the design of subsurface leaching systems. Two of the MADEP criteria that need to be considered in estimating the capacity of the site are that laterals be limited to 100 foot lengths and manifold piping be limited to 200 foot lengths. If subsurface leaching trenches are laid out in 200 foot by 100 foot fields, there is room for approximately 35 leaching fields at the site. Based on 3 gpd/sq foot and 6 square feet of infiltration area per linear foot of trench, a preliminary estimate of the capacity of the McManus site is 1.6 mgd. If 25% of the fields are set aside at any one time to allow loading to the fields to be rotated, the capacity of the site can be estimated to be 1.2 mgd.

MADEP reviewed a draft of this report and indicated that, based on the results of the testing presented, it was feasible that a greater recharge rate than 3 gpd/sq foot could be approved. Specifically, MADEP indicated that a recharge rate of 4 gpd/sq foot could be considered for the site. If the recharge rate of leaching trenches is increased from 3 gpd/sq foot to 4 gpd/sq foot the capacity of the site could increase from the 1.2 mgd cited above to 1.6 mgd.

Although the Town presently believes that subsurface leaching will be the technology employed at the site, it is still possible that rapid infiltration beds may be selected as the most appropriate alternative in the final evaluation. If rapid infiltration beds are used, the capacity of the site increases to approximately 2.1 mgd based on facility layout and the needed buffer area for this

type of technology. Whether leaching trenches or rapid infiltration beds are employed, the opportunity will exist, when full scale facilities are constructed and operational, to demonstrate additional capacity, if appropriate.

4.3 Site Availability

The Town has reviewed the suitability of using this land for effluent recharge in the context of the fact that portions of the site were acquired with Land Bank funds. The Town's legal review has concluded that the proposed use is consistent with the purposes of the land bank legislation. Correspondence related to this determination is provided as Appendix C.

TABLES

TABLE 1
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
TEST SCHEDULE

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday
	6/6/2005	6/7/2005	6/8/2005	6/9/2005	6/10/2005	6/11/2005	6/12/2005	6/13/2005	6/14/2005	6/15/2005
Test Basins 1 + 2	Saturation	Constant Head Test	Falling Head Test							
Test Basins 3 + 5			Saturation	Constant Head Test	Falling Head Test					
Test Basins 4 + 6								Saturation	Constant Head Test	Falling Head Test

TABLE 2
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
CONSTANT HEAD TESTING DATA

Basin 1 Tues 6/7/05

Time	Q(gpm)	Water Depth	Avg. Infiltration Rate (gpd/sq ft)
11:30	5	14	92.3
12:30	5.3	14	97.8
1:35	5.5	14	101.5
1:58	5.5	14	101.5
2:15	5	12	92.3
2:34	5	12	92.3
2:56	5.5	14	101.5
4:00	6	14	110.8

Basin 2 Tues 6/7/05

Time	Q(gpm)	Water Depth	Avg. Infiltration Rate (gpd/sq ft)
10:25	4.5	12	83.1
10:35	5.5	12	101.5
10:52	5.5	12	101.5
11:35	5	12	92.3
12:54	5	12	92.3
1:16	5	12	92.3
2:18	5	12	92.3
2:39	5	12	92.3
3:30	4.5	12	83.1

Basin 3 Thur 6/9/05

Time	Q(gpm)	Water Depth	Avg. Infiltration Rate (gpd/sq ft)
8:33	6	19.5	110.8
10:23	8	20	147.7
10:44	6	20	110.8
11:20	5	19.5	92.3
11:45	5	19	92.3
12:20	5	5	92.3
1:10	5	19	92.3
1:37	6	19	110.8
2:16	5.5	19	101.5
2:43	5.5	19	101.5
3:23	5.5	19	101.5
3:45	5.5	19	101.5
4:09	5.5	19.5	101.5

Basin 4 Tues 6/14/05

Time	Q(gpm)	Water Dep	Avg. Infiltration Rate (gpd/sq ft)
10:00	24	17.5	443.1
10:20	16	17	295.4
11:00	16	17	295.4
11:30	17	17	313.8
12:30	15	17	276.9
1:40	14	17	258.5
2:10	14	17	258.5
2:40	10	17	184.6
3:30	11	17.5	203.1

Basin 5 Thur 6/9/05

Time	Q(gpm)	Water Dep	Avg. Infiltration Rate (gpd/sq ft)
9:50	6	17.5	110.8
10:10	7.5	17	138.5
11:15	6	17	110.8
11:55	6.5	17	120.0
12:40	6	17	110.8
1:00	6.5	17	120.0
1:45	6.5	17	120.0
2:08	6	17	110.8
2:50	6.5	17.5	120.0
3:15	6	17	110.8
3:59	6.5	17.5	120.0

Basin 6 Thur 6/14/05

Time	Q(gpm)	Water Dep	Avg. Infiltration Rate (gpd/sq ft)
11:00	5	15	92.3
11:50	5	16	92.3
1:00	4.5	17	83.1
3:06	4	17	73.8
3:48	4	16.5	73.8

TABLE 3
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
CONSTANT HEAD TESTING RESULTS

Basin ID	Final Stabilized Flow Rate in gal/min (1)	Final Stabilized Flow Rate in gal/day	Basin Area Square Feet (2)	Infiltration Capacity Gal/day/sq. ft	Allowable Loading Rate Gal/day/sq. ft (3)
1	5	7200	78	92.3	9
2	4.5	6480	78	83.1	8
3	5	7200	78	92.3	9
4	10	14400	78	184.6	18
5	6	8640	78	110.8	11
6	4	5760	78	73.8	7
				106.2	11

(1) To be conservative, based on lowest flow rate recorded
(2) $A = 3.14 \times (5\ ft)^2$
(3) Based on EPA guidance indicating loading rates should be based on 10-15% of measured basin infiltration rates

TABLE 4-1
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
FALLING HEAD TESTING RESULTS

Basin 1 **Wed 6/8/05**
Test 1

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
8:45	0	17.5	0.0			
9:14	29	15	2.5	11.60	5.17	78
9:25	11	14	1.0	11.00	5.45	82
9:35	10	13	1.0	10.00	6.00	90
9:46	11	12	1.0	11.00	5.45	82
10:01	15	11	1.0	15.00	4.00	60
10:15	14	10	1.0	14.00	4.29	64
10:27	12	9	1.0	12.00	5.00	75
10:38	11	8	1.0	11.00	5.45	82
10:52	14	7	1.0	14.00	4.29	64
11:05	13	6	1.0	13.00	4.62	69
12:00	55	2.5	3.5	15.71	3.82	57
				12.57	Average	73

Basin 1 **Wed 6/8/05**
Test 2

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
12:11		20	0.0			
12:18	9	19	1.0	9.00	6.67	100
12:25	7	18	1.0	7.00	8.57	129
12:34	9	17	1.0	9.00	6.67	100
12:44	10	16	1.0	10.00	6.00	90
12:53	9	15	1.0	9.00	6.67	100
1:00	7	14	1.0	7.00	8.57	129
1:11	11	13	1.0	11.00	5.45	82
1:21	10	12	1.0	10.00	6.00	90
1:34	13	11	1.0	13.00	4.62	69
1:45	12	10	1.0	12.00	5.00	75
1:56	21	9	1.0	21.00	2.86	43
2:09	13	8	1.0	13.00	4.62	69
2:22	13	7	1.0	13.00	4.62	69
2:30	8	6	1.0	8.00	7.50	113
				10.86	Average	90

Basin 1 **Wed 6/8/05**
Test 3

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
2:46	0	18	0.0			
2:55	9	17	1.0	9.00	6.67	100
3:04	9	16	1.0	9.00	6.67	100
3:14	10	15	1.0	10.00	6.00	90
3:23	9	14	1.0	9.00	6.67	100
3:34	11	13	1.0	11.00	5.45	82
3:43	9	12	1.0	9.00	6.67	100
3:55	12	11	1.0	12.00	5.00	75
4:05	10	10	1.0	10.00	6.00	90
4:16	11	9	1.0	11.00	5.45	82
				10.00	Average	91

TABLE 4-2
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
FALLING HEAD TESTING RESULTS

Basin **2** **Wed 6/8/05**
Test **1**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
9:00		17	0.0			
9:15	15	16	1.0	15.00	4.00	60
9:30	15	15	1.0	15.00	4.00	60
9:45	15	14	1.0	15.00	4.00	60
10:36	51	11	3.0	17.00	3.53	53
10:55	19	10	1.0	19.00	3.16	47
11:35	40	8	2.0	20.00	3.00	45
11:57	22	7	1.0	22.00	2.73	41
				17.57	Average	52

Basin **2** **Wed 6/8/05**
Test **2**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
12:07	0	22	0.0			
12:18	11	21	1.0	11.00	5.45	82
1:24	66	16	5.0	13.20	4.55	68
1:55	31	14	2.0	15.50	3.87	58
2:11	16	13	1.0	16.00	3.75	56
2:26	15	12	1.0	15.00	4.00	60
3:01	35	10	2.0	17.50	3.43	51
				14.70	Average	63

Basin **2** **Wed 6/8/05**
Test **3**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
3:08		18	0.0			
3:36	28	16	2.0	14.00	4.29	64
4:05	29	14	2.0	14.50	4.14	62
4:35	30	12	2.0	15.00	4.00	60
				14.50	Average	62

TABLE 4-3
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
FALLING HEAD TESTING RESULTS

Basin **3** **Fri 6/10/05**
Test **1**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
8:45	0	26	0.0			
8:56	11	25	1.0	11.00	5.45	82
9:08	12	24	1.0	12.00	5.00	75
9:19	11	23	1.0	11.00	5.45	82
9:30	11	22	1.0	11.00	5.45	82
9:43	13	21	1.0	13.00	4.62	69
9:58	15	20	1.0	15.00	4.00	60
10:11	13	19	1.0	13.00	4.62	69
10:24	13	18	1.0	13.00	4.62	69
10:41	17	17	1.0	17.00	3.53	53
10:57	16	16	1.0	16.00	3.75	56
11:16	19	15	1.0	19.00	3.16	47
11:36	20	14	1.0	20.00	3.00	45
11:49	13	13	1.0	13.00	4.62	69
				14.15	Average	66

Basin **3** **Fri 6/10/05**
Test **2**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
11:53	0	22	0.0			
12:37	44	19	3.0	14.67	4.09	61
3:19	162	11	8.0	20.25	2.96	44
3:50	31	10	1.0	31.00	1.94	29
				21.97	Average	45

Basin **3** **Fri 6/10/05**
Test **3**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
3:53	0	18	0.0			
4:35	42	16	2.0	21.00	2.86	43
4:56	21	15	1.0	21.00	2.86	43
				21.00	Average	43

TABLE 4-4
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
FALLING HEAD TESTING RESULTS

Basin 4 **Wed 6/15/05**
Test 1

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
8:37	0	24	0.0			
8:57	20	21	3.0	6.67	9.00	135
9:09	14	18	3.0	4.67	12.86	193
9:37	28	14	4.0	7.00	8.57	129
9:44	7	13	1.0	7.00	8.57	129
9:52	8	12	1.0	8.00	7.50	113
10:01	9	11	1.0	9.00	6.67	100
10:10	9	10	1.0	9.00	6.67	100
10:30	20	8	2.0	10.00	6.00	90
				7.67	Average	123

Basin 4 **Wed 6/15/05**
Test 2

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
10:36	0	24	0.0			
10:42	6	22	2.0	3.00	20.00	300
10:58	16	20	2.0	8.00	7.50	113
11:10	12	18	2.0	6.00	10.00	150
11:24	14	16	2.0	7.00	8.57	129
11:32	8	15	1.0	8.00	7.50	113
11:48	16	13	2.0	8.00	7.50	113
11:57	9	12	1.0	9.00	6.67	100
12:05	8	11	1.0	8.00	7.50	113
12:15	10	10	1.0	10.00	6.00	90
				7.44	Average	135

Basin 4 **Wed 6/15/05**
Test 3

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
12:20	0	24	0.0			
12:26	6	23	1.0	6.00	10.00	150
12:49	23	19	4.0	5.75	10.43	157
12:56	7	18	1.0	7.00	8.57	129
1:28	32	14	4.0	8.00	7.50	113
1:45	17	12	6.0	2.83	21.18	318
2:30	45	7.5	6.5	6.92	8.67	130
				6.08	Average	153

TABLE 4-5
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
FALLING HEAD TESTING RESULTS

Basin **5** **Fri 6/10/05**
Test **1**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
9:20	0	19	0.0			
9:30	10	18	1.0	10.00	6.00	90
9:41	11	17	1.0	11.00	5.45	82
9:54	13	16	1.0	13.00	4.62	69
10:09	15	15	1.0	15.00	4.00	60
10:22	13	14	1.0	13.00	4.62	69
10:36	14	13	1.0	14.00	4.29	64
10:55	19	12	1.0	19.00	3.16	47
11:11	16	11	1.0	16.00	3.75	56
11:36	25	10	1.0	25.00	2.40	36
				15.11	Average	64

Basin **5** **Fri 6/10/05**
Test **2**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
11:40	0	25	0.0			
12:30	50	20	5.0	10.00	6.00	90
3:23	173	9	11.0	15.73	3.82	57
				12.86	Average	74

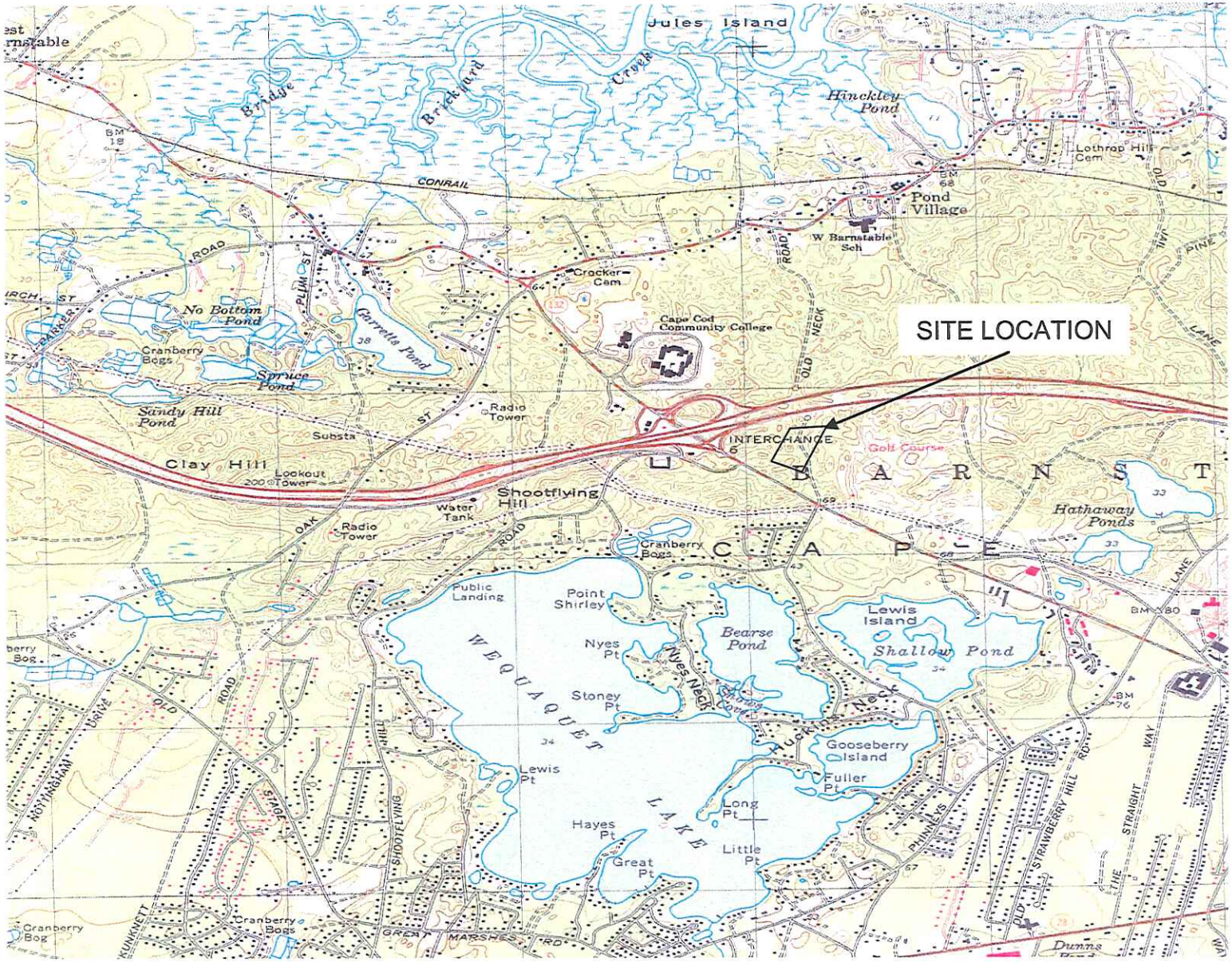
Basin **5** **Fri 6/10/05**
Test **3**

Time	Elapsed Time(min)	Water Depth Level	Change in Water Level	Rate of Change min/inch	Rate of Change inches/hr	Infiltration Rate gpd/sqft
3:40	0	18	0.0			
3:47	7	17	1.0	7.00	8.57	129
3:57	10	16	1.0	10.00	6.00	90
4:10	13	15	1.0	13.00	4.62	69
4:24	14	14	1.0	14.00	4.29	64
4:38	14	13	1.0	14.00	4.29	64
4:47	9	12	1.0	9.00	6.67	100
				11.17	Average	86

TABLE 5
TOWN OF BARNSTABLE
MCMANUS LOADING TEST
DISTANT WELL (50 FEET AWAY) WATER LEVELS

		1B	3B	4B	5B	6B	
5/18/2005	12:00			39.54	47.07	53.63	28.08
6/7/2005	4:00		54.40				
	5:09		54.42				
6/8/2005	8:10		54.46			53.42	
	8:25		54.56	39.21			
	12:00		54.43				
	12:25		54.46				
	1:21		54.45				
	2:30		54.45				
	8:09		54.45				
6/9/2005	11:20			39.17			
	11:45			39.16			
	12:20			39.16		53.42	
	1:10			39.15		53.41	
	1:37			39.16		53.41	
	2:16			39.16		53.41	
	2:43			39.15		53.41	
	3:23			39.15		53.41	
	3:45			39.18		53.41	
	4:09			39.15			
6/10/2005	8:30			39.15			
	9:19			39.15			
	9:58			39.15		53.47	
	11:16			39.14		53.48	
	11:53			39.14		53.48	
	3:19			39.13		53.46	
	4:35			39.12			
	4:56			39.13			
6/13/2005	11:24				46.88		28.16
	1:57				46.88		28.16
	5:30				46.87		28.16
6/14/2005	10:20				46.77		
	11:00				46.77		28.13
	11:30				46.76		28.63
	2:10				46.76		
	2:40				46.75		
	3:30				46.74		
6/15/2005	8:25				46.67		
	9:09				46.67		28.18
	10:30				46.67		28.18
	11:24				46.66		28.18
	12:05				46.66		28.18
	12:26				46.66		
	12:56				46.66		28.18
	2:22						28.18

FIGURES



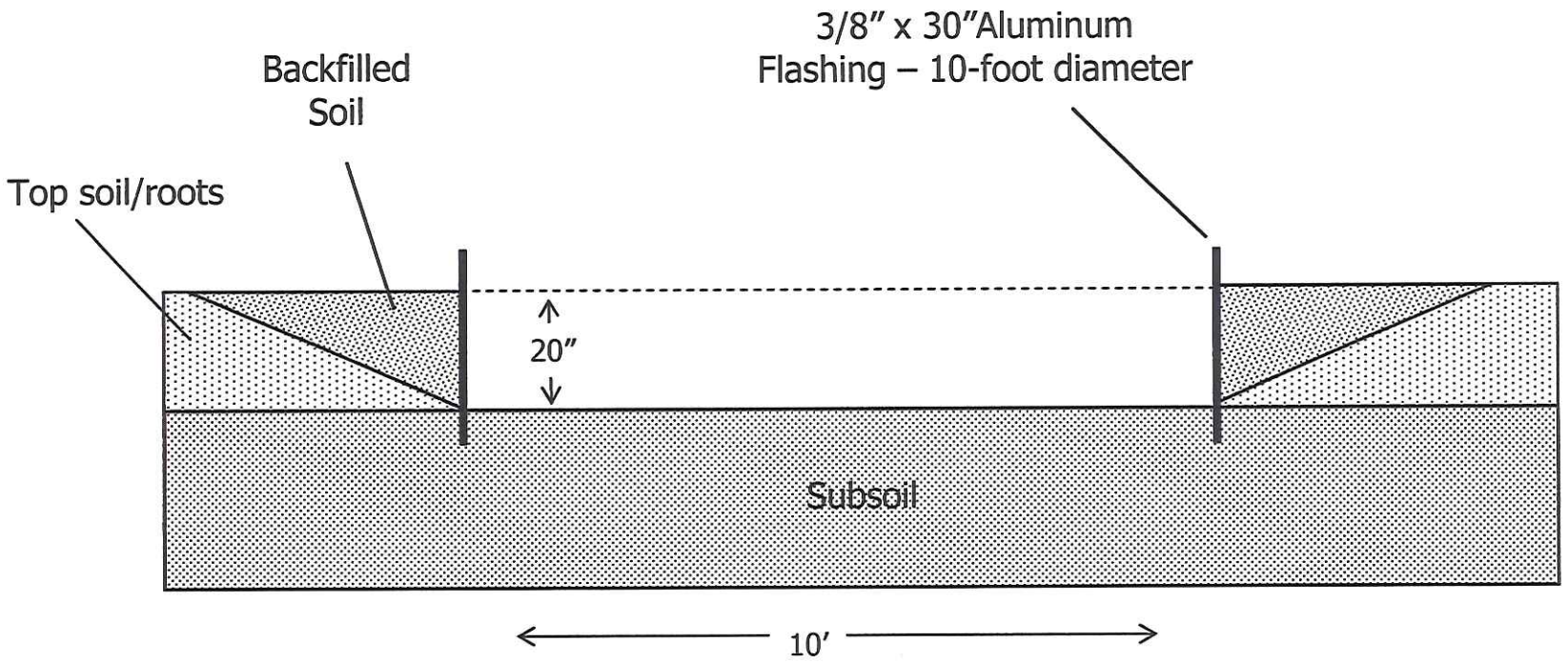
Stearns & Wheler, LLC Environmental Engineers and Scientists HYANNIS, MASSACHUSETTS DATE: 7/05 JOB No: 50076	**TOWN OF BARNSTABLE** **McMANUS LOADING TESTS** **FIGURE 1** **SITE LOCATION MAP**



Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS
DATE: 4/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 2
SITE MAP



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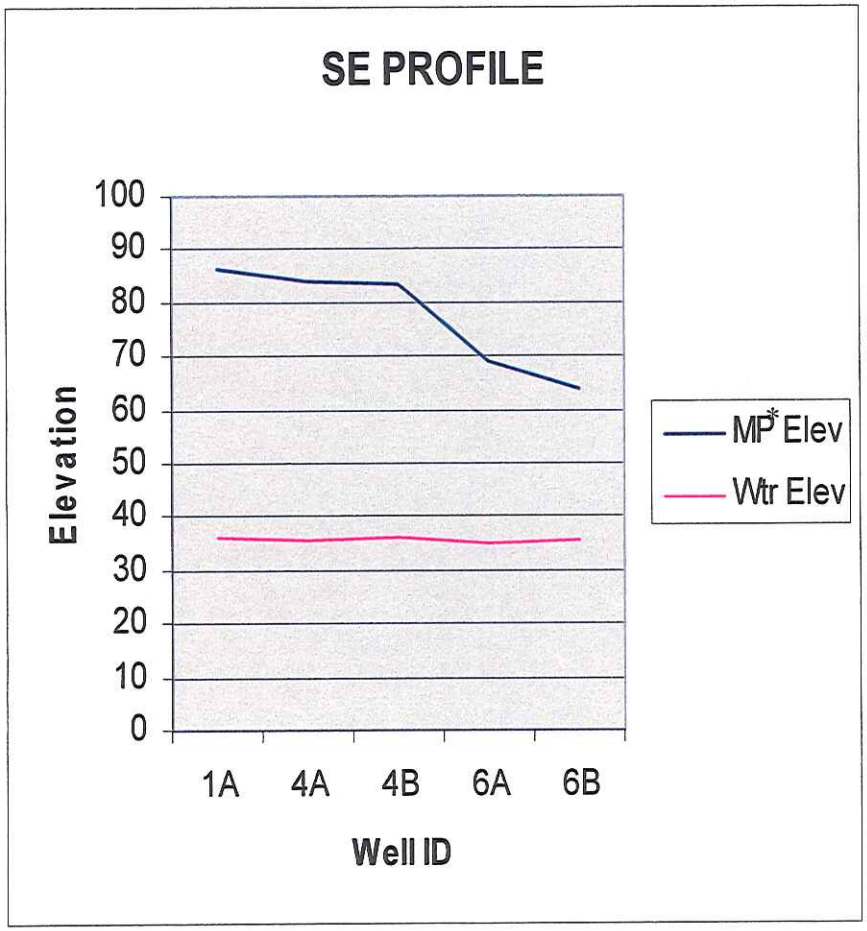
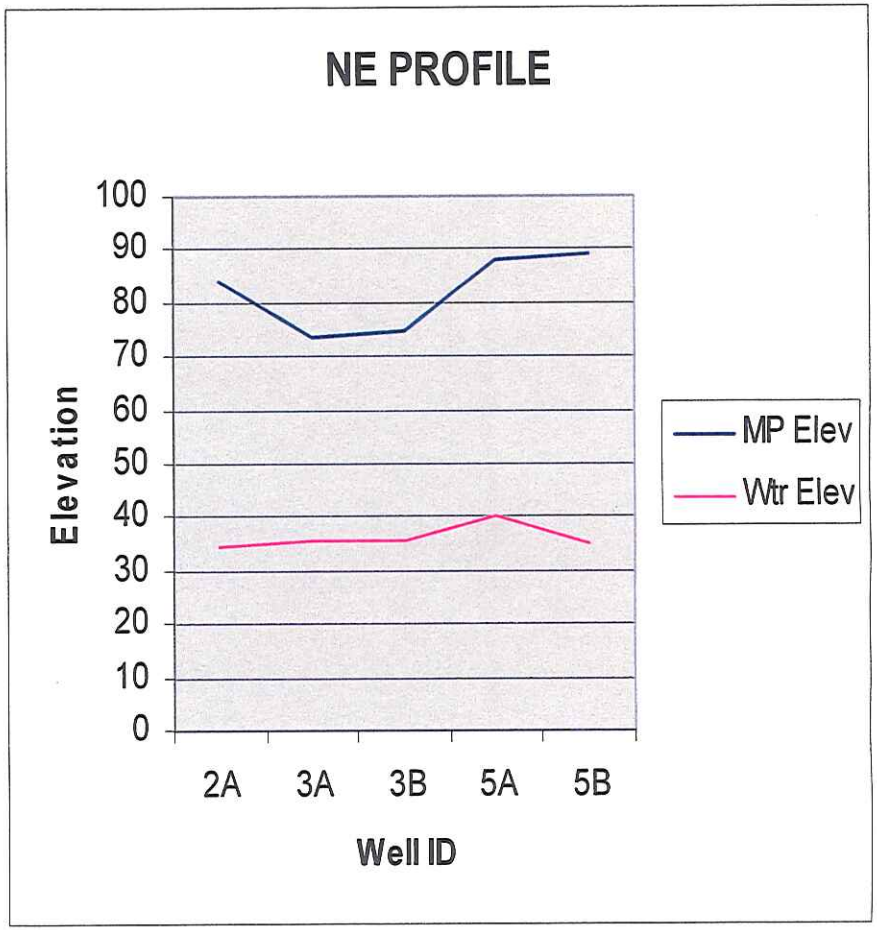
HYANNIS MASSACHUSETTS

DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 3
BASIN SCHEMATIC





*Observation well measuring point elevation
(approximately 2 feet above grade)

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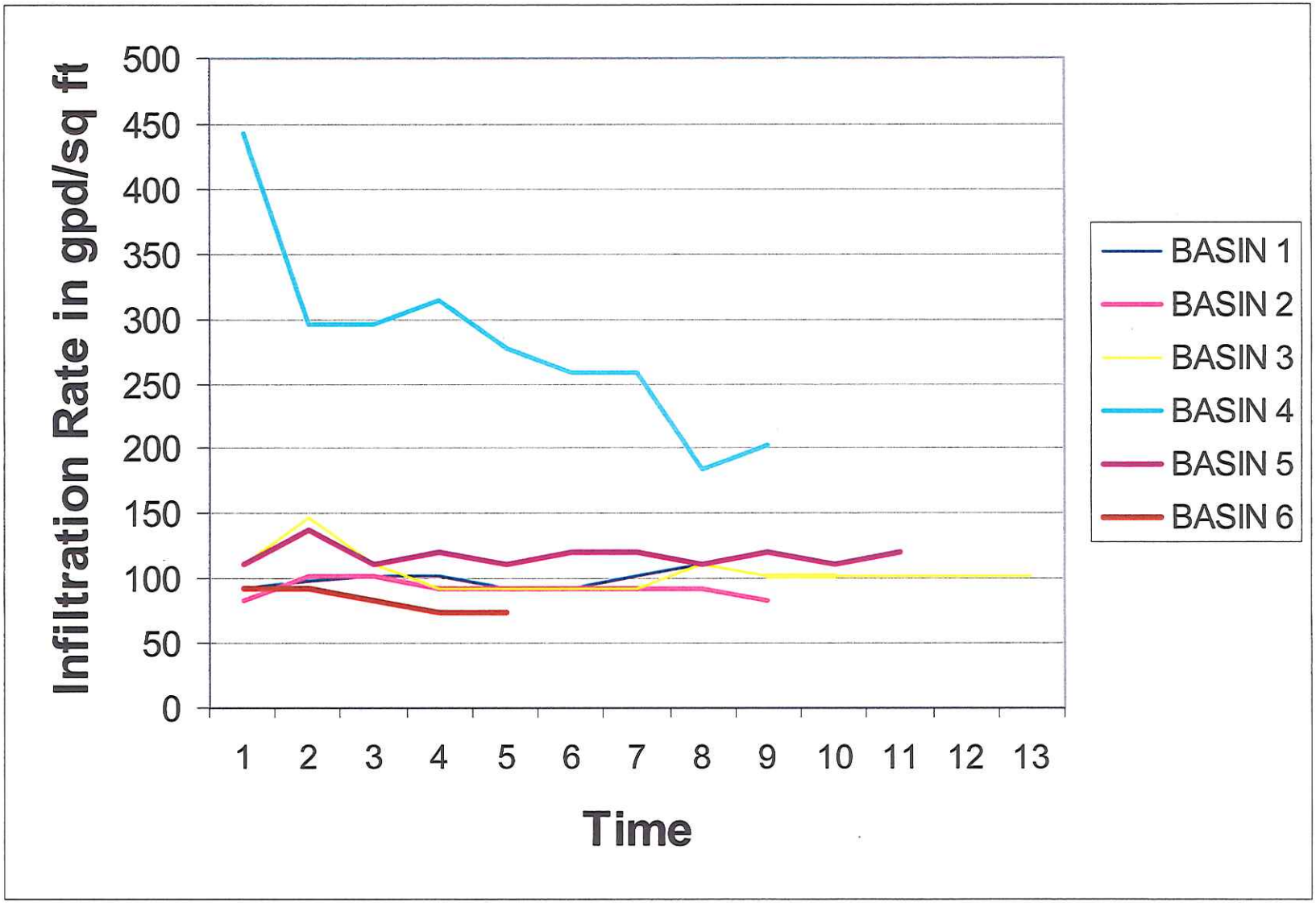
TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 4
LAND SURFACE & WATERTABLE ELEVATIONS



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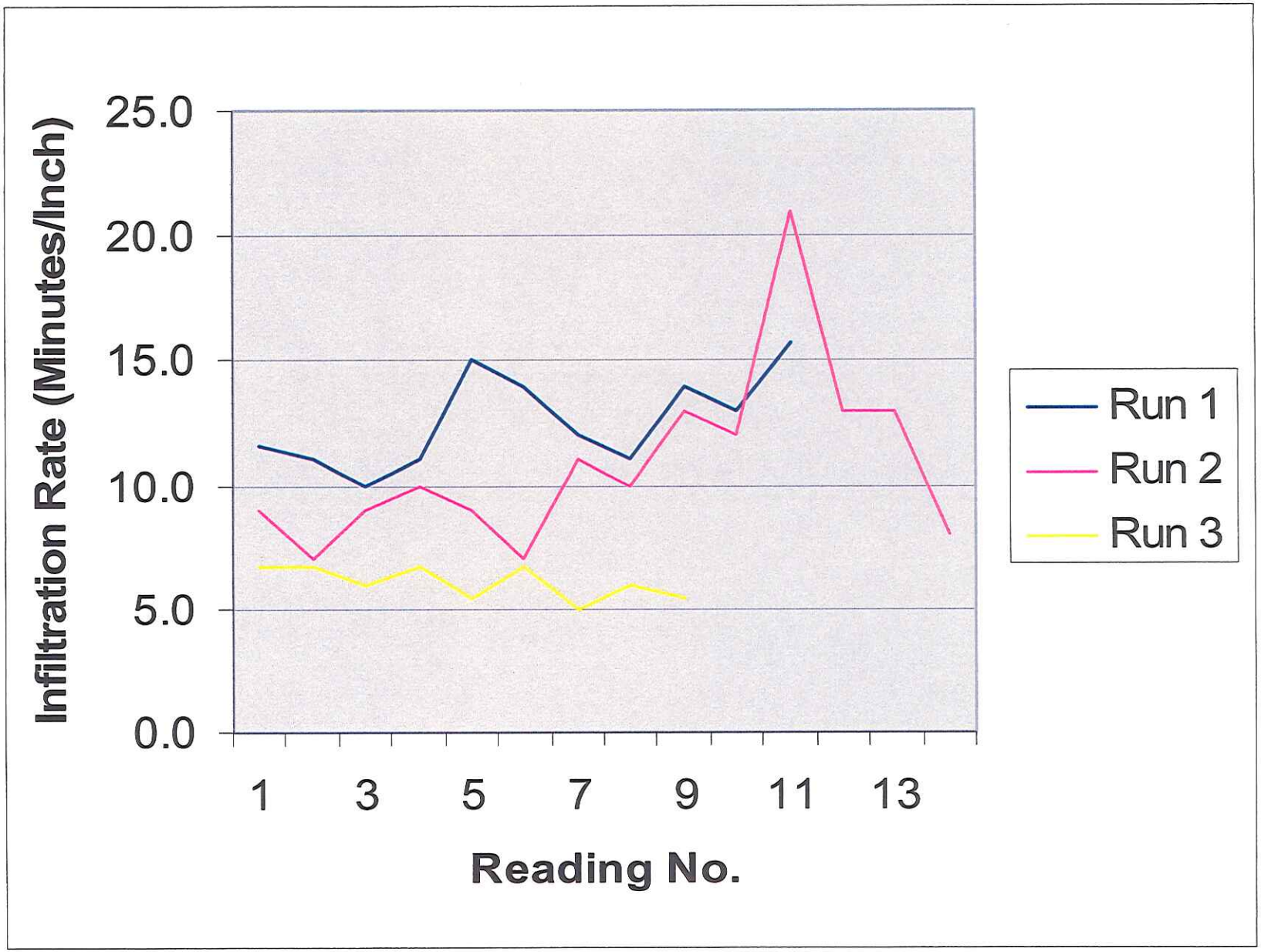
HYANNIS MASSACHUSETTS

DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 5
CONSTANT HEAD TEST INFILTRATION RATES



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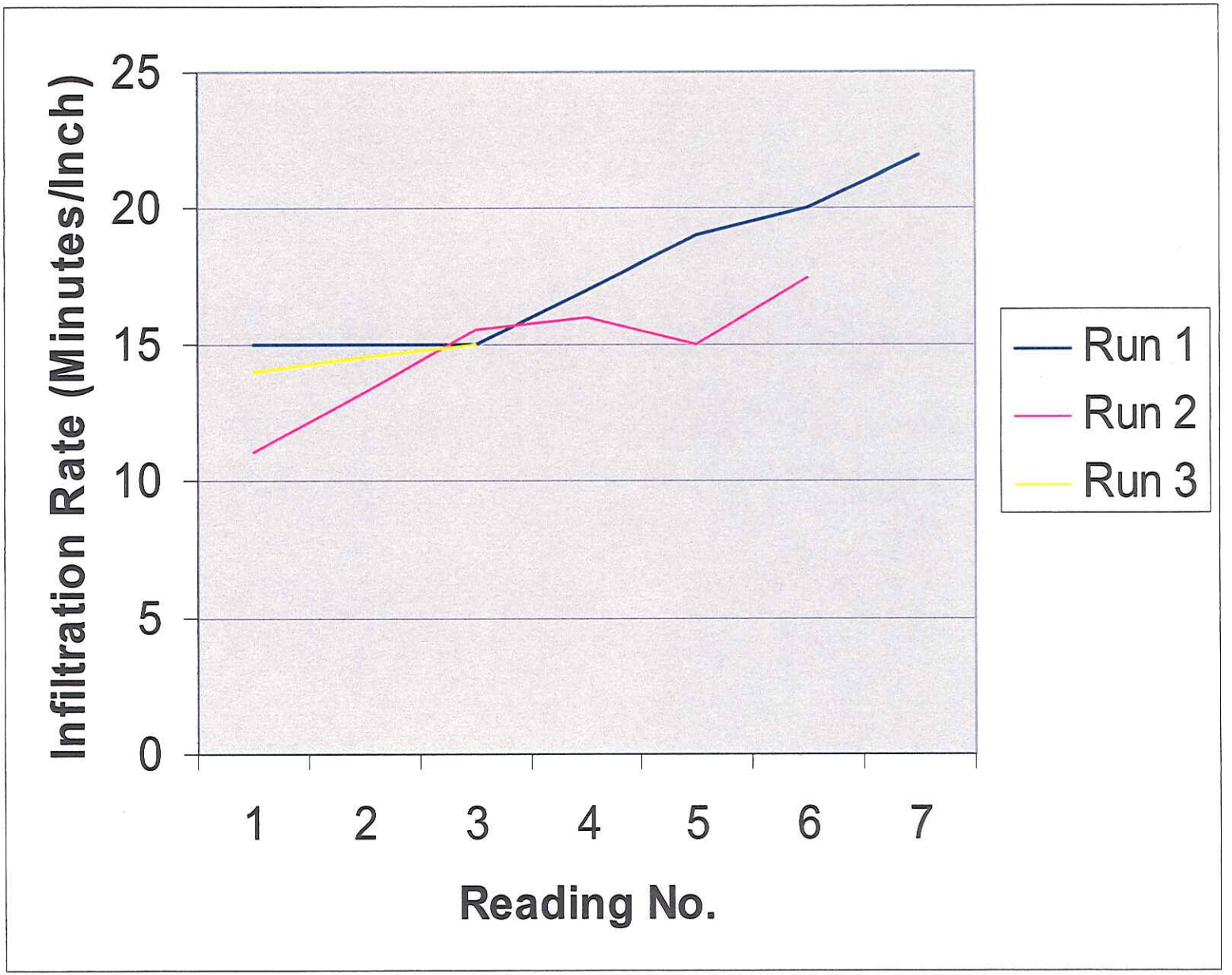
HYANNIS MASSACHUSETTS

DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 6
BASIN 1 FALLING HEAD INFILTRATION RATE



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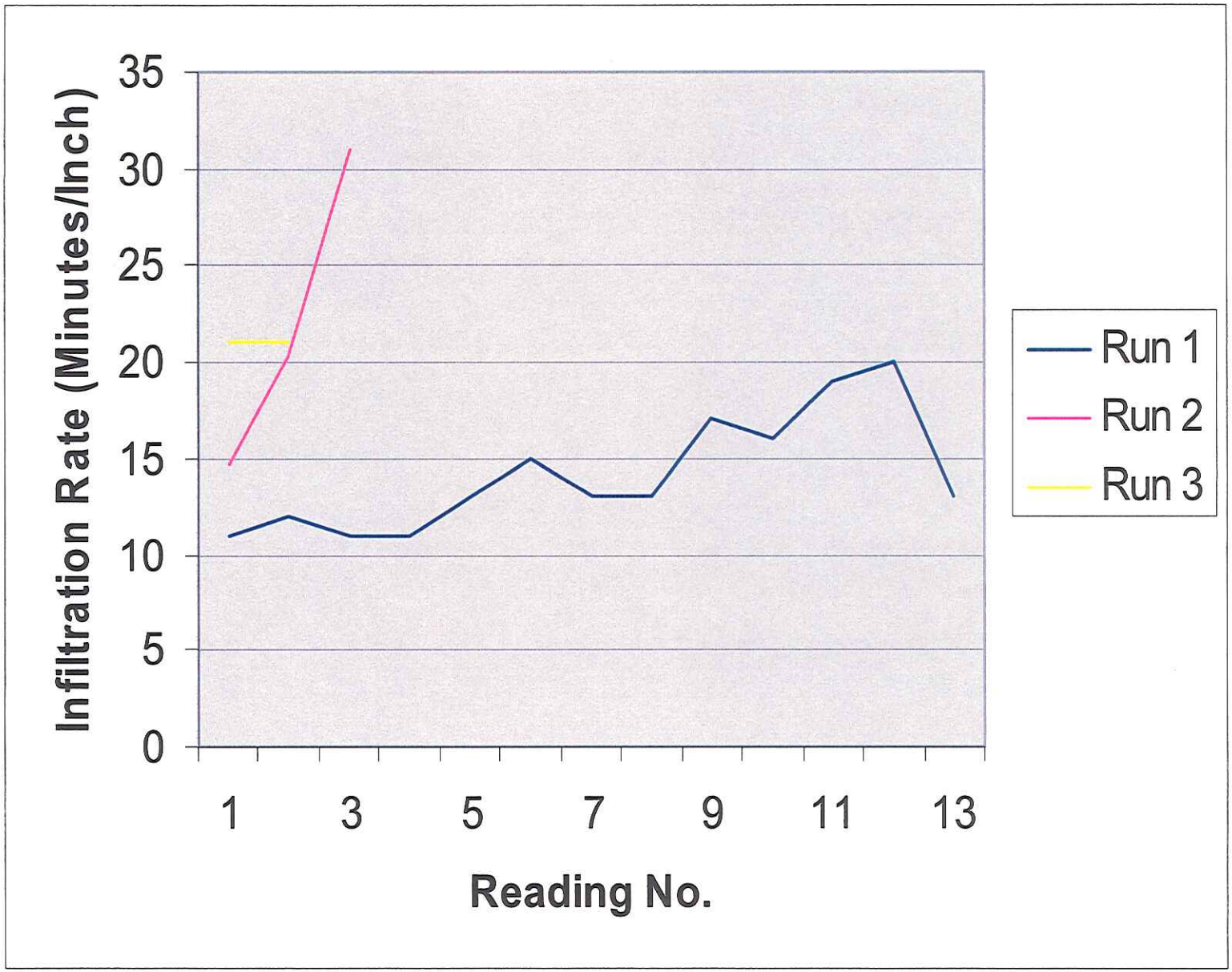
HYANNIS MASSACHUSETTS

DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 7
BASIN 2 FALLING HEAD INFILTRATION RATE



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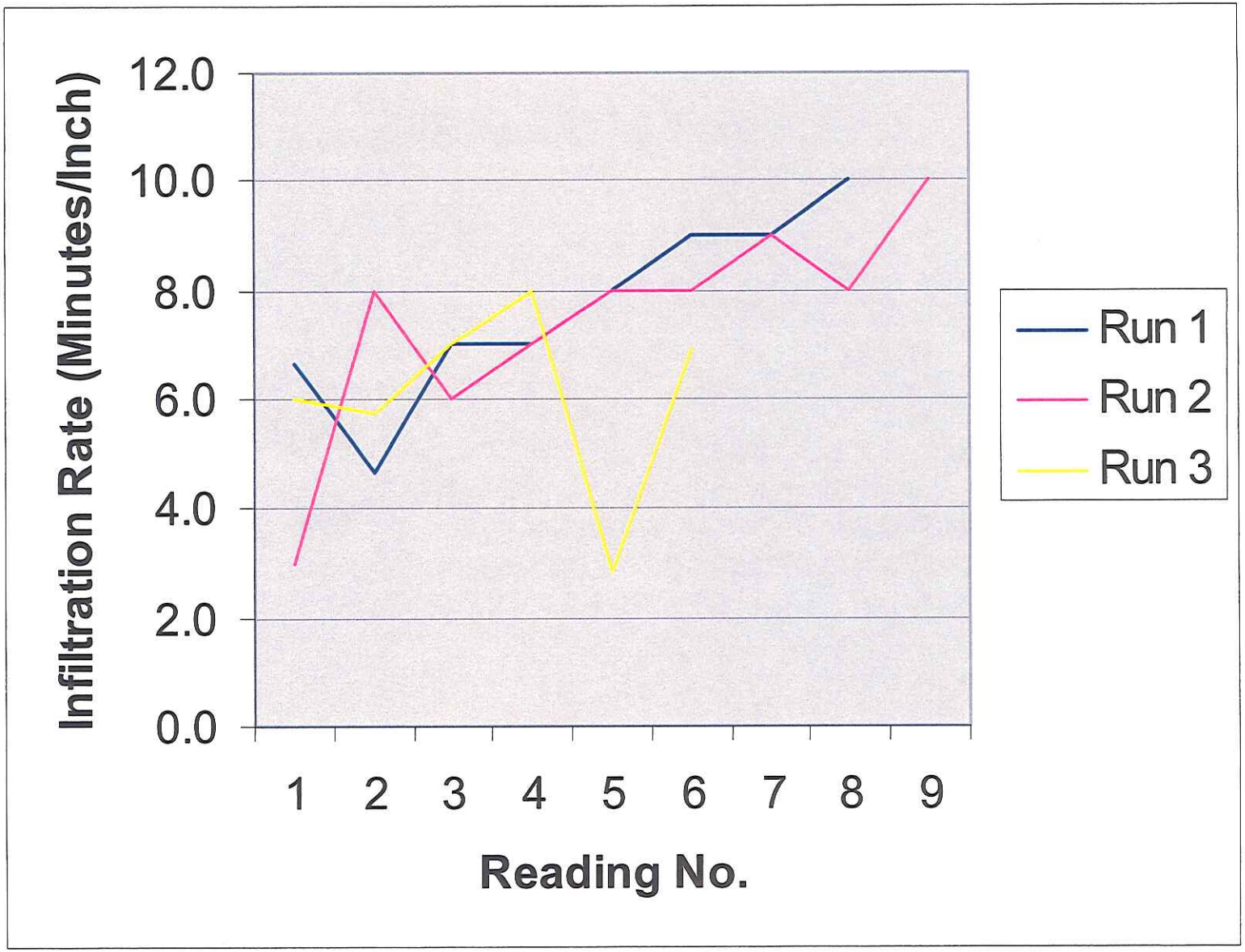
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 8
BASIN 3 FALLING HEAD INFILTRATION RATE



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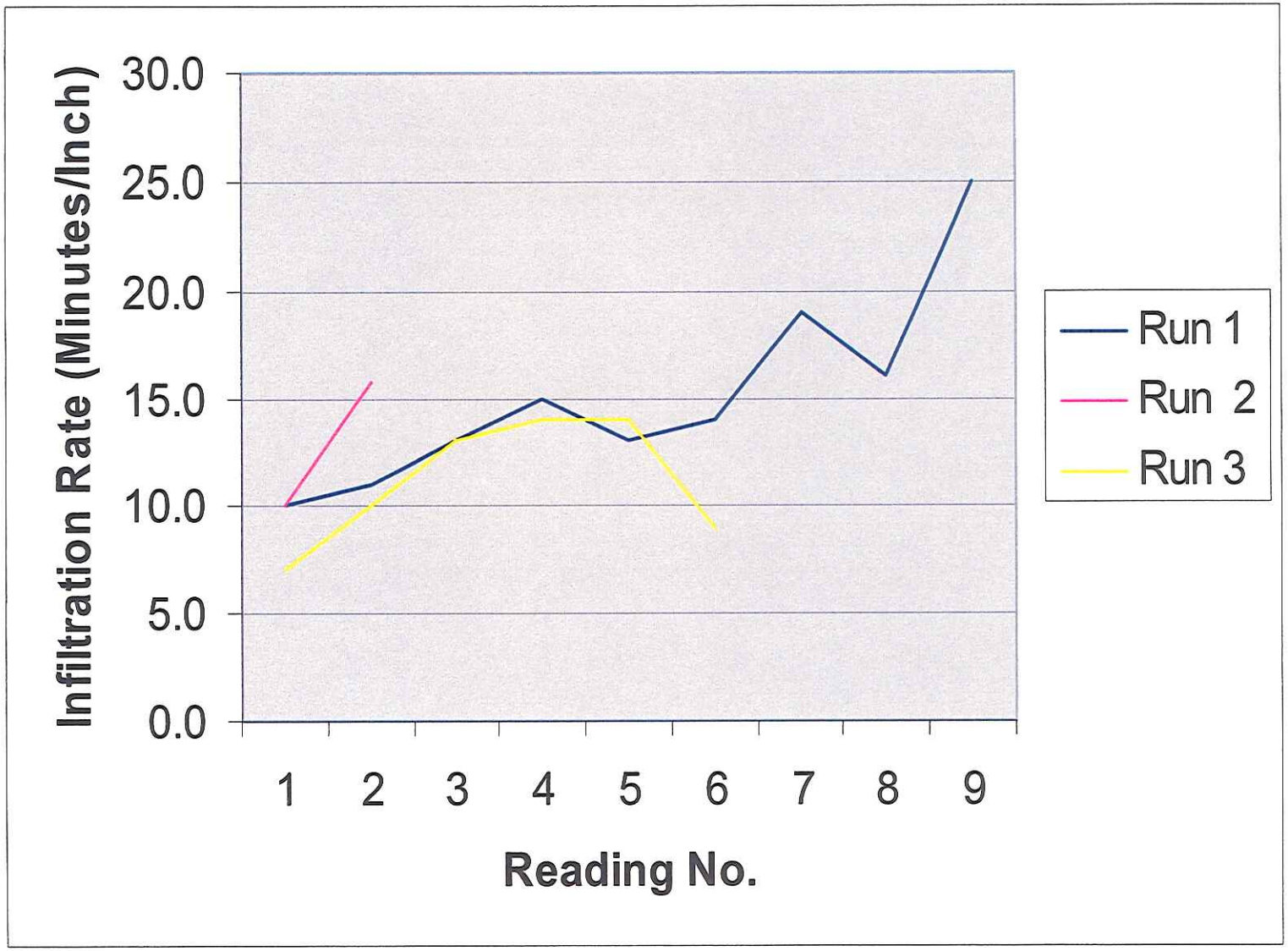
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 9
BASIN 4 FALLING HEAD INFILTRATION RATE



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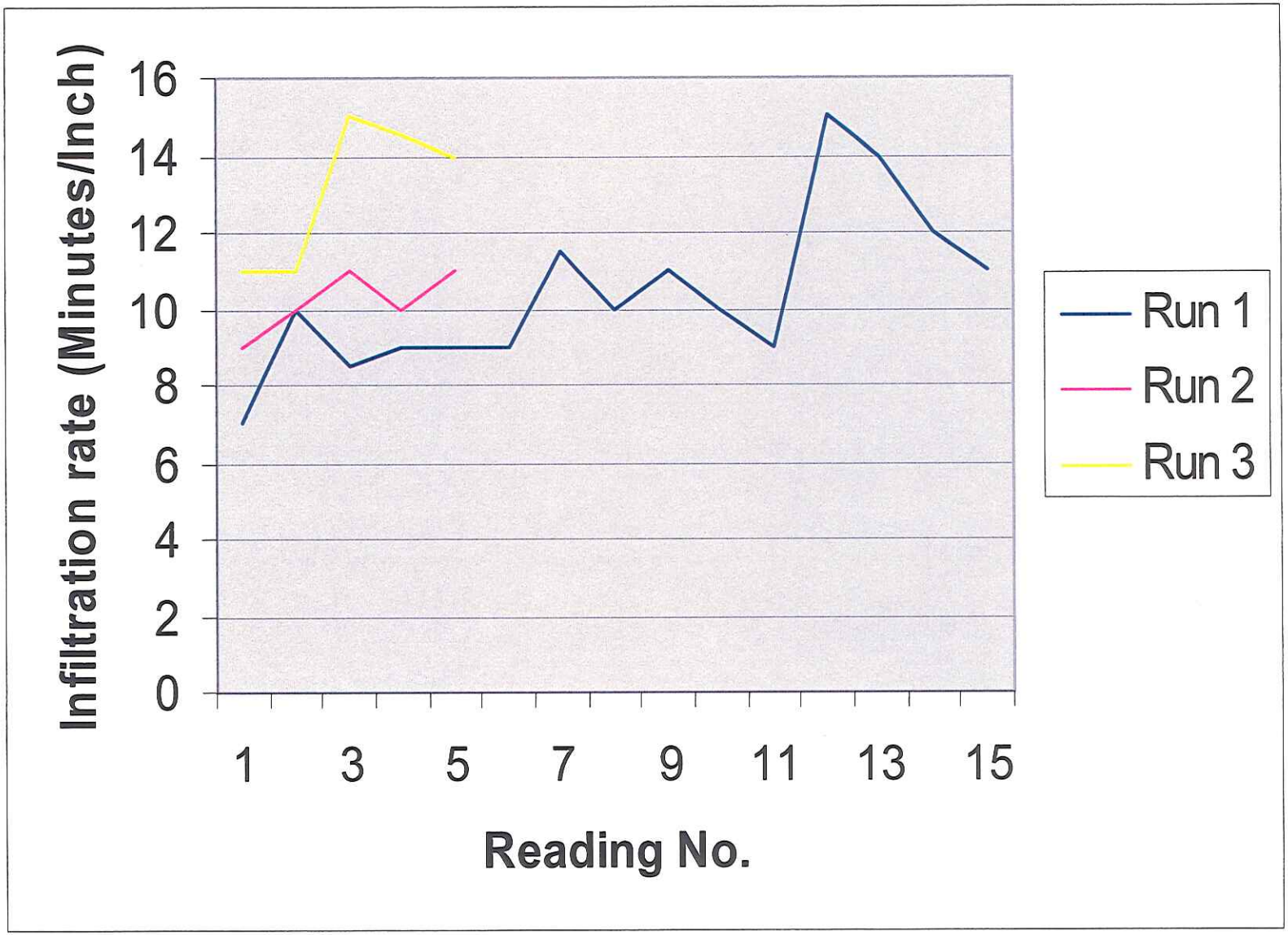
DATE: 7/05

JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 10
BASIN 5 FALLING HEAD INFILTRATION RATE



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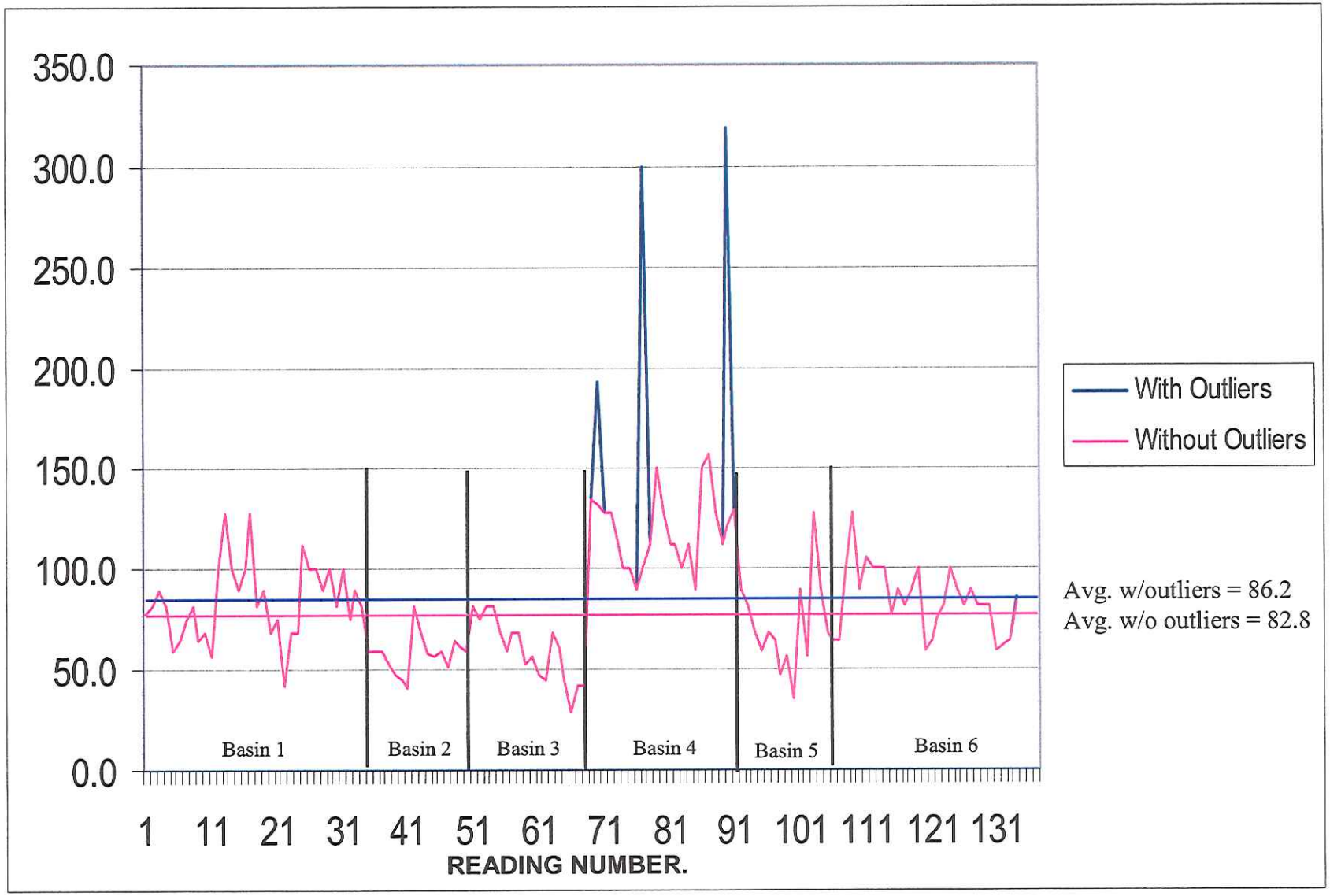
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 11
BASIN 6FALLING HEAD INFILTRATION RATE



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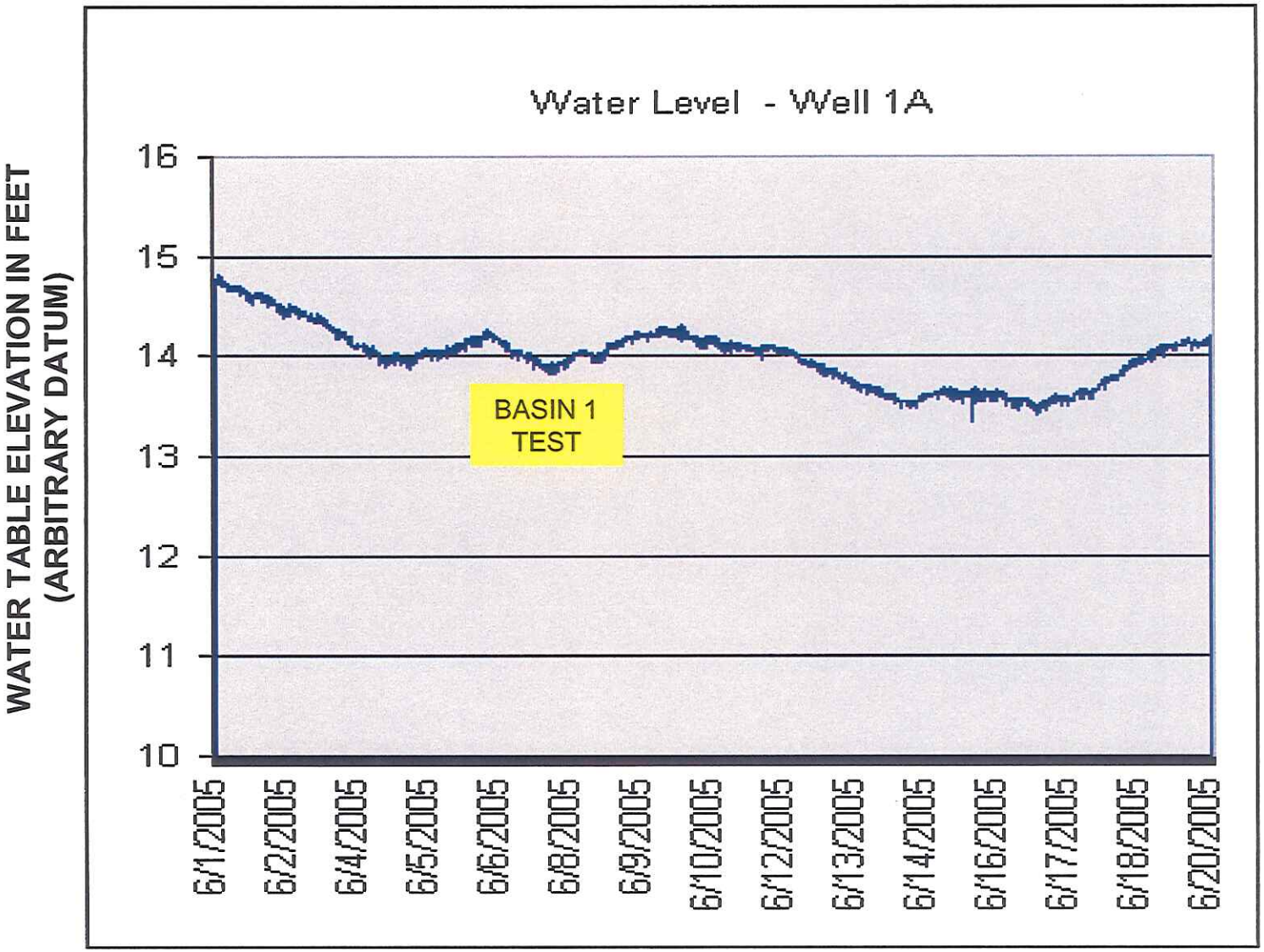
TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 12
FALLING HEAD TEST SUMMARY



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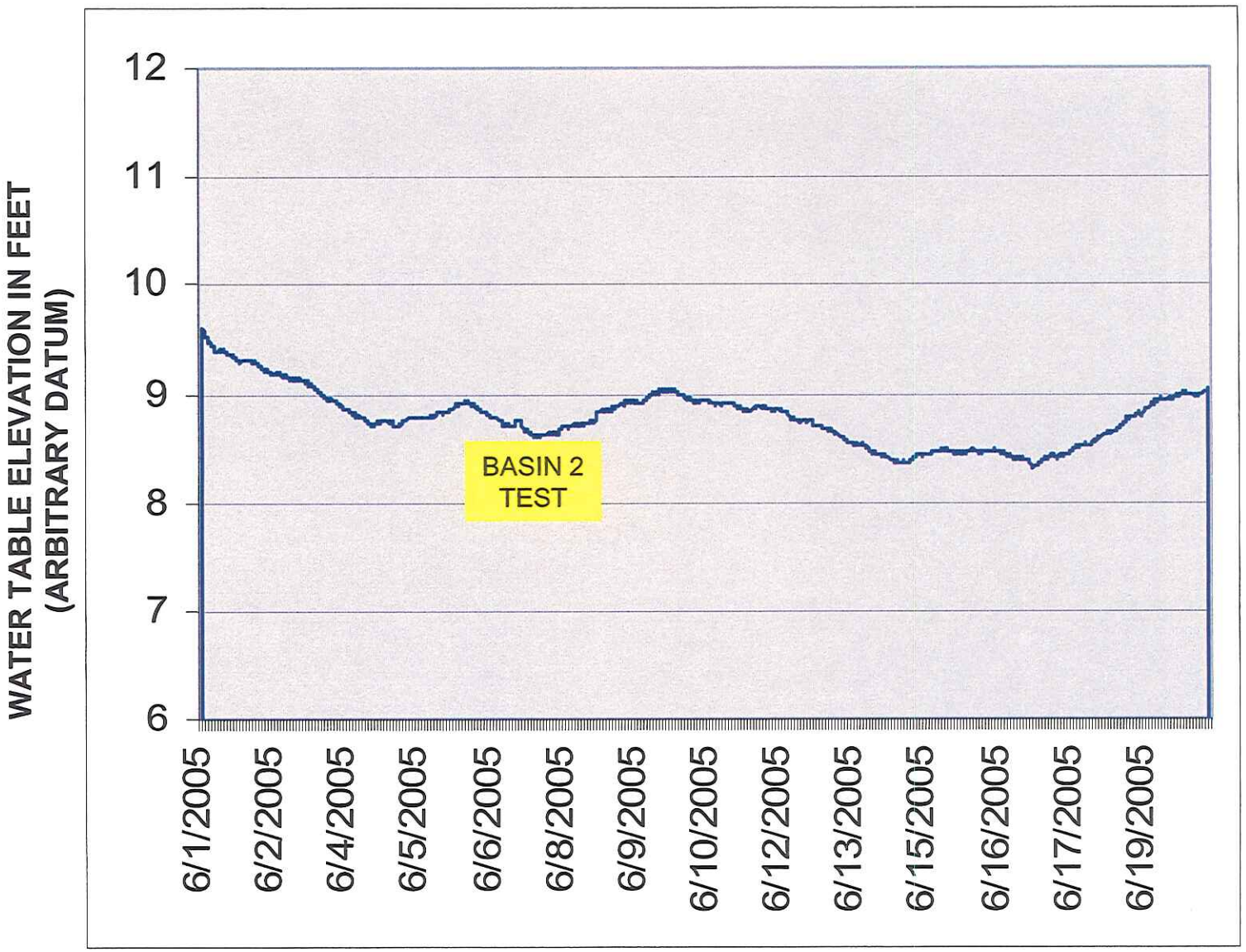
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 13
WELL 1A WATER LEVELS



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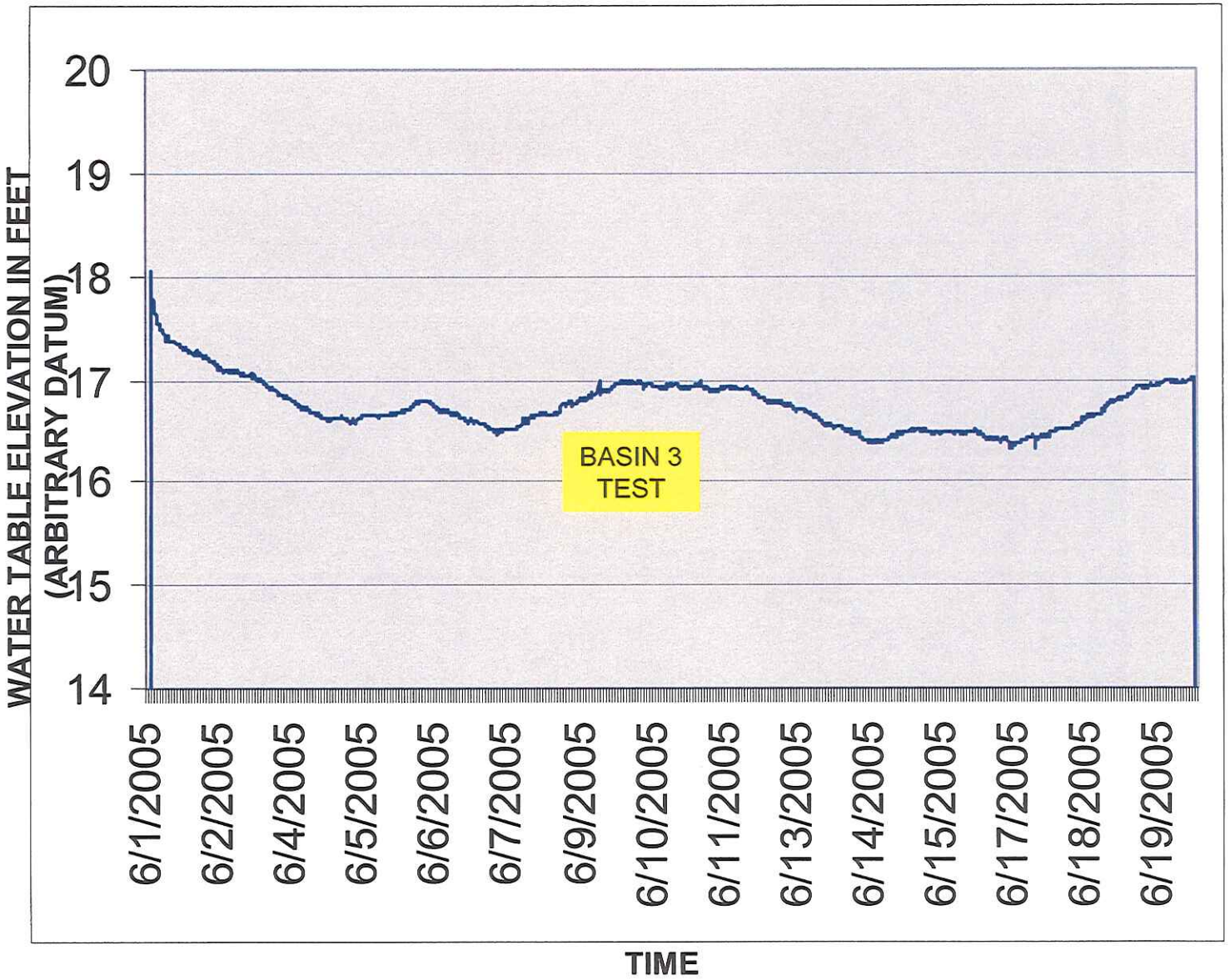
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 14
WELL 2A WATER LEVELS



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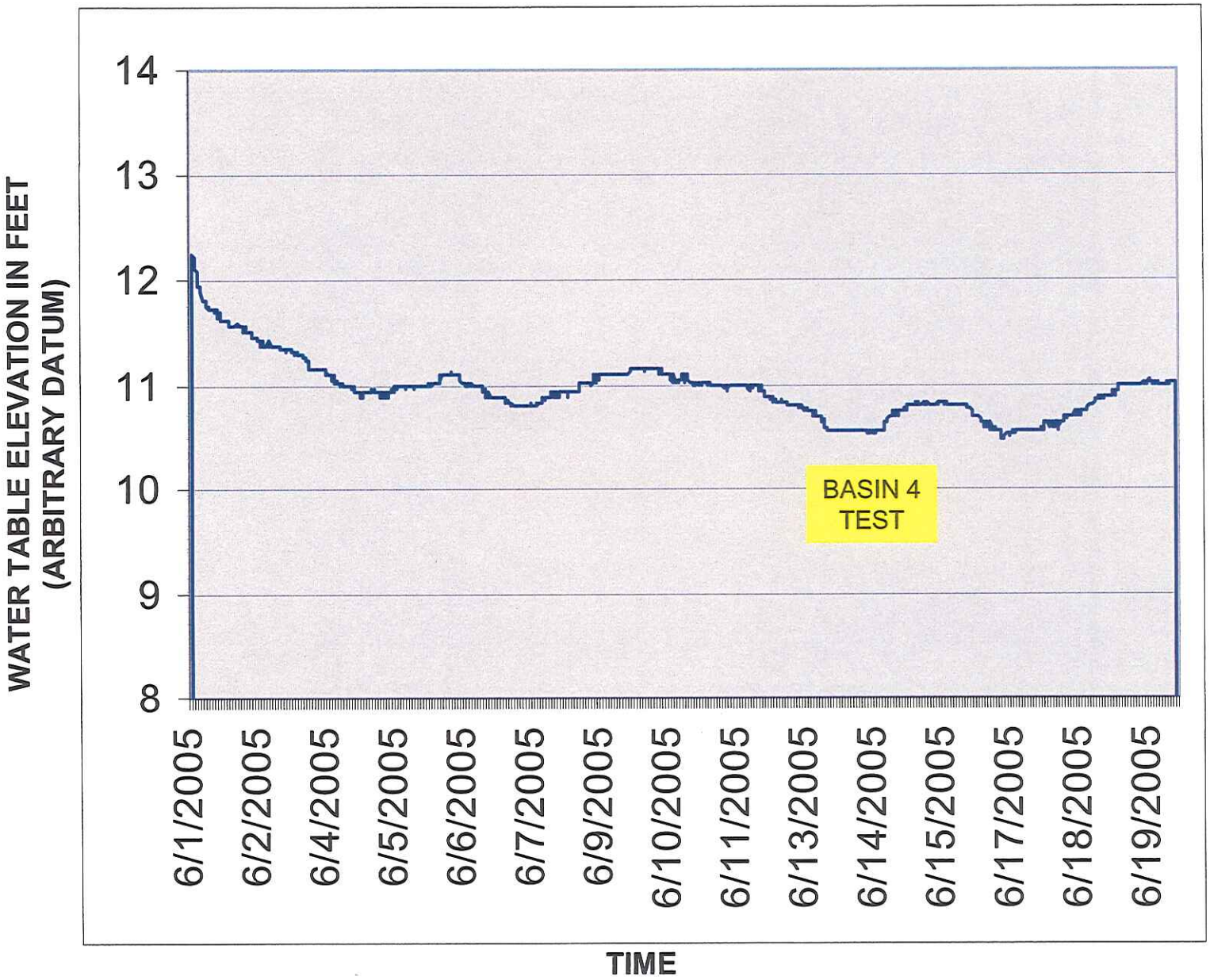
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 15
WELL 3A WATER LEVELS



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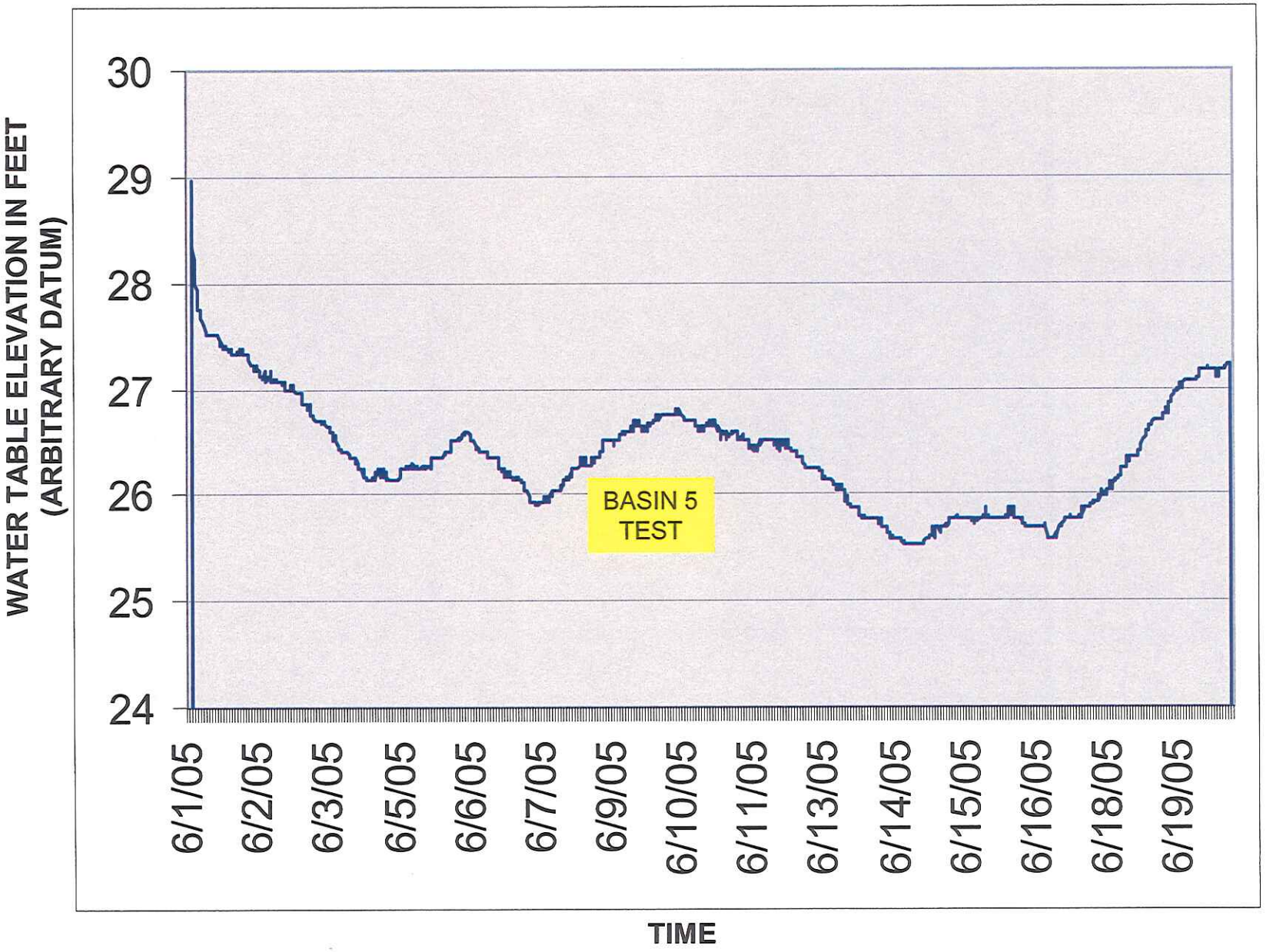
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 16
WELL 4A WATER LEVELS



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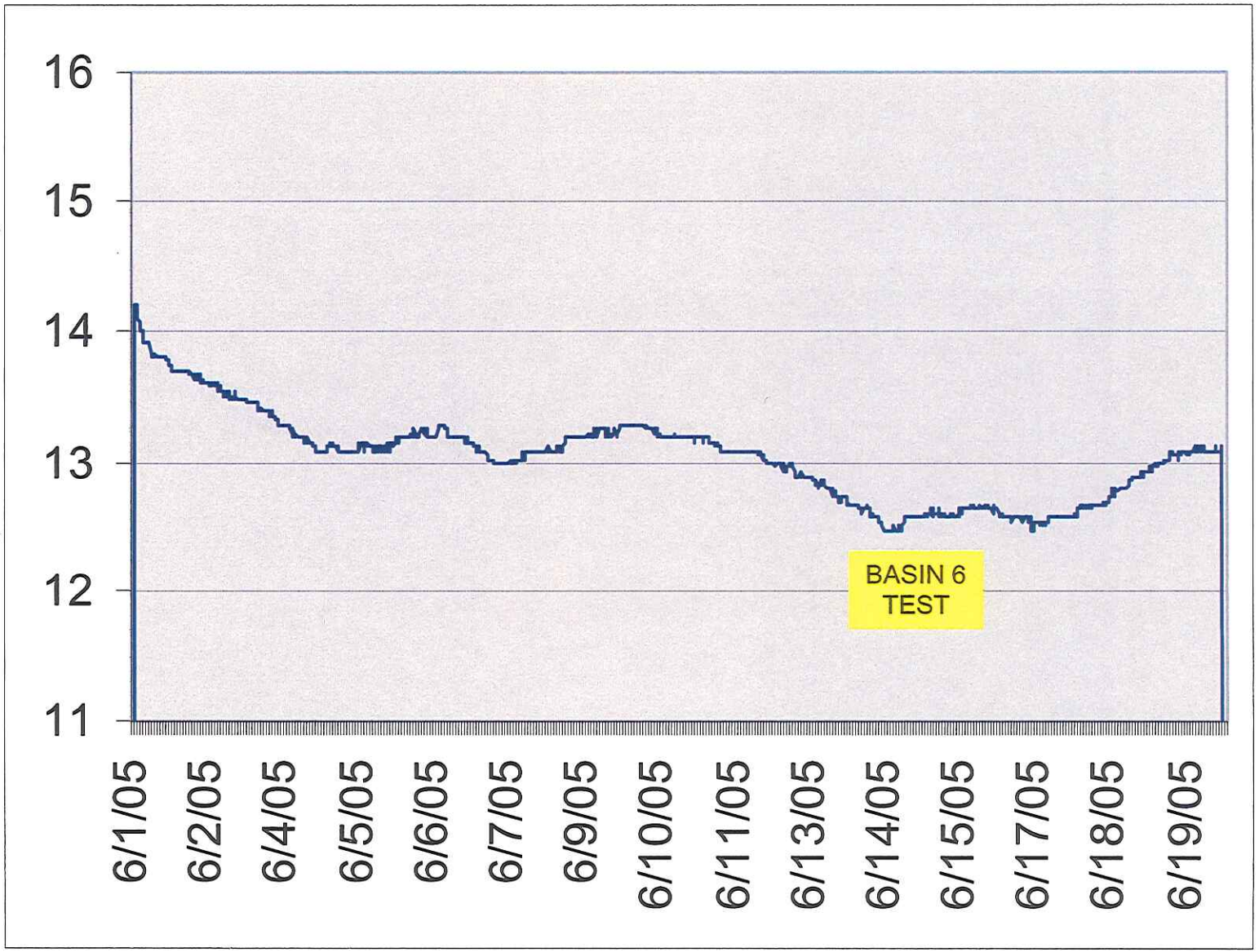
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 17
WELL 5A WATER LEVELS



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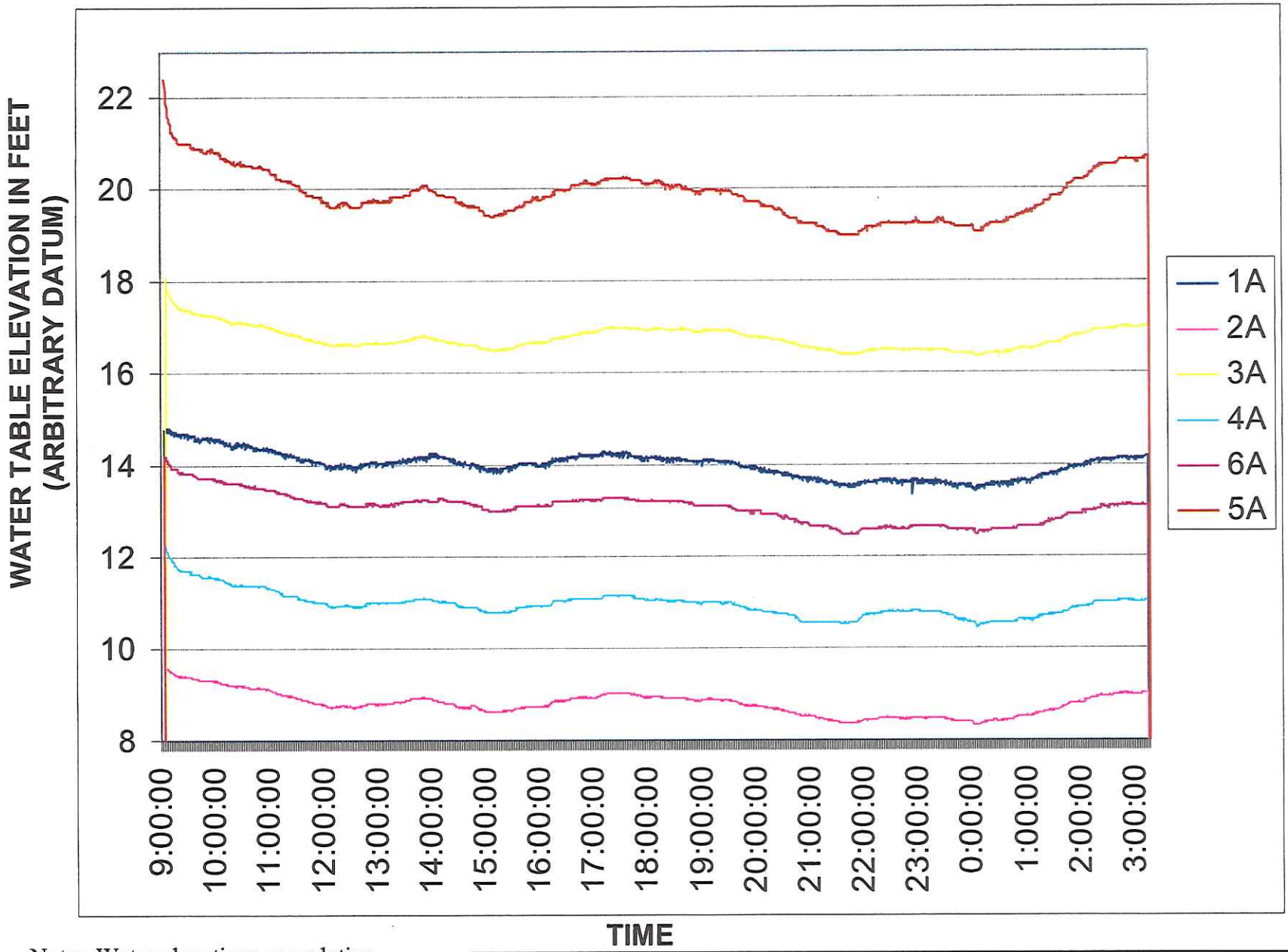
DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 18
WELL 6A WATER LEVELS



Note: Water elevations are relative to each well's starting point only. Elevations listed on axis are not actual elevations and relationship between different wells is not implied

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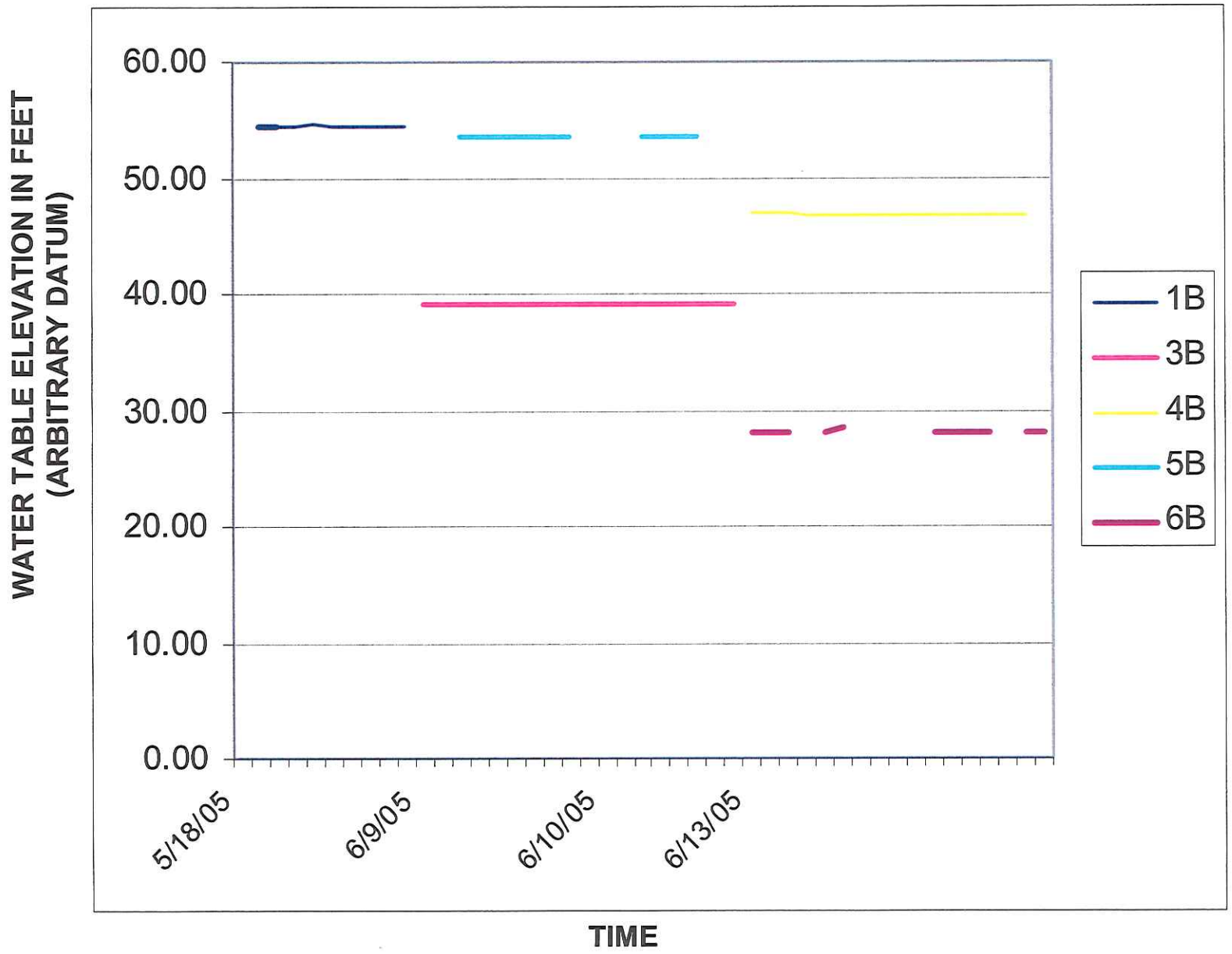
HYANNIS MASSACHUSETTS

DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 19
WATER LEVEL COMPILATION



Note: Water elevations are relative to each well's starting point only. Elevations listed on axis are not actual elevations and relationship between different wells is not implied

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HYANNIS MASSACHUSETTS

DATE: 7/05 JOB No: 50076

TOWN OF BARNSTABLE
McMANUS LOADING TESTS

FIGURE 20
WATER LEVEL COMPILATION - B WELLS

APPENDICES

APPENDIX A

BORING LOGS

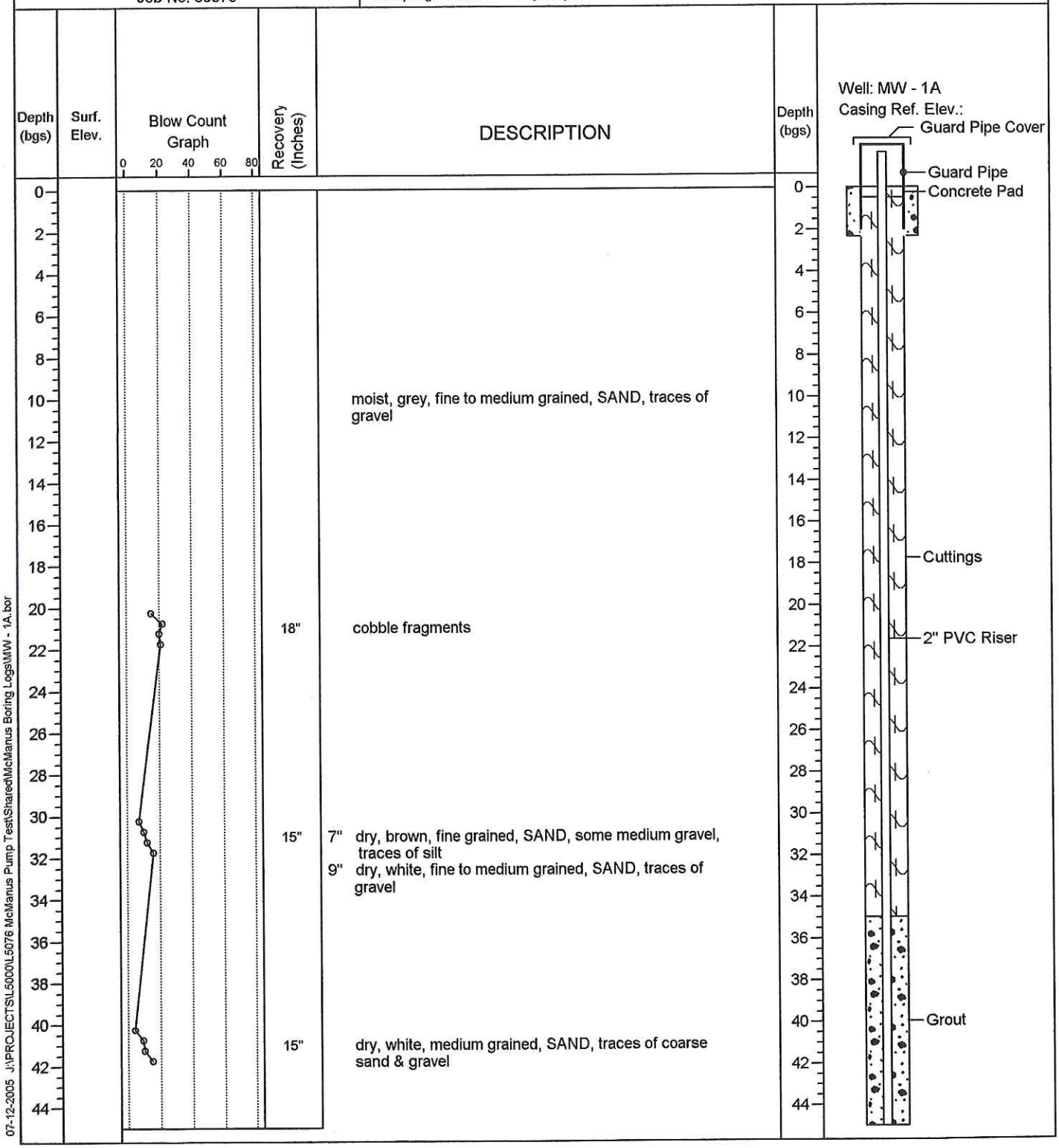
Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 1A

McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/11/05	Field Rep.	: jlk
Date Completed	: 5/11/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 1
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		



07-12-2005 J:\PROJECTS\L5000\L5076 McManus Pump Test\Shared\McManus Boring Logs\MW - 1A.bor

Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 1A

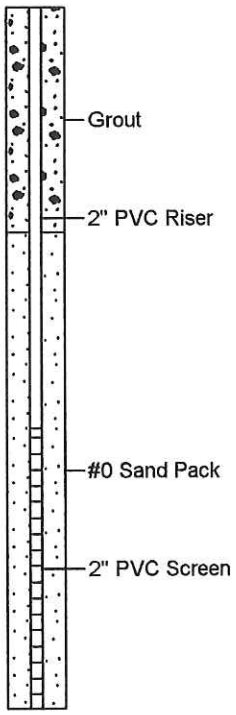
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/11/05	Field Rep.	: jlk
Date Completed	: 5/11/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 1
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
45				dry, white, medium grained, SAND, traces of coarse sand & gravel
47				
49				
51			16"	11" wet, pale brown, medium grained, SAND, some coarse sand, traces of gravel
53				8" wet, pale brown, fine to medium grained, SAND
55				
57				
59				
61			15"	16" wet, pale brown, fine to medium grained, SAND
63				5" wet, pale brown, fine grained, SAND
65			NR	
67				68 - 72' grey, SILTY CLAY (on augers)
69				
71				END of BORING
73				
75				
77				
79				
81				
83				
85				
87				
89				

Well: MW - 1A
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

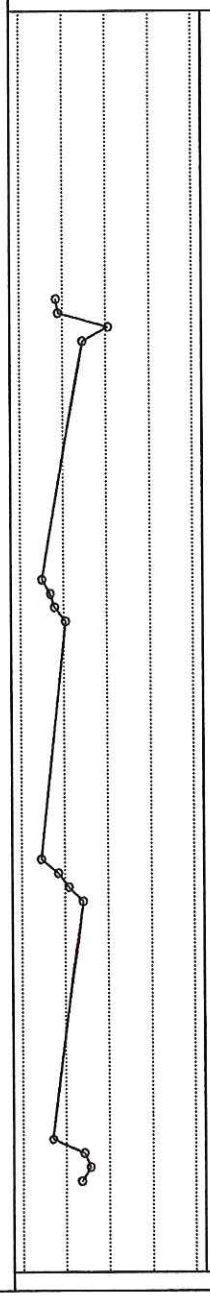
BORING LOG: Boring 2 (abandoned)

McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/6/05	Field Rep.	: jlk
Date Completed	: 5/13/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	:
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

*No Well installed
do to extensive silt/clay layer
from 42' bgs to end of boring.
Basin relocated to 2B location.
Only one well (2A) installed.



Depth (bgs)	Recovery (Inches)	DESCRIPTION
10	19"	15" dry, orange, fine grained, SAND, traces of gravel 4" cobble fragmnts, and fine grained, sand
		cobbles/boulders, 11 -15'
20	20"	dry, pale brown, fine grained, SAND, traces of silt
30	15"	7" dry, white & rusty, SAND, fine grained 2" GRAVEL, some fine grained, sand 6" dry, white, fine grained, SAND
40	19"	3" dry, grey, CLAYEY SILT, traces of gravel 10" dry, medium grained, SILTY SAND
		6" dry, hard, grey-brown, CLAYEY SILT, traces of sand

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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: Boring 2 (abandoned)

McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/6/05	Field Rep.	: jlk
Date Completed	: 5/13/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	:
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

*No Well installed
do to extensive silt/clay layer
from 42' bgs to end of boring.
Basin relocated to 2B location.
Only one well (2A) installed.

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION	Depth (bgs)
45–89			24"	dry, stiff, grey, CLAYEY SILT	45–89
			24"	moist, medium stiff, grey, CLAYEY SILT	
			18"	moist, medium stiff, grey, CLAYEY SILT	
			12"	very moist to wet, medium stiff, grey, CLAYEY SILT	
			12"	very moist to wet, medium stiff, grey, CLAYEY SILT	
			12"	14" very moist to wet, medium stiff, grey, CLAYEY SILT 1" wet, pale brown, fine grained, SAND 3" very moist to wet, grey, SILTY CLAY	
				END of BORING	

07-12-2005 J:\PROJECTS\L5000\L5076 McManus Pump Test\Shared\McManus Boring Logs\MW - 2.bor

Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 2A

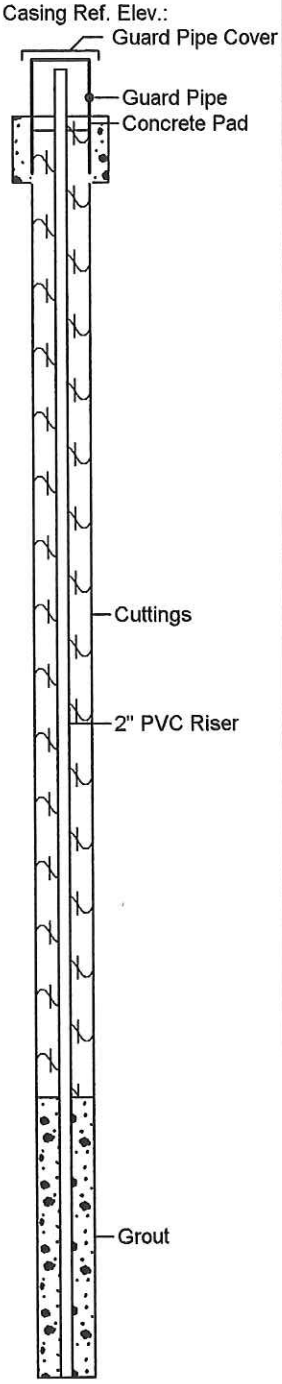
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/13/05	Field Rep.	: jlk
Date Completed	: 5/13/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 2
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
0–12				cobbles/boulders to 20' bgs (no sample)
18–20			18"	3" dry, grey-brown, CLAYEY SILT, and fine grained, sand, traces of gravel 2" cobble fragments 4" dry, grey, fine to medium grained, SILTY SAND 5" slightly moist, stiff, grey, SILT, some medium grained, sand 4" dry, rust-brown, fine grained, SAND, traces of silt
30–32			15"	9" moist, pale brown, medium grained, SAND, traces of gravel 6" moist, grey, SILT, some fine grained, sand
40–42			15"	moist, white, fine to medium grained, SAND, traces of gravel

Well: MW - 2A
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 2A

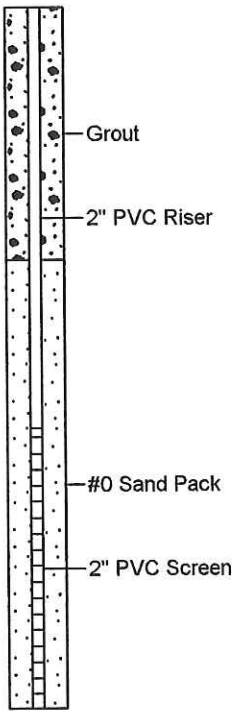
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/13/05	Field Rep.	: jlk
Date Completed	: 5/13/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 2
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
45				
47				
49				
51			16"	wet, white, fine grained, SAND, traces of silt
53				
55				
57				
59				
61			15"	wet, white, fine to medium grained, SAND, traces of gravel
63				
65			NR	
67				
69				
71				
73				
75				
77				
79				
81				
83				
85				
87				
89				

Well: MW - 2A
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 3A

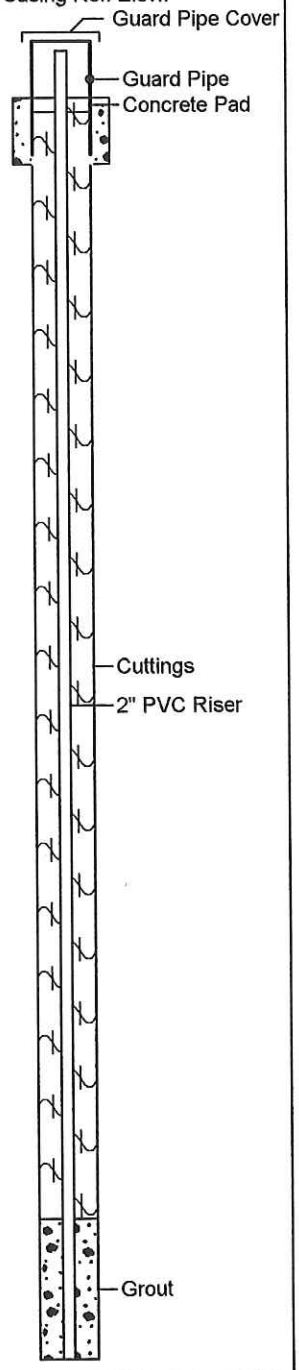
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/4/05	Field Rep.	: jlk
Date Completed	: 5/5/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 3
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
8				gravel/cobbles 7 - 9' bgs
10			4"	gravel/cobble fragments, & fine grained, sand
20			10"	dry, pale brown, fine grained, SAND, & gravel
26				cobbles
30			16"	9" moist, red-brown, fine grained, SAND, traces of silt 7" moist, red-brown, medium grained, SAND, some gravel

Well: MW - 3A
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 3A

McManus Loading Test
Town of Barnstable
Hyannis, MA

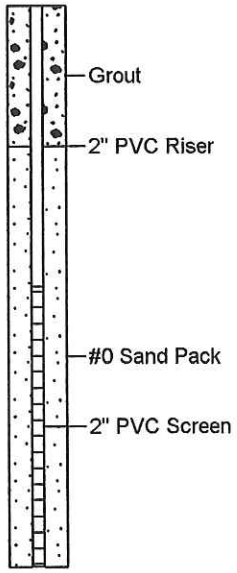
Job No. 50076

Date Started	: 5/4/05	Field Rep.	: jlk
Date Completed	: 5/5/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 3
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
45–89			14"	6" wet, soft, pale brown, SILT, some fine grained, sand 6" wet, fine to medium grained, SAND, & gravel 2" wet, soft, SILT, & fine grained, SAND
			NS	no sample (wash & heave)
			18"	9" wet, fine to coarse grained, SAND 9" wet, medium stiff, grey, SILT, some fine sand
				END BORING

Depth (bgs) 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89

Well: MW - 3A
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 3B

McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

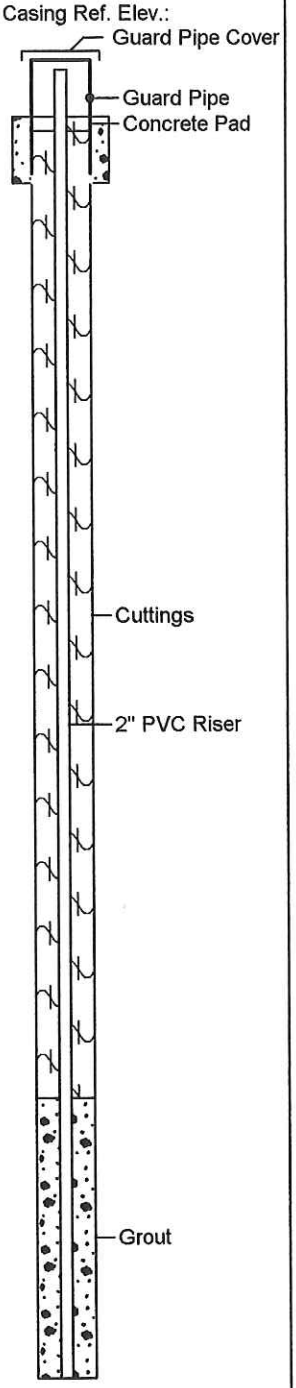
Date Started	: 5/5/05	Field Rep.	: jlk
Date Completed	: 5/5/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: 50' from Basin 3
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs) | Surf. Elev. | Blow Count Graph (0 20 40 60 80) | Recovery (Inches) | DESCRIPTION

Recovery (Inches)	DESCRIPTION
15"	7" moist, pale brown, SANDY SILT, traces of gravel 1" slightly moist, medium stiff,grey, SILT 7" dry, orange-brown, fine grained, SAND
	cobbles 13 - 18' bgs
5"	gravel/cobble fragments, some fine grained, sand
8"	5" cobble fragments 3" dry, pale brown, fine grained, SAND
	cobbles
17"	7" moist, stiff, brown, SILT, traces of gravel & fine grained sand 4" moist, pale brown, medium grained, SAND 6" moist, pale brown, fine grained, SILTY SAND
	cobbles 32 - 42' bgs
16"	8" moist, pale brown, fine grained, SILTY SAND, traces of gravel 5" cobble fragments 1.5" coarse GRAVEL, some fine grained silty sand 1.5" moist, brown, SILT, some fine grained, sand, traces of gravel

Depth (bgs) 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44

Well: MW - 3B
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 3B

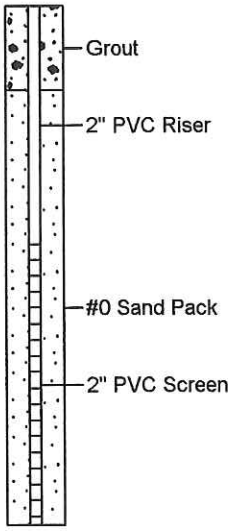
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/5/05	Field Rep.	: jlk
Date Completed	: 5/5/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: 50' from Basin 3
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
45–89			10"	very moist to wet, grey, medium stiff SILT, some fine to medium grained, sand
			9"	very moist to wet, grey, SILT, some fine grained, sand
			20"	14" wet, pale brown, fine grained, SAND 6" wet, pale brown, fine to medium grained, SAND
				END BORING

Well: MW - 3B
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 4A

McManus Loading Test
Town of Barnstable
Hyannis, MA

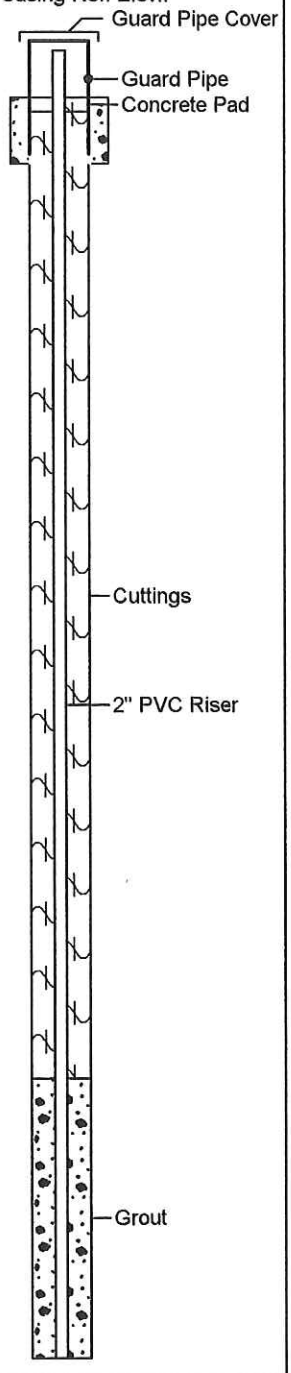
Job No. 50076

Date Started	: 5/12/05	Field Rep.	: jlk
Date Completed	: 5/13/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 4
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
0				
2				
4				
6				
8				
10			14"	10" dry, medium grained, SAND, traces of gravel
12				4" moist, grey, SILT
14				cobbles
16				
18				
20			13"	4" cobble fragments, and fine grained, sand
22				8" dry, white, fine to medium grained, SAND, traces of gravel
24				1" moist, grey, CLAYEY SILT
26				
28				
30			13	dry, white, fine to medium grained, SAND, traces of gravel
32				cobbles
34				
36				
38				
40				
42				
44				

Depth (bgs): 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44

Well: MW - 4A
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 4A

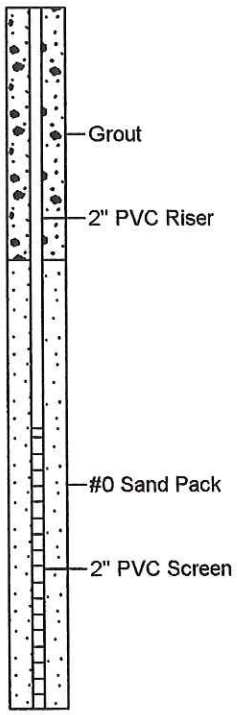
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/12/05	Field Rep.	: jlk
Date Completed	: 5/13/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 4
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
45			NR	
47				
49				
51			16"	wet, pale brown, fine to medium grained, SAND
53				
55				
57				
59				
61			13"	10" moist, stiff, brown, SANDY SILT 3" moist, stiff, grey, CLAY
63				
65			6"	slightly moist, medium stiff, grey-brown, SILTY CLAY, traces of sand
67				
69				
71				END of BORING
73				
75				
77				
79				
81				
83				
85				
87				
89				

Well: MW - 4A
Casing Ref. Elev.:



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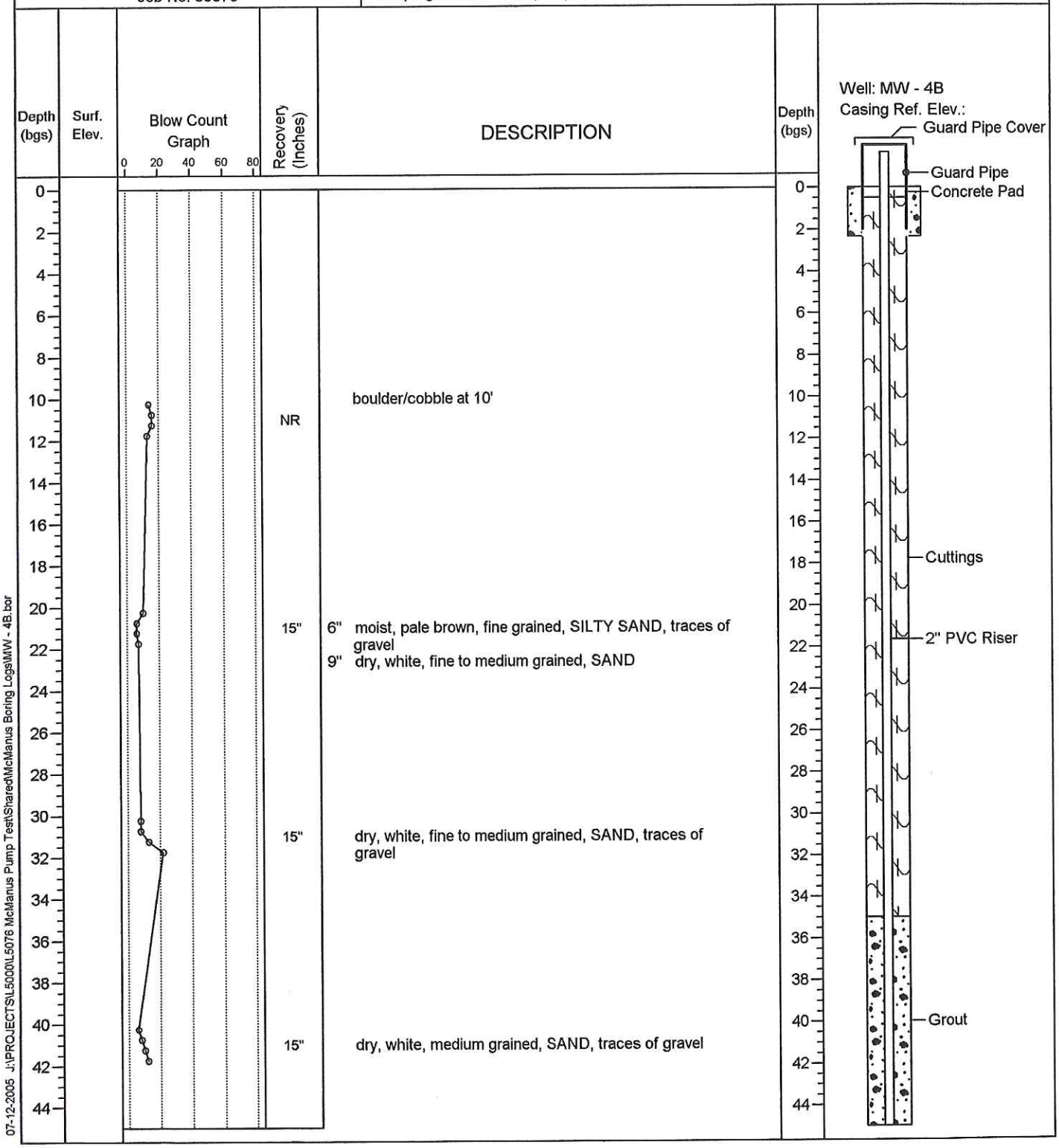
Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 4B

McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/12/05	Field Rep.	: jlk
Date Completed	: 5/12/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: 50 Feet from Basin 4
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 4B

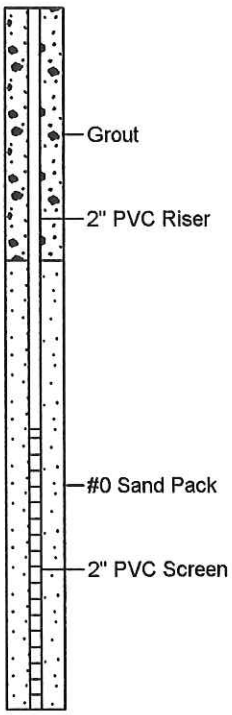
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/12/05	Field Rep.	: jlk
Date Completed	: 5/12/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: 50 Feet from Basin 4
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
45				
47				
49				
51			23"	9" wet, pale brown, medium to coarse grained, SAND 7" wet, pale brown, fine grained, SAND, traces of gravel 7" wet, brown, SANDY SILT, traces of gravel
53				
55			14"	4" wet, grey red, SILTY CLAY 1" wet, pale brown, fine to medium grained, SAND 9" moist, stiff, grey-brown, CLAY, traces of sand
57				
59				
61			7"	wet, pale brown, fine to medium grained, SAND, traces of gravel
63				
65			11"	wet, fine to medium grained, SAND, traces of gravel
67				
69				
71				END of BORING
73				
75				
77				
79				
81				
83				
85				
87				
89				

Well: MW - 4B
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

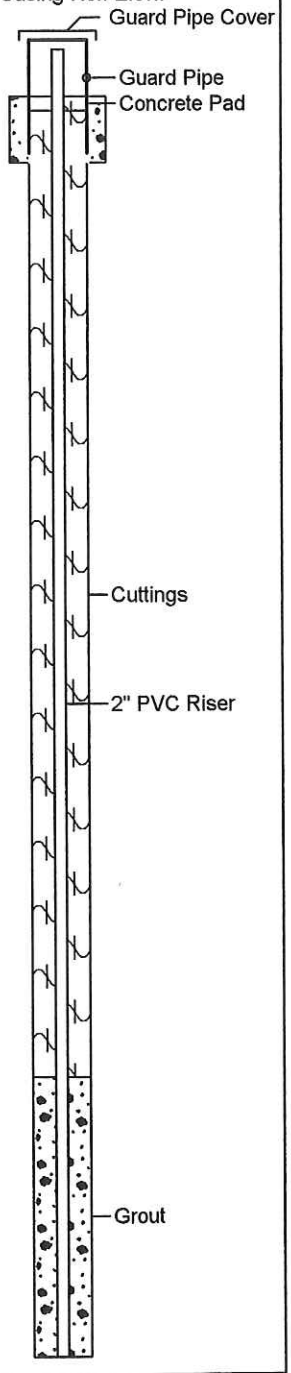
BORING LOG: MW - 5A

McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/16/05	Field Rep.	: jlk
Date Completed	: 5/17/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 5
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
0				
2				
4				
6			16"	10" dry, pale brown, fine grained, SAND, traces of gravel 6" dry, loose, pale brown, SANDY SILT
8				
10				
12				
14				
16			16"	4" dry, white, fine grained, SAND 12" dry, brown, SAND, some gravel, traces of silt
18				cobbles/boulders
20				
22				
24				
26			18"	6" dry, pale brown, fine grained, SAND, traces of silt 4" dry, grey, fine grained, SAND, traces of silt .5" grey, CLAY 7.5" dry, fine to medium grained, SAND, traces of gravel
28				
30				
32				
34				
36			21"	15" moist, pale brown, fine grained, SAND, traces of gravel 6" cobble fragments
38				
40				
42				
44				



Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 5A

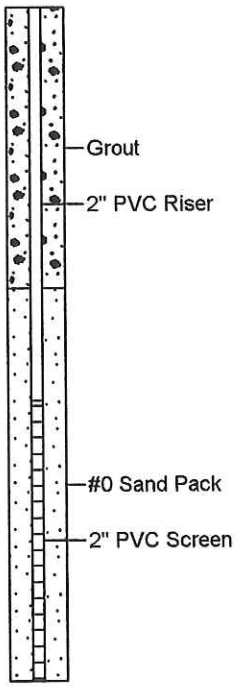
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/16/05	Field Rep.	: jlk
Date Completed	: 5/17/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 5
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
45–89			18"	9" wet, white, fine to coarse, SAND, traces of gravel 9" wet, white, fine grained, SAND, traces of gravel
			16"	8" wet, white, fine grained, SAND 2" wet, white, coarse, SAND, traces of gravel 6" wet, white, fine grained, SAND
			20"	moist, medium stiff, grey, CLAY
				END of BORING

Well: MW - 5A
Casing Ref. Elev.:



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 5B

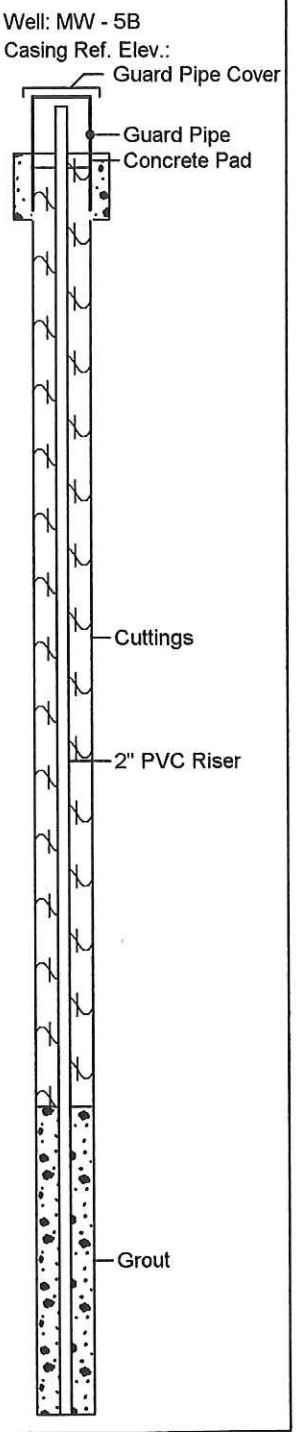
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/16/05	Field Rep.	: jlk
Date Completed	: 5/16/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: 50 feet from Basin 5
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev. 0	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
0	0			
2	-2			
4	-4			
6	-6			
8	-8			
10	-10			slightly moist, brown, CLAYEY SILT
12	-12			
14	-14			
16	-16			
18	-18			
20	-20			
22	-22			
24	-24			
26	-26			
28	-28			
30	-30			dry, fine grained, white, SAND
32	-32			
34	-34			
36	-36			
38	-38			
40	-40			dry, fine grained, white, SAND
42	-42			
44				

Depth (bgs): 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44



Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 5B

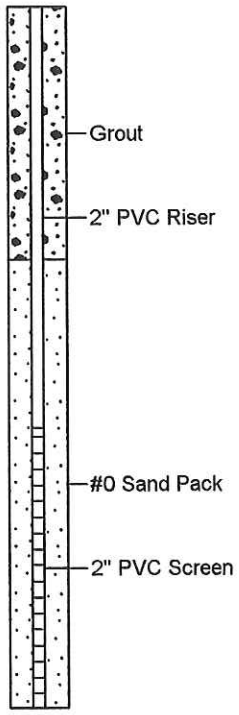
McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/16/05	Field Rep.	: jlk
Date Completed	: 5/16/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: 50 feet from Basin 5
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev. 0	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
45	-45			
47	-47			
49	-49			
51	-51		16"	6" very moist, medium grained, SAND 6" slightly moist, varved, medium stiff, brown, SILT 4" slightly moist, medium stiff, brown, SILT
53	-53			
55	-55			
57	-57			
59	-59			
61	-61		12"	6" wet, grey, CLAY 3" wet, pale brown, medium grained, SAND, traces of gravel 3" wet, pale brown, fine to medium grained, SAND
63	-63			
65	-65			
67	-67			
69	-69			
71	-71			END of BORING
73	-73			
75	-75			
77	-77			
79	-79			
81	-81			
83	-83			
85	-85			
87	-87			
89				

Well: MW - 5B
Casing Ref. Elev.:



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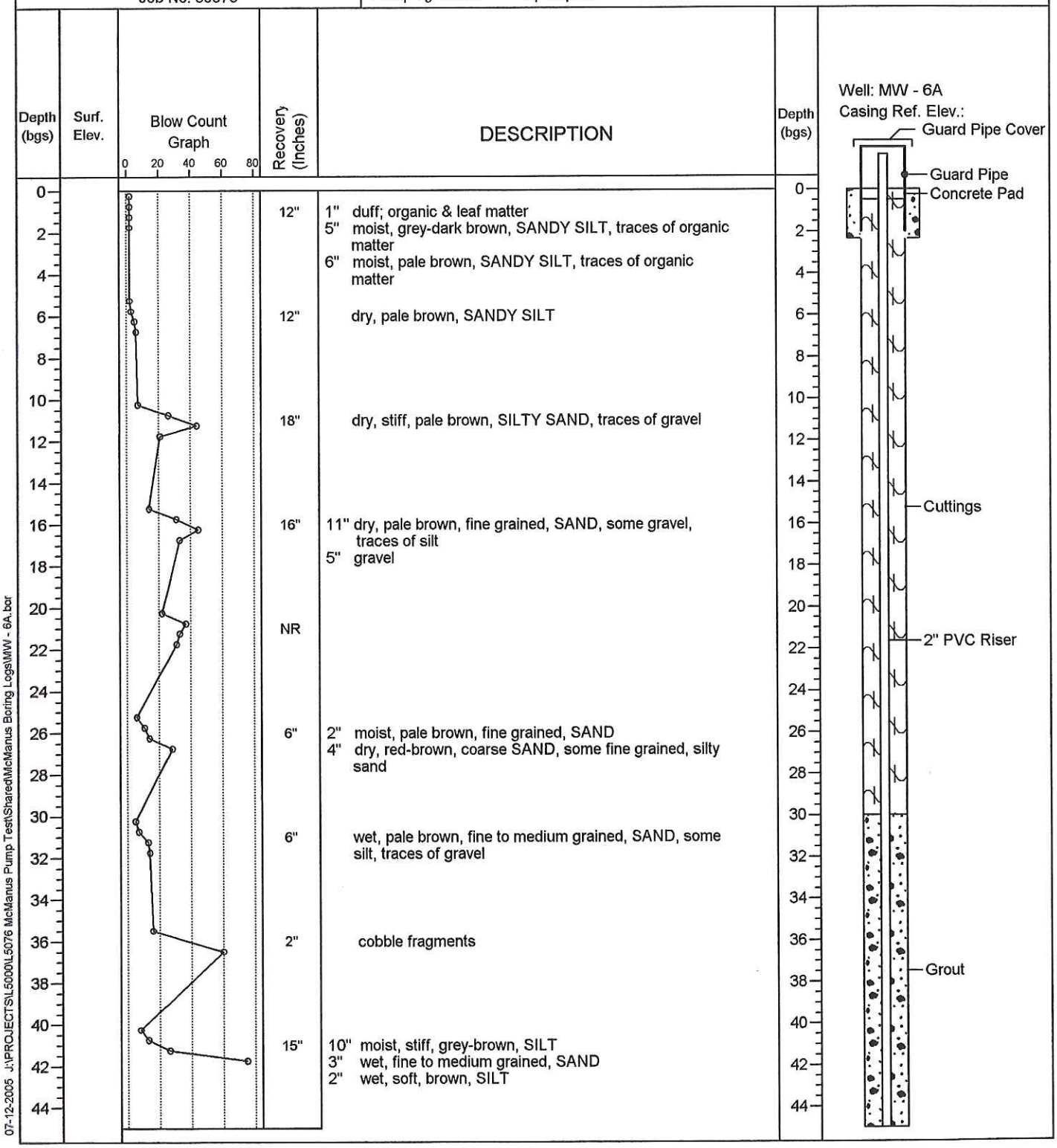
Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 6A

McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/2/05	Field Rep.	: jlk
Date Completed	: 5/3/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 6
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		



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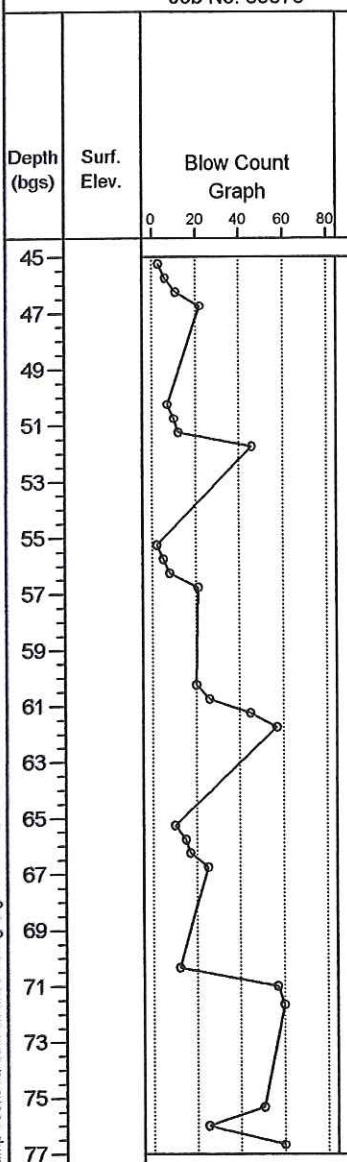
Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 6A

McManus Loading Test
Town of Barnstable
Hyannis, MA

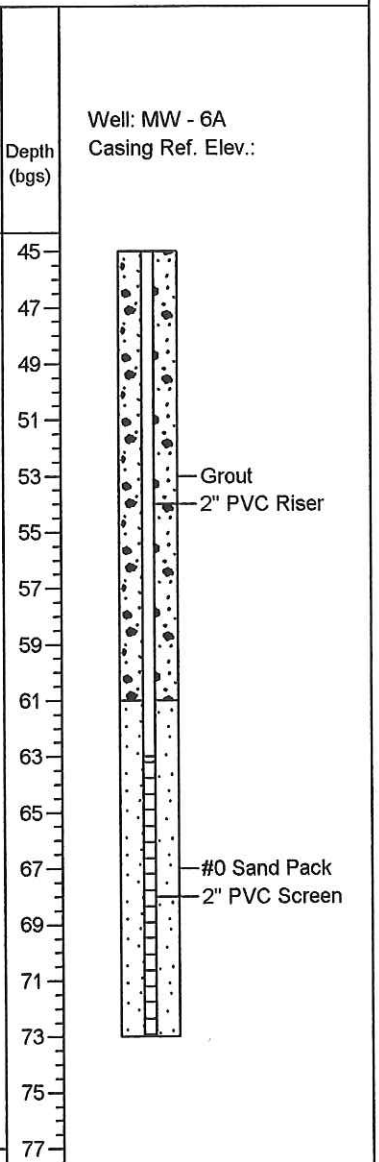
Job No. 50076

Date Started	: 5/2/05	Field Rep.	: jlk
Date Completed	: 5/3/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: Adjacent to Basin 6
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		



Recovery (Inches)	DESCRIPTION
NR	
14"	4" wet, pale brown, fine grained, SAND, traces of silt 5" very moist, pale brown, fine to coarse grained, SAND 5" moist, soft, pale brown, SANDY SILT
20"	10" moist, grey, SILT 10" wet, pale brown, fine to medium grained, SAND
22"	6" very moist to wet, , grey, medium stiff, CLAYEY SILT 16" wet, pale brown, fine to medium grained, SAND, traces of silt
18"	13" wet, pale brown, fine to medium grained, SAND, trace of coarse sand 5" wet, pale brown, fine grained, SAND
6"	slightly moist, hard,grey, SANDY SILT
NR	

END BORING



Well: MW - 6A
Casing Ref. Elev.:

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Stearns & Wheler, LLC
Environmental Engineers and Scientists

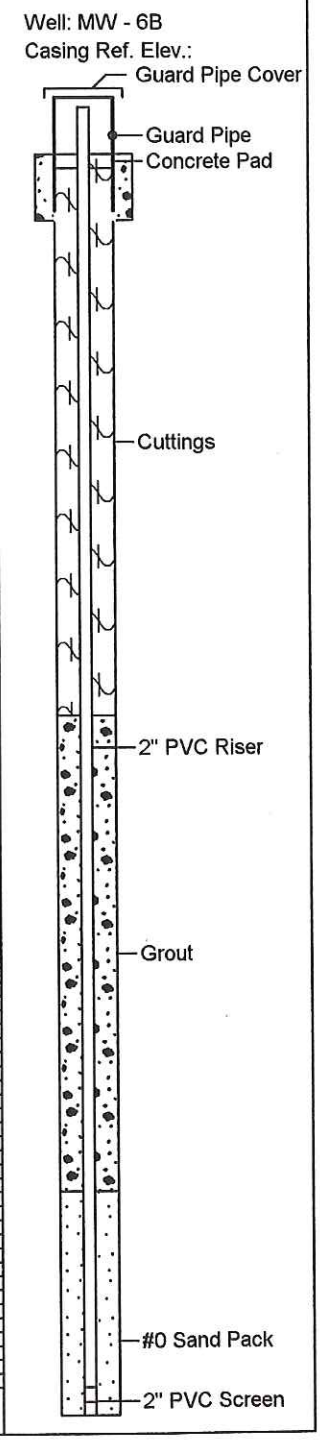
BORING LOG: MW - 6B

McManus Loading Test
Town of Barnstable
Hyannis, MA

Job No. 50076

Date Started	: 5/3/05	Field Rep.	: jlk
Date Completed	: 5/4/05	Logged By	: jlk
Hole Diameter	: 8"	Boring Location	: 50' from Basin 6
Drilling Method	: Hollow Stem Auger		
Sampling Method	: Split Spoon		

Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION
0–6			12"	dry, pale brown, fine grained, SAND, traces of gravel
6–14				cobbles
14–26			10"	dry, pale brown, fine grained, SILTY SAND, & gravel
26–36			NR	
36–40			8"	wet, pale brown, fine to medium grained, SAND
40–44			18"	wet, pale brown, fine to medium grained, SAND



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Stearns & Wheler, LLC
Environmental Engineers and Scientists

BORING LOG: MW - 6B

McManus Loading Test
Town of Barnstable
Hyannis, MA

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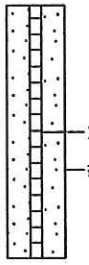
Depth (bgs)	Surf. Elev.	Blow Count Graph (0 20 40 60 80)	Recovery (Inches)	DESCRIPTION	Depth (bgs)
45–89			NR	END BORING	45–89

Well: MW - 6B
Casing Ref. Elev.:



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APPENDIX B

PHOTOGRAPHS



Site preparation for installation of test basin.



Installation of prefabricated test basin.



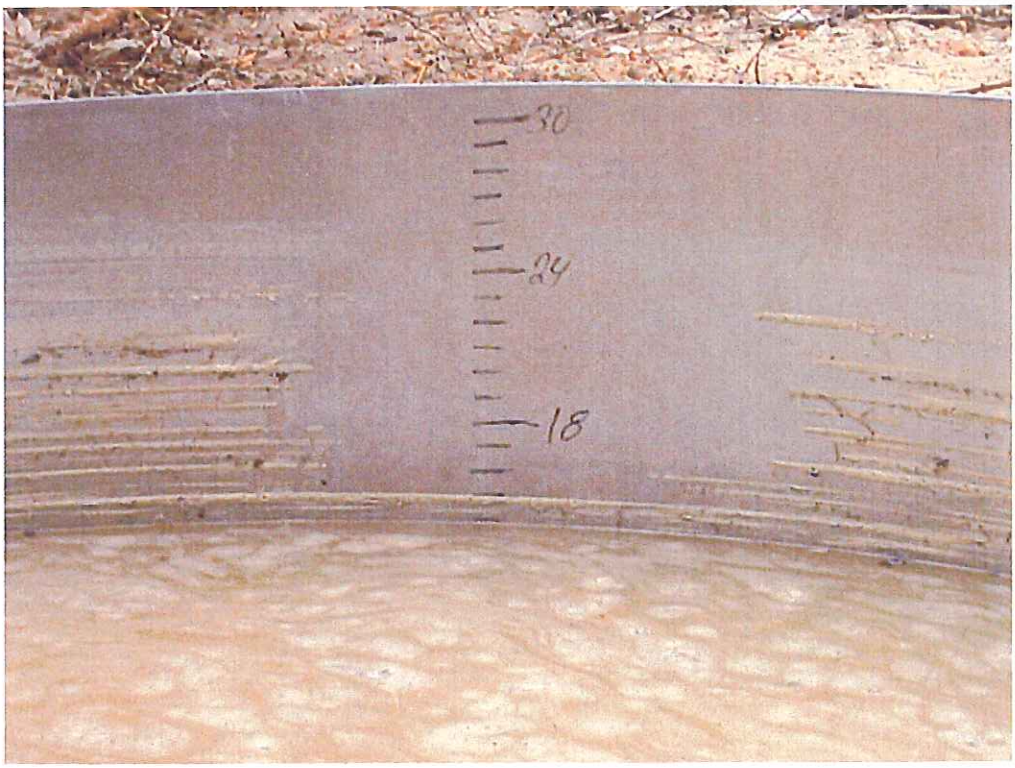
Installed test basin.



Initial saturation of test basin.



Constant head test at approximately 5 gpm.



Measuring rate of infiltration during falling head test.

Town of Barnstable
Department of Public Works
367 Main Street, Hyannis MA 02601
www.engineering@town.barnstable.ma.us

Office: 508-862-4090
Fax: 508-862-4711

Mark S. Ells
Director

CERTIFICATE AS TO TITLE TO PROJECT SITE

I, Robert D. Smith, Attorney At Law, representing the (City/town)

of Barnstable, Massachusetts, herein called the Applicant, as title counsel,

do hereby certify:

1. That I have investigated and ascertained the location of, and am familiar with the legal description of the site or sites being provided by the Applicant for all elements (treatment plant, interceptors, outfalls, pumping stations, force mains, and appurtenances) of the water pollution abatement project for which State Financial Assistance has been offered, identified as CWSRF- 2822. **These sites include Route 132 right-of-way and the Town-owned property identified for effluent disposal facilities and further described in the attached document.**

2. That I have examined the deed records of the county or counties in which this project is to be located and, in my opinion, the Applicant has, or will have at the time of construction, a legal and valid fee simple title or other estate or interest in the site of the project, including the necessary easements and rights-of-way as are necessary to undisturbed use and possession for the purposes of construction and operation for the estimated life of the project.

Dated this 6th day of October 2005.

Robert D. Smith, Town Attorney

APPENDIX C

LAND AVAILABILITY CORRESPONDENCE

TOWN OF BARNSTABLE

OFFICE OF TOWN ATTORNEY
367 MAIN STREET
HYANNIS, MASSACHUSETTS 02601-3907

ROBERT D. SMITH, Town Attorney
RUTH J. WEIL, 1st Assistant Town Attorney
T. DAVID HOUGHTON, Assistant Town Attorney
CLAIRE R. GRIFFEN, Paralegal/Legal Assistant
CLAUDETTE BOOKBINDER, Legal Clerk

TEL. #: (508) 862-4620
FAX #: (508) 862-4724
www.town.barnstable.ma.us

October 4, 2005

Mark Ells, Director
Public Works Department
Town of Barnstable
230 South Street
Hyannis, MA 02601

Re: Effluent Mitigation – McManus Property
Our File Ref: #2004-0292

Dear Mr. Ells:

You have asked me whether or not the town may use the "McManus" property, so-called, located just to the East-Southeast of the intersection of Routes 6 and 132, for the purpose of effluent mitigation. The context upon which the question arises is that the land was acquired with funds from the open "Cape Cod Land Bank" established under Chapter 293 of the Acts of 1998, as amended.

You will recall that we have discussed various methods of effluent mitigation, most notably, surface sand filter beds on the one hand, and sub-surface leaching facilities. It is my opinion that it would be consistent with the purposes of the Land Bank legislation to use the land for sub-surface dispersal of the effluent from our Water Pollution Control Facility, which, as you are aware, is a high quality tertiary-treated effluent, with total nitrogen reductions of 80% to 90%, through sub-surface leaching facilities which leave the surface in an open space condition, for either open space purposes or recreation uses (see the attached memo from Mark Giordano relating to this subject).

In addition, although it is a partial belt-and-suspenders solution, the Eastern-most 16.9 Acres of the parcel was specifically reserved by easement and acquired with DPW funds specifically for the purpose of effluent mitigation (see the attached marked 'Exhibit A' depicting 6.9 acre parcel).

I trust this is sufficient for your purpose as of this date. If more is required, please be in touch.

Sincerely yours,

Robert D. Smith, Town Attorney
Town of Barnstable

RDS:cg
Encs.

Appendix R

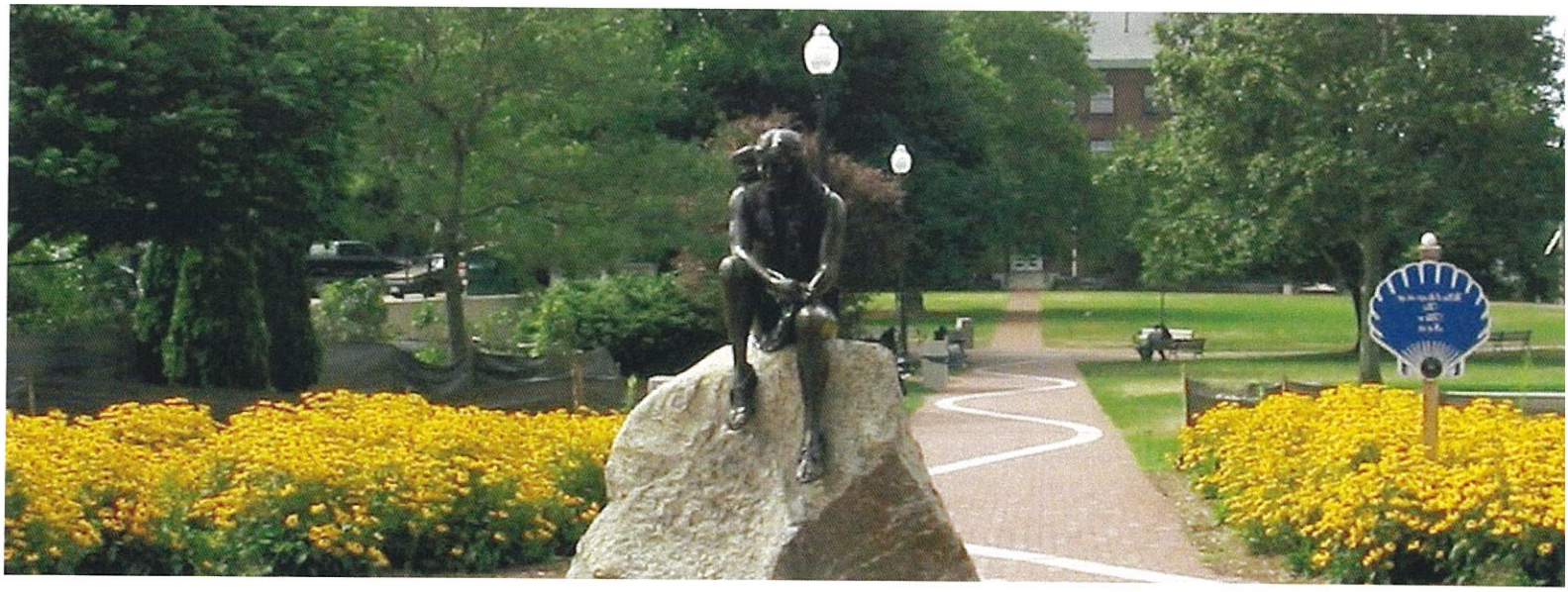
Needs Assessment Report Comprehensive Wastewater Management Planning (CWMP) Project Town of Barnstable, MA; May 2011

GHD | STEARNS & WHELER
CLIENTS | PEOPLE | PERFORMANCE

Needs Assessment Report

Comprehensive Wastewater Management Planning (CWMP) Project

Town of **Barnstable**, MA



Volume 1 of 2 Report Text and Tables
May 2011

WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

Comprehensive Wastewater Management Planning (CWMP) Project

Needs Assessment Report

Volume 1 of 2
Report Text and Tables

Prepared for

TOWN OF BARNSTABLE, MASSACHUSETTS

Prepared by

GHD Inc.
1545 Iyannough Road, Route 132
Hyannis, Massachusetts 02601

May 2011

Project No. 8612474

EXECUTIVE SUMMARY
COMPREHENSIVE WASTEWATER MANAGEMENT PLANNING PROJECT

NEEDS ASSESSMENT REPORT
TOWN OF BARNSTABLE, MASSACHUSETTS

ES.1 PROJECT BACKGROUND

The purpose of the Comprehensive Wastewater Management Planning (CWMP) Project is to provide an environmentally and economically sound plan for wastewater treatment and nutrient management in the Town of Barnstable (Town) for the next 20 years. The CWMP Project will assess the wastewater and nutrient-related needs in the Town; evaluate appropriate mitigation measures for those needs; and develop a recommended plan for improved management systems. This Plan is meant to be consistent with the Town's Local Comprehensive Plan (LCP) which has the goals of:

- Preserve, protect and enhance sensitive natural habitats and systems.
- Provide Town services and infrastructure through an efficient, planned and prioritized process.
- Sustain diverse villages and livable neighborhoods for year round residents while providing housing opportunities for all.

This Needs Assessment Report completes the second of five major phases of the CWMP Project and provides the framework and necessary background information to quantify and understand the wastewater and nutrient management needs in Barnstable. Subsequent phases will utilize this information to identify, screen and evaluate alternative solutions to meet these needs. The first phase was the development of nutrient limits for the Town's coastal estuaries, which has been underway for several years and is summarized in this report.

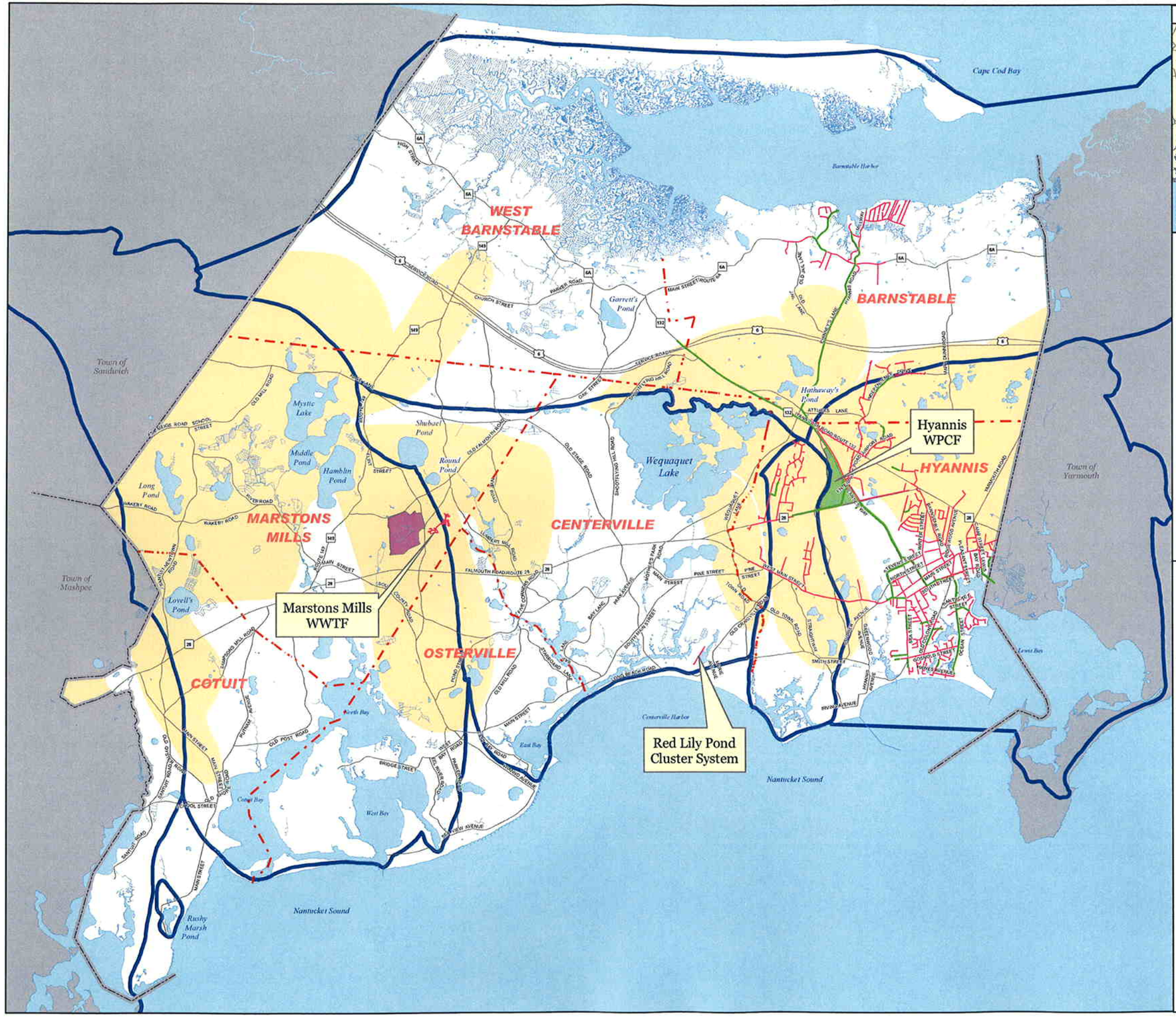
In this Needs Assessment Report, existing and future land use is summarized and projected to the design year 2035. This design year is 20 years after 2015, which is the projected starting point of the implementation of this Plan. We hope to complete this planning project and be started with implementation by 2015.

This Needs Assessment Report was completed through the coordinated efforts of the Town of Barnstable Department of Public Works (DPW) and Growth Management Department (GMD), and Stearns & Wheler GHD serving as the project consultant. Valuable assistance has been provide from the Town's Geographic Information System (GIS) Department, the Cape Cod Commission, and the Massachusetts Department of Environmental Protection (MassDEP) as well as several working groups comprised of Town staff, Stearns & Wheler GHD staff and Town volunteers.

The Town of Barnstable is located in the middle portion of Cape Cod as shown in Figure ES-1. This figure also identifies the watersheds to Popponesset Bay, Rushy Marsh, Three Bay System, Centerville River System, Halls Creek, Lewis Bay, and Barnstable Harbor which are the primary estuarine waters in Barnstable. This figure also illustrates the many freshwater ponds that will be considered in this planning project; and it illustrates the seven villages that comprise the Town: Hyannis, Barnstable, Centerville, Osterville, Marstons Mills, Cotuit, and West Barnstable. It also illustrates the wastewater management facilities owned and operated by the Town.

The Town's water resources: groundwater, drinking water, pond water, and estuarine water form the basis of the Town's human health, environmental health, and economic prosperity. All of these water resources are interconnected and must be properly managed for sustainable development and to meet the three LCP goals listed above.

The Town is faced with several nutrient management and wastewater-related problems as it plans to protect its water resources and plans for growth and economic development. Nitrogen loadings into the Town's coastal watersheds are causing an overproduction of algae in several coastal estuaries and are impacting the water quality and marine resources in the estuaries. Recently completed studies by the Massachusetts Estuaries Project (MEP) indicate most (75 to 85 percent) of the nitrogen originates from wastewater sources. The other sources that comprise the remaining 15 to 25 percent include lawn and agricultural fertilizers, road and roof runoff, and precipitation from the sky. These reports have recommended extensive wastewater nitrogen


WEST BARNSTABLE
BARNSTABLE
HYANNIS
MARSTONS MILLS
CENTERVILLE
OSTERVILLE
COTUIT
Hyannis WPCF
Marstons Mills WWTF
Red Lily Pond Cluster System
Cape Cod Bay
Barnstable Harbor
Nantucket Sound
Centerville Harbor
Lewis Bay
Town of Sandwich
Town of Mashpee
Town of Yarmouth
Garrett's Pond
Hathaway's Pond
Wequaquet Lake
Mystic Lake
Shubael Pond
Middle Pond
Hamblin Pond
Round Pond
Long Pond
Lovell's Pond
North Bay
East Bay
Cotuit Bay
West Bay
Rushy Marsh Pond
Route 6
Route 28
Route 132
Route 149
Route 6A
Route 28
Route 149
Route 132
Route 6A
Route 6
Route 28
Route 6A
Route 6
Route 28
Route 6A
Route 6
Route 28

removal to meet specific nitrogen limits that have been developed for the water bodies. The limits are called Total Maximum Daily Loads (TMDLs).

The Town draws its public water supplies from the groundwater system under the land area of the Town. This groundwater system (for all of Cape Cod) has been designated as a Sole Source Aquifer by USEPA, and as such is a highly protected resource. Current discharges from individual septic systems and from wastewater treatment facilities have the potential to impact this drinking water supply, and there are new MassDEP regulations that must be met to protect the resource.

The Town has many freshwater ponds and lakes which provide fishing, swimming, and other aesthetic resources. Phosphorus loadings into the pond watershed areas (mainly from individual septic systems) are causing an overproduction of algae in several ponds and are impacting the water quality in these ponds. Recently completed studies have documented these impacts and the need to remediate them.

ES.2 FINDINGS AND CONCLUSIONS

The Needs Assessment is designed to identify the Town's specific water-resource, wastewater, and nutrient-management problems and needs. The major findings and conclusions of the various evaluations of the Needs Assessment are summarized below.

A. **Wastewater and Nutrient Management Planning History in Barnstable.** The Town initiated its last wastewater planning process in 1993 with the 20-year planning period of 1994 to 2014. The project was completed in 2007 with state approval of the Final Wastewater Facilities Plan and Final Environmental Impact Report, March 2007 (2007 WWFP). The main focus of that planning project was to address surface and groundwater problems caused by failing septic systems (and even systems that were operating properly but were still impacting drinking waters). The following list briefly summarizes the main recommendations of that project.

- Upgrade and expand the Hyannis Water Pollution Control Facility.
- Extend sewers to the Wastewater Areas of Concern (AOC) in the eastern portion of the Town to address the water quality problems in these areas.

- Defer decision on many of the AOCs in the western portion of the Town until nitrogen limits are set by the State and federal governments with the intent of addressing those nitrogen limits through the current CWMP Project.
- Address wastewater problems in several AOCs with Board of Health solutions and public water supply.

Many of the recommendations have been completed, including:

- Upgrade and expansion of the Hyannis WPCF.
- Initial sewer extensions in the eastern portion of the Town.
- Board of Health solutions and extension of public water supply to the AOCs that need these types of solutions.
- Developed nutrient limits of most of the Town's coastal estuaries.

The extension of sewers in the eastern portion of the Town had been slowed by the Town's historic policy/practice that sewer extension costs be paid by the properties being served by the sewers through property betterments.

B. **Estuarine Water Quality Needs.** The impacts and nitrogen limits to estuarine water quality have been researched and documented by the Massachusetts Estuaries Project and MassDEP for Popponesset Bay, Rushy Marsh Pond, Three Bays System, Centerville River System, Halls Creek, and Lewis Bay. The impacts and nitrogen limits to the estuarine water quality in Barnstable Harbor have not yet been researched and documented but are expected in the next one to two years.

The nitrogen limits developed to date are depicted on Figure ES-2. This figure illustrates the percent of existing wastewater nitrogen load that must be removed to meet the nitrogen total maximum daily load (TMDL) limits for each watershed. It is based on detailed modelling completed by the Massachusetts Estuaries Project as summarized later in this report. The removal percentages illustrated are for the whole watershed, but the detailed modelling indicates that the watershed removals are most efficiently attained by focusing the removal in specific sub-watershed areas. The removals also need to be coordinated with goals to protect drinking water as well as pond waters.

Figure ES-2 also illustrates the following additional information that will be used in the nitrogen removal evaluations:

- Existing sewer system coverage in eastern Barnstable
- Planned sewer extensions as identified in the 2007 WWFP.

It is important to recognize that there is still additional build-out potential in these watersheds that could add additional nitrogen. This means that the future wastewater nitrogen that needs to be removed will be greater than the existing.

Wastewater has been found by the MEP to be the largest source of nitrogen to the Town's estuaries. Typically, it comprises 75 percent to 85 percent of the nitrogen load from the watershed. Fertilizers and runoff from roads and roofs are the other two controllable nitrogen sources and typically comprise 5 percent to 10 percent of the watershed nitrogen loadings. This distribution is site specific for each watershed. Though wastewater from septic systems is by far the largest source in Barnstable, fertilizers and runoff should be managed to reduce their loadings or, at the least, prevent the loads from these sources to increase. These sources are typically managed through "best management practices" that are typically implemented through increased awareness of these sources and public education. Public education on proper management of these two nitrogen sources is needed.

C. **Pond Water Quality Needs.** Phosphorus is typically the limiting nutrient for fresh water systems; therefore, it is the nutrient that stimulates excess algae production and produces water quality problems in ponds. There are no phosphorus TMDLs for Barnstable's ponds, but there has been much monitoring and analysis of pond data in the past.

As part of this Needs Assessment phase of the Project, the pond data was evaluated, and an Action Plan was developed. The evaluation, findings, and main recommended actions are summarized in this report. Many of the ponds are showing signs of water quality impact, and the Action Plan provides a prioritization of the pond water quality needs and step by step recommendations.

D. **Bacterial TMDL Needs.** The following surface water bodies have bacterial TMDLs that may be caused by wastewater, stormwater runoff, and/or animals living in (or frequenting) the waterbodies:

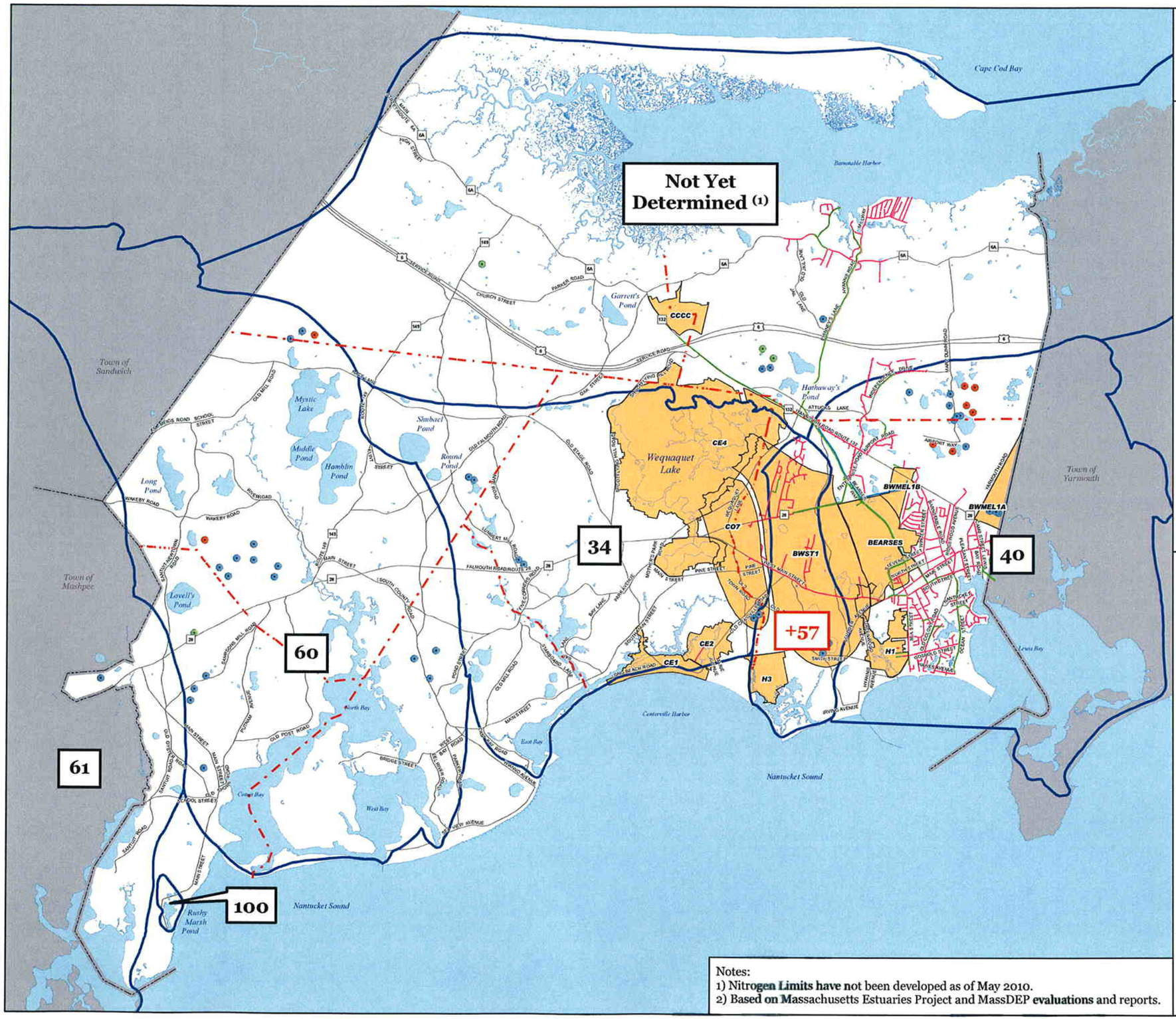
- Barnstable Harbor
- Bumps River
- Hyannis Harbor
- Lewis Bay
- Marsapin Creek
- Mill Creek
- Seapuit River

Stormwater and land-use management solutions to be evaluated in the next phase of the project will consider these TMDLs.

E. **Groundwater Quality and Drinking Water Supplies.** The drinking water quality, as indicated by the water supply annual reports is good. The 2007 WWFP investigated nitrogen impacts to the water supplies and found that most were well protected. Three zones of contribution to water supplies in the eastern portion of the Town were recommended for sewer extension to further protect the water supplies. These are the BWST1, CO7, and BEMELIA areas illustrated on Figure ES-2.

Nitrogen discharges from septic systems previously were the main concern to the water supply zones of contribution. More recently, concerns have been raised about a new category of water contaminant called Contaminants of Emerging Concern (CECs). This general category includes three subgroups – endocrine disrupting compounds, pharmaceuticals, and personal care products. These compounds and potential contaminants are not currently regulated by the federal government because their toxicity is not well understood. Many of these compounds originate from the medications and personal care products that we use and discharge to our septic systems and wastewater treatment facilities.

Advanced wastewater treatment facilities, such as the Hyannis Water Pollution Control Facility and the Marstons Mills Wastewater Treatment Facility, are believed to provide better removals of these compounds than individual septic systems, but there is a lack of data on the performance of individual septic systems for these contaminants.


Not Yet Determined (1)
34
60
61
100
40
+57
Cape Cod Bay
Barnstable Harbor
Town of Sandwich
Town of Mashpee
Town of Yarmouth
Nantucket Sound
Centerville Harbor
Lewis Bay
Garrett's Pond
Hathaway's Pond
Wequaquet Lake
Mystic Lake
Middle Pond
Hamblin Pond
Long Pond
Shubael Pond
Round Pond
Lovell's Pond
North Bay
East Bay
Cotuit Bay
West Bay
Rushy Marsh Pond
CCCC
CE4
CO7
CE2
CE1
H1
H3
BWST1
BWMEL1B
BWMEL1A
BEARSES
Notes:
1) Nitrogen Limits have not been developed as of May 2010.
2) Based on Massachusetts Estuaries Project and MassDEP evaluations and reports.
34 Percent Septic System Nitrogen Removal Suggested by MEP
+57 Percent Additional Nitrogen That Could Be Added (Suggested by MEP)
Planned Sewer Extension
Marine Watersheds
Existing Sewer Force Main
Existing Gravity Sewer
Existing Vacuum Sewer
Existing Well
Proven Future Well
Proposed Future Well
Major Roads
Fire District / Village Lines
Town Boundary
Water Bodies
TOWN OF BARNSTABLE
MASSACHUSETTS
Comprehensive Wastewater and Nutrient Management Plan
Existing Septic System Nitrogen Removal Needed To Meet the TMDLs (2)
Figure ES-2
SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1989
N
W
E
S
Miles
0 0.25 0.5 1 1.5 2
CWNMP_NitrogenRemoval_11x17.mxd J.A.B. 7/27/2010
TOWN OF BARNSTABLE
GEOGRAPHIC INFORMATION SYSTEMS UNIT
FIGURE PREPARED FOR STEARNS & WHELER GHD

MassDEP revised their groundwater discharge regulations in March 2009 to require that all treatment facilities with flows greater than 10,000 gallons per day remove the total organic carbon (TOC) component of their wastewaters to low levels if the discharge is into a Zone of Contribution to public water supply wells. The treatment levels must be less than 3 mg/L if the discharge has a travel time greater than two-years to the well, and less than 1 mg/L if the travel time is less than two years. TOC is not a contaminant by itself, but it is a surrogate of the CECs because most of the CECs are comprised of organic carbon. Research indicates that if the TOC concentration is low, the concentrations of the CEC will be low or non-detectable. This regulatory change has a large impact on the Hyannis Water Pollution Control Facility and the Marstons Mills Wastewater Treatment Facility, both of which discharge their treated waters to zones of contribution to public water supply wells with travel times greater than two years.

F. **Wastewater Treatment and Recharge Facilities and Related Needs.** Most of the properties in the Town are served by individual on-site septic systems that have been documented as contributing the largest percentage of nitrogen (75 to 85 percent) to the coastal estuaries. Nitrogen discharges from these systems need to be remediated to meet the nitrogen TMDLs. These systems also discharge large quantities of phosphorus that impacts water quality in the freshwater ponds. Phosphorus discharges from these systems need to be remediated to address pond water quality impacts.

A group of 71 individual Innovative and Alternative (I/A) septic systems as regulated by MassDEP and the Title 5 regulations are operating in Barnstable. These systems are typically designed to remove approximately 50 percent of the nitrogen in the wastewater and meet a limit of 19 mg/L total nitrogen. Research at the Otis On-Site Septic System Test Facility at the Massachusetts Military Reservation indicates that these systems typically can meet this limit when they are properly designed and operated with a consistent wastewater flow. Data analysis by the Barnstable County Department of Health and Environment on the I/A systems actually installed at Cape Cod properties indicates that only one half to two thirds of the installed systems meet the 19 mg/L limit.

There are two privately owned wastewater treatment facilities in Barnstable located at the Cotuit Landings Stop & Shop and at the Cape Regency Skilled Nursing and Rehabilitation Center. They are sized for approximately 20,000 gpd, and both have demonstrated good nitrogen removal performance to meet their discharge limit of 10 mg/L total nitrogen.

The Town owns and operates three treatment facilities:

- Hyannis WPCF
- Marstons Mills WWTF
- Red Lily Pond Cluster System

These treatment facilities and their collection systems are illustrated on Figure ES-1, and their "needs" are summarized below:

1. **Hyannis WPCF.** The Hyannis WPCF treats an average flow of 1.46 million gallons per day (mgd) and a maximum-month average flow of 1.94 mgd. It has recently been upgraded and expanded and has a maximum-month capacity of 4.2 mgd. The treatment facility has excellent performance and averages 5 mg/L total nitrogen in the treated water as compared to a MassDEP discharge limit of 10 mg/L.

MassDEP has recently (March 2009) revised their groundwater discharge regulations to require a total organic carbon (TOC) limit in the treated water because the recharge is in a zone of contribution to public water supply wells. This project will need to develop a plan (as part of the CWMP) to meet these new TOC limits.

The capacity of the sand infiltration beds has been estimated based on text-book information that may not be accurate for the sandy soil conditions at the site. Therefore, the sand bed capacity may be even greater. A hydraulic loading test in the sand beds would provide a more empirical measure of the capacity of these beds which may become important in the future if some of the bed areas need to be used for new treatment facilities. A hydraulic load test needs to be completed to better estimate the capacity of the sand infiltration beds.

The Hyannis WPCF has a collection system that has grown over time, and its ability to accept more flow is not clearly defined. A computer model was developed for the Hyannis Growth Incentive Zone (GIZ) area of Hyannis when the Town was evaluating that area for the GIZ. The existing computer model should be expanded to cover the whole collection system. This will allow a better understanding of its capacity and how the existing system can be most efficiently expanded to pick up additional flow.

2. **Marstons Mills WWTF.** The Marstons Mills WWTF serves an elementary school, a middle school, and a residential development of 30 homes. The WWTF was recently upgraded and is performing well. Similar to the Hyannis WPCF, its recharge is in a zone of contribution to a public water supply well and, as such, the WWTF will need to increase its treatment to meet the new TOC discharge limit (discussed earlier in this chapter) of 3 mg/L.

3. **Red Lily Pond Cluster System.** This cluster system serves several homes adjacent to Red Lily Pond and Elizabeth Lake. It does not have a discharge permit, and its treatment performance is expected to be similar to a conventional Title 5 septic system.

G. **Informational Needs to Complete the CWMP Project.** This report summarizes the wastewater and nutrient management needs in Town. Some of these are informational needs for the Project Team to continue and complete the CWMP Project. The main information needs are listed below:

- Nitrogen TMDL limits for Barnstable Harbor to be developed by the Massachusetts Estuaries Project and MassDEP.

- Information on the nitrogen load sensitivity once the culvert replacement and dredging is completed at Stewarts Creek in the Lewis bay Watershed.

- Nitrogen TMDL Report for Lewis Bay (the Town has received the Massachusetts Estuary Project Technical Report for this estuary but still needs the TMDL Report).

- Collaborative input from the neighboring towns of Mashpee, Sandwich and Yarmouth and the Cape Cod Water Protection Collaborative on reducing nitrogen loading to the shared watersheds of Popponesset Bay, Three Bays System, Barnstable Harbor, and Lewis Bay.

- Informational needs related to the Barnstable Ponds Action Plan including needed sampling and analysis data.

- Possible revisions to water supply well zones of contribution being completed by the Cape Cod Commission with coordination with the water purveyors and MassDEP.

- Refinement of the sand infiltration bed capacity at the Hyannis WPCF based on a hydraulic load test to assist in future treated water recharge evaluation.

- Expansion of the sewer system computer model to assist in future wastewater collection evaluations.

These information needs should be considered and addressed as the project proceeds.

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GLOSSARY OF COMMON ACRONYMS

ABF	Aerated Biological Filters
ACEC	Areas of Critical Concern
ACRE	Applied Coastal Research and Engineering, Inc.
AOC	Area of Concern
AOP	Advanced Oxidation Processes
APCC	Association to Preserve Cape Cod
ATAD	Autothermal Thermophilic Aerobic Digestion
BAC	Biological Activated Carbon
BAF	Biologically Active Filters
BCDHE	Barnstable County Department of Health and Environment
BCP	Barnstable Comprehensive Plan
BMP	Best Management Practices
BNR	Biological Nitrogen Removal
BOD	Biological Oxygen Demand
BOH	Board of Health
CCC	Cape Cod Commission
CCWPC	Cape Cod Water Protection Collaborative
CEC	Contaminants of Emerging Concern
CFR	Code of Federal Regulation
CMR	Code of Massachusetts Regulations
CNR	Cyclical Nitrogen Removal
COD	Chemical Oxygen Demand
CWA	Clean Water Act
CWMP	Comprehensive Wastewater Management Plan
CZM	Coastal Zone Management
DBP	Disinfection By-Products
DCPC	District of Critical Planning Concern
DCWMP/DEIR	Draft Comprehensive Wastewater Management Plan and Draft Environmental Impact Report
DMF	Division of Marine Fisheries
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DPW	Department of Public Works
DRI	Development of Regional Impact
EDC	Endocrine Disrupting Compounds
EIR	Environmental Impact Report
eMLE	enhanced Modified Ludzack-Ettinger
ENF	Environmental Notification Form
ENR	Enhanced Nitrogen Removal
FAST	Fixed Activated Sludge Treatment
FCWMP/FEIR	Final Comprehensive Wastewater Management Plan and Final Environmental Impact Report
FFL	Falmouth Friendly Lawn

GAC	Granular Activated Carbon
GIS	Geographic Information System
gpd	gallons per day
gpd/im	gallons per day per inch-mile
gpd/sf	gallons per day per square foot
GWDP	Groundwater Discharge Permit Program
HAA	Haloacetic Acids
I/A	Innovative and Alternative
IFAS®	Integrated Fixed Film Activated Sludge
I/I	Infiltration/Inflow
LCP	Local Comprehensive Plan
MassDEP	Massachusetts Department of Environmental Protection
MBBR	Moving Bed Biofilm Reactors
MBR	Membrane Bioreactors
MCL	Maximum Contaminant Level
MEPA	Massachusetts Environmental Policy Act
MEP	Massachusetts Estuaries Project
MF	Microfiltration
MGL	Massachusetts General Law
mgd	million gallons per day
mg/L	milligrams per liter
MIEX	Magnetic Ion Exchange
MLE	Modified Ludzack-Ettinger
MLSS	Mixed Liquor Suspended Solids
MMMS	Marstons Mills middle School
MMR	Massachusetts Military Reservation
MSL	Mean Sea Level
NaOCI	Sodium Hypochlorite
N_2	Nitrogen Gas
NEPA	National Environmental Policy Act of 1970
NERR	National Estuarine Research Reserve
NF	Nanofiltration
NHESP	Natural Heritage and Endangered Species Program
NH_4	Ammonium Cation
NH_3-N	Ammonia Nitrogen
NO_3-N	Nitrate Nitrogen
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Units
OH	Hydroxyl
O&M	Operations & Maintenance

PAC	Powdered Activated Carbon
PALS	Pond and Lake Stewardship
POTW	Publicly Owned Treatment Works
PPCP	Pharmaceuticals and Personal Care Products
ppm	parts per million
psi	per square inch
PSTF	Privately-owned Sewage Treatment Facility
RAS	Return Activated Sludge
RBC	Rotating Biological Contactor
RO	Reverse Osmosis
ROW	Right-of-Way
RPP	Regional Policy Plan
RSF	Recirculating Sand Filter
SBR	Sequencing Batch Reactor
SCADA	Computer system that stands for: Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SMAST	School of Marine Science and Technology
STEG	Septic Tank Effluent Gravity
STEP	Septic Tank Effluent Pump
SWD	Solid Waste Division
TDS	Total Dissolved Solids
THM	Trihalomethane
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UCT	University of Capetown
UF	Ultrafiltration
ULPRO	Ultra Low Pressure Reverse Osmosis
UMass	University of Massachusetts
USDA	U.S. Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
VIP	Virginia Initiative Plant
WAS	Waste-Activated Sludge
WPA	Wetlands Protection Act
WPCD	Water Pollution Control Division
WPCF	Water Pollution Control Facility
WWTF	Wastewater Treatment Facility

ZOC Zone of Contribution

Chapter 1
Introduction

CHAPTER 1

INTRODUCTION

1.1 PROJECT PURPOSE AND PLANNING AREA

The purpose of the Comprehensive Wastewater Management Planning (CWMP) Project is to provide an environmentally and economically sound plan for wastewater treatment and nutrient management in the Town of Barnstable (Town) for the next 20 years. The CWMP Project will assess the wastewater and nutrient-related needs in the Town; evaluate appropriate mitigation measures for those needs; and develop a recommended plan for improved management systems. The primary purpose of the project is to develop a plan to:

- Protect public health and address Board of Health concerns.
- Protect the water supply.
- Meet the nitrogen Total Maximum Daily Load (TMDL) limits for the marine waters in and around Barnstable.
- Protect and remediate pond water quality.
- Address new regulations and public health concerns about Contaminants of Emerging Concern (CEC) including pharmaceuticals, personal care products, and endocrine disrupting compounds.
- Plan for and maintain flexibility to meet future Massachusetts Department of Environmental Protection (MassDEP) and United States Environmental Protection Agency (USEPA) requirements.
- Incorporate the wastewater infrastructure and facilities planning into a cohesive document.

The Town of Barnstable is located in the middle portion of Cape Cod as shown in Figure 1-1. This figure also identifies the watersheds to Popponesset Bay, Rushy Marsh, Three Bay System, Centerville River System, Halls Creek, Lewis Bay, and Barnstable Harbor which are the primary estuarine waters in Barnstable. This figure also illustrates the many freshwater ponds that will be considered in this planning project; and it illustrates the seven villages that comprise the Town:

Hyannis, Barnstable, Centerville, Osterville, Marstons Mills, Cotuit, and West Barnstable. It also illustrates the wastewater management facilities owned and operated by the Town.

1.2 PROJECT ISSUES AND BACKGROUND

The Town of Barnstable is faced with several nutrient management and wastewater-related problems as it plans to protect its water resources and plans for growth and economic development. Nitrogen loadings into the Town's coastal watersheds are causing an overproduction of algae in several coastal estuaries and are impacting the water quality and marine resources in the estuaries. Recently completed studies by the Massachusetts Estuaries Project (MEP) indicate most (75 to 85 percent) of the nitrogen originates from wastewater sources. The other sources that comprise the remaining 15 to 25 percent include lawn and agricultural fertilizers, road and roof runoff, and precipitation from the sky. These reports have recommended extensive wastewater nitrogen removal to meet specific nitrogen limits that have been developed for the waterbodies. The limits are called Total Maximum Daily Loads (TMDLs) as discussed later in this report.

The Town draws its public water supplies from the groundwater system under the land area of the Town. This groundwater system (for all of Cape Cod) has been designated as a Sole Source Aquifer by USEPA, and as such is a highly protected resource. Current discharges from individual septic systems and from wastewater treatment facilities have the potential to impact this drinking water supply, and there are new MassDEP regulations that must be met to protect the resource.

The Town has many freshwater ponds and lakes which provide fishing, swimming, and other aesthetic resources. Phosphorus loadings into the pond watershed areas (mainly from individual septic systems) are causing an overproduction of algae in several ponds and are impacting the water quality in these ponds. Recently completed studies have documented these impacts and the need to remediate these impacts. The studies have identified that phosphorus moves into a pond from its watershed with surface water runoff and groundwater flow. Once it is in the pond it accumulates in the sediments. Under certain conditions it can be released and cause large algal blooms that impact the environmental health, human health, and recreational value of these resources. Several ponds appear to be exceeding their nutrient balances.

Several previous and ongoing projects have developed valuable information that will be referenced and used in this CWMP project. These previous projects are briefly described below.

A. **Background on the 2007 Wastewater Facilities Plan and Subsequent Implementation.** In 1993 the Town initiated a Wastewater Facilities Plan that was completed in 2007. It was a detailed evaluation and planning process that was completed to address wastewater impacts to the Town's water resources. It focused on the ability of individual septic systems to meet the State's sanitary code (Title 5 regulations) and the impacts from failing (and even properly working) systems on the groundwater used for drinking water supplies, and other public health issues. The plan recommended the following upgrades to the Hyannis Water Pollution Control Facility (WPCF) and its collection system:

1. Treatment upgrade and expansion to meet the new (imposed in 1990) nitrogen discharge limit of 10 milligrams per liter (mg/L) total nitrogen, and to improve plant performance and operability.

2. Modified sludge management practices that were required due to the closure of the Town's landfill in Marstons Mills.

3. Sewer system modifications, improvements, and pump station improvements to correct bottlenecks and to allow for sewer system expansions.

4. Water system expansion to several wastewater Areas of Concern (AOC) where it was determined that extending public water supply to these areas best solved the wastewater problems.

5. Sewer system expansion to several documented wastewater AOC where it was determined that the wastewater problems at these areas would be best solved by connecting these areas to the Hyannis WPCF.

6. Additional sludge management improvements as the wastewater (and sludge production) increases in the future.

7. Future development of a new treated water recharge (remote from the Hyannis WPCF) at a 6.9-acre site located along Route 132 near Exit 6 of Route 6.

8. Defer addressing wastewater AOC located in the central and western portions of Town until the nitrogen limits were developed for the Town's coastal estuaries with the intent of incorporating and addressing these wastewater concerns into the current CWMP.

Items 1 through 4 and portions of Item 5 have been implemented. There are additional sewer extensions (of Item 5) that will be implemented during the next 10 years. Items 6 and 7 will be implemented as the sewer extensions of Item 5 proceed. The wastewater AOC (identified in Item 8) that were not addressed will be addressed in this CWMP Project because the Town now has many of the needed nitrogen limits.

The Executive Summary of the 2007 WWFP is attached in Appendix 1-1 and provides a complete summary of that Project.

The Massachusetts Environmental Policy Act (MEPA) approval for the 2007 WWFP is attached in Appendix 1-2, and the Cape Cod Commission (CCC) Development of Regional Impact (DRI) approval is attached in Appendix 1-3. These three documents provide much background on this Project. It is expected that the 2007 WWFP project will provide significant information to allow the CWMP Project to proceed efficiently and consistently. The specific findings of the 2007 WWFP are described in greater detail in Chapter 2, Data Review.

B. **Background on Massachusetts Estuaries Project (MEP) Evaluations and Development of Nitrogen TMDLs.** The MEP is a collaborative effort between several federal, state, regional, and municipal agencies to develop nitrogen thresholds and limits for a group of approximately 90 estuaries in southeastern Massachusetts. The main agencies involved include:

1. Massachusetts Department of Environmental Protection (MassDEP).

2. University of Massachusetts (UMass) School of Marine Science and Technology (SMAST).

3. United States Geological Survey (USGS).

4. Cape Cod Commission (CCC).

5. Applied Coastal Research and Engineering, Inc. (ACRE).

6. Several municipalities that surround the estuaries including the Town of Barnstable.

The nitrogen limits are developed for the estuaries through the following evaluation steps:

1. The watershed of each estuary is delineated by USGS with the use of their regional groundwater flow model.

2. The nitrogen loading to the watershed of each estuary is calculated by CCC and/or SMAST for each of the major nitrogen sources.

3. Sediment cores are collected and estimates of nitrogen loadings from the sediments to the estuary waters are calculated.

4. Detailed surveys of each estuary are completed to quantify the condition and extent of several biological parameters, including eel grass coverage, benthic life forms, etc., and to correlate environmental conditions in healthy areas of the estuary with a nitrogen concentration that is associated with these healthy conditions. This step (with other inputs and considerations) identifies the threshold nitrogen concentration for each estuary.

5. A water quality model is developed for each estuary based on tidal mixing and flushing of the estuary and the nitrogen loads from the watersheds and sediments. The model is calibrated with several parameters, including averages of long-term water quality monitoring data.

6. The model is then run with different watershed loading values to estimate the resulting estuaries' nitrogen concentration for the following scenarios:

   a. Existing conditions.

   b. Buildout conditions.

   c. "No anthropogenic loading" condition, which is the condition of no nitrogen loadings from wastewater, fertilizers, or stormwater sources.

d. "Nitrogen threshold" condition which simulates the upper limit of nitrogen loading that can go into the estuary and still have the water quality meet the nitrogen threshold concentration (identified above in Step 4) at one or more key locations (sentinel stations) in the estuary.

e. Additional alternative scenarios as requested by the municipality or as needed.

Once the nitrogen thresholds and limits are developed and presented for each estuary in a technical report produced by the MEP, MassDEP then prepares a draft TMDL report that presents the nitrogen limits as TMDLs for approval by United States Environmental Protection Agency (USEPA). Several of these documents have been produced for the Town of Barnstable, as listed below:

1. MEP Technical Report for Popponesset Bay; MEP, September 2004.

2. MassDEP TMDL Report for Popponesset Bay; MassDEP, April 10, 2006.

3. MEP Technical Report for Rushy Marsh; MEP, April 2006 (No TMDL Report has been developed).

4. MEP Technical Report for Three Bay System; MEP, April 2006.

5. MassDEP TMDL Report for Three Bay System; MassDEP, September 7, 2007.

6. MEP Technical Report for Centerville River System; MEP, November 2006.

7. MassDEP TMDL Report for Centerville River System; MassDEP, January 29, 2008.

8. MEP Technical Report for Lewis Bay (and Halls Creek); MEP, December 2008.

The Town is awaiting the TMDL Report for Lewis Bay (and Hall's Creek), and the Technical and TMDL Reports for Barnstable Harbor. No TMDL Report is expected for Rushy Marsh because it is so small.

USEPA then reviews these reports and accepts the nitrogen limits as TMDLs which, once accepted, have regulatory status by USEPA and MassDEP.

The main findings of these evaluations and reports indicate that a large percentage of the existing nitrogen loading to the estuarine watersheds must be removed to restore the water quality and habitat of the estuaries. Most of the nitrogen comes from individual septic systems in the watersheds. The findings of these reports are reviewed in detail in Chapter 5, Existing and Future Conditions in the Town of Barnstable.

C. **Background on Water Quality Conditions of the Groundwater System and the Town's Freshwater Ponds.** Many reports and evaluations have been completed on the groundwater system and the Town's freshwater ponds. These water resources have also been impacted by nutrients and other contaminants.

Nitrogen is a major concern in the groundwater because it has a state and federal drinking water standard of 10 mg/L to protect public health. There are also many drinking water standards for specific contaminants that can enter the groundwater when there is improper land use. There has recently been concern about pharmaceuticals, personal care products, and "endocrine disruptors" that are being observed in the groundwater system and are coming from wastewater sources. Drinking water standards have not yet been developed for these categories of manmade compounds. These categories are often called Contaminants of Emerging Concern (CEC) because they have no limits yet and they may pose human-health and/or environmental-health concerns. MassDEP has started to regulate these CECs by requiring a stringent discharge limit of Total Organic Carbon (TOC) for wastewater treatment facility discharges in Zone II areas (areas that can contribute groundwater to public water supply wells). The CECs are typically comprised of organic carbon; therefore, when the TOC concentration in treated water is low, then CEC concentrations will be low or non-detectable.

Phosphorous is typically the nutrient of concern for freshwater ponds. It is the "limiting nutrient" (similar to nitrogen for marine waters), which means that it is the essential plant (algae) nutrient that is in short supply, so that when it is added it will produce an over-abundance of algae, which will impact water quality. Recent studies in Barnstable and across Cape Cod have indicated that wastewater discharge in the watersheds of these ponds is the largest source of phosphorous. Other sources include lawn and agricultural fertilizers, road and roof runoff, and precipitation from the sky.

The groundwater system and the Town's many freshwater ponds are as equally important as the Town's marine waters to the quality of life in Barnstable. Their water quality will be evaluated and addressed as part of this planning project.

D. **Regional Wastewater Management Efforts.** Several regional wastewater management planning efforts are underway to define and implement wastewater and nitrogen mitigation efforts on Cape Cod. These efforts are identified below.

1. Cape Cod Commission and Barnstable County regional efforts, including:

   a. Formation and coordination of the Cape Cod Water Protection Collaborative.

   b. Development of a regional wastewater management plan.

   c. Coordination with USGS and Cape Cod towns to provide groundwater modeling services to towns involved with wastewater planning activities.

   d. Funding assistance and guidance documents for wastewater projects as listed below:

      1) "*Enhancing Wastewater Management on Cape Cod: Planning, Administrative, and Legal Tools,"* Wright-Pierce, July 2004.

      2) "*Sewer Modeling and Preliminary Design Evaluations, Guidance Document and Case Study Report, Popponesset Bay Watershed,"* Mashpee, MA and Stearns & Wheler, November 2005.

      3) "*Effluent Disposal and Reuse Planning: Guidance Document and Case Study Report,"* Town of Barnstable and Stearns & Wheler, 2005.

      4) "*Small Community-Size Wastewater Treatment Technologies Evaluation,"* Town of Yarmouth and Tighe and Bond, June 2005.

5) "*Innovative Septic System Management Project,"* Town of Eastham and BCDHE, 2007.

6) "*Evaluation of Wastewater Management Options for Freshwater Ponds Guidance Document and Case Study Report for the Great Sand Lakes,"* Town of Harwich and Stearns & Wheler, May 2007.

7) "*Groundwater Modeling to Support Comprehensive Wastewater Management Planning; Guidance Document and Case Study Report,"* Town of Falmouth and Stearns & Wheler, June 2009.

8) "*On-Site System GIS Mapping and Management Project,"* Town of Bourne and Norfolk RAM, 2004.

9) "*Tri-Town Septage Facility Evaluation Project,"* Town of Orleans and Wright-Pierce, August 2005.

10) "*Cape Cod Pond and Lake Atlas,"* CCC, May 2003.

11) "*Comparison of Costs for Wastewater Management Systems Applicable to Cape Cod: Guidance to Cape Cod Towns Undertaking Comprehensive Wastewater Management Planning."* Barnstable County Wastewater Task Force, April 2010.

e. Creation of the Cape Keepers Public Education Program.

The Cape Cod Water Protection Collaborative (CCWPC) has recently (February 2010) become active in supporting shared watershed/solution concepts for the following areas:

- Lewis Bay Watershed and possibly sharing wastewater management solutions and costs for Barnstable and Yarmouth.
- Popponesset Bay Watershed and possibly sharing wastewater management solutions and costs for Barnstable, Mashpee, and Sandwich.
- Falmouth, Mashpee, Bourne, and Sandwich regional treatment opportunities at the Massachusetts Military Reserve (MMR).

They will support these concepts through subcommittee meetings, technical assistance, and regulatory support.

The CCWPC is also trying to advance the regulatory acceptance of wetland and watershed modifications as part of a town's plan for nitrogen management. They plan to create a special review process with the State regulatory agencies to streamline the review of the following types of wetland/watershed modifications:

- Sediment removal from behind dams to facilitate greater nitrogen attenuation in ponds. Mill Pond in Marstons Mills is planned to be a test case.
- Tidal restriction removal at coastal ponds/estuaries to increase tidal flushing and reduce nitrogen sensitivity. Enlargement of culverts at Bournes Pond in Falmouth and Parkers River in Yarmouth are planned to be test cases for this type of project.
- Flooding of fallow cranberry bogs to create ponds and facilitate increased nitrogen attenuation in the watershed. No specific test cases have been identified for this type of project.

2. Association to Preserve Cape Cod (APCC), CCC, and Waquoit Bay National Estuarine Research Reserve (NERR) specialty conferences on wastewater issues.

3. Legislative passage of the 2008 Environmental Board Act (as supported by Cape Cod Water Protection Collaborative and Senator Robert O'Leary) to help fund and address Cape Cod's wastewater and nutrient-related problems.

4. Barnstable County Department of Health and Environment (BCDHE) efforts to provide public health technical assistance and to oversee the Alternative On-Site Septic System Test Center to test innovative septic system technologies and management scenarios.

5. Decentralized wastewater treatment seminars and information outreach by technology vendors and advocates to ensure that these technologies are considered in the wastewater planning process.

E. **Wastewater and Nutrient Management Planning Projects in Neighboring Towns.** Barnstable shares estuarine watersheds (illustrated in Figure 1-1) with the following towns:

- Yarmouth for Lewis Bay.
- Mashpee for Popponesset Bay and a small portion of the Three Bays System.
- Sandwich for Popponesset Bay, the Three Bays System, and Barnstable Harbor.

Yarmouth and Mashpee both have ongoing wastewater and nutrient management planning projects. Sandwich is planning to start a wastewater and nutrient management planning project in 2011. The ongoing planning projects for Yarmouth and Mashpee are identified below.

1. Town of Yarmouth Integrated Water Resources Management Planning (IWRMP) Project.

This project was initiated in 2004 to develop a plan to address wastewater and nitrogen loading issues along Route 28; in the watersheds to Lewis Bay, Parkers River, and Bass River; and in water supply areas. This project has considered possible regional wastewater treatment solutions with the Town of Barnstable that resulted in a Technical Memorandum contained in Appendix 1-4. Coordination between the two towns continues.

2. Town of Mashpee Watershed Nitrogen Management Planning (WNMP) Project. This project was initiated in 2000 to address nitrogen loading problems to Popponesset Bay and Waquoit Bay. A portion of this project area is in the Town of Barnstable because the Popponesset Bay Watershed extends into Barnstable. Coordination between the two towns continues.

1.3 TOWN OF BARNSTABLE VISION AND GOALS AS ARTICULATED IN THE BARNSTABLE COMPREHENSIVE PLAN

The Barnstable Comprehensive Plan (2010) is the most recent Local Comprehensive Plan completed by the Town in compliance with Cape Cod Commission guidelines. It articulates a Town Vision and Comprehensive Plan Goals that will help guide the formation of this CWMP.

A. **Vision.** "The seven diverse yet interconnected villages of Barnstable form one community that is an integral part of Cape Cod. As the town in 2008 has been shaped by its past, through

this plan Barnstable will shape a sustainable future. The town will preserve its history, environment and community for future generations through active stewardship of community character and quality of life while balancing growth, infrastructure and natural systems."

B. **Comprehensive Plan Goals.** The following goals are stated for the Comprehensive Plan:

1. Sustain diverse villages and livable neighborhoods for year round residents while providing housing opportunities for all.

2. Preserve, protect and enhance sensitive natural habitats and systems.

3. Provide town services and infrastructure through an efficient, planned and prioritized process.

4. Support and manage the regional resources and services unique to Cape Cod.

5. Preserve and enhance historic and maritime character, public viewsheds and cultural landscapes.

6. Enhance pedestrian activity in historic village centers.

7. Preserve and enhance access to public spaces including the waterfront.

8. Foster and support the creative economy which includes history, culture and arts.

9. Promote traffic reduction, traffic management, alternate transportation modes, property interconnections, and travel demand management.

10. Foster and support public transit while planning for associated parking, pedestrian and bicycle travel needs.

11. Allow development review to be more efficient for applicants and town regulatory bodies in a predictable and fair manner.

12. Develop and support a process to encourage private investments and support appropriate economic development.

13. Fully integrate implementation of plan goals, actions and strategies into the municipal budget and capital planning process.

1.4 PROJECT SCOPE

The project has been divided into seven phases. A brief listing of the tasks associated with each phase of this project follows, and the complete Project Scope for the project as submitted for MassDEP review is included in Appendix 1-5.

A. **Phase I – Environmental Monitoring and Modeling, and Development of Nutrient Limit Targets.**

1. Perform water quality monitoring of coastal embayments and ponds.

2. Collect additional environmental parameters.

3. Assess the nutrient related health of the coastal embayments and ponds.

4. Perform embayment flushing analyses and hydrodynamic model development.

5. Develop existing and future nitrogen loadings to coastal embayments.

6. Perform water quality modeling.

7. Develop nitrogen loading targets.

8. Prepare nutrient loading assessment reports (MEP Technical Reports).

B. **Phase II – Nutrient Management Needs Assessment.**

1. Review and summarize Town issues and data.

2. Review and summarize regulatory issues affecting nutrient management planning.

3. Evaluate, summarize, and describe existing conditions in Town.

4. Identify the goals and objectives of the Town related to nutrient management.

5. Evaluate, summarize, and describe future conditions in Town.

6. Identify nutrient related areas of concern and prepare Nutrient Management Needs Assessment Report.

C. **Phase III - Identification and Screening of Alternative Solutions and Sites.**

1. Identify, review and summarize alternative solutions to meet the Town's nutrient management needs.

2. Screen the alternative solutions to identify the most feasible ones for detailed evaluation.

3. Identify and screen potential sites for nutrient management facilities.

4. Group feasible solutions and sites into alternative nutrient management scenarios.

5. Prepare the Nutrient Management Alternatives Screening Analysis Report.

D. **Phase IV – Detailed Evaluation and Development of the Nutrient Management Plan.**

1. Perform subsurface and/or environmental investigations and modeling for potential nutrient management sites.

2. Prepare a methodology of the planned detailed evaluations for project and regulatory review.

3. Perform present-worth evaluations of the alternative nutrient management scenarios.

4. Perform non-monetary evaluations of the alternative scenarios.

5. Perform an environmental impact analysis of the alternative scenarios.

6. Evaluate the present-worth analysis with the non-monetary evaluation and the environmental impact analysis to select the most appropriate management scenario.

7. Develop and present the recommended Nutrient Management Plan, and prepare the Nutrient Management Plan and Draft Environmental Impact Report (DEIR).

8. Submit the Nutrient Management Plan and DEIR for regulatory and public reviews.

E. **Phase V - Resolution of Remaining Issues and Project Completion.**

1. Resolve remaining issues.

2. Modify the DEIR to prepare the Nutrient Management Plan and Final Environmental Impact Report (FEIR), and submit it for public and regulatory review.

F. **Phase VI – Environmental and Public Review Process.**

1. Establish and utilize a Citizens Advisory Committee.

2. Establish and utilize a Technical Advisory Committee.

3. Prepare and conduct a public participation program.

4. Prepare, submit, and coordinate the public review of the Environmental Notification Form and Development of Regional Impact Document.

5. Coordinate public review of the other project documents.

6. Coordinate and attend meetings and public hearings.

G. **Project Management and Funding**

1. Develop and administer State Revolving Fund loan applications and agreements.

2. Develop and administer contract agreements for specialized services.

3. Provide overall project management and coordination.

As mentioned earlier, the full Project Scope is attached in Appendix 1-5. It was originally prepared in August 2001, submitted and approved by MassDEP in 2005, and updated and used in a State Revolving Fund (SRF) funding application in August 2008. The full Project Scope provides narrative text about the purpose and approach of the major tasks and identifies the tasks that have been completed as of 2008.

1.5 PLANNED PUBLIC REVIEW

Several public outreach and review components are planned and have been initiated for this project. A Citizens Advisory Group has been established to provide oversight and assist with public outreach. Participants in this group (and their affiliations or titles) are listed below.

- Barnstable Representatives:
  - Philip Boudreau, Chairman
  - Rob Anderson
  - Milton Berglund
  - Oliver P. Cipollini, Jr.
  - Lindsey Counsell
  - Stewart Goodwin
  - Gail Maguire
  - Wayne Miller
  - Susan Rask
  - Donald Schwinn
  - George Zoto
- Neighboring Town Representatives:
  - John G. Keenan, Jr., Sandwich
  - Michael R. Richardson, Mashpee

- Doug Peabody, Yarmouth

Coordination meetings have been (and will be) held with MassDEP and CCC staff to coordinate efforts and keep the associated agencies informed. Progress meetings have been and will be convened with interested community groups in the Town. Phase reports (such as this Needs Assessment Report) will be produced through the project to allow interim reviews of the project efforts and public and regulatory comment. A website has been created to allow access to Project information and documents and can be accessed at www.town.barnstable.ma.us/Boards/CitizenAdvisory/default.asp .

1.6 PLANNED ENVIRONMENTAL REVIEW

As identified in the project scope listing, the approach for the environmental review process is to file an ENF document at the end of Phase III to initiate the MEPA and CCC DRI Joint Environmental Review Process. This ENF will summarize the findings of Phases I, II, and III and focus the review on the alternative management scenarios developed at the end of Phase III and their associated environmental impacts and benefits. The ENF will detail how these alternative management scenarios will be evaluated. The subsequent environmental evaluations will be summarized in the Draft Comprehensive Wastewater Management Plan and Draft Environmental Impact Report (DCWMP/DEIR) and in the Final Comprehensive Wastewater Management Plan and Final Environmental Impact Report (FCWMP/FEIR).

1.7 PLANNING PERIOD

The Comprehensive Wastewater Management Plan will provide a recommended plan for wastewater facilities and nutrient management recommendations in Town for the 20-year planning period of 2015 to 2035. This is an approximate period that would start following newly constructed wastewater facilities resulting from the plan. The plan will also be developed with a planning horizon based on the estimated potential buildout of the Town.

1.8 PURPOSE AND ORGANIZATION OF THE NEEDS ASSESSMENT REPORT

The Needs Assessment Report is written to summarize the subtasks identified in Phase II of the project scope. This work includes the research and description of existing conditions in the Town related to wastewater treatment and disposal; the Town's treatment and recharge facilities

(both centralized and decentralized); projected wastewater flows and loadings; and assessment of existing and future conditions.

This Needs Assessment Report is divided into six chapters. Chapter 1 presents general introductory information about the Project. Chapter 2 describes the technical documents reviewed along with Town and regional data. Chapter 3 identifies the regulatory issues (local, regional, state, and federal) that must be considered during the project. Chapter 4 describes the existing wastewater collection, treatment, and recharge facilities as well as the water supply systems. Chapter 5 identifies existing and future conditions in the Town. Chapter 6 provides a summary of the wastewater needs in the Town, and describes the results of the No Action Alternative, which is the expected outcome for the Town if no changes are made to the existing wastewater and nutrient management practices.

Chapter 2
Data Review

CHAPTER 2

DATA REVIEW

2.1 INTRODUCTION

This chapter provides an overview of information used in preparing the Needs Assessment Report for the Town of Barnstable CWMP project. It also identifies ongoing projects which are developing information that may be used by the CWMP project as it proceeds.

2.2 TECHNICAL REPORTS AND DATA

The following technical reports and data were reviewed for the Needs Assessment Report.

A. **"Final Wastewater Facilities Plan and Final Environmental Impact Report for Town of Barnstable", March 2007, Stearns & Wheler (2007 Wastewater Facilities Plan).** The 2007 Wastewater Facilities Plan (WWFP) summarizes the technical evaluations, project decision-making, and recommended plan to address the wastewater needs in Barnstable that were last identified in 1993. The 2007 Wastewater Facilities Plan was developed for the 20 year planning period of 1994 through 2014 (it is noted that the CWMP Project planning period starts in 2015 and runs through 2035 as identified in Chapter 1). Figure 2-1 illustrates the Wastewater Areas of Concern (AOC) that were evaluated.

The 2007 Wastewater Facilities Plan completed many detailed evaluations that will be used as a starting point for the CWMP Project.

There were four main documents that were developed for the 2007 Wastewater Facilities Plan:

1. "WWFP Needs Assessment Report", December 1993, Stearns & Wheler. This technical report summarized the first phase of the WWFP and identified wastewater needs at several town-wide wastewater Areas of Concern (AOC) and at the Hyannis WPCF

2. "WWFP Alternatives Screening Analysis Report", February 1996, Stearns & Wheler. This technical report summarized the second phase of the WWFP and identified and screened (described and selected the best of) the possible solutions to address the wastewater needs identified in 1993.

3. "Draft Wastewater Facilities Plan and Draft Environmental Impact Report", October 2006, Stearns & Wheler. This technical report summarized the detailed evaluations and decision-making process to develop the Draft Plan. These detailed evaluations and the draft plan took ten years to complete, and it utilized several sub-evaluations (and technical reports) that are identified later in this section.

4. "Final Wastewater Facilities Plan and Final Environmental Impact Report", March 2007, Stearns & Wheler. This report finalized the planning project and addressed the questions and issues that were raised for the October 2006 Draft Wastewater Facilities Plan.

There were additional sub-evaluations that were documented in technical reports and memoranda, and were incorporated into the four main documents listed above. These sub-evaluation reports and technical memoranda are briefly listed below:

1. "WWFP Plan of Study", 1990. This document was prepared to outline the needed steps of the whole WWFP process.

2. "Three Bay Nitrogen Evaluations", December 1996, Town of Barnstable. This report summarized detailed evaluations completed by the Town to document nitrogen loading problems to the watershed of the Three Bay System of West Bay, Cotuit Bay, and North Bay (and its connected coves, creeks, and rivers). The evaluations utilized calculations developed by the Buzzards Bay Project that were accepted by the regulatory and scientific community before the Massachusetts Estuaries Project was established in 2002.

3. "Cape Cod Community College Wastewater Planning Evaluations", January 1999, Stearns & Wheler. These evaluations were necessary when MassDEP identified the college as exceeding state standards for their on-site septic system. These evaluations were the basis of subsequent recommendations for the college to connect to the Hyannis WPCF.

4. Treated Water Recharge Evaluations and Interim Reports. From 1997 through 2005. The Town evaluated several treated-water recharge alternatives as listed below:

a. Injection well pilot testing evaluations, September 2003.

b. Benchmark evaluations to investigate groundwater mounding downgradient of the Hyannis WPCF, February 18, 2005.

c. Preliminary evaluation of the McManus property for treated-water recharge, April 2002.

d. Preliminary evaluation of the Barnstable Municipal Airport for treated-water recharge, April 2002.

e. Preliminary evaluation of the Lorusso property for treated-water recharge, November 2003.

f. Preliminary evaluation of the Cape Cod Community College for treated-water recharge, May 2004.

g. Task 8 Report – Candidate site evaluation and comparison, draft report, December 30, 2003.

h. Infiltration loading tests, McManus site, October 2005.

These evaluations were incorporated into the 2007 WWFP documents and recommended plan.

There were also several technical reports called Notices of Project Change (NPC) that described WWFP project changes and the need to make changes in project scope or implement portions of the emerging plan as funding became available. The NPC documents are formal applications to the Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA) to request the change; and these documents resulted in approval certificates from EOEEA. The NPC documents are briefly listed below for requested changes in project scope and for implementation of upgrades at the Hyannis WPCF and the collection system.

1. NPC for Changes in Project Scope.

   a. The March 1996 NPC summarized the main findings of the Phase I Needs Assessment Report and the Phase II Alternatives Screening Analysis Report for environmental review by Massachusetts EOEA and the CCC and prepared a Project Scope for an expanded WWFP Project.

   b. The June 23, 2003 NPC was prepared and submitted for environmental review because more than three years had passed since the last environmental review document, and because in 2003 there was a need for nitrogen management planning to address new nitrogen loading limits being developed by the Massachusetts Estuaries Project (MEP). The June 2003 NPC and resulting Secretary's Certificate limited the recommendations of the WWFP to the AOCs that had been recommended for connection to the Hyannis WPCF in the eastern portion of Barnstable. It was agreed that recommendations on the AOCs in the western part of Town that relied on non-nitrogen removal technologies to address failing or stressed septic system technologies should wait until the MEP was complete, the Town had the scientifically based nitrogen limits, and the nitrogen limits could be addressed through the Town's Nutrient Management Program.

2. NPC for Interim Implementation of upgrades at the Hyannis WPCF and in the collection system. The following upgrades at the Hyannis WPCF and collection system were made through the preparation and approval of several NPC documents:

   a. Construction of a new secondary clarifier (Clarifier No. 3) at the Hyannis WPCF to address capacity limitations at the facility (completed in 1997).

   b. Construction of the following sewer extensions completed in the late 1990's and early 2000's:
      - Sewer replacement and extension along Barnstable Road
      - Sewer replacement and extension along Bearses Way (this was the vacuum sewer project)
      - Sewer extension along Corporation Street
      - Sewer extension along Summerside Lane in Hyannis
      - Sewer repairs at Center Street in Hyannis

- Sewer extensions at Norris Street
- Sewer (forcemain) extension to Cape Cod Community College as part of the Route 132 road reconstruction project

c. Construction of treated-water forcemains as part of the Route 132 road reconstruction project.

d. Construction of Hyannis WPCF Improvements in the late 1990's that included a new Blower building and conversion of the aeration tanks from surface aeration to diffused aeration.

e. Construction of Hyannis WPCF Improvements (finished in 2009) that included:
- A third aeration tank
- Pretreatment Building improvements
- Primary Sludge Building improvements
- Improved yard piping connections

The main findings of the documents identified above were incorporated into the four main documents of the 2007 WWFP.

The main recommendations of the 2007 WWFP included:

1. Wastewater collection system extensions and improvements including:

   a. Sewer extensions and upgrades completed with NPC approvals as listed above.

   b. Upgrade of the Main Street Pump Station (PS) and connection of this PS with a new forcemain directly to the Hyannis WPCF. This recommendation was completed in 2009.

   c. Remaining portions of the Cape Cod Community College sewer extension including:
   - Collection system and pump station at the college
   - Forcemain connection from the pump station at the college to the forcemain installed in Route 132 (close to the Exit 6 interchange)

- Forcemain connection from the previously installed forcemain in Route 132 (at the Bearses Way/Route 132 intersection) to the Hyannis WPCF

d. Sewer extension to the Stewarts Creek Area (AOC H1) to address failed septic systems and Board of Health concerns. This extension is currently under construction and is planned for completion in 2011.

e. New pump station at Lincoln Road and West Main Street with a forcemain to connect to the Hyannis WPCF to address bottlenecks in the West Main Street collection system and Board of Health concerns. This extension is currently under construction and is planned for completion in 2011.

f. Sewer extension to the Lake Wequaquet/Long Pond Area (AOC CE4) to address failed septic systems and Board of Health concerns. This extension was originally proposed for construction in 2010 and 2011 but the project did not receive Town Council approval due to opposition to the project by a portion of the area residents.

g. Sewer extensions to the Following Zone II drinking water protection areas including:

- CO7 Zone II Area
- BWST1A, B, and C Zone II Areas
- BWMEL 1 A and B Zone II Areas

It is noted that the Wequaquet Lake/Long Pond Area (CE4) also includes a Zone II contributing area to the Barnstable Fire District Waster Department (BFD-WD) Wells.

h. Sewer extensions to the following coastal protection areas to address failing septic systems and Board of Health concerns:

- CEI Area at the Craigville Beach area
- CE2 Area at the Red Lilly Pond Area
- H3 Area at the Hyannis port area

i. Sewer extension to the densely developed areas along Bearses Way where there is much housing and many failed septic systems.

j. Old Colony Road pump station improvements to include:

- New SCADA, pump controls and flow meters.
- Further evaluations on the 10-inch force main to increase capacity and subsequent improvements.

k. South Street gravity line replacements to address bottlenecks in this portion of the system.

l. Possible West Main Street gravity line modification and replacements to increase capacity.

A cost summary on these recommendations is provided in Table 2-1.

2. Hyannis WPCF Improvements including:

a. Hyannis WPCF projects completed with NPC approvals as listed previously.

b. Effluent facility additions to allow 0.5 mgd treated-water recharge at the 6.9-acre site including:

- Modifications to the pump gallery at the Hyannis WPCF
- Effluent filtration and UV disinfection
- Piping, valves and sand infiltration beds at the 6.9-acre site

c. Sludge Management improvements and addition of a new employee locker room including:

- Additional thickened sludge storage
- Additional waste activated sludge storage
- Addition of a third sludge thickener in the Septage Building
- Addition of a new employee locker and meeting room to replace the outdated existing one.

The new sludge management facility and employee locker room would be located south of the Septage Pretreatment Building and costs for these improvements are summarized on Table 2-2.

TABLE 2-2

CAPITAL AND O&M COSTS FOR SLUDGE SYSTEM AND EMPLOYEE LOCKER ROOM IMPROVEMENTS RECOMMENDED IN 2007 WWFP

Capital Costs [1]	
New GBT in Septage Building	280,000
New Sludge Storage Facility	1,900,000
New Locker and Meeting Rooms (2,500 sf)	640,000
Subtotal	2,900,000
Process and Yard Piping	290,000
Electrical	440,000
Site Work	58,000
Total Construction Costs	3,700,000
Contingencies (15%)	560,000
Fiscal, Legal, Engineering (25%)	930,000
Total Capital Costs	5,200,000
O&M Costs [1]	
Labor for Sludge Processing	80,000
Electricity	69,000
Polymer and Odor Control Chemicals	59,000
Maintenance and Repair	10,000
Total O&M Costs per year	220,000

Notes:

1. Costs are based on sludge production associated with a maximum month wastewater flow of 4.2 mgd, and on an ENR index of 7700 referenced to June 2006.

The wastewater flows that were estimated to be treated at the Hyannis WPCF from the proposed collection system are summarized on Table 2-3 and sum to slightly less than 4.2 mgd which is the current maximum month capacity of the WPCF.

Table 2-1

Planning Conditions And Cost Summary [1] [2] [10]

Sewer Extensions And Modifications Identified in 2007 WWFP

Areas of Concern (AOC)	Gravity Sewers [5]		Force Main [6]		Low Pressure Sewer [7]			Pump Stations [8]		Restoration & General [9]	Contractors General Conditions, Mobilization & Demobilization	Construction Cost	Contingency Cost (15%)	Fiscal, Legal, And Engineering Cost (25%)	Total Capital Cost
Sewer Extension and/or Improvement	Length	Cost	Length	Cost	# G. Pumps [4]	Length	Cost	Number	Cost						
Main Street Pump Station Replacement	Construction was started in 2010 with completion scheduled for 2011														
Main Street FM Modification and PS Modification	Completed in 2009														
CE4 Area (Wequaquet Lake & Long Pond) [3]	35,600	$5,500,000	17,700	$1,100,000	600	70,000	$13,200,000	4	$4,000,000	$4,400,000	$3,300,000	$31,500,000	$4,700,000	$7,900,000	$44,100,000
Area H1 (Stewarts Creek)	Construction was started in 2010 with completion scheduled for 2011														
Zone II Protection Areas [3]														$0	$0
CO7 Area	20,900	$3,300,000	0	$0	300	25,000	$4,800,000	0	$0	$1,700,000	$1,300,000	$11,100,000	$1,700,000	$2,800,000	$15,600,000
BWST1A Area	44,600	$6,400,000	5,500	$280,000	100	7,100	$1,500,000	2	$2,000,000	$2,000,000	$1,500,000	$13,700,000	$2,100,000	$3,400,000	$19,200,000
BWST1B Area	31,600	$5,000,000	4,400	$260,000	100	8,600	$1,700,000	2	$2,800,000	$1,500,000	$1,400,000	$12,700,000	$1,900,000	$3,200,000	$17,800,000
BWST1C Area	22,400	$3,100,000	0	$0	0	0	$0	0	$0	$990,000	$550,000	$4,600,000	$700,000	$1,200,000	$6,500,000
BWMEL1A Area	9,300	$1,400,000	3,900	$220,000	100	7,500	$1,500,000	1	$1,000,000	$660,000	$550,000	$5,300,000	$800,000	$1,300,000	$7,400,000
BWMEL1B Area	4,800	$770,000	0	$0	0	0	$0	0	$0	$220,000	$110,000	$1,100,000	$200,000	$300,000	$1,600,000
Coastal Protection Areas														$0	$0
CE1 Area	7,800	$1,200,000	6,200	$330,000	50	3,100	$550,000	1	$1,000,000	$440,000	$330,000	$3,900,000	$600,000	$1,000,000	$5,500,000
CE2 Area	6,200	$1,100,000	3,500	$220,000	100	6,800	$1,300,000	1	$1,000,000	$55,000	$550,000	$4,200,000	$600,000	$1,100,000	$5,900,000
H3	13,000	$2,000,000	4,600	$330,000	250	4,000	$770,000	1	$1,000,000	$660,000	$440,000	$5,200,000	$800,000	$1,300,000	$7,300,000
Bearses Way Densly developed Area	24,100	$3,700,000	0	$0	100	11,200	$2,200,000	0	$0	$1,200,000	$880,000	$8,000,000	$1,200,000	$2,000,000	$11,200,000
Old Colony Road PS Improvements									$340,000			$340,000	$60,000	$100,000	$500,000
South Street Line Replacements	3,000	$620,000								$220,000	$110,000	$1,000,000	$200,000	$300,000	$1,500,000
West Main Street Line Replacements	6,000	$1,600,000								$480,000	$320,000	$2,400,000	$400,000	$600,000	$3,400,000
Components to Connect the CCCC															
Route 132 Force Main (FM)	Completed in 2009 and paid by CCCC														
CC Community College Pump Station (PS)	To be paid by CCCC														
FM from Route 132 to WPCF	To be paid by CCCC														

Notes:

1. All costs are referenced to June 2006, ENR 7700 and are for the facilities in the AOC as indicated in Figure 2-1. These costs are based on the AOC being implemented radially from the Hyannis WPCF outward to the AOC. If sewers are implemented in one of the more distant AOC before all of the transmission lines and pump stations are constructed in the closer AOC; the costs will need to be increased for the distant AOC to transmit the flow to the WPCF.
2. All costs are rounded to 2 significant digits except construction costs which have a high number of digits to avoid rounding error in the contingency.
3. The CE4 area also has portions located in a Zone II Protection Area
4. "G. Pumps" is short for grinder pumps.
5. Gravity Sewer Components:
   a) 8- to 12-inch gravity sewer lines of $90 to $180/LF (where: $90/LF for 0 to 12-foot depth and installation in a Town Road and $180/LF for 12- to 18-foot depth and installation in a state road).
   b) Trench dewatering of $100/LF. c) Service laterals of $700 each. d) Lateral fittings of $300 each lateral. e) 4-foot manholes at $4,200 each. f) Miscellaneous (chimneys, cleanouts, etc.) at $5,000 each.
6. Force Main Components:
   a) Force main lines of $65 to $100/LF depending on placement in Town or state roadways. b) Credit for a force main in a trench shared with a gravity main at -$45/LF. c) Air release/flushing manholes at $5,000 each.
7. Low Pressure Sewer Components:
   a) Low pressure sewer main at $45 to $80/LF depending on Town or state road. b) Air release/flushing manholes at $5,000 each. c) Connection to gravity manhole at $2,800 each. d) Grinder pumps at $10,500 each, including pump, panel, installation and engineering.
8. Pump station cost range includes: a) $400,000 each for less than 100 gpm pump station. b) $1,000,000 each for 100 to 500 gpm pump station. c) $1,800,000 each for 500 to 1,000 gpm pump station.
9. Restoration and General Items include: a) Trench base. b) 2-inch trench binder and 1-inch trench top course each at $75/ton. c) 1.5-inch top course, full width overlay at $58/ton. d) Record drawings, erosion controls, final cleanup and site restoration and test pits.
10. Costs do not include any allowance for land acquisition or taking of easements.
11. Based on short- and long- term recommendation of June 2002 evaluation report. Scada and controls were installed as part WPCF Improvements completed in 2009.

TABLE 2-3

FUTURE FLOWS TO THE HYANNIS WPCF PROPOSED IN THE 2007 WWFP

FLOW SOURCES	PROJECTED FLOWS AT DESIGN YEAR 2014(MGD)	
	MAXIMUM MONTH [1]	AVERAGE ANNUAL [2]
Current and Future Flows		
Existing flows at WPCF at 1993	2.1	1.6
Infilling along existing sewers (developed and undeveloped)	0.30	0.22
Bearses Way sewer extension	0.03	0.22
Route 28 and Corporation Street sewer extension	0.01	0.007
Independence Park	0.40	0.30
AOCs in H1, H3, CE1-3	0.47	0.35
AOCs in ZOCs (5% of area)	0.07	0.05
Infilling along proposed AOC sewers	0.05	0.04
Bearses Way AOC (50% of area)	0.20	0.15
Cape Cod Community College	0.03	0.02
Potential Expansion and Additional Infilling		
Growth along existing sewer lines not currently sewered	0.20	0.15
Gravel pit development	0.13	0.10
Industrial Zone north of Kidd's Hill Road	0.10	0.07
TOTAL	**4.2**	**3.1**

Notes:
1. Presented in the 2007 WWFP.
2. Based on Annual Average to Maximum Month Peaking Factor of 0.74 as reported in 1993 Needs Assessment Report.

B. **"Draft Memorandum on Sewer Phasing Evaluation and Implementation Schedule", November 2008, Stearns & Wheler.** This memorandum was prepared to evaluate ways for the sewer extension program to proceed radially outward from the Hyannis WPCF. It was based on the prioritizations of the 2007 WWFP as well as other factors.

The full draft memorandum is attached in Appendix 2-1. Figure 2-3 illustrates the phasing that was being considered at the time of the draft memoranda. The phase numbering on Figure 2-3 indicates a logical grouping and not a priority ranking. The following sewer extensions have proceeded since the 2008 memorandum was developed:

- Lincoln Road PS
- Area H-1 West Sewer Extension
- Area H-1 East Sewer Extension

These projects are currently (2011) under construction.

C. **Additional Wastewater Collection and Treatment Facility Reports and Permits.**

1. 1980 Groundwater Discharge Permit for Hyannis WPCF (attached in Appendix 2-2).

2. 1990 Draft Groundwater Discharge Permit for Hyannis WPCF (attached in Appendix 2-2).

3. March 2010 Groundwater Discharge Permit for Marstons Mills WWTF (attached in Appendix 2-3).

4. Final Preliminary Design Report for Stewarts Creek/Area H-1 Sewer Extension Project, February 2005.

2.3 MAPPING AND DESIGN DRAWINGS

The following maps and plans were reviewed for this Needs Assessment Report:

- Geographic Information System (GIS) mapping from the Town's GID Department.
- Drawings and plans for the following proposed and/or implemented improvement projects for the Hyannis WPCF and collection systems, and Hyannis Water System:
  - Area H-1 East (Stewarts Creek Area) Sewer Extension and Water Main Replacement, October 2009.
  - Area H-1 West (Stewarts Creek Area) Sewer Extension and Water Main Replacement, October 2009

- Main Street Pump Station (new pump station located at intersection of West Main Street and Lincoln Road) Relocation, 2009
- Downtown Water Main Improvements, October 2009
- Maher Water Treatment Plan Improvements, October 2009
- Hyannis Water System SCADA System Upgrade, October 2009
- Hyannis Water System Security and Fire Alarm System, October 2009
- Hyannis Water System Site Improvements, October 2009

2.4 TOWN AND REGIONAL DATA

Additional technical data from Town and regional sources has been received and reviewed as identified below:

1. Town of Barnstable Assessors Data, GIS data, including areas of critical environmental concern (ACECs), wetlands, floodplains, historic districts, existing and planned public well sites, marine water recharge areas, water supply zones of contribution, surface contours, and additional flyover information.

2. WWTF influent and treated-water analytical data.

3. U.S. Census data and Town Annual Reports.

4. Town of Barnstable Comprehensive Plan, Final Draft, June 2008.

5. Town of Barnstable 2005 Open Space and Recreation Plan.

6. Cape Cod Regional Policy Plan

7. Guidance Documents on wastewater planning on Cape Cod prepared (and/or funded) by the Cape Cod Commission and the Cape Cod Water Protection Collaborative as listed in Section 1.2E of Chapter 1.

2.5 MEETINGS AND TELEPHONE CONTACTS

Several meetings and telephone conversations were undertaken to research project information. These meetings and telephone contacts are briefly identified below.

1. Dale Saad, DPW PM and Mark Ells, DPW Director regarding project goals and management, existing information on water and wastewater systems, Town regulations, and recent improvements with the Hyannis WPCF collection, treatment and recharge system, and Hyannis Water System.

2. The Town Land Use and Project Buildout Working Group, comprised of Dale Saad, DPW PM; Jo Anne Miller Buntich, Growth Management Dept. Director; Jackie Etsten, Principal Planner; and Jim Benoit, GIS Coordinator to develop Town buildout analysis and review Town planning documents, GIS information, and Town regulations.

3. Peter Doyle, DPW Water Pollution Control Division Supervisor about facility needs at the Hyannis WPCF and operations and performance data.

4. Glenn Santos, DPW Solid Waste Division Supervisor about groundwater monitoring results and site considerations at the Town of Barnstable Solid Waste Division site in Marstons Mills.

5. Robert Gatewood, Town Conservation Director about freshwater pond water quality and previous evaluations on individual ponds.

6. John Mendes, Terry O'Neil, and Ross Kessler of the Massachusetts Division of Marine Fisheries (DMF) regarding water quality issues related to shellfish resource areas in Barnstable.

7. Jim Benoit of the Town's GIS Department regarding the GIS data.

8. Thomas McKean of Barnstable's Health Department regarding on-site system problem areas, BOH regulations, and the performance of innovative and alternative (I/A) on-site systems.

9. Karen Malkus, Barnstable's Coastal health Resource Coordinator, regarding bathing beach water quality.

10. Town Nutrient Management Citizens Advisory Committee Meetings for policy decisions on wastewater and nutrient management.

11. Brian Dudley regarding the Massachusetts Estuaries Project and coordination of project information.

12. Tom Cambareri of CCC regarding groundwater modeling scenarios for Barnstable.

2.6 ONGOING TOWN PROJECTS

The following projects are ongoing in Barnstable developing information that could be used in the wastewater and nutrient management planning project. Efforts have been made to coordinate our work with these ongoing projects.

A. **Town-Wide Zone II Assessment.** This project is being completed by the Cape Cod Commission for the following technical assistance:

- Evaluate existing approved Town-Wide zoning maps illustrating all groundwater protection areas
- Update database information using information from the four water districts in Barnstable and from adjacent towns
- Update and rerun the groundwater model
- Document recommended changes to Zone II areas
- Recommend changes to town zoning
- Assist with the MassDEP approval process for recommended changes to Zone II areas
- Assist the Town(s) with recommended changes to zoning

B. **Hyannis Water System Improvements Projects.** These projects have been funded by State Revolving Fund (SRF) low interest loans and Federal Stimulus Funds that result in principal forgiveness (grants) toward the projects. The projects have all been designed and bid and the following construction contracts are ongoing:

- Downtown Water Main Improvements
- H1 Area (Stewarts Creek Area) Water Main Replacement
- Maher Water Treatment Plant Improvements
- Site Improvements
- SCADA System Upgrade
- Security and Fire Alarm System Project

C. **Hyannis WPCF and Collection System Improvements.** Similar to the Water System Improvement Projects listed above, a group of projects at the Hyannis WPCF and the collection system have been funded by SRF and Federal Stimulus Funds and the construction projects are ongoing. These projects include:

- Wind Turbine Installation at Hyannis WPCF
- Photovoltaic Installation at Hyannis WPCF
- Energy Efficiency Improvements at the Hyannis WPCF
- Area H1 Sewer Extensions
- West Main Street/Lincoln Road Pump Station and Force Main Installation

D. **Wequaquet Lake (Area CE4) Collection System Design Project.** This design project was initiated with the other Hyannis WPCF and collection system improvement projects because its implementation would have received SRF and Federal Stimulus Funds. This project was put on hold due to opposition from a portion of the property owners in the Wequaquet Lake area and subsequent vote of Town Council. Its implementation is expected to be rescheduled with the other sewer extension projects recommended by the 2007 Wastewater Facilities Plan

E. **Town Investigations on Alternative Funding Methods for Clean Water Protection Projects.** The Town has investigated alternative methods to fund Clean Water Protection projects. These projects have (since 1988) been paid by 100 percent property betterments. The Town investigated other methods that will make the cost of these projects more affordable to the property owners and decided that a 50:50 split of the collection system construction costs between betterments and the Town's General Fund is appropriate. The Town is also pursuing the development of a dedicated Sewer Construction Fund through special legislation.

Chapter 3
Regulatory Issues

CHAPTER 3

REGULATORY ISSUES

3.1 INTRODUCTION

This chapter identifies and briefly discusses the environmental regulations affecting wastewater facilities in the Town of Barnstable. Federal, state, regional, and Town of Barnstable departments and governmental agencies have enacted environmental regulations, which relate to the collection and treatment of wastewater and the recharge of the treated water. The federal regulations are contained in the Code of Federal Regulations (CFR) and are enforced by the United States Environmental Protection Agency (USEPA). The Massachusetts regulations are contained in the Code of Massachusetts Regulations (CMR) and are enforced by MassDEP. The Cape Cod Commission has adopted a Regional Policy Plan, which provides guidance and goals for development and environmental protection on Cape Cod. The Town of Barnstable has adopted regulations and rules to protect the citizens of Barnstable, and a Local Comprehensive Plan to provide growth management and environmental protection for the future. These regulations and plans are intended to protect public health and the natural environment, and are reviewed in this chapter.

Following is a brief summary of some of the regulations that are most applicable for this project. This is not intended to be a comprehensive list of all laws involved in the various regulations. For details on any of the requirements, refer to the actual law or regulation.

3.2 FEDERAL AND STATE REGULATORY ISSUES

A. **Acts and Executive Orders.** The USEPA and MassDEP have been working most recently in two areas applicable to this Project. The first of these efforts is regarding the establishment of Total Maximum Daily Loads (TMDLs) for non-point sources to coastal embayments, and the second is the National Pollutant Discharge Elimination System (NPDES) permitting program for

stormwater. The following is a brief description of each of these regulatory requirements and other state and federal regulatory issues.

1. **TMDLs.** The Federal Clean Water Act (Act) requires states to develop a list of impaired waters, which are waters that are unable to meet state-established water quality standards for their intended use (i.e., drinking water supply, fishing, recreational swimming and boating, or healthy ecosystems for plants and animals). States are then required to develop TMDLs for the impaired waters that are affected by pollutants. A TMDL is a determination of the maximum amount of pollutants that a body of water can withstand.

In 1998, the USEPA required all states to submit strategies for completing TMDLs within 8 to 13 years. Massachusetts submitted a strategy consisting of two stages. The first stage would make use of existing studies and information by working to implement corrective actions where feasible; develop a pilot program to define data collection needs and procedures to be used for TMDL development; and develop and standardize TMDL determination methods for pollutants that did not have well-established protocols. The second stage focuses on developing the TMDLs, beginning with those for pollutants with well-established determination methods.

Once pollutant limits are determined, MassDEP develops a draft TMDL report, followed by a public review and comment period. After addressing public comments, MassDEP submits the TMDL report to USEPA for formal approval. The TMDL development process requires that communities develop plans to restore the health of water bodies and then implement the plans. MassDEP monitors the progress of communities in achieving TMDLs. Restoration of water bodies is an extended process, so MassDEP looks for reasonable progress; if no reasonable progress is being made, enforcement actions may be taken.

The Act requires states to monitor the quality of their water resources to determine if the water meets the standards for intended uses. This information is reported to the USEPA in the Integrated List of Waters. Category 5 of the Integrated List itemizes water bodies that are "impaired or threatened for one or more uses and requiring a TMDL." Therefore, this list becomes the basis for determining the water bodies for which TMDLs will be established.

The water bodies within Barnstable that are listed in the Integrated List as Category 5, Waters Requiring a TMDL for nutrients include Centerville River, Cotuit Bay, North Bay, Popponesset Bay, Prince Cove, Red Lily Pond, Shoestring Bay and West Bay. Waters Requiring a TMDL for

pathogens include Barnstable Harbor, Bumps River, Hyannis Harbor, Lewis Bay, Maraspin Creek, Mill Creek, and Seapuit River. Red Lily Pond also cites noxious aquatic plants in addition to nutrients. Of the water bodies listed, the Three Bays estuary system (Cotuit Bay, North Bay, Prince Cove, Seapuit River, West Bay), the Centerville River/East Bay estuary system (Centerville River, Bumps River, Red Lily Pond), the Popponesset Bay estuary system (Popponesset Bay and Shoestring Bay), the Lewis Bay estuary system (Halls Creek, Hyannis Harbor and Lewis Bay) and Rushy Marsh have been evaluated as part of the Massachusetts Estuaries Project. The Barnstable Harbor estuary system (Barnstable Harbor, Maraspin Creek, Mill Creek) is planned for evaluation as part of the Massachusetts Estuaries Project. These five estuaries have been identified out of 89 for southeastern Massachusetts. As discussed in Chapter 1, nitrogen TMDLs have been established for Popponesset Bay, Three Bays System, and Centerville River/East Bay.

2. **Stormwater and Wastewater Discharges.** Discharges to surface waters are regulated by the USEPA through the NPDES permit program, authorized by the Act. The NPDES program is intended to control water pollution by requiring discharge permits for any point source (i.e., stormwater systems, wastewater systems) that discharge pollutants to waters of the United States. In Massachusetts, NPDES discharge permit application is made to both the USEPA and the MassDEP. USEPA issues the permit after the MassDEP certifies that the discharge meets water quality standards. Progress reports (describing progress on established goals to improve water quality) are submitted on an annual basis by the Town for the Town of Barnstable NPDES Phase II Small MS4 General Permit.

Additionally, MassDEP has recently proposed new regulations which would implement a stormwater management program in Massachusetts in accordance with state and federal clean water laws. The proposed Stormwater Management Regulations **in 314 CMR 21.00,** establish the program whereby the MassDEP would regulate direct and indirect discharges of stormwater to waters of the Commonwealth. In addition to regulating these discharges, the MassDEP would be required to regulate the outlets to both surface and ground waters for such discharge and any treatment works or best management practices associated with these discharges.

USEPA has issued a final 2008 Construction General Permit that governs discharges of stormwater from certain construction sites and requires the development and implementation of Stormwater Pollution Prevention Plan(s) for construction projects beyond one-acre.

3. **NEPA.** The National Environmental Policy Act of 1970 (NEPA) provides the basis for the protection of the environment. This Act ensures that environmental information is provided to the public for use in the decision making process for projects that might affect the environment. According to regulations, the "NEPA process is intended to help public officials make decisions that are based on an understanding of environmental consequences; and take actions that protect, restore, and enhance the environment." This policy has been established to eliminate redundancy and combine NEPA requirements with other concerned agencies' requirements. The NEPA process is the forerunner of similar environmental review processes adopted by state and regional agencies; it allows for the assessment and identification of alternatives for projects concerning the environment.

The Town of Barnstable is not expected to need to enter into the NEPA process because, the Comprehensive Wastewater Management Plan (CWMP) project would be regulated by the Massachusetts Environmental Policy Act (MEPA) and the Cape Cod Commission's Development of Regional Impact (DRI) review process as described in following sections.

4. **Massachusetts Ocean Management Act Regarding Effluent Discharge at an Ocean Outfall.** Formerly the Massachusetts Ocean Sanctuaries Act (Massachusetts General Law (M.G.L.) Section 13, c132A), the Massachusetts Ocean Management Act regulations establish state environmental policy to be enforced in the Ocean Management Planning Area which consists of five Ocean Sanctuaries; the Cape Cod Ocean Sanctuary, the Cape Cod Bay Ocean Sanctuary, the Cape and Islands Ocean Sanctuary, the North Shore Ocean Sanctuary, and the South Essex Ocean Sanctuary. The Massachusetts Oceans Act of 2008 prohibits the dumping or discharge of commercial, municipal, domestic or industrial wastes in an Ocean Sanctuary. The north side of the Town of Barnstable is within the Cape Cod Bay Ocean Sanctuary and the south side of the Town of Barnstable is within the Cape and Islands Ocean Sanctuary as designated by the Massachusetts Ocean Management Act.

The Massachusetts Oceans Act of 2008 signed by Governor Deval Patrick on May 28, 2008 is legislation that required the Secretary of Energy and Environmental Affairs to develop a comprehensive plan to manage development in its state waters, balancing natural resource preservation with traditional and new uses, including renewable energy. The draft Ocean Management Plan was completed on June 30, 2009, and a final plan was promulgated on December 31, 2009.

Upon final adoption, the Ocean Management Plan will be incorporated into the existing Coastal Zone Management Plan and enforced through the state's regulatory and permitting processes, including the Massachusetts Environmental Policy Act (MEPA) which is discussed below and Chapter 91, the state's waterways law.

5. **Governor Kings Executive Order No. 181 on Barrier Beach Areas.** This Executive Order defines barrier beach areas and sets several state policies to restrict and discourage development in these areas. Several policies are included within this Executive Order and include the following; no state funds and federal grants for construction projects shall be used to encourage growth and development in hazard-prone barrier beach areas, and no development shall be permitted in the velocity zones or primary dune areas of barrier beaches identified by the state. The Massachusetts Office of Coastal Zone Management coordinates the state management policy for barrier beach areas.

Responses received from the Massachusetts Office of Coastal Zone Management on Barnstable's previous Wastewater Facilities Plan, include recommendation of check valve systems being incorporated into the design of any sections of collection infrastructure for existing development within barrier beach designated areas.

6. **Executive Order No. 385, Planning for Growth.** Executive Order 385 seeks to resolve conflicts between environmental quality and development activity through proactive and coordinated planning oriented toward long-term, sustainable development. With respect to planning for growth, Section 1 of Executive Order 385 encourages:

a. Economic activity and growth which is supported by adequate infrastructure and which does not result in, or contribute to, avoidable loss of environmental quality and resources, and

b. Infrastructure development designed to minimize the adverse environmental impact of economic activity.

Section 5 of Executive Order 385 promotes rehabilitation and revitalization of existing developed areas as preferable over construction of new development.

B. **Regulations.**

1. **MEPA Environmental Review.** CWMP projects in Massachusetts include an environmental review process that is governed by the Massachusetts Environmental Policy Act (MEPA) and Cape Cod Commission's DRI review process. In general, the MEPA process, as described in **301 CMR 11.00**, establishes thresholds, procedures, and timetables for a multi-level review process. If a project exceeds review thresholds or if state funding is requested for a project, the project proponent begins the review process by preparing and filing an Environmental Notification Form (ENF) with the Secretary of Energy and Environmental Affairs. A 30-day review period follows, during which the Secretary receives agency and public comments and holds a site visit and consultation session. At the close of the ENF review period, the Secretary determines whether an Environmental Impact Report is necessary and issues a MEPA certificate. If an Environmental Impact Report is required, it is prepared by the proponent and submitted to the Secretary of Energy and Environmental Affairs. The Environmental Impact Report is reviewed at both draft and final stages by agencies and the public. After completion of the Secretary's review, state agencies may act on the project.

The Town will be expected to enter the MEPA process as part of the CWMP Project and the Project scope (identified in Chapter 1) indicates that the ENF will be filed after the Needs Assessment and Alternatives Screening portions of the Project.

2. **Wetlands Protection.** The Wetlands Protection Act (M.G.L. c.131, s.40) and parallel state regulations (**310 CMR 10.00**) were enacted to safeguard wetlands, associated resource areas, and floodplains from overdevelopment. The Wetlands Protection Act covers any wet area where the groundwater level is at or near the surface of the ground for a long enough period during the year to support a community of wetland-type vegetation. Wet areas include any salt or fresh-water marsh, meadow, swamp, or bog.

Areas subject to protection under the Wetlands Protection Act are referred to as resource areas. Resource areas are protected by a surrounding 100-foot buffer zone in which landscape alterations are regulated. The Wetlands Protection Act also covers construction on land subject to flooding or coastal storms. Generally, the regulations apply to two types of floodplain: those lands bordering directly on bodies of water, and those lands subject to flooding (called "Isolated Land Subject to Flooding") which do not border bodies of water.

The state regulates activities that involve filling, dredging, or excavating in or near a wetland or water body. The regulations govern additional construction activities, including site preparation, the removal of trees or bushes, vista pruning, and the changing of land contours.

A Notice of Intent must be filed for work in any resource area. The Notice of Intent requires a detailed description of the planned activity, and the applicant must show that if the resource area will be altered, the benefits will outweigh the damage. For work outside the resource areas but within a 100-foot buffer zone around a bordering vegetated wetland, bank, dune, or beach, the owner has the option of filing a "Request for Determination" to show that the work will not alter a resource area. If the Conservation Commission agrees, it will issue a "Negative Determination," permitting the work as presented. If the Conservation Commission decides that the work will alter a resource area, it will issue a "Positive Determination" and require a full hearing and the filing of a Notice of Intent.

Stormwater Management Standards have been revised and incorporated into the Wetlands Protection regulations of 310 CMR 10.00 and new sections have been added. Promulgated in January 2008, the standards encourage stormwater recharge, the increased use of low impact development techniques, improved operation and maintenance of stormwater best management practices, and the removal of illicit connections to stormwater management systems. Refer to 314 CMR 21.00, Stormwater Management Regulations for more details on this regulation.

3. **Massachusetts Rivers Protection Act.** This law is an amendment to the Wetlands Protection Act and establishes a Riverfront Area, which is included in the resource areas protected by the Wetlands Protection Act. The law authorizes conservation commissioners to regulate activities that occur within the Riverfront Area and establishes protection of the natural integrity of rivers as a state priority.

Permits for work in Riverfront Areas will be denied if a significant adverse impact would result or if there is a "practicable and substantially equivalent economic alternative" that will have less impact on the resource area. Certain activities are exempt from the Rivers Protection Act, including renovation of abandoned cranberry bogs and activities associated with wastewater treatment plants and their related structures, conveyance systems, and facilities.

4. **On-Site Treatment and Discharge.** Title 5 of the Massachusetts State Environmental Code provides minimum standards for the "protection of public health, safety, welfare and the environment by requiring the proper location, construction, upgrade, and maintenance of on-site sewage disposal systems and appropriate means for the transport and disposal of septage." The regulations contained in **310 CMR 15.00** come under the jurisdiction of the MassDEP and are enforced in conjunction with local health departments through permits, inspections, and financial penalties.

As defined by the regulations, an individual sewage disposal system is "a system or series of systems for the treatment and disposal of sanitary sewage below the ground surface." Systems typically consist of a septic tank, a distribution box, and a soil absorption system. These systems may also include tight tanks, shared systems, or alternative systems if allowed by local and state regulations. The design considerations for Title 5 systems include minimum setbacks, minimum separation from groundwater, sizing guidance, and soil requirements.

The regulations are generally enforced by local health departments. The local Board of Health, due to specific problems or concerns, can and may impose more stringent requirements. Individuals and/or communities can receive a variance from the regulations; however, it must be in accordance with 310 CMR 15.00.

5. **Water Resources, Treatment and Supply of Potable Water.** The Safe Drinking Water Act of 1974 is federal legislation that dictates the regulation of potable water in the United States. Major amendments were made to the Safe Drinking Water Act in 1986 and mandate that 25 additional contaminants come under regulation every 3 years. This legislation is incorporated into the regulations of 40 CFR 141, 142, and 143, which are maintained and enforced by USEPA.

Massachusetts is a primacy state for the regulation of potable water, which means that MassDEP is the primary agency for maintaining and enforcing the drinking water regulations. Massachusetts' regulations contained in **310 CMR 22.00** closely parallel the federal regulations and establish the maximum contaminant level (MCL) of the regulated contaminants in drinking water.

The Safe Drinking Water Act provides guidelines on the establishment of wellhead protection programs, which Massachusetts has established in 310 CMR 22.21. The program delineates three zones around each public water supply. The Zone I delineation is the area immediately around the well or well field which must be owned by, or in the control of, the water purveyor. The Zone I for a well producing 100,000 gpd or greater has a minimum diameter of 800 feet. The Zone II delineation is the area of an aquifer that contributes water to a well under the "most severe pumping and recharge conditions that can be realistically anticipated." The regulations define these conditions as 180 days of pumping at safe yield with no recharge from precipitation. Zone II areas are typically determined by a hydrogeologic study involving particle-transport computer modeling. The Zone II is bounded by the groundwater divide and by the contact of the aquifer with less permeable material. The Zone III delineation is the area beyond the Zone II from which surface water and groundwater drain into the Zone II.

The allowed land use within each zone is regulated by the wellhead protection program. Land use activities within Zone I areas must be related to the water supply or have no significant adverse impact on water quality. The following land uses are prohibited from being sited in a Zone II area:

- Landfills or open dumps.
- Land filling of sludge or septage.
- Automobile graveyards and junkyards.
- Stockpiling of contaminated snow or ice.
- Petroleum, fuel oil, and heating oil bulk stations and terminals.
- Treatment or disposal works for wastewater other than sanitary sewage.
- Facilities that generate, treat, store, or dispose of hazardous materials.
- Floor drainage systems in hazardous waste and hazardous material processing or storage facilities.

There are exceptions to the prohibition of wastewater treatment plants listed as the sixth bullet above. These exceptions are reviewed by MassDEP on a case-by-case basis.

6. **Regulations for the Land Application of Sludge and Septage.** The land application of sludge and septage, as well as the distribution of compost material made from WWTF sludge, are regulated by MassDEP in **310 CMR 32.00** and the July 2005 federal standards contained in 40 CFR Part 503. Current state regulations are more stringent.

Under the MassDEP regulations, sludge, septage, and compost (collectively called "material") are classified as Type I, II, or III, depending upon chemical, pathogen, organic content, and sludge stabilization processes used. The sludge classification determines how the material is ultimately used or disposed of. Type I material can be used on any site and requires no further MassDEP regulations, while Type II and III materials require additional regulation on the ultimate use, the application site, and allowable application rates. Compost must be classified as Type I to be sold or otherwise distributed to the public.

7. **Clean Water State Revolving Fund Program.** This regulation described in **310 CMR 44.00** gives the Commonwealth the authority and responsibilities to select, approve and regulate water pollution abatement projects receiving financial assistance under the State Revolving Fund Program. In 2006, modifications to the regulations were proposed and then promulgated in 2007, integrating smart growth principles into the regulations. Eligible projects include comprehensive wastewater management planning or the design and construction costs associated with implementing planning recommendations for water pollution abatement. Revisions were promulgated in January 2009 to modify requirements related to flow limits in sewer construction to promote sustainable development.

8. **Surface Water Discharge Permitting.** The purpose of the Massachusetts Surface Water Discharge Permit Program described in **314 CMR 3.00** is to implement the provisions of the Massachusetts Clean Waters Act and the Federal Clean Water Act and provides the MassDEP authority to assume delegation from the USEPA to administer the NPDES permit program. 314 CMR 3.06 provides authority to the MassDEP to issue general permits for surface water discharges, including general permits for storm water discharge from small municipal separate sewer systems regulated under the USEPA's Phase II Storm Water Regulations set forth in the applicable provisions of 40 CFR Part 122, Subpart B.

9. **Surface Water Quality Standards.** In addition to the limitations imposed by the Massachusetts Ocean Management Act, the Massachusetts Surface Water Quality Standards define the activities that are prohibited in inland water classes and coastal and marine classes for surface water bodies. For the purposes of applying **314 CMR 4.00** to the Town of Barnstable, the surface waters of the Commonwealth are classified as shown in 314 CMR 4.06, where the water in Barnstable Harbor (excluding Freezer Point and the developed marina water) is designated SA for Shellfishing and is also designated an Outstanding Resource Water (**314 CMR 4.06**). The SA designation indicates an excellent habitat for fish, other aquatic life and

wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. The Outstanding Resource Water classification means that the quality of these waters shall be protected and maintained and new and increased discharges are generally prohibited.

10. **Groundwater Discharge Permitting.** Discharges and treated water recharge to the groundwater system are regulated by the Massachusetts Ground Water Discharge Permitting Program Regulations (the "Ground Water Regulations"), contained in **314 CMR 5.00**. Recent revisions promulgated in March 2009, make a number of changes to streamline the existing permitting process and reduce the time it takes for an applicant to obtain a groundwater discharge permit. In addition, these revisions eliminated the need for another set of regulations previously contained in the Ground Water Quality Standards, **314 CMR 6.00**. MassDEP developed changes to 314 CMR 5.00 that incorporate the provisions of 314 CMR 6.00 and provides important protection to groundwater quality. The Ground Water Regulations currently contain a list of specific effluent limits. These limits are based on the maximum contaminant limits set forth in the Drinking Water Regulations at the time MassDEP promulgated the Ground Water Regulations.

The revised regulations also include new limitations on total organic carbon (TOC) concentrations in discharged effluent. For treated wastewater discharged within a Zone II with a travel time of greater than two years to the source, the revised permit program establishes the following maximum (Maximum Day) allowable concentrations.

1. Total Suspended Solids (TSS) shall not exceed 10 mg/L
2. Turbidity shall not exceed 5 nephelometric turbidity units
3. Effluent shall be filtered and disinfected to achieve an effluent limitation of 200 fecal coliform organisms per 100 mL
4. TOC shall not exceed 3.0 mg/L
5. Total nitrogen and Nitrate nitrogen shall not exceed 10 mg/L

For travel times of less than two years, or for discharge arrangements that do not include soil aquifer treatment, limitations become increasingly stringent, with concentrations limited as follows.

1. TSS shall not exceed 5 mg/L
2. Turbidity shall not exceed 2 NTU
3. Biological oxygen demand (BOD) shall not exceed 10 mg/L
4. Total nitrogen and nitrate nitrogen shall not exceed 5 mg/L
5. Effluent shall be oxidized, filtered and disinfected to achieve an effluent fecal coliform limitation of no detectable colonies per 100 mL over a continuous seven day sampling period, and no sample shall exceed a limit of 14 colonies per 100 mL
6. TOC shall not exceed 1.0 mg/L

These new TOC limitations are intended to provide increased protection of groundwater supplies, limiting both the amount of naturally occurring organic carbon introduced to the groundwater as well as synthetic forms of organic carbon that may be present in treated discharge. Further, because many contaminants of emerging concern (CECs) including endocrine disrupting compounds (EDCs), pharmaceuticals, and personal care products (PPCPs) are organic in nature, reductions in total organic carbon are expected to generate similar reductions in concentrations of CECs introduced to groundwater through reductions in total carbon concentrations.

This regulation also provides that the MassDEP may issue an individual groundwater discharge permit that authorizes the reuse of effluent from permitted sewage treatment facilities in accordance with the Reclaimed Water Permit Program and Standards, **314 CMR 20.00,** promulgated in March 2009. These regulations establish a program to regulate and permit reclaimed water systems and establish requirements for the use, sale, distribution and offering for use, sale and distribution of reclaimed water.

11. **Sewer System Extension and Connection Permit Program. 314 CMR 7.00** establishes the program whereby sewer system extensions and connections are regulated and permitted by the MassDEP and was adopted to insure proper operation of wastewater treatment facilities and sewer systems within the Commonwealth.

12. **Toxic/Incompatible Discharges to Wastewater Collection Systems.** In the early 1980s, the USEPA established nationwide industrial pretreatment standards contained in 40 CFR 403, General Pretreatment Regulations for Existing and New Sources of Pollution, to regulate the discharge of industrial pollutants to Publicly Owned Treatment Works (POTWs). The general goals of this program are to limit those toxic/incompatible discharges, which could: (1)

pass through a plant inadequately treated; (2) harm a plant's treatment processes, thereby preventing the plant from complying with its permit; or (3) reduce opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.

When these regulations were established, all communities with POTW flows greater than 5 mgd were required to establish local industrial pretreatment programs. The programs are needed by larger plants that receive significant industrial and commercial wastewater flows.

Massachusetts's Operation and Maintenance Standards for Wastewater Treatment Plants (**314 CMR 12.00**) parallel the federal regulations. Revisions promulgated in March 2009 clarified the responsibility of contract operators for operating and maintaining wastewater treatment facilities in accordance with approved operation and maintenance plans and staffing plans, and for performing the monitoring, reporting, and recordkeeping required by the facility's discharge permit.

Paragraph 12.09.2 of the Massachusetts regulation also states that a POTW with a design flow of 5 mgd or less may be required to establish a POTW Pretreatment Program.

Though the Hyannis WPCF is smaller than 5 mgd, the Town of Barnstable implemented a Pretreatment Program in 1989 to monitor, regulate, and minimize toxic/incompatible discharges to the collection system, thereby protecting the treatment process and receiving waters.

13. **Privately Owned Sewage Treatment Facilities and Publicly Owned Treatment Works.** Privately owned sewage treatment facilities (PSTFs) are the private version of the POTWs. Publicly Owned Treatment Works are defined in **314 CMR 12.02** as "any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial waste of a liquid nature which is owned by a public entity. A POTW includes any sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment." In Massachusetts, there are detailed requirements at the State level, which apply stringent requirements on the location and operation of PSTFs.

Current MassDEP regulations require the use of a PSTF or POTW for any residential or commercial discharge greater than 10,000 gpd. MassDEP reviews the performance of these facilities under its Groundwater Discharge Permit (GWDP) Program (314 CMR 5.00).

14. **Reclaimed Water Use.** The Reclaimed Water Permit Program and Standards Regulations (the "Reclaimed Water Regulations"), **314 CMR 20.00**, are a new set of regulations promulgated in March 2009. Reclaimed water is defined as domestic wastewater that is treated to a level such that it is suitable for beneficial reuse. Eliminating or reducing the concentrations of microbial and chemical constituents of concern through treatment and/or limiting public or worker exposure to the water via design or operational controls achieves making reclaimed water suitable and safe.

The regulations establish a system of classification and standards specific to the proposed use. The highest standards apply to those proposed uses with greatest potential for exposure to the public. These regulations do not include standards for indirect aquifer discharge. Those standards are included in the revisions to the Groundwater Discharge Permitting Program Regulations in 314 CMR 5.00.

3.3 REGIONAL REGULATORY ISSUES

A. **The DRI Review Process.** In accordance with the Cape Cod Commission Act, Chapter 716, the Cape Cod Commission has the authority to review and regulate Developments of Regional Impact (DRIs). This review is carried out by the Cape Cod Commission in accordance with Administrative and Enabling regulations.

The Town will be expected to enter the MEPA and DRI process as part of a full CWMP. The review process will be a joint review.

B. **Cape Cod Commission Regional Policy Plan.** The Cape Cod Commission Act calls for an update to the plan every five years (previous editions were released in 1991, 1996, and 2002). The current Regional Policy Plan went into effect October 30, 2008.

The Regional Policy Plan establishes "minimum review performance standards" and development review policies that are used by the Cape Cod Commission for the review of Developments of Regional Impact (DRI). The goal of the water resources minimum performance standards is to preserve the high quality of the groundwater (the source of Cape Cod's drinking water) as well as the marine and fresh surface waters, which are connected to and dependent on the groundwater for ecological health and sustenance. The water resources classification system includes the following: drinking water, coastal embayments, ponds, sewage treatment facility

standards, stormwater management standards, and natural resources standards. The reader is directed to the most current Regional Policy Plan for further information specifically relating to the minimum performance standards developed for each goal. Overall, the water resources minimum performance standards state a maximum nitrogen load of 5 parts per million unless there will be no adverse impacts on resources.

C. **Cape Cod Commission Development of District of Critical Planning Concern.** The Cape Cod Commission is charged with recommending the designation of Districts of Critical Planning Concern, or DCPCs. The districts are generally nominated by a town or several towns. After going through an extensive public hearing process, the Commission recommends or decides not to recommend the nominated districts for approval by the Barnstable County Assembly of Delegates and the County Commissioners. If ultimately approved, the districts allow a town or a group of towns to adopt special rules and regulations to protect natural, coastal, scientific, cultural, architectural archaeological, historic, economic, or recreational resources or values of regional, statewide, or national significance. The rules that the nominating communities create and adopt (known as "implementing regulations") then govern development in the designated DCPC area.[1]

There are two DCPC in the Town of Barnstable with implementing regulations as identified below.

- Barnstable DCPC. The Barnstable DCPC was designated in September 2001 to manage residential growth and encourage affordable housing over nearly 60 square miles. Similar to an overlay district, the DCPC includes all vacant, buildable parcels that are capable of being used for new residential development. Through the DCPC process, the Town of Barnstable adopted a rate-of-development ordinance, with a building rate and cap phased in over several years, to allow for adequate infrastructure (roads, wastewater, police, and more) and to support the implementation of the town's affordable housing action plan. The ordinance sets limits on construction permits for two types of dwelling units: affordable and market-rate. Although appealed through litigation, the DCPC was ultimately upheld by the state's highest court, the Massachusetts Supreme Judicial Court. Through the DCPC,

[1] Text from www.capecodcommission.org/DCPC/

the town also adopted a health regulation that allows for the construction of shared and innovative wastewater disposal systems.[2]

- Craigville Beach/Centerville and Village Center DCPC. The Craigville Beach area and the Centerville Village Center area are contiguous areas, encompassing about 380 acres of land and 66 acres of open water, but have somewhat separate issues. The Craigville beach area includes a barrier beach along Nantucket Sound, an estuary system behind it, and freshwater ponds. It encompasses many summer homes and cottages and a former "Christian Camp Meeting" area, which is recognized within a National Register Historic District. The Town nominated the area for five DCPC purpose: a natural and ecological resource district; a cultural, historic, and architectural resource district; a wastewater management district; and a waterfront management district. The Centerville Village Center area includes an existing business zoning district and residential parcels including the Main Street National Register Historic District. The town nominated the area for two DCPC purposes: an economic resource district and a cultural, historic, and architectural resource district.[3] Enabling regulations including an ordinance have been passed in Barnstable for these areas.

3.4 TOWN OF BARNSTABLE ORDINANCES AND REGULATIONS

The following text summarizes plans and regulations developed and adopted by the Town of Barnstable pertaining to treatment of wastewater, comprehensive planning and growth management. Chapter excerpts are from the Code of the Town of Barnstable.

A. **Town of Barnstable Local Comprehensive Plan.** The Town of Barnstable's most current version of the Local Comprehensive Plan (LCP) is the 2008 Final Draft. The vision statement of the LCP states, "The seven diverse yet interconnected villages of Barnstable form one community that is an integral part of Cape Cod. As the town in 2008 has been shaped by its past, through this plan Barnstable will shape a sustainable future. The town will preserve its history, environment and community for future generations through active stewardship of community character and quality of life while balancing growth, infrastructure and natural systems."

[2] Text from www.capecodcommission.org/DCPCbrochureMarch2008.pdf
[3] Text from www.capecodcommission.org/DCPCbrochureMarch2008.pdf

Comprehensive plan goals and related needs include the following with respect to natural resources and environmental quality within the Town of Barnstable are as follows:

- Preserve, protect and enhance sensitive natural habitats and systems.
- Provide town services and infrastructure through an efficient, planned and prioritized process.
- Support and manage the regional resources and services unique to Cape Cod.
- Preserve and enhance historic and maritime character, public viewsheds and cultural landscapes.
- Preserve and enhance access to public spaces including the waterfront.

B. The Code of the Town of Barnstable.

Part 1, General Ordinances:

Chapter 184, Sewers and Water: This chapter includes regulations on building sewers and connections and use of public sewers.

Chapter 232, Wastewater Discharge: The purpose of this chapter is to "protect the public health, safety and welfare by maintaining quality groundwater through the regulation of the volume of certain wastewater discharges. Within zones of contribution to existing and proposed public supply wells, the maximum allowable wastewater discharge from new individual on-site sewage disposal systems shall not exceed 330 gallons per acre per day."

Chapter 240, Zoning, Article XI, Growth Management: The purpose of this article is to "ensure that a harmonious pattern and predictable rate of development occurs in Barnstable, which protects the health, safety and welfare of current and future Barnstable residents. This article establishes a development rate adequate to ensure that the Town, with prudent reliance on local and other financial sources and in compliance with the revenue generating guidelines of Proposition 2 1/2, can and will provide infrastructure and operate in a manner which provides current and future Barnstable residents with an adequate and responsible level of Town services, as defined by relevant, commonly accepted professional standards."

"It is anticipated by this Growth Management article that during the time until buildout occurs, the Town will strive to upgrade its infrastructure to keep pace with its total population, as

outlined in the Capital Improvements Plan and consistent with the growth rate established by this article. This includes the preparation of a long-term capital plan and a commitment to make contributions, as practical, to infrastructure and to the established Capital Trust Fund as appropriate to fund infrastructure, promote affordable housing and protect the environment."

Part III, Board of Health Regulations:

Chapter 353, Nuisances, Article II, Maintenance of Private Sewage Systems: This article includes the maintenance of private sewage systems.

Chapter 360, On-Site Sewage Disposal Systems: This chapter is comprehensive for on-site sewage disposal systems including all requirements and additional regulations.

Chapter 385, Variance Requests: This chapter provides variance request regulations with respect to on-site sewage disposal systems.

Part IX, Department of Public Works Regulations:

Chapter 901, Sewers Connections: This chapter includes permitting, design and installation requirements.

The CWMP must comply with the vision and goals of the Barnstable Comprehensive Plan, and ordinances and regulations of the Town.

Chapter 4

Existing Wastewater and Water Supply Systems

CHAPTER 4

EXISTING WASTEWATER AND WATER INFRASTRUCTURE

4.1 INTRODUCTION

The Town's existing wastewater and water facilities are described in this chapter, and pertinent system characteristics are summarized.

A. **Wastewater Facilities.** The Town of Barnstable DPW operates three wastewater treatment facilities: the Hyannis Water Pollution Control Facility (WPCF), Marstons Mills Wastewater Treatment Facility (WWTF), and Red Lily Pond cluster system.

There are two privately owned WWTF's in Barnstable: the Cotuit Stop and Shop WWTF, and the Cape Regency Skilled Nursing and Rehabilitation Center WWTF.

There are 71 Innovative/Alternative (I/A) individual home treatment systems in Barnstable as regulated by the MassDEP Title 5 regulations. These are systems that typically provide a greater level of nitrogen removal as compared to regular Title 5 septic systems.

The great majority of properties in Barnstable utilize septic systems as regulated by MassDEP Title 5 regulations. These septic systems have been identified as the largest source of nitrogen to the coastal estuaries by the Massachusetts Estuaries Project.

B. **Water Supply Facilities.** There are four water purveyors that provide public water supply to the properties in Barnstable.

The Town DPW operates the Hyannis Water System which supplies public water supply to properties in the Village of Hyannis.

Three water/fire districts provide public water supply to other portions of Barnstable listed below:

- Barnstable Fire District Water Department provides water supply to the Village of Barnstable.
- The Centerville Osterville Marstons Mills (COMM) Fire District Water Department provides water supply to those three villages.
- The Cotuit Water District provides water supply to that village.

The West Barnstable Fire District has a Water Commission but does not currently provide any Water Supply infrastructure. A few properties in the Fire District/Village area are served by neighboring Fire/Water Districts.

West Barnstable is the only village that relies almost exclusively on private water supply wells; though there are a few properties in the other villages that still utilize private wells.

4.2 HYANNIS WATER POLLUTION CONTROL FACILITY (WPCF)

A. **History of Hyannis WPCF.** A primary wastewater treatment facility utilizing an Imhoff tank was constructed at the present site on Bearses Way around 1936. Effluent discharge to groundwater via sand infiltration beds has been continuously practiced at this site since that time. The facility provided primary treatment until completion of the secondary upgrade in 1980. Most of the facilities presently in use were added under six construction projects, which are described below. Figure 4-1 is a site plan showing the present site layout.

1. **Pretreatment Building Construction**. The pretreatment building was completed and placed in service in 1975. The building included an influent receiving well, a hand-cleaned bar screen, one comminutor, an aerated grit chamber, and a Parshall flume. The project also added a septage receiving station and two 15,000-gallon septage storage tanks. (This building has since been upgraded as described in a subsequent project.)

2. **Secondary Treatment Additions**. The main secondary treatment upgrade was completed and began operation in 1980. This project added the existing primary clarifiers, aeration tanks, final settling tanks, post-chlorination tanks, control building, effluent pumps, sludge handling facility, and two centrifuges. One of the old primary settling tanks was

converted to a sludge thickener. The sludge holding tanks were covered and mixers were installed.

3. **Septage and Odor Control Additions**. A construction contract completed in 1991 added a new septage receiving station and septage processing building. The septage processing building contains septage storage and degritting facilities, two gravity belt thickeners, and grease concentration equipment. A Sludge Process Blower Building was constructed to provide aeration of the sludge holding tanks. Three new odor control systems were added at the pretreatment building, septage handling building, and the sludge process blower building.

4. **New Secondary Clarifier Additions**. A construction contract completed in 1997 added a new 85-foot diameter clarifier, new return sludge pumps, and new waste sludge pumps. A flow distribution box was also added between the aeration tank and the clarifiers to replace a butterfly valve flow splitting arrangement to provide more accurate flow splitting.

5. **Modified Ludzak Ettinger (MLE) Process Addition with Diffused Aeration**. A construction contract completed in 2001 converted the biological treatment process to the MLE nitrogen removal process in Aeration Tank Nos. 1 and 2. The aeration technology was converted from surface aeration to diffused aeration and a blower building was added with four blowers.

6. **Aeration Tank Expansion and Other Improvements**. A construction contract completed in 2009 added a third aeration tank and one new blower in the blower building to enhance the treatment capacity and redundancy by 50 percent. The following improvements were also made:

a. Pretreatment building improvements to replace flow metering, grit removal, and screening equipment.
b. Primary sludge pump replacement.
c. Yard piping to allow primary sludge pumping to the pretreatment building.
d. Piping and site modifications to new improved tanker truck loading.
e. Pretreatment building drain improvements to allow both gravity belt thickeners to operate at the same time.
f. Additional odor control facilities added.

B. **Summary of Existing Centralized Wastewater Flows and Loadings.** Wastewater treatment facility staff regularly sample and record the flows of wastewater and septage. Much of the recorded data is reported to MassDEP in monthly reports, while other data is utilized by the WPCF staff as part of their monitoring and process control operations. As part of this project, three years of data (September 2006 through August 2009) was analyzed to determine the current flows and loadings to performance of the Hyannis WPCF. The flow data that was used for flow analysis was from the period of January 2008 through August 2009. Wastewater flow data before January 2008 was recorded with the old flow meter which is believed to have been reading high. Monthly averages were computed and are summarized in Appendix 4-1.

1. **Plant Influent.** Plant influent is a combination of wastewater from the collection system and septage. Wastewater from the collection system arrives at the WPCF via several force mains that terminate at the pretreatment building. The daily flows are recorded and reported to MassDEP in a monthly report. A typical monthly report is attached in Appendix 4-2. Septage is transported to the WPCF by septage haulers. The volume of septage is recorded on the monthly report.

Table 4-1 summarizes the average annual, minimum month, maximum month, and peak day influent flows during the period of January 2008 through August 2009.

TABLE 4-1

INFLUENT FLOWS, HYANNIS WPCF

FLOW AVERAGE	SEWAGE FLOW (MGD)	SEPTAGE FLOW (MGD)	TOTAL FLOW (MGD)	TIME OF OCCURRENCE(1)
Average annual	1.46	0.04	-	-
Maximum month	1.94	-	-	August 2009
Minimum month	0.85	-	-	January 2008
Peak day(2)	2.38	0.07	2.45	August 29, 2009

Notes:
(1) Dates of sewage flow for maximum month, minimum month, and peak day.
(2) The total for peak day is a summation of the sewage flow and septage flow that occurred on their respective peak flow dates.

A representative sample of the primary effluent (as an indicator of plant influent) is analyzed twice weekly for 5-day biochemical oxygen demand (BOD_5) and total suspended solids (TSS).

This sample is taken from the effluent of the primary settling process because it best describes the influent to the biological treatment process which needs the best influent data for process control. The plant influent load will be higher than the primary effluent load because some of the BOD, TSS, and nitrogen is removed in the primary settling tanks. The WPCF effluent is sampled two times per week and analyzed for BOD_5, TSS, nitrate nitrogen (NO_3-N), and total Kjeldahl nitrogen (TKN).

BOD_5 is used to gauge the strength of wastewater, as it is a measure of the quantity of oxygen that will be required to biologically stabilize the organic matter present in the wastewater. The nitrogen analysis of the effluent provides a measure of the nitrogen loading to the groundwater system.

2. **Septage.** The Hyannis WPCF receives and treats septage and trap grease (all referred to as "septage") from haulers located in and around Hyannis. The WPCF tracks the number of septage loads discharged to the system and the gallons of septage. Septage treatment includes grit removal and aeration before it is thickened for transport off site.

3. **Waste-Activated Sludge (WAS).** WAS from the aeration tanks is pumped to two gravity belt thickeners (GBT) located in the Septage Processing Building or to a blended-sludge tank within this building. Thickened sludge from the GBTs is pumped by plunger pumps into thickened sludge tanks where it is stored until it is trucked to a regional disposal facility.

4. **Screenings and Grit.** Grit is collected in the septage receiving building and the pretreatment building. It is disposed of as a solid waste at a permitted landfill.

C. **Summary of Overall WPCF Performance.** Overall facility performance is indicated by the quality of the treated effluent recharged at the sand infiltration beds. Monthly averages of the WPCF influent and effluent from 2006-2009 are plotted on Figure 4-2 for BOD_5, Figure 4-3 for TSS, and Figure 4-4 for nitrogen (effluent only).

Figure 4-2 indicates that the facility performs well at removing BOD with an average annual removal rate of 97 percent and an average effluent concentration of 6.0 mg/L. The current groundwater discharge limit is 30 mg/L of BOD. The monthly average BOD concentrations evaluated have not exceeded this value.

Figure 4-3 indicates that the facility performs well at removing TSS with an average annual effluent concentration of 7 mg/L. The current groundwater discharge limit for the Hyannis WPCF is 30 mg/L of TSS.

Figure 4-4 indicates that the facility performs well at removing Total Nitrogen (TN), Amonia Nitrogen (NH_3–N) and Nitrate Nitrogen (NO_3-N) with an average TN effluent concentration of 5 mg/L. The current groundwater discharge limit for the Hyannis WPCF is 10 mg/L TN.

The Hyannis WPCF recharges its treated water into portions of three Zone II areas (areas of land that could contribute groundwater to a public water supply well), and MassDEP may require that the WPCF meet a new effluent limit of 3 mg/L total organic carbon (TOC), especially if the plant is expanded. This parameter is not currently monitored but several samples have been collected and analyzed since October 2009, and the average TOC concentration in the treated water was 7.1.

D. **Existing Wastewater Treatment Facilities.** The Hyannis WPCF is comprised of septage handling, pretreatment, primary, secondary, and disinfection treatment facilities. These facilities are illustrated on the Site Plan of Figure 4-1. The existing wastewater and septage treatment flow schematics are presented on Figures 4-5 and 4-6, respectively. The sludge flow schematic is illustrated on Figure 4-7. An inventory of the treatment facilities and process equipment is presented in Appendix 4-3.

1. **Pretreatment Facilities.** The pretreatment facilities consist of a manual bar screen, an automated mechanically cleaned climber screen, a shaftless screw conveyor for the screenings, a Parshall flume for flow measurement, an aerated grit chamber and associated blowers, cyclone, and classifier. The aerated grit chamber is designed to remove grit solids and heavier inert solids from the influent wastewater through the use of diffused aeration and a grit screw conveyor. There is also odor control equipment consisting of a caustic/hypochlorite scrubber and hydrogen peroxide chemical addition.

2. **Primary Clarification.** Following pretreatment, the wastewater flows by gravity to a junction box which is a concrete structure that divides the flow between two primary clarifiers. Each primary clarifier is a circular 60-foot diameter tank with a 10-foot sidewater depth. Based on a design surface overflow rate of 1,000 gal/ft^2/day and a peak overflow rate of 3,000 gal/ft^2/day from *"Guidelines for the Design of Wastewater Treatment Works,"* New

England Interstate Water Pollution Control Commission (NEIWPCC), the capacity of the primary clarifiers is 6.8 mgd average and 17 mgd peak.

Underflow from the primary clarifiers is removed by two variable speed progressive cavity pumps located in the primary pump building. These pumps were installed in 2009 and are in "like-new" condition. Each pump suction line is equipped with a 3 HP grinder. The grinders are similar to each other; one was installed in 1993 and one in 2009. The pump room, which is located below grade, is served by a single Myers sump pump that is in good operating condition.

3. **Aeration Facilities/MLE Process.** In 2001, the existing aeration tanks were upgraded to a MLE process with diffused aeration. This process consists of an anoxic zone at the start of the flow train followed by a switch zone (a zone that can be anoxic or aerobic depending on the seasonal loadings) and then an aerobic zone. The MLE process utilizes an internal recycle of nitrified effluent from the nitrification (aerobic) zone to the anoxic zone for denitrification.

There are three parallel reactor trains, each with a volume of 170,000 cubic feet. This process has a capacity of 4.2 mgd on a maximum month basis.

Aeration is provided by a bank of five 100 HP, multi-stage centrifugal blowers located in the blower building. The blowers are equipped with electrically operated butterfly valves for inlet throttling control. The blower control valves are controlled by a pressure signal from sensors in the common discharge header. There are also electrically operated butterfly valves in the air distribution piping. Dissolved oxygen (DO) probes in the aeration tanks provide a control signal for the distribution valves.

Non-aerated compartments of the reactors are equipped with two 6 HP submersible mixers in each tank.

Nitrate recycle is achieved by a single 10 HP speed-controlled submersible pump located at the end of the aerobic section of each train. Anoxic sections of the reactors are covered and vented to a biofilter for odor control. The biofilter was installed in 2009 and is equipped with a single 20 HP fan with a nominal capacity of 5,000 scfm.

4. **Secondary Clarification.** Prior to November 1997, there were two 70-foot diameter circular secondary clarifiers with side-water depths (swd) of 10 feet. A third 85-foot diameter

clarifier was constructed in November 1997 with a swd of 13 feet. In 2001, the MLE process with diffused aeration and an anoxic selector was installed in the aeration tanks. Based on a Peak Hourly overflow rate of 800 gpd/sf and adjusting that rate for the shallow swd of the clarifiers (especially the 2 older 70-foot diameter clarifiers) the Peak Hour capacity of the three clarifiers is 7.1 mgd. This capacity is correlated to a Maximum Day capacity of 4.7 mgd at a Peak Hour to Maximum Day ratio of 1.5, and to a Maximum Month capacity of 4.4 mgd at the current Maximum Day to Maximum Month ratio of 1.1.

Underflow from the secondary clarifiers is recirculated to the aeration process by three 10 HP variable speed, horizontal end suction centrifugal pumps (return activated sludge pumps) located in the secondary pump building. Flow rate is metered by a 12-inch magnetic flow meter on the discharge header.

Waste sludge is sent to a sludge holding tank or directly to thickening equipment by two progressive cavity pumps located in the secondary pump building. These pumps are 15 HP and are speed controlled by an adjustable belt drive.

5. **Disinfection.** The Hyannis WPCF utilizes sodium hypochlorite for effluent disinfection. The facilities consist of two parallel chlorine contact chambers, each with a volume of 9,800 cubic feet. Based on a peak flow contact time of 15 minutes (NEIWPCC), the capacity of the chlorination facilities is 13.8 mgd. The hypochlorite feed system consists of a storage tank, two diaphragm metering pumps, and a water circulating pump.

6. **Treated Water Pumping Facilities.** The disinfected treated water pumping facilities include four 50 HP, vertical centrifugal pumps located in the basement of the control building. The pumps are controlled by a bubbler-type level control system in the pump wet well. One pump is controlled by a VFD.

7. **Sand Infiltration Beds.** The treated water from the chlorine contact tanks is currently pumped to four groups of sand infiltration beds. Routing of the treated water is controlled through manual operation of valves. The four groups contain 47 beds in total and a total of 1,127,000 square feet of bed area. These sand infiltration beds are illustrated on Figure 4-8.

It is noted that new alternative energy generating facilities will be constructed on these beds (construction starting in 2010).

A photovoltaic energy system will be constructed on beds 2 – 7 and 9 – 10. Once the photovoltaic system is installed, these beds cannot be used for treated water recharge. Also, bed No. 8 cannot be used for treated water recharge because it will be isolated from the treated-water distribution system.

A wind turbine system (2 turbines) will be installed on beds 33 and 34 which will remove these beds from treated-water recharge operations.

The beds that can no longer be used for treated water recharge after construction of the alternative generating facilities are also illustrated on Figure 4-8. Once the beds are removed from service, the 36 remaining beds will have a total area of 851,000 sf.

The infiltration beds contain four feet of sand with an effective size of 0.30 to 0.60 mm. The sides of the beds are covered with four inches of crushed stone screened to obtain a size of 1-1/2 to 3-1/2 inches. The soils under the sand and crushed stone are predominately native soils and some fill material classified as a clean sand or gravel. The O&M manual for the WPCF states that the average design hydraulic loading of the sand beds is 10 gallons per day per square foot of bed area (gpd/sf). Based on a total of 851,000 square feet of bed area, a hydraulic loading of 10 gpd/sf, and the assumption that 30 percent of the beds should be held in reserve at the maximum month condition, a total sand bed capacity of 6 mgd is estimated. In practice, plant personnel have had no problems with ponding in the sand beds and have never had trouble recharging the treated water. Operating experience indicates that the beds themselves can pass more than 6 mgd. The plant staff has observed that some beds provide faster infiltration than others. Consideration should be given to completing a hydraulic load test to develop a more empirical design hydraulic loading rate.

Though the sand layers of the infiltration beds may be capable of passing more than 6 mgd, the ultimate capacity of the beds is uncertain. This is due to many site specific considerations that are independent of the WPCF recharge such as seasonal and multi-year variations in the height of the groundwater table. Due to this uncertainty in the physical capacity in the groundwater system, the 2007 WWFP was approved with an Adaptive Use Management Plan that allows

treated water recharge up to 4.2 mgd with the following actions identified if seasonal high groundwater levels become too high:

- Permitting and construction of new recharge facilities at an approved (in the 2007 WWFP) site near the Route 6 and Route 132 interchange.
- Continued evaluation of additional treated water recharge sites and concepts.
- Further evaluation of the high groundwater impacts to verify they are correlated to the WPCF recharge.
- Installation of additional monitoring wells.
- Potential additional groundwater modeling.
- Drainage modifications and groundwater pumping to mitigate the impacts.
- Approval requests, permitting, and implementation of additional treated water recharge sites and concepts.
- Discontinuation of sewer extension until the impacts are addressed.
- Possible purchase of affected properties and creation of open space.
- Diversion of flow to the new site at the Route 6 and Route 132 interchange.

8. **Septage Receiving and Handling Facilities.** The Hyannis WPCF currently treats and produces several types of wastewater residuals, including sludge, septage, trap grease, screenings, and grit. Septage and trap grease are collected from Town residences and commercial establishments and hauled to the Hyannis WPCF for treatment. Screenings, grit, and sludge are produced by the Hyannis WPCF as a result of treating wastewater, septage, and trap grease, and must be disposed of off site.

A flow schematic of the septage facility is shown in Figure 4-6. The septage handling facilities are housed within the septage processing building. Septage is off-loaded from transport trucks into a receiving station equipped with a rock trap and bar rack before flowing to a 50,000-gallon raw septage storage tank. The raw septage is then pumped to a single screw-type grit classifier through two parallel trains each consisting of a 3 HP grinder, a 50 HP recessed impeller pump, and a cyclone degritter. The degritted sludge flows by gravity to one of two degritted septage storage tanks where it is co-mingled with the primary and/or WAS. The combined sludge is then thickened by two parallel trains, each consisting of a 3 HP grinder, a 20 HP variable speed progressive cavity pump, and two 2-meter gravity belt thickeners (GBTs). The GBTs have a total capacity of 1,440,000 gallons per week based on a loading rate of 400 gpm per machine and an operating frequency of six hours per day, five days per week. Thickened sludge discharged from

each GBT is pumped to a storage tank by one of two 5 HP, 9-inch, duplex plunger pumps. The contents of the thickened sludge storage tank are pumped to a truck and disposed of off site. All four storage tanks are mixed and aerated by five positive displacement blowers. Most of the septage handling equipment has been in service since 1991.

9. **Plant Water System.** Water for in-plant use is supplied by three 15 HP horizontal centrifugal pumps located in the secondary pump building. The pumps are controlled by VFDs to maintain a pressure setpoint in the common pump discharge header. These pumps were placed in service in 2000 and appear to be in good operating condition.

10. **Summary of Facility Capacities.** The treatment and/or flow capacities of the major treatment facilities are summarized below:

TABLE 4-2

CAPACITY SUMMARY OF EXISTING HYANNIS WPCF PROCESSES

COMPONENT	CAPACITY (MGD)
Parshall Flumes	
Minimum	0.6
Peak	15.6
Aerated Grit Chamber (Peak Hour)	20
Primary Clarifiers	
Maximum Month	6.8
Peak Hour	17
Aeration Tanks (Maximum Month)	4.2
Secondary Clarifiers	
Maximum Month	4.4
Maximum Day	4.7
Peak Hour	7.1
Chlorination Facilities (Peak Hour)	13.8
Sand Infiltration Beds (Maximum Month)	6

4.3 HYANNIS WPCF COLLECTION SYSTEM

A. **System History and Description.** Figure 4-9 illustrates the existing (January 2010) collection system in the Town of Barnstable. (Construction was started on the Stewarts Creek {AOC H1} Sewer Extension and the new Lincoln Road/Main Street Pump Station in Spring of 2010.)

The earliest gravity sewer lines were constructed in downtown Hyannis in 1937. A majority of the downtown area is sewered with 8- and 10-inch vitrified clay sewers. A trunk line runs the length of South Street, and ranges in size from 8- to 10-inches in diameter. Prior to 1989, the trunk line ran to a pump station at South Street. This station was replaced in 1989 by a new pump station located at Old Colony Road. The downtown sewer area has been expanded a number of times, through the addition of gravity sewers and small pump stations. A majority of the sewage eventually flows to the trunk lines on South Street and into the Old Colony Station.

Sewers were added along Ocean Street and the Bay Shore Road area in 1968. These asbestos cement (AC) sewer pipes range from 8- to 16-inch in diameter, with 8-inch being used on most of the residential streets. The sewage is pumped via three pump stations. Two pump stations share a common force main which connects with the Old Colony Road station force main in route to the wastewater treatment facility.

The sewers along West Main Street are 8- to 18-inches asbestos cement lines which are constructed in 1972. This trunk line served a large commercial area of Hyannis, and ends at the Main Street station. The Main Street station originally discharged to the South Street gravity line and to the Old Colony Road station; but in 2009 a new force main was installed from the Main Street station to the Hyannis WPCF.

The sewers serving the areas surrounding Gosnold Street, Old Colony Road, and Oak Neck Road are 8-inch and 10-inch PVC lines which were installed in 1989. The sewage is pumped through a combination of 5 separate pump stations to the intersection of South Street and Ocean Street, where it flows to the Old Colony station.

The Village of Barnstable system was constructed in 1980, and serves Main Street (Route 6A), Hyannis Road, Millway Road, Commerce Road, and the residential streets off Commerce Road. All of the residential streets are served by 8-inch sewers, which flow to 14- to 18-inch trunk lines

at the end of Freezer Road Pump Station. All of the sewers installed under this contract are asbestos cement.

The sewers in Independence Park and the surrounding commercial areas are 8- to 21-inch PVC lines and were constructed in 1994. They lead to two pump stations, one on Independence Drive and the second at the end of Enterprise Road (at the Hyannis WPCF site).

The vacuum sewer system is located in Bearses Way and Route 28 and leads to the vacuum sewer station at the Hyannis WPCF site. This system was constructed in 2003. The vacuum lines range from 6- to 10-inch PVC vacuum lines.

There has been infilling after these major sewer extensions to connect additional areas and roads including:

- Corporation Street
- Summerside Lane
- An additional portion of North Street

A sanitary sewer typically has a rated design life of 50 years. However, with proper system maintenance and appropriate repairs, it is possible to extend the life of a sewer significantly. A breakdown of the age and lengths of various lines in the system is presented in Table 4-3 below:

TABLE 4-3

OVERVIEW OF HYANNIS WPCF SEWER SYSTEM

TIME PERIOD	APPROXIMATE LENGTH OF SEWERS INSTALLED (FEET)	PREDOMINANT MATERIAL	OVERALL PERCENTAGE
1937 - 1940	20,000	Vitrified clay	9
Unknown*	15,000	Vitrified clay	7
1944 – 1958	7,000	Asbestos cement	3
1965 – 1969	21,000	Asbestos cement	10
1970 – 1980	52,000	Asbestos cement	25
1981 – 1990	69,000	PVC	32
1991 - 2009	30,000	PVC	14
* No year was listed on record drawings, or record drawings were not located as reported in 1993 Needs Assessment Report.			

Most of the sewers in the Town of Barnstable are well under 50 years old. The earliest downtown Hyannis lines reached a 50-year life in 1987. However, based on information received from the operation and maintenance staff, these sewers are inspected and maintained regularly, and are operating with minimal problems.

B. Summary of Existing Collection System Facilities.

1. **Gravity and Vacuum Sewers.** The Town of Barnstable's wastewater collection system consists of approximately 41 miles of 8- through 21-inch gravity and vacuum sanitary sewers (exclusive of building laterals) within the Villages of Barnstable and Hyannis. A majority of the lines are 8 inches in diameter serving the side streets.

As discussed in Chapter 2, the 2007 WWFP documents the Town plan to extend sewers to several Wastewater Areas of Concern and to improve several bottlenecks in the existing collection system. These extensions and improvements as detailed in the plan would add up to 46 miles of new collection system.

2. **Pump Stations and Force Mains.** In addition to the sewers, the Town of Barnstable owns, operates, and maintains 24 pump stations. These range in size from very small stations serving private developments to larger stations which serve downtown areas while also accepting flow from one or more smaller stations.

Most of the pump station force mains discharge to gravity sewers. Some, however, discharge into shared force mains which pump directly to the treatment facility. A schematic of the stations showing the general flow pattern is presented in Figure 4-10. There is a total of approximately 11 miles of force mains, ranging in size from 4-inch to 20-inch diameter.

Table 4-4 summarizes information on the force mains for each of the Town owned stations, including size, material, age, and location of discharge.

In addition to the stations maintained by the Town, there are a number of pump stations which discharge into the sanitary sewer system, but are privately maintained. No specific records are kept on these stations, and a listing is presented in Table 4-5.

TABLE 4-4

HYANNIS WPCF SUMMARY OF PUMP STATIONS AND FORCEMAINS

PUMP STATION [1]	YEAR BUILT	PUMP HORSEPOWER	PUMP STATION DESIGN FLOW (GPM)	FORCE MAIN SIZE (INCHES)	FORCE MAIN MATERIAL	APPROXIMATE LENGTH FORCE MAIN (FT)	DISCHARGE LOCATION
Freezer Road	1975	50	750	12 [2]	DIP	17,000	Water Pollution Control Facility
Rendevous Lane	1975	3	75	4	DIP	1,700	Gravity sewer on Rendezvous Lane
Route 6A	1975	5	350	8	DIP	1,300	Gravity sewer on Main Street
Main Street	2009/1972	16	650	8 / 14	DIP	8,600	Water Pollution Control Facility
Old Colony Road	1989/1956	75	2300	16 / 20	AC	10,000	Water Pollution Control Facility
Brant Lane	1986	5	80	4	DIP	1,100	10-inch gravity sewer on Old Strawberry Hill Road
Mark's Path	1989	30	300	6	DIP	1,900	Water Pollution Control Facility
Sea Meadow	1988	7 ½		4	DIP	2,700	Water Pollution Control Facility
Sudbury Lane	1984	1	100		N/A	N/A	Gravity sewer on LaFrance
Kalmus Beach	1989	20	450	8	DIP	5,700	15-inch gravity sewer at intersection of South and Ocean Streets
Estey Avenue	1989	7 ½	400	8	PVC	410	Gravity sewer on Estey Avenue
Sea Street	1981	n/a	200	4	DIP	860	8-inch gravity sewer on Sea Street
Toby Circle	1989	n/a	170	6	PVC	1,500	Gravity sewer on Old Colony Road
Oak Neck Road	1989	3 ¾	120	4	PVC	450	Gravity sewer on Chase Street
Sea Street Beach	1989	n/a	100	4	PVC	520	Gravity sewer at intersection of Sea/Gosnold & Morris

TABLE 4-4 (continued)

PUMP STATION [1]	YEAR BUILT	PUMP HORSEPOWER	PUMP STATION DESIGN FLOW (GPM)	FORCE MAIN SIZE (INCHES)	FORCE MAIN MATERIAL	APPROXIMATE LENGTH FORCE MAIN (FT)	DISCHARGE LOCATION
Periwinkle	1981	3	130	4	PVC	1,000	8-inch gravity sewer on Sea Street
Bay Shore Road	1968	30	450	8/10	AC	1,700	10-force main at Ocean Street pump station
Baxter Road	1983	2	500	4	PVC	230	8-inch gravity sewer on Baxter Road
Gosnold Street	1968	3	2200	6	AC	1,000	8-inch gravity sewer on Ocean Street
Ocean Street	1968	30	380	10	AC	1,100	20-inch force main at South Street
Independence Drive			230			1,300	Gravity sewer on Independence Drive
Enterprise Road			1500			100	Water Pollution Control Facility
Bearses Vacuum Station	2003	15	280	6	DIP	700	Water Pollution Control Facility
West Main Street/ Lincoln Road[2]	2011	60	600	8 / 12	DIP	8,400	Water Pollution Control Facility
Marston Ave/ H1[2]	2011	15	600	4	DIP	4,200	Gravity sewer on West Main Street

Notes:

1. All stations have two pumps, with the exception of Old Colony Road, which has three pumps.
2. This station and Force Main is currently under construction with completion estimated in 2011. Once complete it will have two pumps with 600 gpm capacity, and space for two additional pumps.
3. Approximately 8,500' of 4- and 6-inch dual force main was installed in Route 132 as part of that road reconstruction to service a planned pump station at the Cape Cod Community College as discussed in Chapter 2.

DIP= Ductile iron pipe
AC=Asbestos cement
PVC=Polyvinyl chloride

TABLE 4-5

LISTING OF PRIVATE PUMP STATIONS

Baxter, Hudson	133 Pleasant Street
Barnstable Airport	660 Barnstable Road
Barnstable Housing Authority	200 Stevens Street
Baxter, Warren	77 Pleasant Street
BJ's	420 Attucks Lane
Calvery Baptist Church	25 Lincoln Road
Cape Cod Hospital	27 Park Street
Cape Cod Mall	793 Iyannough Road
Cape Crossroads	800 Bearse's Way
Christmas Tree Shop	655 Route 132
Christy's Plaza	489 Bearse's Way
Christy's/Dunkin Donuts	317 Falmouth Road
D'Angelo's	702 Iyannough Road
D'Angelo's, Minuteman Press & others	181 Falmouth Road
Day's Inn	702 Iyanough Road
D'Olympio's	55 Iyannough Road
Four Points Sheraton	1255 Iyannough Road
Gosnold Treatment Center	71 Pleasant Street
Heritage House Motel	259 Main Street
Holiday Inn	707 Iyannough Road
Hyannis Marina	21 Arlington Street
Hyannis Nissan	268 Stevens Street
Hyannis Regency	1127 Iyannough Road
Hyannis Resort	287 Iyannough Road
Independence Medical LLC	70 Independence Drive

Infinium Software	75 Attucks Lane
Main Street Apartments	30 Main Street
New England Telephone	49 Ocean Street
New Hope Com. Baptist Church	105 Stevens Street
New World Bank	417 Barnstable Road
Northeast Dental	274 Barnstable Road
Off Track Bedding	167 Corporation Street
Pet Supplies	685 Route 132
Pixy 103 Radio	154 Barnstable Road
Royal Hyannis Hotel	1470 Iyannough Road
Sentinel Products Corp.	70 Airport Road
Steamship Authority	71 South Street
Tiki Port Restaurant	720 Iyannough Road
Tracy Volkswagen	686 Iyannough Road
Woman's Body Shop	155 Attucks Lane

C. **Sewer Capacity.** The hydraulic capacity of the collection system was completed in 1993 as summarized in the Needs Assessment Report of the 2007 WWFP. The analysis identified several bottlenecks related to existing flows and several have since been corrected. Others are recommended for improvements as listed in Chapter 2.

Infrastructure evaluations for the Hyannis Growth Incentive Zone developed a limited SewerCAD model for the collection system in the downtown Hyannis area. This model developed additional capacity information for this area of Town and led to recommendations to upgrade the Main Street and Old Colony Road pump stations, make improvements to the South Street gravity lines, and develop a new pump station at West Main Street/Lincoln Road to intercept future flows from the western part of town and direct that flow to the Hyannis WPCF. The Main Street pump station modifications are now complete and the West Main Street/Lincoln Road pump station is scheduled for completion in 2011.

The SewerCAD model should be expanded to the complete collection system and incorporate the sewer extensions proposed by the 2007 WWFP. Use of the SewerCAD model is the most efficient way to evaluate capacity limitations especially as alternative sewer routes are considered.

D. **Infiltration/Inflow (I/I).** Infiltration is the leakage of groundwater into the sewer through cracks or openings in the sewer pipes and/or manholes. Inflow is the flow of surface water into the sewer through storm drains, roof leaders, and/or sump pumps in basements of buildings.

The last infiltration/inflow (I/I) investigation was completed in 1988 by Whitman and Howard Engineers. They found no pattern of increased wastewater flow during or immediately following rain events. This finding indicates that inflow is negligible. This finding makes sense because there are no combined sewers in Barnstable; therefore there is no inflow from storm drains. Also, the Town enforces the sewer use regulations that specifically do not allow connection to roof leaders or sump pumps to the sewers; therefore, there should be no inflow from these sources.

The 1988 I/I investigations did estimate as much as 0.55 mgd of infiltration on average and 0.7 mgd of peak infiltration based on measurements of nighttime inflow that was assumed to be infiltration.

When the I/I investigation report was submitted, the Town questioned the assumption that the nighttime flows were equivalent to infiltration because there are a large number of commercial establishments that can contribute nighttime flow including motels, restaurants, nightclubs, and the Cape Cod Hospital. The nature of these businesses in a tourist area makes it plausible that nighttime activities and after hours cleanup cause a sewer discharge during the early morning hours. The Town performed BOD testing in an attempt to determine the components of the nighttime flows. Low BOD values would support the idea that most of the flow would be infiltration; however, the results showed BOD levels which were close to or higher than domestic sewage.

The Town also questioned the possibility of infiltration occurring where the sanitary sewers are above groundwater. Infiltration which occurs in the wastewater collection system is directly related to groundwater levels. Thus, infiltration should be prevalent only in those sewers which are below the groundwater table. The fact that Whitman & Howard identified most of the infiltration coming from three subareas where the sewer lines are above the groundwater further

justified the Town's belief that nighttime flows should not be classified as I/I. An anomaly existed in the data, which could not be resolved without further investigative work.

During the 1993 Needs Assessment evaluation for the 2007 WWFP, performing additional sampling, inspection, and/or television inspection work was recommended. It was understood that infiltration and inflow do not have significant impacts on existing treatment plant operations or permit compliance. Therefore, it was decided not to pursue further I/I investigations with the exception of yearly television inspection work.

As part of the 1993 Needs Assessment evaluation for the 2007 WWFP, it was decided to reduce the previous average infiltration estimate by 100,000 gpd to adjust for the data anomaly.

As part of the CWMP Project, the average water consumption for all of the properties connected to the Hyannis WPCF was summed and compared to the average influent flow at the WPCF. The average water consumption was 1.53 mgd and the WPCF influent (summarized on Table 4-1) was 1.46. It is understood that not all water consumption becomes wastewater due to non-potable water uses of irrigation, outdoor car and boat washing, etc. A factor of 90 percent is used to convert water consumption to wastewater generation rates. Using this approach, an average annual infiltration of 0.08 mgd is estimated. This value represents 6 percent of wastewater generation summed for all the properties served, and 6.5 percent of the total flow to the Hyannis WPCF. When this average annual I/I value is used with the gravity sewer lengths and diameters discussed previously, an infiltration rate of 210 gallons per day per inch mile (gpdim) is calculated which is slightly below the typical range of 250 to 500 gpdim as recommended by the New England Interstate Water Pollution Control Commission (NEIWPCC) in their "Guides for the Design of Wastewater Treatment Works" (also referenced as Technical Report No. 16 or TR-16). It is understood that I/I will increase at times of rainy weather and high groundwater conditions. And maximum month and peak day escalating factors should reflect these periodic increases.

It is generally considered not cost effective to remove infiltration where less than 10,000 gpdim exists. The cost of locating and removing it are generally greater than the cost of transportation and treatment.

4.4 MARSTONS MILLS WWTF

A. **Background.** The Marstons Mills WWTF is located at 730 Osterville-West Barnstable Road. The facility serves an elementary school, middle school, associated athletic fields, as well as a residential neighborhood of 30 homes. The Site Plan for this facility is illustrated in Figure 4-11.

B. **Treatment Facilities.** The facility is a satellite wastewater treatment facility recharging to 34 leaching pits located in the athletic fields. The permitted design flow for this system is 32,000 gpd. Currently, the existing facility treats up to 22,000 gpd (based on monthly reports provided by the WWTF operations staff).

Each school and the housing complex is served by a septic tank. The schools are also served by grease traps prior to the septic tanks. The septic tanks are used for primary settling and grit removal. The septic tanks for the housing complex and the elementary school are 18,000 gallons, and the middle school septic tank is 30,000 gallons. The septic tank serving the middle school also receives return flows from the treatment facilities' denitrification filter's backwash and waste sludge from the secondary process.

The two flows are then combined in an 18,000 gpd flow-equalization tank, located at the head end of the existing WWTF. The combined wastewater flow is aerated in this tank by coarse bubble diffusers which mix the wastewater and reduce the potential for odors. Air for the flow-equalization tank is provided by two positive displacement blowers. The contents of the flow-equalization tank is pumped to the distribution box where the influent flow is split using V-notch weirs to two rotating biological contactor (RBC) units for removal of BOD and ammonia-nitrogen (NH_3-N). NH_3-N is converted to NO_3-N by biological nitrification. Currently, a portion of the flow entering the distribution box from this tank is recycled back to the flow-equalization tank through a gravity drain in the bottom of the splitter box. This provides some treatment (low BOD influent).

Each RBC unit is 12 feet in diameter by 21 feet long and provides a site for biological microbial growth. The rotating shaft brings the microorganisms in contact with both the organic matter in the wastewater and oxygen in the atmosphere, and also keeps the system mixed. The two RBCs at the facility offer a combined total surface area of 158,000 ft^2. Following RBC treatment, the wastewater flows by gravity from the RBCs into the 10-foot diameter clarifier for removal of the

settleable solids and the floatable scum. Polymer is added to the RBC effluent to facilitate better clarification. The sludge and scum are collected and flow into a mudwell where they are eventually mixed with backwash water from the denitrification filters and recycled back to the 30,000-gallon septic tank serving the middle school.

After leaving the secondary clarifier, the secondary effluent passes through two denitrification filters which biologically remove nitrate (nitrate is biologically converted to nitrogen gas which is released to the atmosphere) and filter out any remaining suspended solids. Methanol is added to the flow to provide a supplemental carbon source before the denitrifying filters to assist the biological denitrification. Each filter is backwashed every other day into the mudwell, where backwash is combined with the sludge and scum from the secondary clarifier and returned to the 30,000-gallon septic tank. The existing filters provide a total filtering area of approximately 54 ft^2. Treated water from the denitrification filter flows through and then is collected in a clearwell and flows through an ultraviolet light disinfection chamber and a V-notch weir for flow measurement.

Flow from the clearwell enters the dosing chamber, which can be aerated. The final effluent is alternately distributed between two leaching areas by the two dosing pumps. Two-thirds of the flow is pumped to an area of 22 leaching pits located beneath the middle school football field area. The remaining flow is distributed to 12 leaching pits located beneath the elementary school softball field area.

Figure 4-12 illustrates the flow schematic of this WWTF.

This WWTF was originally constructed in 1994 to serve two schools and the athletic fields. In 2006 it was upgraded and expanded to serve a new residential neighborhood. Before 2006 the performance of the WWTF was very poor due to irregular flows (that are typical of a school system) and other factors. The residential neighborhood helped even out the flows and the operation of the WWTF was conveyed from the Barnstable School Department to the Barnstable Department of Public Works Water Pollution Control Division (WPCD). The WPCD staff has improved operations and plant performance significantly. Since December 2008, there have been no permit exceedances and effluent total nitrogen has been less than 5 mg/L

Monthly operating data was analyzed for the period of October 2006 through September 2009 to evaluate system performances. This data is summarized in Appendix 4-4 and the influent and effluent trends are illustrated on the following figures:

- Figure 4-13, Effluent Flows
- Figure 4-14, Influent and Effluent BOD concentrations
- Figure 4-15, Influent and Effluent TSS concentrations
- Figure 4-16, Effluent Nitrogen concentrations.

The discharge of this WWTF is in the Zone II area (an area of land that could contribute groundwater to a public water supply well), and MassDEP may require that the WWTF meet a new effluent limit of less than 3 mg/L total organic carbon (TOC), especially if the plant is expanded. This parameter is not currently monitored but four samples have been analyzed since October 2009 and the average TOC concentration in the effluent was 8.4.

4.5 RED LILY POND CLUSTER SYSTEM

The Red Lily Pond cluster septic system is located west of the Red Lily Pond and Elizabeth Lake in Centerville. Figure 4-17 illustrates the site plan of this cluster system.

The system is comprised of a low-pressure collection system and grinder pumps. The wastewater flow is conveyed to two septic tanks, and the septic tank effluent flows to two sets of infiltration chambers. The Town Department of Public Works, Water Pollution Control Division operates the system.

The system was constructed in 1993 to reduce phosphorus impacts to Red Lily Pond and Elizabeth Lake from the individual septic tank discharges that were occurring before 1993. The system was not designed for nitrogen and phosphorus removal, but was designed to relocate the septic tank effluent to a new location that is outside of the watersheds to the ponds. No performance sampling of the system occurs and it is assumed to produce comparable effluent to any conventional single family septic system.

4.6 PRIVATE WASTEWATER TREATMENT FACILITIES

There are two privately owned WWTF facilities in Barnstable located at the Cotuit Stop and Shop Plaza along Route 28 and the Cape Regency Skilled Nursing and Rehabilitation Center in Centerville as illustrated on Figure 4-18. These treatment systems were required by MassDEP because the properties were located too far from an existing public sewer to connect and they have land uses that could produce wastewater flows greater than 10,000 gallons per day. When properties exceed this flow threshold, they are required to meet some stringent treatment requirements (compared to the MassDEP Title 5 requirements), and comply with a MassDEP discharge permit.

The following text briefly describes these small privately owned WWTF's.

A. **Cotuit Landing Stop and Shop WWTF.** This WWTF is a membrane bioreactor (MBR) treatment system with a permitted maximum-day capacity of 21,600 gpd (0.022 million gallons per day). It started operations several years ago (pre 2006) and has operated well. Performance data was reviewed for 2006 through 2009 and the WWTF typically produces treated water in the 2 to 7 mg/L total nitrogen range. The plant did have a few exceedances above 10 mg/L total nitrogen during that period. The influent flow is typically in the range of 0.005 to 0.009 mgd, but there have been a couple of peak day readings at 0.02 mgd.

This WWTF was designed with a larger capacity than was needed for the shopping center so that additional flow could be connected in the future if needed. The finding that the WWTF has seen a couple of peak day readings near its flow capacity indicate that it may not have as much reserve capacity as originally believed.

B. **Cape Regency Skilled Nursing and Rehabilitation Center WWTF.** This WWTF is also a MBR treatment system with a permitted maximum day capacity of 0.02 mgd. It started operations in 2009 and eight months of data was reviewed. During that time the plant performed well. Effluent total nitrogen was in the range of 3 to 5 mg/L and the maximum day flow at the plant was 0.013 mgd.

4.7 INDIVIDUAL HOME I/A SYSTEMS.

There are a total of 71 properties with individual-home I/A systems as illustrated on Figure 4-18. These are individual-home septic systems that are typically designed to provide greater treatment of dissolved and suspended solids and nitrogen. Their installation is typically required by the Board of Health or other local regulating agency to replace a failed septic system or allow development of a property that might not allow the use of a regular Title 5 septic system. The locations of these systems are quite scattered across the Town except for two concentrations in the Craigville Beach area and along Falling Leaf Pond in Osterville. The ones at the Craigville Beach area are reflective of the high groundwater conditions, dense development, and past failing septic systems as documented in the 2007 WWFP (this area was recommended for sewer extension in the 2007 WWFP). The concentration at Falling Leaf Pond in Osterville was for nitrogen removal requirements.

These systems are typically comprised of an engineered treatment process that is located between the septic tank and the leaching (recharge) system of a conventional Title 5 septic system. They have aerated and anoxic components that support the biological treatment system. MassDEP requires that these systems remove approximately 50 percent of the nitrogen in the wastewater and produce an effluent of less than 19 mg/L total nitrogen. Research of these systems at the Septic System Test Center located at the Massachusetts Military Reservation and overseen by the Barnstable County Department of Health and Environment indicates that these systems can provide this level of nitrogen removal performance when they are sited, designed, constructed, and operated properly. Studies by Barnstable County Department of Health and Environment of the systems that are actually installed at peoples homes across Cape Cod often do not perform this well at nitrogen removal. Approximately half of the systems at Cape Cod homes meet the 19 mg/L requirement and the other half does not meet it. The research for the requirement exceedances includes insufficient design and operations.

Review of the data from the 71 systems in Barnstable indicates similar performance. These systems did not meet the expected performance forty percent of the time which is slightly better than the Cape Cod system performance.

4.8 INDIVIDUAL HOME SEPTIC SYSTEMS

The great majority of properties in Barnstable are served by individual-home traditional septic systems. These systems are generally very good at removing suspended solids from the raw wastewater in a septic tank so that the septic tank effluent can be infiltrated into the ground and returned to the groundwater system. This feature of traditional septic systems protects against the fouling (plugging) of the infiltration system which would cause a system failure and bring the wastewater to the ground surface. As a result they are good at protecting human health because they prevent human exposure to the wastewater. They are not very good at protecting environmental health. Research indicates that they only remove 25 to 40 percent of nitrogen in the septic tank and in the leaching system so that the discharge that reaches the groundwater system has a nitrogen concentration of approximately 24 mg/L total nitrogen. The Massachusetts Estuaries Project uses this value (23.63 mg/L total nitrogen) in their nitrogen modeling evaluations. Due to this high nitrogen discharge concentration, and the high wastewater flow coming from all the individual septic systems in Town; the groundwater system receives a high nitrogen load which is then conveyed to the estuaries. The Massachusetts Estuaries Project (discussed in detail in the next chapter) has determined that individual septic systems are the largest source of nitrogen to the estuaries. Typically this source comprises 75 to 85 percent of the total nitrogen load to the estuaries.

Remediating the current nitrogen load from individual-home septic systems to the estuaries will be the most significant need of this project.

4.9 COMMUNAL SEWAGE HOLDING (TIGHT) TANKS

The Cape Cod Condominium Complex was a cottage community in the northeast corner of Barnstable (illustrated on Figure 4-18) that was converted to condominiums. This portion of Barnstable has soils with low infiltration capacity and the individual septic systems at this site have failed. Due to the septic failures and the long distance of the site from the municipal sewers, the condominium complex has installed a sewage holding tight tank which must be pumped out periodically. The property owners have investigated other options of wastewater management that have not proceeded.

4.10 WATER SUPPLY INFORMATION

A. **Description of Existing Facilities.** Water supply in the Town of Barnstable is provided by four different water purveyors. The Town of Barnstable Hyannis Water System provides water to the Village of Hyannis and has 12 supply wells. The Barnstable Fire District provides water to the Village of Barnstable by means of four active supply wells. The Cotuit Water District actively uses five wells to provide water to the Village of Cotuit. The Centerville-Osterville-Marstons Mills (C-O-MM) Water District utilizes 19 wells for supplying water to the Villages of Centerville, Osterville, and Marstons Mills. The Village of West Barnstable does not currently have a public water supply system, although some of the neighboring water districts have fire hydrants within the Village and provide water service to a few properties in West Barnstable. The West Barnstable Fire District has a Water Commission and an approved well site, but no wells or distribution system. All of these wells have Zone II delineations in accordance with MassDEP requirements. The Zone II delineation is the area of the land that could contribute groundwater to the well under "the most severe pumping and recharge conditions that can be realistically anticipated." The regulations define these conditions as 180 days of pumping at safe yield and no recharge from precipitation. The Zone II areas are typically determined by a hydrogeologic study involving particle transport computer modeling at the time that the water supply well is permitted. The delineation provides specific land use restrictions as identified in Chapter 2, Section 2.3.B.

The Town of Barnstable has delineated Zone of Contributions (ZOC) areas which are similar to the Zone II areas but created by a separate computer modeling study. These ZOC areas have become a zoning overlay. It is noted that the Town is currently rechecking its Zone II delineations through a contract with the Cape Cod Commission as identified in Chapter 2, Section 2.6.A.

Figure 4-19 illustrates the areas of Town served by public water supplies, and the ZOC areas. It is noted that most of the Town is served by public water supply except the village of West Barnstable.

The following table summarizes average monthly pumping flows for the four water purveyors. The data is a compilation of three years' worth of data (2006, 2007, and 2008) from annual reports submitted to MassDEP.

TABLE 4-6

AVERAGE MONTHLY WATER SUPPLY PUMPAGE[1, 2]

MONTH	WATER PURVEYOR				
	BARNSTABLE FIRE DISTRICT	C-O-MM	COTUIT	HYANNIS WATER SUPPLY	TOTAL
January	0.3	1.4	0.3	1.9	3.9
February	0.3	1.4	0.3	1.9	3.9
March	0.2	1.5	0.3	1.8	3.8
April	0.3	1.8	0.4	2.1	4.6
May	0.5	2.9	0.6	2.6	6.7
June	0.7	4.5	0.9	3.3	9.4
July	0.9	5.5	1.1	4.0	11.5
August	0.9	5.4	1.0	3.9	11.2
September	0.6	3.9	0.8	3.0	8.4
October	0.4	2.3	0.5	2.4	5.5
November	0.3	1.5	0.3	1.9	4.1
December	0.3	1.5	0.3	2.7	4.9
Average Annual	0.5	2.8	0.6	2.6	6.5
Maximum Month[3]	0.9	5.5	1.1	4.0	11.5
Minimum Month[4]	0.2	1.4	0.3	1.8	3.8

Notes:

(1) All values are in millions of gallons per day (mgd).
(2) Data based on annual reports from 2006, 2007, and 2008 to MassDEP.
(3) Maximum month for all water purveyors was July.
(4) Minimum month was February for C-O-MM and Hyannis Water Supply, March for Barnstable Fire District, and December for Cotuit.

Comparison of the average annual, minimum month, and maximum month averages indicates the land use (and water consumption) seasonality in these villages. Peaking factors have been summarized in the following table to illustrate how minimum month and maximum month pumpage compares with the average annual pumpage for that purveyor.

TABLE 4-7

PUMPAGE PEAKING FACTORS

MONTH	WATER PURVEYOR[2]				
	BARNSTABLE FIRE DISTRICT	C-O-MM	COTUIT	HYANNIS WATER SUPPLY	TOTAL
Average Annual[1]	0.5	2.8	0.6	2.6	6.5
Maximum Month[1, 3]	0.9	5.5	1.1	4.0	11.5
Minimum Month[1, 4]	0.2	1.4	0.3	1.8	3.8
Maximum Month Peaking Factor[5]	1.9	2.0	1.9	1.5	1.8
Minimum Month Peaking Factor[5]	0.5	0.5	0.5	0.7	0.6

Notes:
(1) Values are in millions of gallons per day (mgd).
(2) Data based on annual reports from 2006, 2007, and 2008 to MassDEP.
(3) Maximum month for all water purveyors was July.
(4) Minimum month was February for C-O-MM and Hyannis Water Supply, March for Barnstable Fire District, and December for Cotuit.
(5) Peaking factors are the ratio of the maximum or minimum month flow divided by the average annual flow.

These peaking factors will be used to estimate seasonal variations in wastewater flow generation.

B. **Capacity.** Each supply well has an associated pumping capacity, as reported at the time of the Zone II delineation for each well. These capacity values (based on active, inactive, and potential wells) are summarized in Table 4-8 and are compared to the average-annual and maximum-month pumping rates of the water purveyors. This comparison indicates sufficient capacity for existing water demands.

TABLE 4-8

SUMMARY OF WATER SUPPLIES, PUMPING RATES, AND CAPACITIES 2006-2008

WATER SUPPLY	AVERAGE ANNUAL PUMPING RATE (MGD)	AVERAGE MAX MONTH PUMPING RATE (MGD)	RATED CAPACITY (MGD)
Barnstable Fire District	0.5	0.9	5.3
C-O-MM Fire District	2.8	5.5	14.7
Cotuit Fire District	0.6	1.1	4.4
Hyannis Water Supply	2.6	4.0	11.7
TOTAL	**6.5**	**11.5**	**36**

4.11 WATER CONSERVATION EFFORTS

Each water district and purveyor has developed several ways to promote water conservation by their customers.

A. **Barnstable Fire District.** The Barnstable Fire District Water Department implements water conservation through the three primary mechanisms described below.

1. An inclining usage rate is in place for all users to encourage water conservation by charging higher rates for larger volumes. The rate schedule is as follows:

- $3.00 per thousand gallons for the first 45,000 gallons of use per six months.
- $4.25 per gallon for water use between 45,000 and 200,000 gallons.
- $7.00 per gallon for water use over 200,000 gallons.

2. The Water Department includes tips for efficient water use in its annual Consumer Confidence Report (CCR).

3. Periodically, the Water Department includes water conservation messages and reminders in water bills.

B. **C-O-MM.** The C-O-MM Water Department utilizes a variety of conservation measures, as discussed below.

1. An inclining usage rate is in place for all users, both residential and commercial, which encourages water conservation by charging higher rates for larger volumes. The rate schedule is as follows:

   - $35.00 for the first 20,000 gallons of use per six months (cost of $1.75 per thousand gallons for the first 20,000 gallons).
   - $2.90 per thousand gallons between 21,000 – 200,000 gallons.
   - $3.95 per thousand gallons from 201,000 gallons and up.

2. A list of voluntary water conservation steps is posted on the website (www.commwater.com) and is also distributed with the summer water bills. The voluntary measures include:

   - Avoid outside water use between 9:00 AM and 6:00 PM.
   - Odd numbered houses water on odd numbered days of the month and even numbered house water on even numbered days of the month.
   - Maintain lawn minimum height at 2-inches to protect roots and retain soil moisture.
   - Install rain shutoff devices on automatic sprinklers.

3. Public education measures include annual visits to local school and extensive material on the website (http://www.commwater.com/default.htm), including water conservation tips and a "Kids Korner" for young children.

4. Water efficient devices, including low flow showerhead and aerated faucets, are available to users at the office and are also made available at the annual Marstons Mills River Day and the Annual Meeting.

The Water Department has considered other conservation measures, such as moisture sensors for automatic sprinklers and a toilet rebate program to encourage replacement of 7-gallon-per-flush toilets. However, these measures have proved cost prohibitive and have not been able to be implemented.

C. **Cotuit Fire District**. The Cotuit Fire District Water Department currently implements several conservation measures, described below.

1. The Cotuit Fire District's Water Department has implemented an ascending rate fee structure, with unit costs increasing as water use increases, to encourage efficient water use. Water rates are as follows:

- $1.80 per 1,000 gallons for the first 30,000 gallons of water used per six months.
- $2.45 per thousand gallons between 30,000 – 80,000 gallons.
- $2.70 per thousand gallons between 80,000 – 120,000 gallons.
- $3.00 per thousand gallons over 120,000 gallons.

2. The Water Department dedicates a full page of their annual Consumer Confidence Report (CCR) to conservation and water use efficiency measures. The CCR presents information on ways in which water may be inadvertently wasted, including how much water is typically used for different uses, how much water is lost from hoses and dripping faucets, etc. In addition, conservation tips are provided, including a discussion on xeriscape techniques to reduce outdoor water use.

3. The Water Department provides indoor and outdoor water conservation kits free of charge, available at the Department office.

4. Each summer, the Water Department takes out an advertisement in the local newspaper encouraging the community to implement voluntary water conservation measures, including asking even-numbered houses to limit lawn watering to even-numbered days of the month while odd-numbered houses limit watering to odd-numbered days of the month.

The Water Department does not currently have an education program in place targeting schools, but may implement such a program in the future. Similarly, the Department may implement a rebate program for water-efficient devices in the future.

D. **Hyannis Water Supply.** The Hyannis Water Supply has a multi-faceted conservation program as listed below:

1. The residential fee structure is a primary means of encouraging water conservation. Residential water users are subject to an inclining user fee, which involves increased unit costs as the water use increases. The rates encourage the users to consume as little as possible.

2. The Water Supply Division provides water-efficient devices free of charge, including shower timers, faucet aerators, low flow showerheads, and toilet flappers, to its customers.

3. Public education efforts make up another facet of the conservation program. The Water Supply Division has teamed with private companies to encourage use of water-conserving devices. It has also teamed with the Cape Cod Commission and AmeriCorps to provide water fairs at local schools. Coloring books are provided as an education tool for children.

4. The Water District leak detection program inspects half of the system every year, which means the entire system is checked for leaks every two years. When leaks are detected, they are repaired as soon as possible.

It is noted that commercial users are subject to a flat fee structure due to the inherently variable water demands of various commercial establishments. For example, an insurance office has a significantly smaller use than a restaurant.

In addition to the conservation measures currently in place, the Hyannis Water Supply Division plans to improve in various areas. They would like to be able to target commercial water users in a way that takes into account the variable nature of commercial uses. They would like to promote conservation in relation to lawn irrigation. Discussion with District staff indicates that many municipal and state buildings have outdated devices, and the Water Supply Division would like to be able to develop and implement a program to upgrade the devices to more efficient ones. In addition, the Division would like to be able to be able to perform a statistical performance evaluation to determine what parts of the conservation program are working and where improvement needs to be made.

Chapter 5

Existing and Future Conditions in the Town of Barnstable

CHAPTER 5

EXISTING AND FUTURE CONDITIONS IN THE TOWN OF BARNSTABLE

5.1 INTRODUCTION

This chapter provides a description of the existing and future conditions in the Town of Barnstable with respect to land use, water consumption, nutrient loading, and wastewater generation. Embayment water quality, groundwater hydrology and quality, ponds and lakes, and other natural and physical characteristics, as well as protected cultural areas, and population and demographics within Barnstable are discussed.

Existing and future conditions are analyzed on a Town-wide scale as well as on a village and watershed level to provide a detailed understanding to develop the wastewater and nutrient management needs of the Town.

5.2 PLANNING AREA AND COMPONENT DELINEATIONS

As discussed in Chapter 1, the Project Planning Area is the Town of Barnstable but there are several water-resource and nutrient-management issues that extend beyond the town borders and must be considered. Figure 1-1 illustrates the planning area and several of these water resource areas that extend beyond the town boundaries.

The planning area contains several watershed areas to the following main marine estuaries that have (or will have) nutrient limits:

- Popponesset Bay
- Rushy Marsh (No formal nitrogen TMDL limits are expected to be developed for this water body due to its small size and history of shoaling.)
- Three Bay System
- Centerville River System
- Halls Creek

- Lewis Bay
- Barnstable Harbor

All of these watersheds except the Rushy Marsh, Centerville River System, and Halls Creek watersheds extend beyond the town boundaries into the neighboring towns as illustrated on Figure 1-1. Coordination with these neighboring towns is needed to develop a successful plan to meet the nitrogen limits for these estuaries.

Figure 1-1 also illustrates the public water supply Zones of Contribution (ZOC) areas. These areas include Zone II areas and are the areas that may provide groundwater to public water supply wells. Several of these ZOC areas extend across town borders.

The Town of Barnstable is also unique due to the Village structure and delineation within the town itself. Figure 1-1 illustrates the Town's seven villages: Barnstable, West Barnstable, Cotuit, Marstons Mills, Osterville, Centerville and Hyannis, all of which have their distinct character.

These areas, and their overlapping nature, are considered in this chapter.

5.3 TOWN GOALS WITH RESPECT TO WASTEWATER AND NUTRIENT MANAGEMENT

Chapter 1 of this report references the vision statement and comprehensive plan goals of the Town of Barnstable as outlined in the Barnstable Comprehensive Plan (BCP).

In summary, this project will work within the guidelines of this vision and their goals, and strive to meet the following Town specific goals outlined in the BCP pertaining to wastewater and nutrient management:

- Growth shall be located in areas where infrastructure capacity is in place or has the ability to absorb development impacts through concurrently planned expansion. Redevelopment of existing developed areas is the preferred form of development (Goal 1.1).
- Manage residential development and redevelopment to protect sensitive embayments and drinking water supply, offset growth incentives in the Growth Incentive Zones

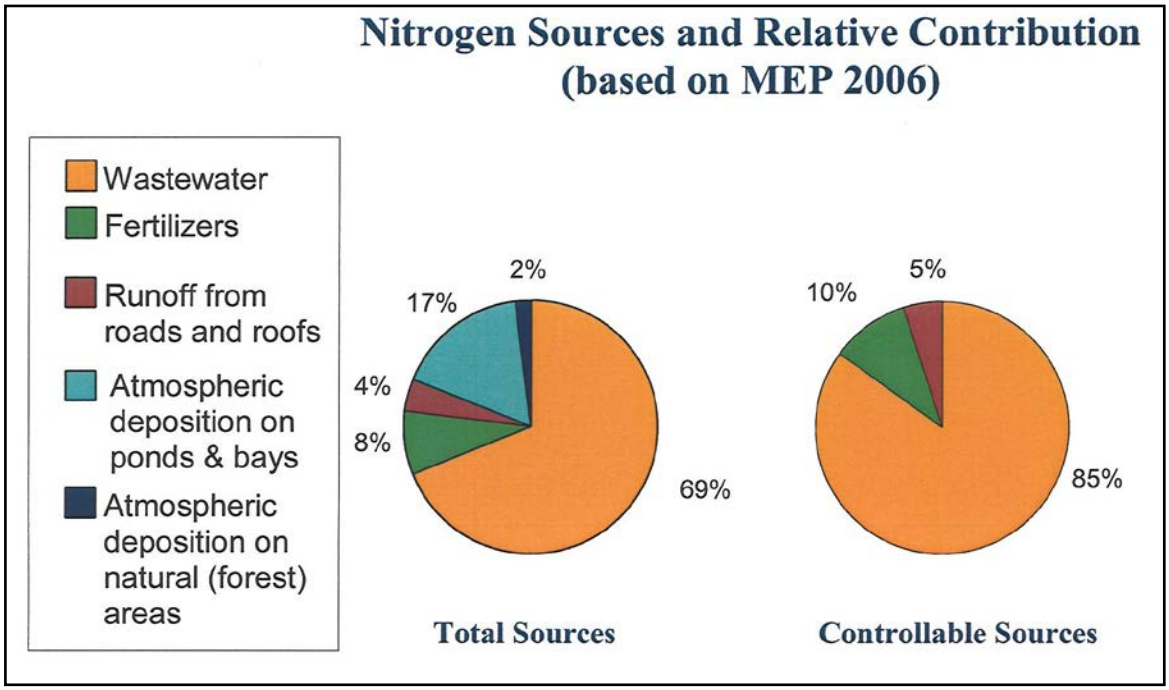
(GIZ) and densely developed residential areas, manage traffic circulation, preserve open lands, agricultural lands and cultural, historic and scenic landscapes (Goal 1.6).

- Minimize wastewater contamination of water resources from private or public wastewater management systems to improve drinking water quality, with the ultimate goal of achieving an untreated water supply, and to improve the ecological integrity of streams, ponds and coastal embayments using all available data including MEP data (Goal 2.6.1).
- Encourage, in coordination with the Wastewater Facilities Plan, the use of public and private wastewater treatment facilities in appropriate areas where they will provide environmental or other public benefits (Goal 2.6.2).
- Encourage the use of innovative or alternative wastewater treatment technologies to achieve higher quality effluent discharge to better protect natural resources, especially water resources with the ultimate goal of achieving an untreated water supply and ecological integrity of streams, ponds and coastal embayments (Goal 2.6.3).
- Provide adequate wastewater treatment facilities to meet community need while protecting the quality and quantity of our sole source aquifer (Goal 4.3.1).
- Provide infrastructure required for growth centers and redevelopment areas (Goal 3.5).

5.4 EMBAYMENT WATER QUALITY RELATED TO NITROGEN IMPACTS AND MEP REPORT FINDINGS

One of the largest issues associated with wastewater and nutrient management planning on Cape Cod is the marine water quality impacts from the nitrogen in wastewater (particularly septic system) discharges. Nitrogen is typically the limiting nutrient in marine waters, which means that the other essential nutrients for plant growth (e.g., phosphorus, potassium, etc.) are in sufficient supply, and the addition of nitrogen to marine water will produce a corresponding growth of algae. Algae are the suspended and attached plant material that can foul the water, making it unattractive for swimming, fishing, and boating. The algae will typically settle to the bottom of the embayment, smothering shellfish resources and, through decay, deplete oxygen in the water. The oxygen depletion can cause unpleasant odors and produce fish kills. As documented in the Massachusetts Estuaries Project (MEP) Technical Reports, the excessive nitrogen loading to the Town's embayments is damaging these water resources and could impact property values and ultimately the tourist and summer home economy of many portions of Barnstable.

The excessive nitrogen loading originates from several sources, including roof and road runoff, lawn and agricultural fertilizers, and atmospheric deposition. On Cape Cod, wastewater from on-site systems is the largest nitrogen source in the watershed. The illustration below depicts the typical sources and relative quantity of nitrogen to the estuaries:



The pie chart on the left illustrates the relative quantity of all the sources, or "Total Sources," while the chart on the right illustrates the relative quantity of the sources that could be controlled in the future, also called "Controllable Sources." Although it is not feasible to effect a change on the nitrogen that infiltrates from atmospheric deposition, we can control the nitrogen loadings from the other sources. The wastewater source represents 69 percent of the "Total Sources" and 85 percent of the "Controllable Sources" depicted above. Collecting and treating the wastewater provides the best chance of solving this problem.

The estuary depicted in these charts is the Three Bay System, and the chart and preceeding paragraph of text is from the Guidance Document prepared by Three Bay Preservation Inc. entitled "Understanding Nitrogen Pollution and Wastewater Management at Three Bays and Cape Cod". Each estuary will have unique percentages for its nitrogen sources; but they tend to be similar to the percentages presented above.

Chapter 1 (Section 1.2.B) of this Needs Assessment Report provided detailed background on the development of nitrogen limits and Total Maximum Daily Limits (TMDL) for the group of 89 estuaries in Southeastern Massachusetts, of which five have large watersheds in Barnstable. The TMDLs are developed through the following steps:

1. The Massachusetts Estuaries Project develops threshold nitrogen concentrations for the estuaries and nitrogen loading limits for the watersheds to these esturies. These evaluations and nitrogen limits are documented in a Technical Report for each estuary.
2. Massachusetts Department of Environmental Protection (MassDEP) reviews the Technical Report for each estuary and then develops a TMDL Report for it. The TMDL Report is submitted to USEPA for their review and approval.
3. USEPA reviews the TMDL Report for compliance with respect to the Federal Clean Water Act and, if acceptable, issues a TMDL for the estuary.

As discussed in Chapter 1, final Technical Reports have been issued for Popponesset Bay, Rushy Marsh, Three Bays System, and Centerville River System. TMDL Reports and USEPA TMDLs have been issued for all of these except Rushy Marsh, and a TMDL Report and formal nitrogen limit is not expected for Rushy Marsh due to its small size and history of shoaling. A draft Technical Report has been issued for Lewis Bay. No reports have been issued for Barnstable Harbor.

As stated in the MEP reports, overall indication of biological health and determination of site-specific nitrogen thresholds for an estuary requires integration of key habitat parameters such as infauna and eelgrass, sediment characteristics, and nutrient related water quality information, particularly dissolved oxygen (DO) and chlorophyll a. These characteristics are briefly described below.

- **Infaunal Communities (Benthic Organisms).** These organisms are defined as aquatic animals that live within the bottom substratum rather than on the surface. These organisms are an important indicator to the overall health of an embayment, especially in areas that do not support eelgrass beds. For example, a healthy habitat area would present low organic matter loading and high DO where a stressed habitat area would present high organic matter loading and low DO. The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they

live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Howes, B.L., et al. 2004).

- **Eelgrass Distribution.** Eelgrass distribution studies were conducted by the MassDEP Eelgrass Mapping Program and used by the MEP technical team. These studies incorporate surveys at different intervals and historical data from aerial photographs. The primary use of the data is to indicate if eelgrass currently and/or previously exists (existed) in a basin and if large-scale system-wide shifts have occurred. The loss of eelgrass is believed to be from high nitrogen concentrations, the production of algae that results from the high nitrogen concentrations, and the subsequent shading of the eelgrass (Howes, B.L., et al. 2004).
- **Water Quality.** Dissolved oxygen levels near atmospheric equilibrium are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they occur rarely. DO levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. Conversely, biological processes that consume oxygen from the water column vary directly with temperature, explaining why the lowest levels of oxygen are found in the summer in southeastern Massachusetts embayments when the biological respiration rates are greatest (Howes, B.L., et al 2004).

Evaluation of these characteristics by the MEP has developed an understanding of the health of the embayments and the amount of nitrogen that needs to be removed to remediate current nitrogen impacts as discussed below.

A. **Popponesset Bay Estuary.** The Popponesset Bay Estuary is classified overall as having high quality within the Popponesset Bay Central Basin, significant impairment within the upper areas of Popponesset Bay, including Shoestring and Ockway Bays and significant impairment to degraded embayments within the Mashpee River. Within the Popponesset Bay System, wastewater from on-site septic systems represents 66 percent of the overall nitrogen load and 82 percent of the local controllable nitrogen load.

The local controllable load represents nitrogen sources that could be potentially regulated by municipalities, therefore local controllable loads do not include nitrogen loading from water body surface areas and "natural" surfaces.

B. **Rushy Marsh.** The Rushy Marsh Pond Estuary is classified overall as having severe degradation in both the channel and main basin as provided in the MEP Technical Report. Historically, Rushy Marsh was connected to Nantucket Sound through an inlet and once the inlet closed, a culvert was constructed to connect the marsh with the Sound. Within Rushy Marsh, wastewater from on-site septic systems represents 54 percent of the overall nitrogen load and 89 percent of the local controllable nitrogen load. MEP determined however, that removal of the entire nitrogen load would still result in an estuarine system that is significantly impaired, and this is due to restricted tidal flushing. There are currently no plans to issue a TMDL for this estuary and plans to remediate the water quality include opening the inlet through an improved culvert design. Once the outlet is reopened, monitoring will continue to verify improvements to water quality.

C. **Three Bays Estuary.** The Three Bays Estuary is classified overall as having moderate impairment in Cotuit Bay and West Bay, moderate to significant impairment in the lower portion of North Bay, significant impairment to severe degradation is Prince Cove and the upper portion of North Bay and severe degradation in Warrens Cove. Within the Three Bays System overall, wastewater from on-site septic systems represents 69 percent of the overall nitrogen load and 85 percent of the local controllable nitrogen load.

D. **Centerville River Estuary.** The Centerville River Estuary is classified overall as having healthy habitat conditions in the upper reaches of the Centerville River and in Bumps River, healthy to moderately impaired in the mid reaches of the Centerville River and healthy to significantly impaired in the lower reaches of the Centerville River. Scudder Bay is classified as having moderate impairment and East Bay as having moderate to significant impairment. Within the Centerville River System overall, wastewater from on-site septic systems represents 80 percent of the overall nitrogen load and 87 percent of the local controllable nitrogen load.

E. **Halls Creek Estuary.** Halls Creek was evaluated as part of the MEPs work on Lewis Bay and is classified overall as having healthy habitat conditions. Because Halls Creek is classified as a salt marsh and not an embayment; its salt marsh structure does not support eelgrass and has a high tolerance to nitrogen inputs. The present condition of Halls Creek is below the nitrogen

threshold for this system, meaning the nitrogen threshold is not currently being exceeded. Within the system overall, wastewater from on-site septic systems represents 62 percent of the overall nitrogen load and 66 percent of the local controllable nitrogen load; the recharge from the Hyannis WPCF represents 10 percent of the overall nitrogen load and 10 percent of the local controllable nitrogen load.

F. **Lewis Bay Estuary.** The Lewis Bay Estuary is classified overall as having moderate impairment in Mill Creek and Hyannis Inner Harbor, and significant impairment in Uncle Roberts Cove and the Lewis Bay main basin. Within the Lewis Bay System overall, wastewater from on-site septic systems represents 55 percent of the overall nitrogen load and 63 percent of the local controllable nitrogen load. The load from on-site septic systems is lower for this estuary because a portion of the watershed is currently sewered. Within the Lewis Bay System overall, the WWTF represents 20 percent of the overall nitrogen load and 22 percent of the local controllable nitrogen load.

G. **Summary of Wastewater Nitrogen Load Reductions to Meet TMDLs.** Figure 5-1 summarizes the loading reductions that would be necessary to achieve the TMDL by reducing existing on-site subsurface wastewater disposal system loads, and ignoring the other sources of nitrogen. This figure and the resulting removals for each watershed is based on detailed water quality modeling completed by the Massachusetts Estuaries Project. As part of their modeling evaluations summarized in their Technical Report, they evaluated the septic system nitrogen removals needed to meet the TMDL on a sub-watershed by sub-watershed basis. They used judgment on which sub-watersheds to target for nitrogen removal and which ones to leave as they are. The judgment appears to be based on the nitrogen sensitivity of the individual sub-estuary and if the sub-watershed to that sub-estuary provides natural nitrogen attenuation. The judgment also appears to be based on the level of tidal flushing that individual sub-estuaries receive. Information on more detailed sub-watershed removals suggested by the Massachusetts Estuaries Project is attached in Appendix 5-4.

It is noted that this model to remove only septic tank effluent from selected sub-watersheds is only one of many possible ways to meet the TMDLs. It is recognized that there was some judgment applied to select these sub-watersheds.

Additional development and land use has occurred in Barnstable since the MEP evaluations were completed and development will continue as allowed by zoning and other land use requirements.

The MEP also conducted a buildout analysis for each of the estuarine watershed areas to understand how the nitrogen source would increase at the buildout condition. As the nitrogen load from the various sources increases over time, and the nitrogen limit (TMDL) remains the same; therefore a higher percentage of wastewater nitrogen removal must be considered as part of wastewater and nutrient management planning for the future and Appendix 5-4 also contains an estimate of the loading reductions that would be necessary to achieve the TMDL by reducing future on-site disposal system loads, ignoring all other sources of nitrogen. These values were developed by incorporating MEP's buildout analysis into their landuse model for each of the estuaries.

H. **Summary of Nitrogen Loadings to the Estuaries by Town.** Three of the estuaries that have nitrogen limits have watersheds that extend into the neighboring towns of Mashpee, Sandwich, and Yarmouth. Barnstable will need to work with these towns to meet the nitrogen limits in these shared watersheds.

Table 5-1 summarizes the nitrogen loadings to the estuaries by Town, as developed from information in the MEP Technical Reports and information developed by MassDEP. The Percentage of Total Nitrogen Load column in the table provides perspective on inter-municipal cooperation that is needed.

TABLE 5-1

SUMMARY OF EXISTING WATERSHED NITROGEN LOADINGS TO THE ESTUARIES BY TOWN

	EXISTING UNATTENUATED NITROGEN LOADING[6]									
	Total		**Barnstable**		**Mashpee**		**Sandwich**		**Yarmouth**	
Estuary	**kg/yr**	**% of total**	**kg/yr**	**% of total**	**kg/yr**	**% of total**	**kg/yr**	**% of total**	**kg/yr**	**% of total**
Popponesset Bay[1]	49,000	100	6,200	13	32,000	65	11,000	22	0	0
Rushy Marsh[2]	160	100	160	100	0	0	0	0	0	0
Three Bays Estuary[3]	69,000	100	59,000	86	150	0	9,700	14	0	0

EXISTING UNATTENUATED NITROGEN LOADING[6]										
	Total		**Barnstable**		**Mashpee**		**Sandwich**		**Yarmouth**	
Estuary	**kg/yr**	**% of total**	**kg/yr**	**% of total**	**kg/yr**	**% of total**	**kg/yr**	**% of total**	**kg/yr**	**% of total**
Centerville River Estuary[2]	62,000	100	62,000	100	0	0	0	0	0	0
Halls Creek[2]	10,000	100	10,000	100	0	0	0	0	0	0
Lewis Bay[4]	57,000	100	31,000	54	0	0	0	0	26,000	46
Barnstable Harbor[5]	N/A		N/A		N/A		N/A		N/A	

1. Loadings are from page 71 of 347 of "Intermunicipal Watershed Planning and TMDL Implementation to Restore Embayment Water Quality on Cape Cod", November 2008, MassDEP and UMass SMAST.
2. Total loads are from tabular summaries ("rainbow" spreadsheets) in the MEP Technical Reports.
3. Loadings are from page 109 of 347 of "Intermunicipal Watershed Planning and TMDL Implementation to Restore Embayment Water Quality on Cape Cod", November 2008, MassDEP and UMass SMAST.
4. Developed from MEP data by Stearns & Wheler GHD.
5. Nitrogen load information is not available (N/A) yet from the MEP.
6. All loadings rounded to two significant digits.

5.5 GROUNDWATER HYDROLOGY AND QUALITY

The groundwater in Barnstable provides drinking water supplies and recharges the ponds, wetlands, and coastal estuaries. All groundwater in Barnstable is supplied by the Sagamore Lens which is shared by the Towns of Bourne, Sandwich, Falmouth, Mashpee and Yarmouth; and the groundwater resources on Cape Cod as a whole are classified as a sole-source aquifer by USEPA.

A. **Flow Direction and Elevation.** Generally, the groundwater system (Sagamore Lens) is at its highest elevation in the mid section of the Town. Groundwater flows in a northerly direction towards Barnstable Harbor and in a southerly direction into Nantucket Sound. Figure 5-3 illustrates the generalized groundwater contours and elevations (based on evaluations completed for the 2007 WWFP) and indicates the direction of flow.

B. **Public Water Supplies.** As discussed in Chapter 4, the Town DPW operates the Hyannis Water System which supplies public water supply to properties in the Village of Hyannis. Three water/fire districts provide public water supply to other portions of Barnstable listed below:

- Barnstable Fire District Water Department provides water supply to the Village of Barnstable.
- The Centerville-Osterville-Marstons Mills (C-O-MM) Fire District Water Department provides water supply to those three villages.
- The Cotuit Fire District Water Department provides water supply to that village.

The West Barnstable Fire District has a Water Commission but does not currently have any Water Supply infrastructure.

According to the Town's LCP, the water suppliers own and maintain 443 miles of mains, 16 interconnections between the water suppliers in Barnstable and abutting town districts/water departments, 41 wells and 10 storage tanks. Over 2 billion gallons of water per year is pumped; and, combined, the suppliers own approximately 1,233 acres of watershed property. Figure 5-3 illustrates the Zones of Contribution (Zone I and II areas) to the public water supplies in the Town of Barnstable.

Public water supply systems have testing requirements for inorganic, volatile organic, and synthetic organic compounds, turbidity, disinfectants/disinfection byproducts, bacteria and radionuclides depending on a system's MassDEP approved plan. MassDEP also has a list of drinking water guidelines for chemicals that do not have maximum contaminant levels (MCLs) or maximum residual disinfectant levels (MRDLs).

Annually, public water supply systems must deliver to their customers a Consumer Confidence Report (CCR) which is an annual report on drinking water quality in their community. Reports are due every July 1 for the previous calendar year. The reports are mandated by the federal Safe Drinking Water Act and MassDEP is the state agency authorized to implement and enforce the CCR rule. The CCR summarizes concentrations of regulated and unregulated contaminants that were detected in the water supply during the previous year. Systems are not required to report on contaminants that were not detected. If a detected contaminant exceeds the standard or MCL, MassDEP is notified and the public water system must notify their consumers about the potential health effects and what they must do until the problem is solved. Community water systems are

defined as public water systems that have at least fifteen service connections or regularly serve at least 25 year-round residents.

Because water systems are not required to report on contaminants that were not detected in the water supply, the exact water quality parameters that are included in the reports vary by system. In general, water quality parameters reported in annual CCRs for groundwater systems include microbial constituents (total coliform and fecal coliform or E. Coli), regulated inorganic contaminants (arsenic, barium, nitrate, nitrite, perchlorate, alpha emitters), and regulated volatile organic compounds (chlorine, cis 1,2-dichloroethylene, total trihalomethanes, haloacetic acids, trichloroethylene, tetrachloroethylene). Lead and copper are reported based on 90th percentile concentrations and number of samples exceeding the action level, according to the Lead and Copper Rule. In addition, utilities may report monitoring results for currently unregulated contaminants which have been detected, such as sodium, sulfate, chloroform, methyl-tert-butyl-ethter (MTBE), and dichlorofluoromethane.

Table 5-2 summarizes the water quality parameters reported in the CCRs prepared by the Barnstable Fire District Water Department, C-O-MM Fire District Water Department, and the Cotuit Fire District Water Department.

(continued)

TABLE 5-2

SUMMARY OF CONSUMER CONFIDENCE REPORT (CCR) DATA FOR LOCAL WATER DEPARTMENTS

REGULATED CONTAMINANTS	MAXIMUM CONTAMINANT LEVEL (MCL)	MCL GOAL (MCLG)	BARNSTABLE FIRE DISTRICT WATER DEPARTMENT[1]	C-O-MM FIRE DISTRICT WATER DEPARTMENT[2]	COTUIT FIRE DISTRICT WATER DEPARTMENT[3]
			Range of Detections	**Range of Detections**	**Range of Detections**
Nitrate (ppm)	10	10	0.47 – 0.71	Not detected – 5.0	1.4 – 2.7
Alpha emitters (pCi/L)	15	0	Not reported	0.9	0 – 0.9
Radium	5	None	Not reported	Not reported	0 – 0.9
Lead and Copper	**Action Level (AL)**	**MCLG**	**90th Percentile / Samples Above the AL**	**90th Percentile / Samples Above the AL**	**90th Percentile / Samples Above the AL**
Lead (ppb)	15	15	7.7 / 1 site above AL	6 / 0 out of 45	2 / 0 out of 10
Copper (ppm)	1.3	1.3	0.79 / 2 sites above AL	0.820 / 0 out of 45	0.48 / 0 out of 10
Microbiological Contaminants	**MCL**	**MCL Goal**	**Range of Detections**	**Range of Detections**	**Range of Detections**
Turbidity (NTU)	Treatment Technique	None	Not detected – 1.0	Not reported	Not reported
Unregulated Contaminants	**Secondary MCL**	**Office of Research Standards Guideline**	**Range of Detections**	**Range of Detections**	**Range of Detections**
Chloroform (ppm)	--	60	0.88 – 2.9	Not detected – 2.3	Not detected – 1.1
Sodium (ppm)	--	20	13 – 24	5.2 – 31	8.9 – 19
Sulfate (ppm)	250	--	Not detected – 9.6	5.1 – 11	5.2 – 8.4
MTBE (ppm)	20 - 40	70	Not reported	Not detected – 0.27	Not reported

Notes:
(1) Data provided in the Barnstable Fire District Water Department's 2009 Consumer Confidence Report.
(2) Data provided in the C-O-MM Fire District Water Department's 2009 Consumer Confidence Report.
(3) Data provided in the Cotuit Fire District Water Department's 2009 Consumer Confidence Report.

C. **Water Quality.**

1. **Sampling at Hyannis WPCF.** A groundwater monitoring program was established for the Hyannis WPCF and was evaluated and summarized in the Town's 2007 WWFP. Several wells are sampled on a monthly basis and data since December 2004 was reviewed. The groundwater samples were analyzed for pH, specific conductance, ammonia, nitrate, chloride, copper, iron, manganese, sodium and sulfate. Once per year, the samples are also analyzed for potassium, volatile organics and total trihalomethanes. Although there have been fluctuations in the levels of individual constituents during this period of time there have been no dramatic changes in water quality and no alarming trends.

During this period of monthly testing, it had also been noted that there have been no detections of copper above the detectable limits. This is probably due to the corrosion control programs initiated by the water suppliers.

As discussed in Chapter 4; the Hyannis WPCF is operating very well and meeting its permit limits. As discussed in Chapter 3, Regulatory Issues, revised regulations may also include new limitations on total organic carbon (TOC) concentrations for treated waters recharged to Zone II areas. These new TOC limitations are intended to provide increased protection of groundwater supplies, limiting both the amount of naturally occurring organic carbon introduced to the groundwater as well as synthetic forms of organic carbon that may be present in treated water. Further, because many contaminants of emerging concern (CECs) including endocrine disrupting compounds (EDCs), pharmaceuticals, and personal care products (PPCPs) are organic in nature, reductions in total organic carbon are expected to generate similar reductions in concentrations of CECs introduced to groundwater through reductions in total carbon concentrations. As discussed in Chapter 4, Existing Wastewater and Water Infrastructure, the Hyannis WPCF does not have a current TOC limit and this parameter is not currently monitored. Several TOC samples have been collected and analyzed since October 2009, and based on data collected to-date, the average TOC concentration in the treated water was 7.1 mg/L.

2. **Sampling at Marstons Mills WWTF.** Sampling is required at the Marstons Mills WWTF as a result of their groundwater permit. Six groundwater monitoring wells are sampled for the parameters and at the frequency shown in Table 5-3.

TABLE 5-3

MONITORING WELL SAMPLING AT MARSTONS MILLS WWTF

PARAMETER	FREQUENCY OF ANALYSIS
Static Water Level	Monthly
pH	Monthly
Total Nitrogen (NO_2+NO_3+TKN)	Quarterly
Nitrate-Nitrogen	Quarterly
Nitrite-Nitrogen	Quarterly
Total Kjeldahl Nitrogen	Quarterly
Total Phosphorus (as P)	Quarterly
Orthophosphate (as P)	Quarterly
Volatile Organic Compounds	Annually

In addition, routine monitoring includes UV intensity, influent biological oxygen demand (BOD), influent and effluent total solids (TS), effluent total suspended solids (TSS), and effluent coliform.

3. **Sampling at Barnstable Solid Waste Division Site.** Groundwater monitoring for the Landfill has been performed since 1981. In all, there are 38 groundwater-monitoring wells in and around the Barnstable Landfill, including the three public supply wells operated by the Centerville Osterville Marston Mills (C-O-MM) Water Department. Based on historical results and MassDEP requirements, 33 of these wells are typically sampled on a semi-annual basis as part of the Landfill-monitoring program.

Water samples are analyzed for general chemistry parameters, volatile organics (VOCs), filtered metals, and field parameters. The general chemistry parameters analyzed include alkalinity, chloride, sulfate, and total dissolved solids (TDS). Filtered metals include arsenic (As), barium

(Ba), iron (Fe), manganese (Mn), and lead (Pb). Field parameters (pH, temperature, dissolved oxygen (DO), and conductivity) are measured in the field at each sample location.

The overall frequency of detection of organic compounds in the Landfill's monitoring array continues to be fairly low. In all, the data for organic compounds indicates only subtle groundwater impacts from the Landfill, with no indication of a significant change in groundwater quality over time. Likewise, the inorganic data indicate that water quality is largely constant over time in the monitoring well array. The groundwater analytical results over the last several years are very stable and do not vary from one sampling round to the next.

In the future, this site may be considered as a potential location for a new WWTF or treated water recharge site. As such, the nitrogen species of ammonium, nitrate, and total nitrogen should be added to the groundwater monitoring program to establish a recent baseline assessment.

4. **Water Supply Sampling**. Water supply sampling in the Town of Barnstable is done by each water supplier according to their MassDEP approved plan. As discussed above, annual reports are distributed to water supply customers annually outlining water quality sampling results.

Water quality as it relates to embayment water quality is discussed above in Section 5.4 and water quality as it related to ponds and lakes is discussed in the following section.

5.6 PONDS AND LAKES

The fresh surface water resources in the Town of Barnstable are numerous and consist of lakes, ponds, rivers, wetlands, and vernal pools. A brief discussion of these water bodies follows.

A. **Lakes and Ponds.** There are 25 great ponds within the Town of Barnstable as defined by the MassDEP as any pond or lake of 10 or more acres.

The following great ponds are illustrated on Figure 5-3.

- Garretts Pond
- Hamblin Pond
- Hathaway Pond (lower portion)
- Long Pond
- Lovell's Pond
- Middle Pond
- Mystic Lake
- Round Pond
- Rushy Marsh Pond (originally tidal)
- Shubael Pond
- Wequaquet Lake (including Bearse Pond)

According to the CCC Pond and Lake Atlas, there are 184 ponds in Barnstable totaling 1,892 acres. The atlas serves as a status report on the Cape Cod Pond and Lake Stewardship (PALS) program and reviews water quality data collected by volunteers during the 2001 PALS snapshot in order to gain Cape Cod specific nutrient indicators of pond impacts. Of the 184 ponds located within the Town of Barnstable, 38 ponds were sampled and of those 38, 28 were considered impacted by the CCC for chlorophyll a and total nitrogen and 21 were considered impacted for total phosphorus.

As part of this CWMP process, a pond water quality evaluation was completed, and an action plan to manage the ponds was developed. The report by EcoLogic LLC and Stearns & Wheler is attached as Appendix 5-1 and is entitled "Action Plan for the Barnstable Ponds", December 2009. This report builds on the data summary and analysis completed by the Cape Cod Commission as reported in the following recent reports:

- "Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities, Final Report", CCC, July 2008.
- "Lake Wequaquet Water Quality Assessment, Final Report", SMAST, January 2009.
- "First Order Assessment of the Indian Ponds (Mystic Lake, Middle Pond, and Hamblin Pond), Final Report", CCC, March 2006.

The Action Plan Report is a very detailed technical report that provides further water quality evaluation, identifies and considers various alternatives for protection and restoration of the Barnstable Ponds, and presents a detailed summary of existing conditions, recommended actions, and priorities for managing the ponds. The following Table 5-4 is a repeat of Table 11 in the Action Plan Report (in Appendix 5-1) and summarizes these key findings, priority, and recommendations. The ponds are grouped according to their depth.

TABLE 5-4

POND SUMMARY OF EXISTING CONDITIONS, MANAGEMENT PRIORITY, AND RECOMMENDED ACTIONS [1]

POND	PRIORITY [2] (LOW-MODERATE-HIGH-PROTECT)	FINDINGS [3] (TROPHIC STATES: O, M, E, H)	RECOMMENDED ACTIONS [4]
Ultra-Shallow			
Aunt Betty's	Low	M; Limited public access	Education, watershed BMP
Bog	Low	M; Impacted/at risk	Education, watershed BMP
Dunn's	Moderate	E; Impacted	Education, watershed BMP
Fawcett's	Low	M; Impacted/at risk; potential for increased residential development	Education, watershed BMP; guide future development to minimize nutrient export
Hathaway (South)	Protect	O; Un-impacted	Low impact recreational use & education in protected watershed
Little Parker	High	H; Impacted; does not support desired uses	Watershed BMPs; mitigate symptoms to improve aesthetics and recreational use: hand-pulling, benthic barriers
Little/Stony	Moderate	E; Impacted/at risk	Education, watershed BMP
Lumbert	Low	M; Private; Impacted/at risk	Education, watershed BMP
Mary Dunn	Low	O; Impacted/at risk	Education, watershed BMP
Mill (MM)	Protect	O; Impacted; Conservation area	Low impact recreational use & education in protected watershed
Mill (WB)	Moderate	E; Impacted	Education, watershed BMP
Red Lily (North, South)	Low	O; Impacted/at risk; Limited public access	Education, watershed BMP

POND	PRIORITY [2] (LOW-MODERATE-HIGH-PROTECT)	FINDINGS [3] (TROPHIC STATES: O, M, E, H)	RECOMMENDED ACTIONS [4]
Shallow			
Bearse	Moderate	M; Impacted/at risk; fanwort; potential for increased residential development	Macrophyte survey, strategies to control exotics; consider reducing density of future development
Coleman	Low	M; Impacted	Mitigate symptoms of eutrophication in recreational areas (benthic mats, hand harvesting); watershed BMPs
Eagle	Protect	E; At risk; watershed in land trust	Consider hand pulling emergent vegetation to improve shoreline access; maintain trails and prevent erosion
Elizabeth	Moderate	E; Impacted; Limited public access	BMPs, control stormwater on roadways
Garrett's	Low	O; At risk; limited public access	Education, watershed BMPs
Hinckley	High	E; Impacted	Stormwater management, septic inspections
Joshua	High	O; At risk; Town beach, natural vegetation; reference pond indicative of pristine conditions	Priority for protection, education, BMPs
Long (C'Ville)	High	E; Impacted; Town beach, highly developed; Does not support desired uses	Stormwater management, septic inspections, mitigating measures to improve recreational use: benthic mats, hand-pulling
Long (MM)	Moderate	E; Impacted; Conservation area; moderately protected	Education, watershed BMPs
Muddy	Moderate	E; Impacted/at risk	Education, watershed BMPs
No Bottom	Low	M; Impacted	Education, watershed BMPs
Parker	Moderate	E; Impacted	Education, watershed BMPs
Round (MM)	Moderate	E; Impacted/at risk; Private	Education, watershed BMPs
Schoolhouse	High	H; Impacted; does not support desired uses	

POND	PRIORITY [2] (LOW-MODERATE-HIGH-PROTECT)	FINDINGS [3] (TROPHIC STATES: O, M, E, H)	RECOMMENDED ACTIONS [4]
Shallow	Moderate	M; Impacted/at risk; vegetated shoreline; potential for increased residential development	Controls on future density and/or BMPs to minimize phosphorus migration to pond from surface runoff and groundwater
Deep			
Crystal	Low	M; Impacted	Education, watershed BMPs
Hamblin	High	O; At risk; Town Beach, conservation land; alum-treated; potential for increased residential development	Monitor for effectiveness of alum treatment; controls on future density and/or BMPs to minimize phosphorus migration to pond from surface runoff and groundwater
Hathaway (North)	High	O; At risk; Town beach, mix of conservation land and development	Continue acquisition of hydrologically important parcels in watershed
Lovell's	High	M; Impacted; Town beach closed; blue-green algal bloom; does not support desired uses	Priority for monitoring deep water phosphorus levels and N/P ratio; consider nutrient inactivation
Micah	Protect	O; At risk; Undeveloped, reference pond	Priority for monitoring deep water phosphorus levels
Middle	Protect	O; At risk; Public access, very clear	Priority for monitoring deep water phosphorus levels; consider acquisition of key parcels to control density
Mystic	High	M; Impacted/at risk; Public access, endangered mussels; permit phase for alum application; potential for increased residential development	Priority for alum treatment program; guide future development to minimize surface runoff and groundwater nutrient input
Neck	Moderate	O; Impacted/at risk;	Period monitoring to detect symptoms of degradation; watershed BMPs;

POND	PRIORITY [2] (LOW-MODERATE-HIGH-PROTECT)	FINDINGS [3] (TROPHIC STATES: O, M, E, H)	RECOMMENDED ACTIONS [4]
Shubael	High	O; Impacted; Town beach, exceptionally clear water potential for increased residential development	Priority for monitoring deep water phosphorus levels; septic inspections; guide future development to minimize nutrient input from surface runoff and groundwater seepage
Wequaquet	High	M; Impacted; Town beach, potential for future residential and commercial growth	Priority for monitoring deep water phosphorus levels; septic inspection; consider density controls on future development

Notes:
(1) This table is from "Action Plan for the Barnstable Ponds", December 2009, EcoLogic LLC and Stearns & Wheler GHD and summarizes the key findings and recommendations of that report.
(2) Higher priority assigned to ponds with town beach and/or public access.
(3) Trophic states: O – Oligotrophic; M – Mesotrophic; E – Eutrophic; H –Hypereutrophic. Definition of these trophic states and the ways that limnologists quantify these parameters is provided in the Barnstable Action Plan Report in Appendix 5-1 starting on page 6 and summarized in Table 3.
(4) These recommendations are described in Appendix B of the Action Plan Report.
BMP- Best Management Practices

The findings of the Action Plan Report go beyond a typical Needs Assessment evaluation and provide detailed recommendations that can be implemented as the full CWMP project proceeds. These recommendations will be incorporated into the Final CWMP report with updates.

B. **Wetlands.** Wetlands are identified as both fresh and salt water. The Town has conservation regulations and ordinances in place which regulate activities within the 100 foot buffer zone of a resource area. Resource areas include a surface water body, vegetation or unvegetated wetland, any land under said waters, and any land subject to flooding or inundation by groundwater, surface water, tidal action or coastal storm flowage.

Wetlands result from both salt water and fresh water and are valuable for flood protection, nutrient uptake and release, wildlife habitat and propagation, groundwater recharge, and open space for recreation and scenic beauty. The Wetlands Protection Act is administered and enforced by MassDEP's Wetlands Program. The Wetlands Protection Act imposes restriction on

the removal, filling, dredging, or alteration of any designated wetland. The wetland delineations within the Town are shown on Figures 5-3 and 5-4.

C. **Vernal Pools.** Vernal pools are temporary bodies of freshwater that provide critical habitat for a number of vertebrate and invertebrate wildlife species. Certified vernal pools and potential vernal pools have been identified by the Natural Heritage & Endangered Species Program in the Town of Barnstable and are shown on Figure 5-4.

5.7 BATHING BEACH RESOURCES

An important resource to the Town of Barnstable is its bathing beaches which attract residents and tourists alike. The beach sites which fall under the Town's Recreation Division include the following saltwater and freshwater beaches:

Marine Public Beaches:

- Covells
- Craigville
- Dowses
- Kalmus Beach
- Loop Beach
- Millway Beach
- Sea Street Beach (also known as Keyes Beach)
- Veteran's Beach

Freshwater Public Beaches:

- Hamblin's Pond Beach
- Joshua's Pond Beach
- Lake Wequaquet Beach
- Lovells Pond

All other ponds, beaches and ways to water in the Town fall under the jurisdiction of the Department of Marine & Environmental Affairs including Sandy Neck Beach or the Harbor Master.

Water quality bacteria monitoring is performed by the Barnstable County Board of Health and Environment in collaboration with the Barnstable Health Department, which test public and semi-public beaches weekly for indicator organisms during the summer bathing season (June to August). Sampling is performed for 26 public marine beaches and 15 public freshwater beaches for the presence of the indicator organism Enterococcus bacteria; in addition to 14 semi-public marine and freshwater beaches. The state bacterial standard for Enterococcus is 104 cfu/100mL (colony forming unit per milliliter) and levels above that cause public bathing beach closures to insure the safety of public health.

Table 5-5 displays the occurrence of bathing beach closures due to elevated levels of bacteria over the past three years according to the data supplied by the Town of Barnstable Coastal Health Resource Coordinator. From the data below it appears the most closures occurred during this time period in the villages of Cotuit and Hyannis. Exceedances of the bacterial health standard were not all experienced after a storm event; exceedances after a storm event are typically indicative of stormwater runoff causing the elevated bacteria levels.

TABLE 5-5

SUMMARY OF BATHING BEACH CLOSURES BY VILLAGE (2007-2009)

SAMPLE DATE	BEACH	VILLAGE	RESULT[(1)] ON FIRST TEST	RESULT[(1)] ON RETEST	DATE REOPENED	STORM EVENT[(2)]
06/23/09	Bone Hill Rd	Barnstable	>400	242	06/25/2009	Yes
08/04/09	Hathaway Pond	Barnstable	240	8	08/05/2009	Yes
06/23/09	Indian Trail	Barnstable	154	202	06/25/2009	Yes
07/09/07	Millway	Barnstable	>400	2	07/10/2007	Yes
06/23/09	Millway	Barnstable	>400	>400	06/25/2009	Yes
06/23/09	Scudder Lane	Barnstable	>400	>400	06/26/2009	Yes
08/27/07	Covells	Centerville	256	<2	08/28/2007	No
06/30/08	Covells	Centerville	268	26	07/03/2008	Yes
06/30/08	Craigville	Centerville	130	48	07/03/2008	Yes
07/23/07	Fifth Ave	Centerville	334	<2	07/24/2007	Yes
08/27/07	Fifth Ave	Centerville	168	2	08/28/2007	No
06/16/08	Shallow Pond	Centerville	280	52	06/18/2008	Yes

SAMPLE DATE	BEACH	VILLAGE	RESULT[1] ON FIRST TEST	RESULT[1] ON RETEST	DATE REOPENED	STORM EVENT[2]
08/11/08	Cordwood Rd	Cotuit	188	12	08/13/2008	Yes
08/18/08	Cotuit Bay Shore (semi-public)	Cotuit	116	<2	08/19/2008	No
06/23/09	Cotuit Bay Shores	Cotuit	110	74	06/24/2009	Yes
07/30/07	Crockers Neck	Cotuit	248	2	07/31/2007	Yes
07/21/09	Crocker's Neck	Cotuit	184	10	07/22/2009	No
07/28/09	Crocker's Neck	Cotuit	132	<2	07/29/2009	No
08/04/09	Crocker's Neck	Cotuit	310	4	08/06/2009	Yes
08/18/09	Crocker's Neck	Cotuit	>400	<2	08/19/2009	No
08/25/09	Crocker's Neck	Cotuit	206	344	08/27/2009	No
06/02/09	Cross St	Cotuit	108	2	06/03/2009	No
08/11/08	Little River Rd	Cotuit	154	22	08/13/2008	Yes
08/06/07	Loop	Cotuit	134	6	08/07/2007	No
06/04/07	Oregon	Cotuit	238	<2	06/05/2007	Yes
08/11/08	Oregon	Cotuit	220	4	08/13/2008	Yes
07/28/09	Oregon	Cotuit	114	<2	07/29/2009	No
06/16/08	Ropes	Cotuit	>400	66	06/18/2008	Yes
06/30/08	Ropes	Cotuit	106	72	07/03/2008	Yes
08/11/08	Ropes	Cotuit	>400	20	08/13/2008	Yes
06/23/09	Ropes	Cotuit	110	14	06/24/2009	Yes
06/16/08	Estey Ave	Hyannis	156	<2	06/18/2008	Yes
06/30/08	Kalmus (Ocean)	Hyannis	374	40	07/02/2008	Yes
05/31/08	Kalmus (Yacht)	Hyannis	>400	8	06/03/2008	N/A
06/04/07	Kennedy Memorial	Hyannis	>400	4	06/05/2007	Yes
07/09/07	Keyes	Hyannis	124	2	07/10/2007	Yes
05/21/08	Keyes	Hyannis	236	6	05/23/2008	N/A
06/16/08	Keyes	Hyannis	>400	28	06/18/2008	Yes
07/21/08	Keyes	Hyannis	126	2	07/23/2008	Yes
07/28/08	Keyes	Hyannis	164	2	07/30/2008	Yes
08/18/08	Keyes	Hyannis	212	2	08/19/2008	No
06/04/07	Veteran's	Hyannis	>400	4	06/05/2007	Yes
05/31/08	Veteran's	Hyannis	118	6	06/03/2008	N/A

SAMPLE DATE	BEACH	VILLAGE	RESULT[1] ON FIRST TEST	RESULT[1] ON RETEST	DATE REOPENED	STORM EVENT[2]
06/04/07	East (Town) Eugenia Fortes	Hyannisport	>400	2	06/05/2007	Yes
08/11/08	East (Town) Eugenia Fortes	Hyannisport	156	16	08/13/2008	Yes
06/18/07	Hamblins Pond	Marstons Mills	560	220	06/19/2007	Yes
06/25/07	Hamblins Pond	Marstons Mills	640	12	06/26/2007	No
07/28/08	Middle Pond	Marstons Mills	740	16	07/30/2008	Yes
06/04/07	Prince Cove	Marstons Mills	>400	50	06/05/2007	Yes
06/30/09	Regency Drive Homeowners	Marstons Mills	496	32	07/01/2009	Yes
07/21/08	Garrett Pond	West Barnstable	444	<4	07/23/2008	Yes
06/23/09	Sandy Neck	West Barnstable	106	42	06/24/2009	Yes

Note:

1. Results are in units of Enterococci Colony Forming Units (CFU) per 100 milliliter.
2. N/A in the "Storm Event" column means sampling was done during the pre-season.

5.8 SHELLFISH RESOURCES

The Town of Barnstable has many shellfish resource areas and commercial fisherman rely on productive and healthy shellfish beds for their livelihoods. Shellfish resources are also important recreationally.

The Town's Natural Resource Division is responsible for the protection and enhancement of the town's natural resources, enforcement of various laws relating to fish and game, marine and recreational use, land management and environmental laws. The division also provides protection and enhancement of the town's shellfish resources.

Management by the Town's Natural Resource Division includes the following:

- Managing and performing shellfish propagation projects for select species of economically and recreationally important shellfish.
- Assisting the Massachusetts Division of Marine Fisheries with constant water quality monitoring of local classified areas and instituting management protocols for the areas. Water quality testing and shellfishery management by the state are mandated by the Federal Food and Drug Administration's National Shellfish

Sanitation Program for areas used for the public consumption of shellfish. Assessing coastal zone projects and performing surveys and reports for such projects. Performing shellfish surveys for resource management purposes.

- Formulating, integrating, disseminating and maintaining shellfishery management information for the general public.
- Interacting with federal, state and local authorities, agencies and groups regarding shellfish management, regulatory, enforcement, educational and private shellfish aquaculture issues.
- Report, grant and contract writing as well as comprehensive review studies including GIS/GPS mapping.

Shellfish resources within the Town of Barnstable are illustrated on Figure 5-5. Designated shellfish resources are categorized by the Division of Marine Fisheries (DMF) as follows:

- *Approved* – Open for harvest of shellfish for direct human consumption subject to local rules and state regulations.
- *Conditionally Approved* – During the time area is approved it is open for harvest of shellfish for direct human consumption subject to local rules and state regulations.
- *Conditionally Restricted* – During the time area is restricted it is only open for the harvest of shellfish with depuration subject to local rules and state regulations.
- *Management Closure* – Closed for harvest of shellfish. Not enough testing has been done in the area to determine whether it is fit for shellfish harvest or not.
- *Prohibited* – Closed for harvest of shellfish.
- *Restricted* – Open for harvest of shellfish with depuration subject to local rules and state regulations or for the relay of shellfish.

Figure 5-5 is a large scale view of the resource areas and in many cases there are many designations within one area. For additional site specific shellfish information, access the Town of Barnstable, Natural Resource Division's website at: http://www.town.barnstable.ma.us/MarineEnvironmental/Shellfishing. Click on "Shellfish Area Maps" to search for specific resource areas within the Town.

Figure 5-5 also illustrates the anadromous fish presence within the Town, shellfish suitability areas, shellfish sampling stations and presence within the lobster harvest zone. The "anadromous fish presence" GIS-layer includes known coastal anadromous fish spawning habitat

and runs within the Town of Barnstable. The "shellfish suitability areas" GIS-layer comprises habitats suitable for ten species of shellfish along the coast of Massachusetts, the ten species represented are:

- American Oyster
- Bay Scallop
- Blue Mussell
- European Oyster
- Ocean Quahog
- Quahog
- Razor Clam
- Sea Scallop
- Soft-shelled Clam
- Surf Clam

The shellfish sampling stations shown on Figure 5-5 range from sites for collecting water quality and shellfish samples, to monitoring marine biotoxins such as Paralytic Shellfish Poison (PSP) or as it is commonly referred to "Red Tide", to locations of marines and mooring fields; several sampling stations are located in and around the Town of Barnstable as indicated on Figure 5-5. The Town of Barnstable is also located within the "lobster harvest zone."

5.9 ADDITIONAL NATURAL RESOURCES AND PHYSICAL CHARACTERISTICS

A. **Topography, Geology and Soils.** The topography of the Town of Barnstable is illustrated in Figure 5-6 and the geology of the Town is illustrated in Figure 5-7. The topography of the Town ranges from 0 to 266 feet, with the highest elevation being within the area of Route 6.

Figure 5-7 illustrates the Town's soils as being primarily of the following classifications, although several classifications exist:

- *Barnstable Outwash Plain Deposits* – Mostly gravelly sand with some pebble and small boulders. North part of the deposits includes some clay till, clayey silt, and large boulders. Some areas may be underlain by silt and clay.
- *Mashpee Pitted-Plain Deposits* – Mostly gravelly sand with some pebble and small boulders.

- *Sandwich Moraine Deposits* – A veneer of sandy to silty till from 3 - 25 feet thick underlain by stratified sand and gravel.
- *Glacial Lake Deposits* – Deposits associated with the proglacial lake in Cape Cod Bay. Mostly a discontinuous veneer of clay and silt over ice-contact deposits composed of gravelly sand, gravel, till and large boulders.
- *Marsh & Swamp Deposits* – Mostly decaying marine marsh plants mixed varying amounts of sand, silt and clay. Underlain by glacial, marine, and freshwater deposits, capped by live marine marsh plants.
- *Dune Deposits* – Mostly sand derived from beach deposits, deposited by wind action to form dunes.

Refer to Figure 5-7 for additional classifications and for geologic classification areas.

Figure 5-8 was developed to illustrate the soil classifications within the Town of Barnstable. The soil classifications displayed on this figure can be found in the Barnstable County Soil Survey (U.S. Department of Agriculture (USDA), 1993). The predominant soil types in the Town of Barnstable are as follows with their USDA description:

- *Ipswich-Pawcatuck-Matunuck* – very deep, level, very poorly drained soils; are in tidal areas that are subject to daily inundation by salt water.
- *Hooksan Series* – very deep, excessively drained soils on vegetated sand dunes adjacent to beaches along the coast.
- *Enfield Series* – very deep, well drained soils on outwash plains.
- *Carver Series* – very deep, excessively drained soils on outwash plains, on moraines, and in areas of glacial lake deposits; slopes range from 0 to 35 percent.
- *Plymouth Series* – very deep, excessively drained soils on moraines and outwash plains and in areas of glacial lake deposits; slopes range from 0 to 35 percent.

As shown on Figure 5-8, many defined classifications of soils exist within the Town of Barnstable.

B. **Floodplains and Velocity Zones.** Floodplains are nature's way of buffering land areas from excessive storm events because they act to dissipate the wind and wave action generated during these storms. V-Zones are designated by FEMA and are defined as areas susceptible to 100-year coastal flooding with high velocity wave action.

Also designated by FEMA, A-Zones are areas where flooding is predicted to occur once every 100 years. This flooding occurs with minimal associated wave action, and these areas are typically located landward of the V-Zones, typically in salt marshes and low elevation areas of Barnstable. The surface elevations in these areas typically lie below 10 feet mean sea level. The flood zones throughout the Town are illustrated in Figure 5-9.

C. **Critical Wildlife and Plant Habitat.** There are several regions within the Town of Barnstable that have been identified as combined habitats of rare species and wildlife by the Massachusetts Division of Fisheries, Natural Heritage and Endangered Species Program (NHESP). The combined habitat layers is a combination of seven NHESP layers including; Priority Habitats of Rare Species, Estimated Habitats of Rare Wildlife, BioMap Core Habitat, BioMap Supporting Natural Landscape, Living Waters Core Habitats, Living Waters Critical Supporting Watersheds and Natural Communities. Figure 5-4 also illustrates combined resource areas where wetlands and NHESP habitat layers overlap.

D. **Protected Natural Areas.** The following includes a summary of Areas of Critical Environmental Concern, Districts of Critical Planning Concern, Town Conservation Lands and Open Space.

1. **Areas of Critical Environmental Concern (ACECs).** With 90 percent located within the Town of Barnstable, the Sandy Neck Barrier Beach System was designated an ACEC in 1978. The ACEC boundary generally follows the 100-year floodplain elevation on the landward side and mean low water on the seaward side of Barnstable Harbor as shown on Figure 5-4. Sandy Neck is one of the largest barrier beach systems in New England and extends eastward approximately seven miles and shelters Barnstable Harbor and the extensive salt marsh habitat. The Code of the Town of Barnstable has ordinances including Chapter 177, Sandy Neck and Chapter 601, Sandy Neck Beach.

2. **District of Critical Planning Concern (DCPC).** The Town of Barnstable has three designated Districts of Critical Planning Concern (DCPCs), the Pond Village DCPC and the Craigville Beach/Centerville Village Center DCPC which is shown on Figure 5-4 and the Barnstable DCPC which encompasses the entire Town of Barnstable and is not shown on Figure 5-4. The Town of Barnstable is also located within one nominated county-wide DCPC known as the Ocean Management Planning DCPC.

The Barnstable DCPC was designated in February 2001 throughout the entire town to address the rate of residential growth and subsequently the Growth Management Ordinance was adopted to manage residential development.

The Pond Village DCPC was designated in January 2006 for the Pond Village area of Barnstable Village to protect freshwater pond quality, a portion of Barnstable Harbor and the historic and scenic character of a 115-acre area north of Route 6A near Barnstable village. This DCPC also resulted in a two-acre minimum lot size for this area.

The Craigville Beach/Centerville Village Center DCPC includes the Centerville Village Center area which includes an existing business zoning district, other non-residential parcels, and residential parcels including the Main Street National Register Historic District. The Village DCPC has two purposes: an economic resource district and a cultural, historic, and architectural resource district. The Craigville Beach area of the DCPC includes a barrier beach along Nantucket Sound, an estuary system behind it, and freshwater ponds. It encompasses many summer homes and cottages, a portion of which is recognized within a National Register Historic District. The DCPC has five purposes: a natural and ecological resource district; a cultural, historic, and architectural resource district; a hazard district; a wastewater management district; and a waterfront management district. The Town is (2010) working on implementing regulations for the Craigville Beach area.

On December 16, 2009, the Barnstable County Commissioners nominated the Ocean Management Planning DCPC in anticipation of the final Massachusetts Ocean Management Plan. The nominated DCPC includes all the ocean waters and land below and air above within Barnstable County, starting from a line drawn 0.3 nautical miles seaward from mean high water and extending three nautical miles from MHW, or the state jurisdictional boundary, whichever is farther. This DCPC area includes 576,745 acres.

3. **Town Conservation Lands and Open Space.** The 2005 Final Open Space and Recreation Plan (an update is expected in 2010) developed for the Town of Barnstable, incorporates the goals of protecting natural resources, conserving open space and providing a varied recreation program.

According to this plan, the Town's existing open space and recreation lands are both privately and publicly owned. "Most of the privately owned conservation lands are designated as state Chapter 61 properties, restricted by conservation easements or in the form of unprotected quasi public recreation lands such as those on school fields and golf courses. Publicly owned open space and recreation lands are more numerous. There are a total of 6,304 acres owned and managed by the Town of Barnstable Conservation Division. An additional 894 acres is listed as Open Space acquired with Land Bank funds equaling a total of 7,198 acres of municipally owned conservation land. By contrast, there are only 111 acres owned and managed by the Town of Barnstable Recreation Division. This amounts to 1.5 percent of the Conservation total of 7,198 acres." (2005 Open Space and Recreation Plan).

Protected open space is associated with the following groups; Town Conservation, Town Land Bank, Town CPA Open Space, State Owned Protected Land, Fire District with Conservation Restriction, Barnstable Land Trust, Mary Barton Conservation, Massachusetts Audubon Society, The Nature Conservancy, Orenda Wildlife Land Trust, Three Bays Preservation, Inc., Compact of Cape Cod Conservation Trusts, Trustees of Reservations, and Private Land with Conservation Restriction and is shown on Figure 5-10, Open Space Map. Recreational land use areas can be seen in Figure 5-11, Land Use Map.

The following are lists Barnstable's major conservation and recreation areas according to the Open Space and Recreation Plan:

- Hathaways Pond Conservation area – 60 acres in Hyannis
- Crocker Neck Conservation Area – 97 acres in Cotuit
- Whelan Conservation Area – 12.9 acres in Centerville
- Long Pond Conservation Area – 37 acres in Cotuit
- Sandy Neck Barrier Beach Ecosystem – 6 miles long and 0.5 miles wide along the northern Cape Cod Bay coast of Barnstable.
- West Barnstable Conservation Area – 1,114 acres in West Barnstable
- Old Jail Lane Conservation Area – 180 acres in Barnstable Village

5.10 PROTECTED CULTURAL AREAS

There are several areas in the Town of Barnstable that have historic importance, scenic and archaeological significance as discussed in this section.

The Town of Barnstable has two designated local historic districts; the Old Kings Highway Local Historic District and the Hyannis Main Street Waterfront Historic District. These areas include many contributing historical structures. Figure 5-12 reflects these local historic districts. The Town of Barnstable also has a Historical Commission which was established to assist the Town in the preservation and protection of historical buildings and settings; in addition each village has a historical society except for Hyannis, in which the Civic Association acts as the historical society.

As shown on Figure 5-12, the National Register Historic Districts within the Town of Barnstable are as follows:

- Old Kings Highway National Historic District
- Sandy Neck Cultural Resources District
- Barnstable Harbor Historic District
- Hyannis Road Historic District
- West Barnstable Historic District
- Santuit Historic District
- Cotuit Historic District
- Wianno Historic District
- Centerville Historic District
- Craigville Historic District
- Hyannisport Historic District
- Kennedy Compound National Historic Landmark
- Municipal Group Historic District
- Pleasant Street School Street Historic District

5.11 POPULATION AND DEMOGRAPHICS

According to the 2009 Town Annual Report, the year round population in the Town of Barnstable is approximately 50,000 with the seasonal population increasing to approximately 145,500 during the summer months.

According to 2000 U.S. Census data, residents aged 65 and over comprises 20.1 percent of the Town's population, and the median age of residents within the Town was 42.3. In 1980 the

median age was 36.4 and in 1990 was 38.1 years of age. This median age statistic implies the Town has an aging population. Consequently, the average household size continues to decrease in the Town of Barnstable; in 1980 the average household size was 2.57, in 1990 it was 2.47 and in 2000 it was 2.38. According to the Town's BCP, those residents between the ages of 55 and 64 comprised an additional 10.6 percent of the population with the single fastest growing sector being the 45 – 54 age group that at 15 percent has increased 46 percent since the 1990 census.

With respect to race, according to 2000 U.S. Census data, 91.9 percent of the Town of Barnstable is white, 2.7 percent is black or African American, and 2.3 percent is two or more races. Social characteristics of the Town include 90.4 percent of the population having a high school diploma or higher and 32.2 percent having a Bachelor's degree or higher. Foreign born residents make up 6.9 percent of the population and 8.9 percent of the population speak a language other than English at home. 19.7 percent of the Town population has disability status.

According to the Executive Office of Labor and Workforce Development, the unemployment rate in the Town of Barnstable during 2009 was as low as 7.0 in July of 2009 and as high as 10.2 in January of 2009 with a yearly average of 8.3. The unemployment rate during December 2009 in the Town of Barnstable was 9.5, just above the state wide rate of 9.4. This is an increase from the average unemployment rate in 2008 of 5.1. These rates are not seasonally adjusted for population. The 2000 U.S. Census also shows 76.2 percent of housing units being owner-occupied and 23.8 percent of housing units being renter-occupied.

5.12 LAND USE AND EVALUATIONS TO QUANTIFY WATER CONSUMPTION AND WASTEWATER FLOWS

A. **Introduction.** Understanding the current and future land use in Town as well as the associated water consumption and wastewater generation is critical to developing a CWMP. Extensive evaluations have been completed to evaluate existing land use, water consumption and wastewater generation rates; projected estimates of the future land use, water consumption and wastewater generation at the buildout condition; and to summarize this information on a Town-wide, village-wide, and watershed basis. This information has also been developed on a parcel by parcel basis in the Town's Geographic Information System (GIS) so that it can be summarized for any geographic area in Town.

The parcel by parcel buildout evaluations were completed through a Town Land Use and Projected Buildout Working Group comprised of the following individuals:

i. Dale Saad, DPW and CWMP Project Manager
ii. Jo Anne Miller Buntich, Growth Management Department Director
iii. Jackie Etsten, Principal Planner
iv. Jim Benoit, GIS Coordinator
v. Nathan Weeks, P.E., Stearns & Wheler GHD Project Manager
vi. Jessica Janney, Stearns & Wheler GHD Project Engineer

Over several months this group worked to develop this data in the Towns GIS where it can be used for this project as well as for future planning, implementation, and monitoring projects.

Appendix 5-3 provides a summary of how the buildout data was developed.

B. **Existing Land Use.** Figure 5-11 illustrates the town-wide existing land use grouped into the following categories according to the land use code assigned to each parcel by the Town's Tax Assessing Department.

- Residential – defined with land use codes starting with 1
- Commercial – defined with land use codes starting with 3 and 4; also includes industrial uses
- Mixed Use – defined with land use codes starting with 0
- Agricultural – defined with land use codes starting with 6 and 7
- Recreational – defined with land use codes starting with 8
- Tax Exempt – defined with land use codes starting with 9

Table 5-6 summarizes the existing land use by village and watershed in Barnstable. A detailed listing of the land use codes used to develop this summary is attached in Appendix 5-2.

TABLE 5-6

LAND USE SUMMARY PER VILLAGE AND MARINE WATERSHED [1]

VILLAGE	EXISTING PARCEL EVALUATION BY VILLAGE						
	Residential	**Commercial**	**Recreational**	**Agricultural**	**Tax Exempt**	**Mixed Use**	**Total**
Cotuit	2,284	25	1	4	126	17	2,457
Osterville	2,580	78	0	1	91	21	2,771
Marstons Mills	3,836	52	0	11	168	19	4,086
Centerville	5,890	57	0	6	185	15	6,153
Hyannis	5,878	781	0	0	363	109	7,131
Barnstable	1,901	161	1	6	309	16	2,394
West Barnstable	1,414	36	3	4	334	27	1,818
Total	23,783	1,190	5	32	1,576	224	26,810
MARINE WATERSHED	**EXISTING PARCEL EVALUATION BY MARINE WATERSHED**						
	Residential	**Commercial**	**Recreational**	**Agricultural**	**Tax Exempt**	**Mixed Use**	**Total**
Popponesset Bay	771	13	0	0	29	8	821
Three Bays	5,224	129	1	13	237	38	5,642
Centerville River	7,683	69	0	5	259	20	8,036
Halls Creek	2,219	43	0	0	57	10	2,329
Lewis Bay	3,148	759	0	0	317	97	4,321
Barnstable Harbor	3,743	164	4	11	642	43	4,607
Rushy Marsh Pond	15	0	0	0	3	0	18
Uncategorized[2]	980	13	0	3	32	8	1,036
Total	23,783	1,190	5	32	1,576	224	26,810

Notes:
(1) Land use data taken from FY2010 Assessor's Database. This summary does not include individual condominium units which are summarized to a single parcel per condominium complex. This table summarizes a GIS query and the counts are not rounded.
(2) This includes all parcels not within the MEP watersheds listed.

This summary provides the ability to characterize the existing land use in broad terms for the Town, but it has limitations with respect to quantifying future land use, water consumption, and wastewater generation due to the following observations:

- There are wide variations in the land use within each group.

- Residential properties can have one dwelling unit per parcel or several dwelling units.
- Commercial properties can have varying amounts of building square footage.
- Mixed Use and Tax Exempt properties can have combinations of dwelling units, commercial area, institutional uses such as schools and churches, and conservation land.
- Many properties, particularly in West Barnstable, are not served by public water systems; therefore it is difficult to empirically estimate their water consumption and wastewater generation.

Based on these observations it was determined that the number of existing and future dwelling units needed to be quantified as well as the existing and future commercial square footage to obtain a more fundamental and concise measure of land use.

C. **Existing and Future Dwelling Units and Non-Residential Building Square Footage.** All parcels in Town were evaluated by the number of dwelling units and the non-residential building square footage that they contain. This existing land use information was readily available in the Town's Assessing Database and is summarized on Table 5-7 for the villages and marine watersheds.

(continued)

TABLE 5-7

EXISTING DWELLING UNIT AND NON-RESIDENTIAL BUILDING SQUARE FOOTAGE EVALUATION BY VILLAGE AND MARINE WATERSHED

VILLAGE	EXISTING PARCEL EVALUATION BY VILLAGE	
	Total Existing Residential Dwelling Units	**Total Existing Non-Residential Sq. Ft.**
Cotuit	2,229	157,157
Osterville	2,784	731,585
Marstons Mills	3,744	755,175
Centerville	5,809	667,892
Hyannis	8,803	9,207,263
Barnstable	1,823	2,473,418
West Barnstable	1,238	535,421
Total	26,430	14,527,911
MARINE WATERSHED	**EXISTING PARCEL EVALUATION BY MARINE WATERSHED**	
	Total Existing Residential Dwelling Units	**Total Existing Non-Residential Sq. Ft.**
Popponesset Bay	754	70,513
Three Bays	5,307	1,083,805
Centerville River	7,726	1,640,270
Halls Creek	2,478	442,303
Lewis Bay	5,554	8,878,019
Barnstable Harbor	3,612	2,261,552
Rushy Marsh Pond	8	0
Uncategorized(2)	991	151,449
Total	26,430	14,527,911

Notes:
(1) This table summarizes a GIS query and the counts are not rounded.
(2) This includes all parcels not within the MEP watersheds listed.

A buildout analysis was then completed to estimate future dwelling units and commercial square footage in the future conditions as allowed by current zoning. This was completed by the Land Use and Projected Buildout Working Group with the following additional considerations:

- Parcels with known conservation restrictions were not included in the buildout analysis.
- Buildout potential for each parcel was based on current zoning regulations and considered vacant buildable lots as well as currently developed properties that could be further subdivided to add additional residences or commercial space.
- Predicted growth centers (i.e. Hyannis Growth Incentive Zone (GIZ)) were analyzed at buildout.
- The Working Group used professional judgment for mixed use parcels and "ultimate" buildout for the GIZ.

These estimates were then entered into the Town's GIS database. Table 5-8 summarizes the estimated quantity of dwelling units and non-residential building square footage per village and per watershed that could occur at the buildout conditions. It also estimates the percent of buildout for each of the geographic areas. This table indicates that there is significant additional development that can occur in portions of Barnstable as allowed by current zoning.

A summary of the procedure used to develop the buildout estimates is included in Appendix 5-3.

(continued)

TABLE 5-8

DWELLING UNIT AND NON-RESIDENTIAL BUILDING SQUARE FOOTAGE EVALUATION BY VILLAGE AND MARINE WATERSHED AT BUILDOUT [1]

VILLAGE	BUILDOUT EVALUATION BY VILLAGE			
	Total Residential Dwelling Units at Buildout		Total Non-Residential Sq. Ft. at Buildout	
	Number	Percentage of Existing Numbers	Number	Percentage of Existing Numbers
Cotuit	2,634	118%	296,493	189%
Osterville	3,353	120%	1,638,393	224%
Marstons Mills	4,657	124%	1,495,468	198%
Centerville	6,246	108%	1,133,867	170%
Hyannis	11,897	135%	28,836,804	313%
Barnstable	3,703	203%	8,688,829	351%
West Barnstable	2,051	166%	1,176,707	220%
Total	34,541	131%	43,266,560	298%
MARINE WATERSHED	**BUILDOUT EVALUATION BY MARINE WATERSHED**			
	Total Residential Dwelling Units at Buildout		Total Non-Residential Sq. Ft. at Buildout	
	Number	Percentage of Existing Numbers	Number	Percentage of Existing Numbers
Popponesset Bay	994	132%	175,194	248%
Three Bays	6,609	125%	2,377,124	219%
Centerville River	8,326	108%	2,316,220	141%
Halls Creek	2,808	113%	757,645	171%
Lewis Bay	8,490	153%	30,698,013	346%
Barnstable Harbor	6,138	170%	6,415,391	284%
Rushy Marsh Pond	10	125%	0	0%
Uncategorized[2]	1,166	118%	526,973	348%
Total	34,541	131%	43,266,560	298%

Notes:
(1) Buildout data based on FY2007 Assessor's maps/data.
(2) This includes all parcels not within the MEP watersheds listed.

It is important to note that buildout could be construed as a speculative term, meaning that judgment is placed based on conditions that may or may not exist. As an example, zoning can change in the future; some land use types such as 40B developments/affordable housing projects and other special cases can find exemptions from zoning. However, the work completed presents a reasonable estimate of buildout for planning purposes based on the current Town zoning and accepted land use judgment.

This evaluation provides a perspective on the buildout conditions but it is still limited because not all of these dwelling units and commercial properties have public water supply; therefore, water consumption and wastewater generation cannot be estimated directly from this data.

D. **Estimates of Existing and Future Buildout Water Consumption and Wastewater Generation.** Existing water consumption per dwelling unit and per 1,000 sf non-residential space was developed by identifying the parcels with public water supply that only had dwelling units and only had non-residential square footage; and then identifying the number of dwelling units and non-residential square footage for those properties. This evaluation is summarized in Table 5-9.

Also existing wastewater generation per dwelling unit and per 1,000 sf non-residential space was then developed by multiplying the water consumption values by 90 percent to estimate the quantity of water consumption that actually becomes wastewater (the remaining 10 percent is assumed to be a measure of non-potable uses such as irrigation, outdoor showers, car washing, etc.). This factor is consistent with the calculations made by the MEP. Table 5-9 also summarized these wastewater generation estimates.

This water consumption evaluation methodology using dwelling units and 1,000 non-residential sq ft building area differs slightly from the evaluation methodology used by the MEP as part of their watershed evaluations. They developed typical water consumption for "all developed residential parcels" that had public water supplies, and then used this value (specific for each watershed) to estimate water consumption (and nitrogen loading) at properties with no public water supplies and for buildout projections at vacant properties. The use of dwelling units and 1,000 non-residential sf is believed to be a more precise measure of land use and water consumption, and makes best use of the Town's GIS database. Also the Town GIS utilized more up to date water consumption data. As a check of the MEP water consumption methodology, the water consumption data was queried by the Town GIS Department for all residential parcels with

public water consumption. Table 5-10 summarizes the water consumption for the residential parcels in the marine watershed areas using the two methodologies along with the water consumption value per dwelling unit developed earlier.

(continued)

TABLE 5-9
WATER CONSUMPTION AND WASTEWATER GENERATION CALCULATION SUMMARY BY VILLAGE AND MARINE WATERSHED

MARINE WATERSHED	DWELLING UNIT EVALUATION					COMMERCIAL BUILDING SQUARE FOOTAGE (Sq. Ft.) EVALUATION				
	Number of Residential Parcels with Public Water and Dwelling Units (but No Commercial Sq. Ft.)	Water Consumption[1] (Gal/Day) for these Parcels	Number of Dwelling Units (DU) for these Parcels	Estimated Water Consumption per DU (Gal/DU)	Estimated Wastewater Generation[2] per DU (Gal/DU)	Number of Commercial Parcels with Public Water and Commercial Sq. Ft. (but No Dwelling Units)	Water Consumption[1] (Gal/Day) for these Parcels	Commercial Sq. Ft. for these Parcels	Estimated Water Consumption per Commercial Area (Gal/1,000 Sq. Ft.)	Estimated Wastewater Generation[2] per Commercial Area (Gal/1,000 Sq. Ft.)
Popponesset Bay	683	129,535	707	183	165	16	5,399	61,762	87	79
Three Bays	4,398	1,055,211	4,887	216	194	136	54,230	984,490	55	50
Centerville River	6,996	1,279,501	7,567	169	152	82	77,086	1,585,654	49	44
Halls Creek	2,071	445,625	2,468	181	163	43	74,820	408,160	183	165
Lewis Bay	2,990	804,161	5,353	150	135	621	625,657	8,314,797	75	68
Barnstable Harbor	2,054	467,916	2,357	199	179	102	105,052	1,652,510	64	57
Rushy Marsh Pond	6	2,044	8	255	230	0	0	0	0	0
Uncategorized	797	200,688	942	213	192	17	18,896	142,411	133	119
Totals/Averages	19,995	4,384,681	24,289	181	176	1,017	961,140	13,149,784	73	66

VILLAGE	DWELLING UNIT EVALUATION					COMMERCIAL BUILDING SQUARE FOOTAGE (Sq. Ft.) EVALUATION				
	Number of Residential Parcels with Public Water and Dwelling Units (but No Commercial Sq. Ft.)	Water Consumption[1] (Gal/Day) for these Parcels	Number of Dwelling Units (DU) for these Parcels	Estimated Water Consumption per DU (Gal/DU)	Estimated Wastewater Generation[2] per DU (Gal/DU)	Number of Commercial Parcels with Public Water and Commercial Sq. Ft. (but No Dwelling Units)	Water Consumption[1] (Gal/Day) for these Parcels	Commercial Sq. Ft. for these Parcels	Estimated Water Consumption per Commercial Area (Gal/1,000 Sq. Ft.)	Estimated Wastewater Generation[2] per Commercial Area (Gal/1,000 Sq. Ft.)
Cotuit	1,990	413,242	2,122	195	175	39	11,004	137,117	80	72
Osterville	2,335	639,547	2,743	233	210	86	44,659	664,015	67	61
Marstons Mills	3,138	624,491	3,317	188	169	51	28,181	722,310	39	35
Centerville	5,308	951,033	5,677	168	151	60	56,272	622,619	90	81
Hyannis	5,524	1,377,622	8,598	160	144	664	715,937	8,632,661	83	75
Barnstable	1,561	347,711	1,687	206	186	107	91,575	2,005,393	46	41
West Barnstable	139	31,036	145	214	193	10	13,514	365,669	37	33
Totals/Averages	19,995	4,384,681	24,289	181	175	1,017	961,140	13,149,784	73	66

Notes:

(1) Water consumption data is from the following time periods:
- Barnstable Water District: October 2006 - September 2008 (2 years)
- C-O-MM Water District: January 2008 - December 2009 (2 years)
- Cotuit Water District: October 2006 - September 2009 (3 years)
- Hyannis Water District: April 2006 - March 2009 (3 years)

(2) Based on 90% of water consumption assuming 10% of water consumption used for non-potable uses such as irrigation, outdoor showers, car washing, etc.

TABLE 5-10

AVERAGE EXISTING RESIDENTIAL WATER CONSUMPTION PER RESIDENTIAL PARCEL

WATERSHED	TOWN WATER DATA AND METHODOLOGY (GPD)[1]	MEP WATER DATA AND METHODOLOGY (GPD)[2]
Popponesset Bay	189	154
Three Bays	240	227
Centerville River	182	204
Halls Creek	214	175
Lewis Bay	255	175
Barnstable Harbor	228	N/A
Uncategorized[3]	252	N/A
Average	217	184

Notes:

(1) Based on water consumption data from the following years:
- Barnstable Water District: October 2006 – September 2008 (2 years)
- C-O-MM Water District: January 2008 – December 2009 (2 years)
- Cotuit Water District: October 2006 – September 2009 (3 years)
- Hyannis Water District: April 2006 – March 2009 (3 years)

(2) Based on water consumption data from the following years:
- 2000 for the Towns of Barnstable and Sandwich and 2001 for the Town of Mashpee (Popponesset Bay)
- 2004 for the Town of Barnstable, 2001 for the Town of Mashpee and 2000 for the Town of Sandwich (Three Bays)
- 2004 for the Town of Barnstable (Centerville River)
- 2004 for the Towns of Barnstable and Yarmouth (Lewis Bay/Halls Creek)
- 2004 for the Town of Barnstable (Rushy Marsh Pond)

This includes all parcels not within the MEP watersheds listed.

Comparison of the two methodologies illustrates similar findings of water use and wastewater generation, though the Town data analysis indicates an 18 percent higher water consumption. This could be due to more recent data or a more accurate GIS.

When the water consumption and wastewater generation rates for the future dwelling units and commercial space with units of gallons per day per dwelling unit (gpd/DU) and gallons per day per 1,000 square feet of commercial space (gpd/1000sf) respectively and applied to the buildout projections for the village and marine watersheds; the future flows for the Town become more apparent. These flows are summarized in Tables 5-11, 5-12, and 5-13 for the residential, non-residential, and total land uses respectively.

TABLE 5-11

RESIDENTIAL WATER CONSUMPTION AND WASTEWATER GENERATION AT BUILDOUT BY VILLAGE AND MARINE WATERSHED[1]

VILLAGE	RESIDENTIAL EVALUATION BY VILLAGE			
	Total Residential Dwelling Units at Buildout	**Average Water Consumption per Dwelling Unit (gal/day)**	**Future Residential Water Flow (mgd)**	**Future Residential Wastewater Flow (mgd)**
Cotuit	2,634	209	0.55	0.50
Osterville	3,353	258	0.86	0.77
Marstons Mills	4,657	203	0.94	0.85
Centerville	6,246	179	1.12	1.01
Hyannis	11,897	160	1.91	1.72
Barnstable	3,703	206	0.76	0.68
West Barnstable	2,051	232	0.48	0.43
Total	34,541	189	6.5	5.9
WATERSHED	**RESIDENTIAL EVALUATION BY WATERSHED**			
	Total Residential Dwelling Units at Buildout	**Average Water Consumption per Dwelling Unit (gal/day)**	**Future Residential Water Flow (mgd)**	**Future Commercial Wastewater Flow (mgd)**
Popponesset Bay	994	197	0.20	0.18
Three Bays	6,609	235	1.55	1.40
Centerville River	8,326	180	1.50	1.35
Lewis Bay	11,425	160	1.83	1.65
Barnstable Harbor	6,012	202	1.22	1.10
Rushy Marsh Pond	10	277	0.00	0.00
Uncategorized[2]	1,165	234	0.27	0.24
Totals	34,541	189	6.5	5.9

Notes:
(1) All flows are in million gallons per day (mgd) and are annual averages.
(2) This includes all parcels not within the MEP watersheds listed

TABLE 5-12

NON-RESIDENTIAL WATER CONSUMPTION AND WASTEWATER GENERATION AT BUILDOUT BY VILLAGE AND MARINE WATERSHED[1]

VILLAGE	NON-RESIDENTIAL EVALUATION BY VILLAGE			
	Total Non-Residential SF at Buildout	**Average Water Consumption per 1,000 SF of Non-Residential Use (gal/day)**	**Future Non-Residential Water Flow (mgd)**	**Future Non-Residential Wastewater Flow (mgd)**
Cotuit	296,493	84	0.02	0.018
Osterville	1,638,393	76	0.12	0.108
Marstons Mills	1,495,468	40	0.06	0.054
Centerville	1,133,867	96	0.11	0.099
Hyannis	28,836,804	83	2.39	2.151
Barnstable	8,688,829	46	0.40	0.36
West Barnstable	1,176,707	40	0.05	0.045
Total	43,266,560	74	3.20	2.88
WATERSHED	**NON-RESIDENTIAL EVALUATION BY WATERSHED**			
	Total Non-Residential SF at Buildout	**Average Water Consumption per 1,000 SF of Non-Residential Use (gal/day)**	**Future Non-Residential Water Flow (mgd)**	**Future Non-Residential Wastewater Flow (mgd)**
Popponesset Bay	175,194	95	0.02	0.02
Three Bays	2,377,124	60	0.14	0.13
Centerville River	2,316,220	52	0.12	0.11
Lewis Bay	31,946,417	79	2.52	2.27
Barnstable Harbor	5,924,632	70	0.42	0.38
Uncategorized[2]	526,973	141	0.07	0.06
Totals	43,266,560	74	3.20	2.88

Notes:
(1) All flows are in million gallons per day (mgd) and are annual averages.
(2) This includes all parcels not within the MEP watersheds listed

TABLE 5-13

DAILY FUTURE WASTEWATER FLOWS BY VILLAGE AND MARINE WATERSHED[1]

VILLAGE	FUTURE RESIDENTIAL WASTEWATER FLOW (MGD)	FUTURE NON-RESIDENTIAL WASTEWATER FLOW (MGD)	TOTAL AVERAGE ANNUAL WASTEWATER FLOW (MGD)
Cotuit	0.50	0.02	0.51
Osterville	0.77	0.11	0.89
Marstons Mills	0.85	0.05	0.90
Centerville	1.10	0.10	1.11
Hyannis	1.7	2.15	3.9
Barnstable	0.68	0.36	1.0
West Barnstable	0.43	0.05	0.47
Total	5.9	2.9	8.8
WATERSHED	**FUTURE RESIDENTIAL WASTEWATER FLOW (MGD)**	**FUTURE NON-RESIDENTIAL WASTEWATER FLOW (MGD)**	**TOTAL AVERAGE ANNUAL WASTEWATER FLOW (MGD)**
Popponesset Bay	0.18	0.02	0.19
Three Bays	1.4	0.13	1.5
Centerville River	1.4	0.11	1.5
Lewis Bay	1.7	2.3	3.9
Barnstable Harbor	1.1	0.38	1.5
Rushy Marsh Pond	0.00	0.00	0.00
Uncategorized[2]	0.24	0.06	0.32
Total	5.9	2.9	8.8

Notes:
(1) All flows are in million gallons per day (mgd) and are annual averages.
(2) This includes all parcels not within the MEP watersheds listed

E. **Buildout Projections for the Area Served by the Hyannis WPCF Collection System and Planned Sewer Expansion.** The buildout potential of the properties served by the Hyannis WPCF Collection System (illustrated in Figure 4-9) was evaluated and is summarized in Table 5-14 by watershed.

TABLE 5-14

SUMMARY OF EXISTING AND BUILDOUT WATER CONSUMPTION AND WASTEWATER GENERATION FOR THE CURRENT WPCF

WATERSHED AREA	EXISTING WATER CONSUMPTION (MGD)	EXISTING WASTEWATER GENERATION (MGD)	ADDITIONAL LAND USE AND FLOWS			
			DWELLING UNITS	NON-RESIDENTIAL AREA (1,000SF)	WATER CONSUMPTION FLOW (MGD)	WASTEWATER GENERATION FLOW (MGD)
Barnstable Harbor	0.16	0.14	95	553	0.05	0.04
Centerville River	0.05	0.05	3	62	0.004	0.003
Halls Creek	0.22	0.20	100	269	0.07	0.06
Lewis Bay	1.1	0.99	2,121	12,647	1.26	1.14
Total	1.5	1.3			1.4.	1.3

Note:
(1) All flows are in million gallons per day (mgd) and are annual averages.

Significant additional land use and growth is possible in the Hyannis area as allowed by the Growth Incentive Zone (GIZ). The Massachusetts Estuaries Project recognized the growth potential in their Technical Report (page 46) for Lewis Bay and presented a similar additional wastewater flow value of 1.25 mgd.

Several planned sewer extensions will provide additional flow to the Hyannis WPCF as summarized in Table 5-15.

TABLE 5-15

SUMMARY OF EXISTING AND BUILDOUT WATER CONSUMPTION AND WASTEWATER GENERATION FOR THE PLANNED SEWER EXTENSIONS[6] AS ILLUSTRATED IN FIGURE 2-1

WASTEWATER AOC AND SEWER EXTENSION AREA[1]	EXISTING WATER CONSUMPTION (MGD) FROM:		FUTURE LANDUSE AND WATER CONSUMPTION IN TOTAL AOC AREAS			FUTURE WASTEWATER GENERATION (MGD)[6]		
	Total AOC Area	Parcels Currently Connected to Hyannis WPCF	Number of Dwelling Units (DU)	Commercial Area (1,000 sf)	Water Consumption Flow (mgd)[2][6]	Total AOC Area[3]	Total Additional Wastewater Flow for Total Area[4]	Additional Flow for Planned Sewer Area[5]
Bearses Way	0.21	0.07	1.129	1,870	0.34	0.31	0.24	0.12
Water Supply ZOC's								
- BWMEL 1A	0.02	0	166	1,314	0.13	0.11	0.11	0.01
- BWMEL 1B	0.03	0.03	51	1,044	0.09	0.08	0.05	0.00
- BWST 1	0.58	0.26	3,158	1,424	0.67	0.61	0.37	0.02
- CO 7	0.13	0.02	868	514	0.19	0.17	0.16	0.01
CCCC	0.004	0	125	625	0.07	0.06	0.06	0.06
CE1	0.03	0	181	62	0.04	0.03	0.03	0.03
CE2	0.02	0.001	176	53	0.04	0.03	0.03	0.03
CE4	0.13	0	1,011	201	0.20	0.18	0.18	0.18
H1	0.06	0.02	289	132	0.08	0.07	0.07	0.05
H3	0.04	0	263	1	0.05	0.04	0.04	0.04
Totals[6]	1.3	0.40	7,517	7,240	1.9	1.7	1.7	0.55

Notes:
(1) Planned as part of 2007 WWFP.
(2) Based on 180 gal/DU and 73 gal/1000sf commercial area which are Town-wide averages.
(3) Based on 90% of water consumption becoming wastewater flow.
(4) Flow from the total planned area minus the existing flow from that area.
(5) The following AOC areas are only planned for partial sewering (see Table 2-3).
- Bearses Way at 50% of area.
- Water Supply ZOC's at 5% of area.

(6) These estimates are made for overlapping areas and are subject to change as the CWMP proceeds. The flow estimates are in million gallons per day (mgd) and are annual averages. These estimates do not include Infiltration/Inflow (I/I) that could occur in the future collection system.

When these future flows (at buildout) to the Hyannis WPCF are summed with other additional flows as listed on Table 2-3, a projected average annual flow of 3.8 mgd is indicated with an estimated maximum month flow of 5.5 as summarized on Table 5-16.

TABLE 5-16

SUMMARY OF PROJECTED FLOWS TO THE HYANNIS WPCF AT THE BUILDOUT CONDITION

FLOW SOURCES	PROJECTED FLOWS AT BUILDOUT (MGD)	
	Maximum Month[(1)]	**Average Annual**
Existing flow from existing collection system	1.94	1.46
Additional flow from buildout along existing collection system	2.2	1.3
Additional flow from AOC's[(3)]	0.73	0.55
- Bearses Way[(2)]		0.12
- BWMEL 1A[(2)]		0.01
- BWMEL 1B[(2)]		0.00
- BWST 1[(2)]		0.02
- CO 7[(2)]		0.01
- CCCC		0.06
- CE1		0.03
- CE2		0.03
- CE4		0.18
- H1		0.05
- H3		0.04
Allowance for I/I at the AOC's[(4)]	0.04	0.03
Allowance for potential expansion and additional infilling from Table 2-3		
- Independence Park	0.13	0.10
- Gravel Pit Development	0.10	0.07
- North of Kids Hill Road	0.40	0.3
Total	5.5	3.8

Notes:

(1) Maximum month flows are estimated using the current maximum month to average annual peaking factors (observed in Table 4-1) for all of the listed sources except the allowances for Independence Park, the Gravel Pit Development, and potential development North of Kids Hill Road which are carried over from Table 2-3 as developed in the 2007 WWFP.

(2) These flows do not represent the total flow that could come from these areas. Smaller portions of these areas were recommended in the 2007 WWFP as discussed in Chapters 2 and 5.

(3) Illustrated in Figure 2-1.

(4) Estimated at 6% of wastewater flow (section 4.3D).

It is noted that the summary in Table 5-15 does not include an allowance for future I/I. MassDEP requires planning for the additional flows that can come from I/I. Chapter 4, section 4.3 describes the analysis of the I/I in the existing collection system currently quantified at 0.08 mgd or 6 percent of the wastewater generation.

It is noted that the 2007 WWFP estimated wastewater flows to the WPCF for the design year 2014 (summarized in Table 2-3). This projection appears to be accurate based on the sewer extensions completed and the current flows experienced at the Hyannis WPCF.

Developing treatment capacity for the existing and planned wastewater flows to the Hyannis WPCF in the future (and possibly buildout) condition will be an important wastewater need to address in subsequent portions of the CWMP Project.

F. Estimated Water-Consumption and Wastewater Generation Estimates for the Design Year of 2035.

The previous two report sections (Section 5.12.D and E) investigated land use, and the resulting water consumption and wastewater generation for the buildout conditions as allowed by current zoning. As observed in Table 5-8 there is the potential for significant additional growth in Hyannis, Barnstable Village, and West Barnstable. The other villages have less potential for growth.

Hyannis' growth is expected to occur in the Growth Incentive Zone (GIZ) which was created to accommodate growth in this regional center. Much of Barnstable Village's growth will occur south of Route 6 in the Independence Park area.

A CWMP project needs to estimate future growth and projected wastewater flows at the buildout condition. It also needs to understand if the buildout conditions will be attained in the project planning period of 2015 to 2035.

An evaluation was completed to investigate Barnstable's past growth trends from 1998 to 2010, and to estimate if the buildout conditions would be attained by the design year of 2035. The period of 1998 to 2010 was chosen because it included times of economic growth as well as recession in Barnstable. It also was the time period with the best data (from the Assessors Department) for the number of residential dwelling units and non-residential building square

footage per Fire District. A regression analysis was completed on this data, the findings are summarized below.

TABLE 5-17

SUMMARY OF GROWTH TRENDS FROM 1998 TO 2010

VILLAGE/FIRE DISTRICT[1]	RESIDENTIAL GROWTH (NEW DWELLING UNITS PER YEAR)	NON-RESIDENTIAL GROWTH (NEW SQUARE FOOTAGE PER YEAR)
Barnstable	19	51,000
C-O-MM	167	37,000
Cotuit	42	2,500
Hyannis	69	99,000
West Barnstable	20	7,400
Town-Wide	317	197,000

Notes:
(1) The data was available per Fire District and not available per village for the C-O-MM Fire District.

The full regression analysis is attached in Appendix 5-5.

Based on these growth rates, the projected land use was calculated for the end of the Design year of 2035; and the year when buildout would occur was estimated.

TABLE 5-18

PROJECTED LAND USE IN 2035, AND ESTIMATED YEAR OF BUILDOUT

VILLAGE/FIRE DISTRICT	PROJECTED LAND USE IN 2035		FUTURE YEAR WHEN DWELLING UNIT BUILDOUT IS ESTIMATED[2]	FUTURE YEAR WHEN NON-RES. SQ. FT. BUILDOUT IS ESTIMATED[2]
	Number of Dwelling Units	Non-Residential Building Square Footage		
Barnstable	2,393	3,870,000	2105	2129
C-O-MM	14,256	3,140,000	2016	2065
Cotuit	2,634	220,000	2015	2063
Hyannis	10,619	11,910,000	2053	2206
West Barnstable	1,837	730,000	2046	2095
Town-Wide	31,738	19,870,000	2061	2153

Notes:
(1) The data was available per Fire District and not available per village for the C-O-MM Fire District.
(2) Based on the land use of 2010, projected buildout conditions resulting from zoning as of 2010, and the observed growth rates from 1998 to 2010.

It is noted that this evaluation has several simplifying assumptions including:

- Linear growth as observed from 1998 to 2035 projected into the future.
- Growth stopping once buildout is attained.
- No changes to the current zoning.
- No variances from the current zoning.

Even with these simplifying assumptions it allows an estimate of the projected water use and wastewater generation in the design year of 2035 as summarized below.

TABLE 5-19

PROJECTED WATER CONSUMPTION AND WASTEWATER GENERATION IN 2035

VILLAGE	WATER CONSUMPTION (MGD)			WASTEWATER GENERATION (MGD)		
	Residential	Non-Residential	Total	Residential	Non-Residential	Total
Barnstable	0.49	0.18	0.67	0.44	0.16	0.60
C-O-MM	3.0	0.22	3.3	2.74	0.20	2.9
Cotuit	0.55	0.02	0.57	0.5	0.02	0.51
Hyannis	1.7	0.99	2.7	1.5	0.89	2.4
West Barnstable	0.43	0.03	0.46	0.39	0.03	0.41
Town-Wide	6.0	1.5	7.5	5.4	1.3	6.7

These estimates of land use, water consumption, and wastewater generation for the existing, Design Year 2035, and buildout conditions in Barnstable are part of a useful GIS tool to understand and project these characteristics for any part of the town. This tool will be valuable once detailed evaluations start to develop solutions for the wastewater areas of need.

Chapter 6

Needs Assessment Summary

CHAPTER 6

NEEDS ASSESSMENT SUMMARY

6.1 INTRODUCTION

The purpose of the Comprehensive Wastewater Management Planning (CWMP) project is to address wastewater and nutrient management issues for all areas of the Town of Barnstable. The purpose of the Needs Assessment Report is to clearly define the wastewater and nutrient-related needs of the Town and identify data gaps that need to be addressed as the Project proceeds so that solutions to the needs can be found in subsequent phases of the Project.

The purpose of this chapter is to summarize these wastewater and nutrient management needs as developed and described in previous chapters.

6.2 WASTEWATER AND NUTRIENT MANAGEMENT PLANNING HISTORY IN BARNSTABLE AND RELATED NEEDS

The Town initiated its last wastewater planning process in 1993 with the 20-year planning period of 1994 to 2014. The project was completed in 2007 with state approval of the Final Wastewater Facilities Plan and Final Environmental Impact Report, March 2007 (2007 WWFP). The main focus of that planning project was to address surface and groundwater problems caused by failing septic systems (and even systems that were operating properly but were still impacting drinking waters). The following list briefly summarizes the main recommendations of that project. (A complete listing of the findings and recommendations of that project can be found in Chapter 2.)

- Upgrade and expand the Hyannis Water Pollution Control Facility.
- Extend sewers to the Wastewater Areas of Concern (AOC) in the eastern portion of the Town to address the water quality problems in these areas.
- Defer decision on many of the AOCs in the western portion of the Town until nitrogen limits are set by the state and federal governments.

- Address wastewater problems in several AOCs with Board of Health solutions and public water supply.

Many of the recommendations have been completed, including:

- Upgrade and expansion of the Hyannis WPCF.
- Initial sewer extensions in the eastern portion of the Town.
- Board of Health solutions and extension of public water supply to the AOCs that need these types of solutions.
- Developed nutrient limits of most of the Town's coastal estuaries.

The extension of sewers in the eastern portion of the Town has been slowed by the Town's historic policy/practice that sewer extension costs be paid by the properties being served by the sewers through property betterments. Several residents in the sewer extension areas have argued against this policy/practice. As a result, the Town has investigated alternative funding methods for the Clean Water Projects and revised the policy to provide a 50:50 split for sewer extension costs between property betterments and a Town fund. The Town is also pursuing a dedicated Sewer Construction Fund through special legislation.

6.3 REGIONAL WASTEWATER AND NUTRIENT MANAGEMENT ISSUES AND RELATED NEEDS

There are several regional wastewater and nitrogen management issues that must be addressed as part of this CWMP Project, as briefly listed below:

- The Massachusetts Estuaries Project has developed nitrogen limits for many coastal estuaries and their watersheds on Cape Cod and (with the help of the Town) for most of Barnstable's estuaries.
- There is Cape-wide and Town-wide concern about the high cost to mitigate the nitrogen loadings and meet the new nitrogen limits.
- The watersheds of several Town estuaries extend into the neighboring Towns of Mashpee, Sandwich, and Yarmouth.
- The Towns of Mashpee and Yarmouth have been working on comprehensive wastewater and nutrient management planning projects for several years, and Sandwich will initiate a project in 2010 or 2011.

- The Cape Cod Water Protection Collaborative is the County entity tasked with supporting the Cape Towns with their planning projects. They have identified the shared estuaries of (and watersheds to) Popponesset Bay and Lewis Bay as high-priority areas to find multi-town solutions.

The main wastewater and nutrient-related needs that result from these issues are summarized below:

- Coordination with the Towns of Mashpee, Sandwich, and Yarmouth; and with the Cape Cod Water Protection Collaborative to develop feasible solutions to the shared estuaries and watersheds is needed.
- The Town needs to consider all potential wastewater and nutrient management solutions that could reduce costs to the Town and Town residents.

6.4 TOWN VISION AND GOALS WITH RESPECT TO WASTEWATER AND NUTRIENT MANAGEMENT PLANNING

Barnstable's most recent completed Local Comprehensive Plan articulates a Town vision as well as several Comprehensive Plan Goals as listed below.

Vision. "The seven diverse yet interconnected villages of Barnstable form one community that is an integral part of Cape Cod. As the Town in 2008 has been shaped by its past, through this plan Barnstable will shape a sustainable future. The Town will preserve its history, environment and community for future generations through active stewardship of community character and quality of life while balancing growth, infrastructure and natural systems."

Comprehensive Plan Goals. The following goals are stated for the Comprehensive Plan:

1. Sustain diverse villages and livable neighborhoods for year-round residents while providing housing opportunities for all.

2. Preserve, protect, and enhance sensitive natural habitats and systems.

3. Provide Town services and infrastructure through an efficient, planned, and prioritized process.

4. Support and manage the regional resources and services unique to Cape Cod.

5. Preserve and enhance historic and maritime character, public viewsheds, and cultural landscapes.

6. Enhance pedestrian activity in historic village centers.

7. Preserve and enhance access to public spaces, including the waterfront.

8. Foster and support the creative economy, which includes history, culture, and arts.

9. Promote traffic reduction, traffic management, alternate transportation modes, property interconnections, and travel demand management.

10. Foster and support public transit while planning for associated parking, pedestrian and bicycle travel needs.

11. Allow development review to be more efficient for applicants and Town regulatory bodies in a predictable and fair manner.

12. Develop and support a process to encourage private investments and support appropriate economic development.

13. Fully integrate implementation of plan goals, actions, and strategies into the municipal budget and capital planning process.

This vision and these Town goals need to guide the formation of the Comprehensive Wastewater Management Plan.

6.5 ESTIMATED LAND USE GROWTH PROJECTIONS IN BARNSTABLE AND RELATED NEEDS

Evaluations completed as part of this Project, and summarized in Chapter 5, provide estimates of the existing and future land use in the Town. Use of the Town's Geographic Information System (GIS) has developed this information in terms of the number of residential dwellings and the amount of non-residential building space for each property in the Town as allowed by current zoning. These estimates are summarized below in terms of land use increase (percent [%]) for each of the villages.

TABLE 6-1

PROJECTED LAND USE INCREASES PER VILLAGE AREA[1]

VILLAGE	RESIDENTIAL DWELLINGS	NON-RESIDENTIAL SQ-FT AREA
Cotuit	118%	189%
Osterville	120%	229%
Marstons Mills	124%	198%
Centerville	108%	170%
Hyannis	135%	313%
Barnstable	203%	351%
W. Barnstable	166%	220%

These projected increases in land use as allowed by current zoning will add to the wastewater and nutrient loading problems. They need to be considered as solutions are developed.

6.6 WATER QUALITY NEEDS

A. **Estuarine Water Quality Needs.** The impacts and nitrogen limits to estuarine water quality have been researched and documented by the Massachusetts Estuaries Project and MassDEP for Popponessett Bay, Rushy Marsh, Three Bays System, Centerville River System, Halls Creek, and Lewis Bay. The impacts and nitrogen limits to the estuarine water quality in Barnstable Harbor have not yet been researched and documented. These nitrogen limits are needed to complete the CWMP Project and develop a Town-wide Plan.

The nitrogen limits developed to date are summarized in Chapter 5 and are illustrated on Figure 5-1 and in Appendix 5-4 for the existing and build-out conditions. Figure 5-1 illustrates the percent of existing wastewater (septic system) nitrogen load that must be removed to meet the nitrogen total maximum daily load (TMDL) limits. The figure offers a broad perspective look at the amount of wastewater nitrogen loading that needs to be addressed. The figure (and the additional information in Appendix 5-4) indicates that the nitrogen mitigation needs to be focused on specific watersheds and subwatersheds. Some subwatersheds need 100 percent wastewater nitrogen removal to meet the limits.

Septic system discharges have been found by the MEP to be the largest source of nitrogen to the Town's estuaries. Typically, these discharges comprise 75 percent to 85 percent of the nitrogen load from the watershed. Fertilizers and runoff from roads and roofs are the other two controllable nitrogen sources and typically comprise 5 percent to 10 percent of the watershed nitrogen loadings. This distribution is site specific for each watershed. Though septic systems are by far the largest source in Barnstable, fertilizers and runoff should be managed to reduce their loadings or, at the least, prevent the loads from these sources to increase. These sources are typically managed through "best management practices" that are typically implemented through increased awareness of these sources and public education. Public education on proper management of these two nitrogen sources is needed.

B. **Pond Water Quality Needs.** Phosphorus is typically the limiting nutrient for fresh water systems; therefore, it is the nutrient that stimulates excess algae production and produces water quality problems in ponds. There are no phosphorus TMDLs for Barnstable's ponds, but there has been much monitoring and analysis of pond data in the past.

As part of this Needs Assessment phase of the Project, the pond data was evaluated, and an Action Plan was developed for the ponds. The evaluation, findings, and main recommended actions are summarized in Table 5-4. The full report on this evaluation is attached in Appendix 5-1.

Many of the ponds are showing signs of water quality impact, and the Action Plan needs to be initiated to develop further information and begin remediation.

C. **Groundwater Quality and Drinking Water Supplies.** The drinking water quality, as indicated by the water supply annual Consumer Confidence Reports (CCR) is good. The 2007

WWFP investigated nitrogen impacts to the water supplies and found that most were well protected. Three zones of contribution to water supplies in the eastern portion of the Town were recommended for sewer extension to further protect the water supplies. These areas are the CO7, BWST1, and BWMEL1 areas, as illustrated on Figure 2-1. These sewer extensions need to proceed to further protect these water supplies.

Nitrogen discharges from septic systems previously were the main concern to the water supply zones of contribution. More recently, concerns have been raised about a new category of water contaminant called Contaminants of Emerging Concern (CECs). This general category includes three subgroups: endocrine disrupting compounds, pharmaceuticals, and personal care products. These compounds and potential contaminants are not currently regulated by the federal government because their toxicity is not well understood. Many of these compounds originate from the medications and personal care products that we use and discharge to our septic systems and wastewater treatment facilities.

Advanced wastewater treatment facilities, such as the Hyannis Water Pollution Control Facility and the Marstons Mills Wastewater Treatment Facility, are believed to provide better removals of these compounds than individual septic systems, but there is a lack of data on the performance of individual septic systems for these contaminants.

MassDEP revised their groundwater discharge regulations in March 2009 to require that all treatment facilities with flows greater than 10,000 gallons per day remove the total organic carbon (TOC) component of their wastewaters to less than 3 mg/L if the discharge is greater than a two-year travel time from the well, and less than 1 mg/L if the travel time is less than two years. TOC is not a contaminant by itself, but it is a surrogate of the CECs because most of the CECs are comprised of organic carbon. Research indicates that if the TOC concentration is low, the concentrations of the CEC will be low or non-detectable. This regulatory change has a big impact on the Hyannis Water Pollution Control Facility and the Marstons Mills Wastewater Treatment Facility, both of which discharge their treated waters to zones of contribution to public water supply wells with travel times greater than two years.

The Town needs to develop a plan as part of this CWMP Project on how it will meet this new regulation.

The Cape Cod Commission has been retained by the Town to re-delineate the zones of contribution to the water supplies in the Town. As part of this effort, the Town and this Project will need to:

- Work with the Commission, the water purveyors, and MassDEP on the re-delineation.
- Create revised zoning overlays to correspond with the new delineations.

D. **Bacterial TMDL Needs.** The following surface water bodies have bacterial TMDLs that may be caused by wastewater, stormwater runoff, and/or animals living in (or frequenting) the waterbodies:

- Barnstable Harbor
- Bumps River
- Hyannis Harbor
- Lewis Bay
- Marsapin Creek
- Mill Creek
- Seapuit River

Stormwater and land-use management solutions to be evaluated in the next phase of the project will consider these TMDLs.

6.7 WASTEWATER TREATMENT AND RECHARGE FACILITIES AND RELATED NEEDS

Most of the properties in the Town are served by individual on-site septic systems that have been documented as contributing the largest percentage of nitrogen (75 to 85 percent) to the coastal estuaries. Nitrogen discharges from these systems need to be remediated to meet the nitrogen TMDLs. These systems also discharge large quantities of phosphorus that is impacting water quality in the freshwater ponds. Phosphorus discharges from these systems need to be remediated to address pond water quality impacts.

A group of 71 individual Innovative and Alternative (I/A) septic systems as regulated by MassDEP and the Title 5 regulations are operating in Barnstable. These systems are typically designed to remove approximately 50 percent of the nitrogen in the wastewater and meet a limit

of 19 mg/L total nitrogen. Research at the Otis On-Site Septic System Test Facility at the Massachusetts Military Reservation indicates that these systems typically can meet this limit when they are properly designed and operated with a consistent wastewater flow. Data analysis by the Barnstable County Department of Health and Environment on the I/A systems actually installed at Cape Cod properties indicates that only 60 percent of the installed systems meet the 19 mg/L limit. Data review of the 71 systems in Barnstable indicates similar performance.

There are two privately owned wastewater treatment facilities in Barnstable located at the Cotuit Landings Stop & Shop and at the Cape Regency Skilled Nursing and Rehabilitation Center. They are sized for approximately 20,000 gpd, and both have demonstrated good nitrogen removal performance to meet their discharge limit of 10 mg/L total nitrogen.

The Town owns and operates three treatment facilities:

- Hyannis WPCF
- Marstons Mills WWTF
- Red Lily Pond Cluster System

These treatment facilities and their collection systems are illustrated on Figure 1-1, and their "needs" are summarized below:

A. **Hyannis WPCF.** The Hyannis WPCF treats an average flow of 1.46 million gallons per day (mgd) and a maximum-month average flow of 1.94 mgd. It has recently been upgraded and expanded and has a maximum-month capacity of 4.2 mgd. The treatment facility has excellent performance and averages 5 mg/L total nitrogen in the treated water as compared to a MassDEP discharge limit of 10 mg/L.

MassDEP has recently (March 2009) revised their groundwater discharge regulations to require a total organic carbon (TOC) limit in the treated water because the recharge is in a zone of contribution to public water supply wells. This project will need to develop a plan (as part of the CWMP) to meet these new TOC limits.

The capacity of the sand infiltration beds has been estimated based on text-book information that may not be accurate for the sandy soil conditions at the site. Therefore, the sand bed capacity may be even greater. A hydraulic loading test in the sand beds would provide a more empirical

measure of the capacity of these beds which may become important in the future if some of the bed areas need to be used for new treatment facilities. A hydraulic load test needs to be completed to better estimate the capacity of the sand infiltration beds.

The Hyannis WPCF has a collection system that has grown over time, and its ability to accept more flow is not clearly defined. A computer model was developed for the Hyannis Growth Incentive Zone (GIZ) area of Hyannis when the Town was evaluating that area for the GIZ. The existing computer model should be expanded to cover the whole collection system. This will allow a better understanding of its capacity and how the existing system can be most efficiently expanded to pick up additional flow.

B. **Marstons Mills WWTF.** The Marstons Mills WWTF serves an elementary school, a middle school, and a residential development of 30 homes. The WWTF was recently upgraded and is performing well. Similar to the Hyannis WPCF, its recharge is in a zone of contribution to a public water supply well and, as such, the WWTF will need to increase its treatment to meet the new TOC discharge limit (discussed earlier in this chapter) of 3 mg/L. The CWMP Project will need to evaluate options to meet this new limit.

C. **Red Lily Pond Cluster System.** This cluster system serves several homes adjacent to Red Lily Pond and Elizabeth Lake. It does not have a discharge permit, and its treatment performance is expected to be similar to a conventional Title 5 septic system. No modifications to this system are indicated at this time.

6.8 INFORMATIONAL NEEDS (DATA GAPS)

The preceding sections summarized the wastewater and nutrient management needs in Town. Some of these are informational needs for the Project Team to continue and complete the CWMP Project. The informational needs as identified in previous chapter sections are listed below.

- Nitrogen TMDL for Barnstable Harbor to be developed by the Massachusetts Estuaries Project and MassDEP.
- Nitrogen TMDL for Lewis Bay. (The Town has received the Massachusetts Estuaries Technical Report on this estuary but still needs the TMDL Report.)
- Revised funding policy for Clean Water Projects in Barnstable.

- Collaborative input from the neighboring towns of Mashpee, Sandwich, and Yarmouth; and the Cape Cod Water Protection Collaborative on reducing nitrogen loadings to the shared watersheds of Popponesset Bay, Three Bays System, Barnstable Harbor, and Lewis Bay.
- Informational needs related to the Barnstable Ponds Action Plan including needed sampling and analysis data.
- Possible revisions to water supply well zones of contribution being completed by the Cape Cod Commission with coordination with the water purveyors and MassDEP.
- Refinement of the sand infiltration bed capacity at the Hyannis WPCF based on a hydraulic load test to assist in future treated water recharge evaluations.
- Expansion of the sewer system computer model to assist in future wastewater collection evaluations.

These informational needs shall be considered and addressed as the project proceeds.

6.9 NO ACTION ALTERNATIVE

The No Action Alternative is always developed as part of a CWMP project to identify the likely outcome of not acting on the current wastewater problems in the Town of Barnstable. Degradation of Popponesset Bay, Three Bay System, Centerville River System, and Lewis Bay will continue from the excessive nitrogen loading in the watersheds to these water bodies, primarily from the on-site septic systems. The MEP technical reports used colored maps to illustrate how the nitrogen concentrations would increase from their current levels to the projected buildout levels defined by current zoning. The increased nitrogen would promote further algal blooms, fish kills, eel grass loss, and other impacts to the habitat of the marine estuaries.

A portion of the Eastern side of Barnstable probably would be sewered as allowed by the 2007 Wastewater Facilities Plan. These areas are illustrated on Figure 2-1.

If the Town did not demonstrate progress to meet the nitrogen TMDLs, MassDEP would most likely initiate an enforcement action against the Town as allowed by state law[1].

[1] Based on discussions with the Cape Cod Water Protection Collaborative and MassDEP.

If the Town did not demonstrate progress to meet the new TOC discharge limit, MassDEP would most likely initiate an enforcement action against the Hyannis WPCF and the Marstons Mills WWTF as allowed by state law[1].

If progress is not made on the Barnstable Ponds Action Plan, pond water quality will decline.

6.10 NEXT STEPS TO IDENTIFY SOLUTIONS FOR WASTEWATER NEEDS.

The Needs Assessment Report documents the second phase of the project. (The first phase was the development of nutrient limits which was initiated several years ago and is summarized in this Needs Assessment Report.) The next phase of the project will identify and screen alternative solutions to meet the wastewater and nutrient management needs. These technologies and solutions will be described, and advantages and disadvantages will be summarized. Infeasible technologies and solutions will then be eliminated from further evaluation. The subsequent phases will evaluate the feasible technologies and solutions in detail, and present the recommended CWMP with draft and final Environmental Impact Reports. Also a public education/participation program will be provided throughout the project to inform and involve the public in this effort.

Appendix 1-1 of Appendix R:

Final Wastewater Facilities Plan and Final Environmental Impact Report for the Town of Barnstable; March 2007

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Needs Assessment Report

Comprehensive Wastewater Management Planning (CWMP) Project

Town of **Barnstable**, MA



Volume 2 of 2 Report Figures and Appendices
May 2011

WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

Comprehensive Wastewater Management Planning (CWMP) Project

Needs Assessment Report

Volume 2 of 2
Report Figures and Appendices

Prepared for

TOWN OF BARNSTABLE, MASSACHUSETTS

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May 2011

Project No. 8612474

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GLOSSARY OF COMMON ACRONYMS

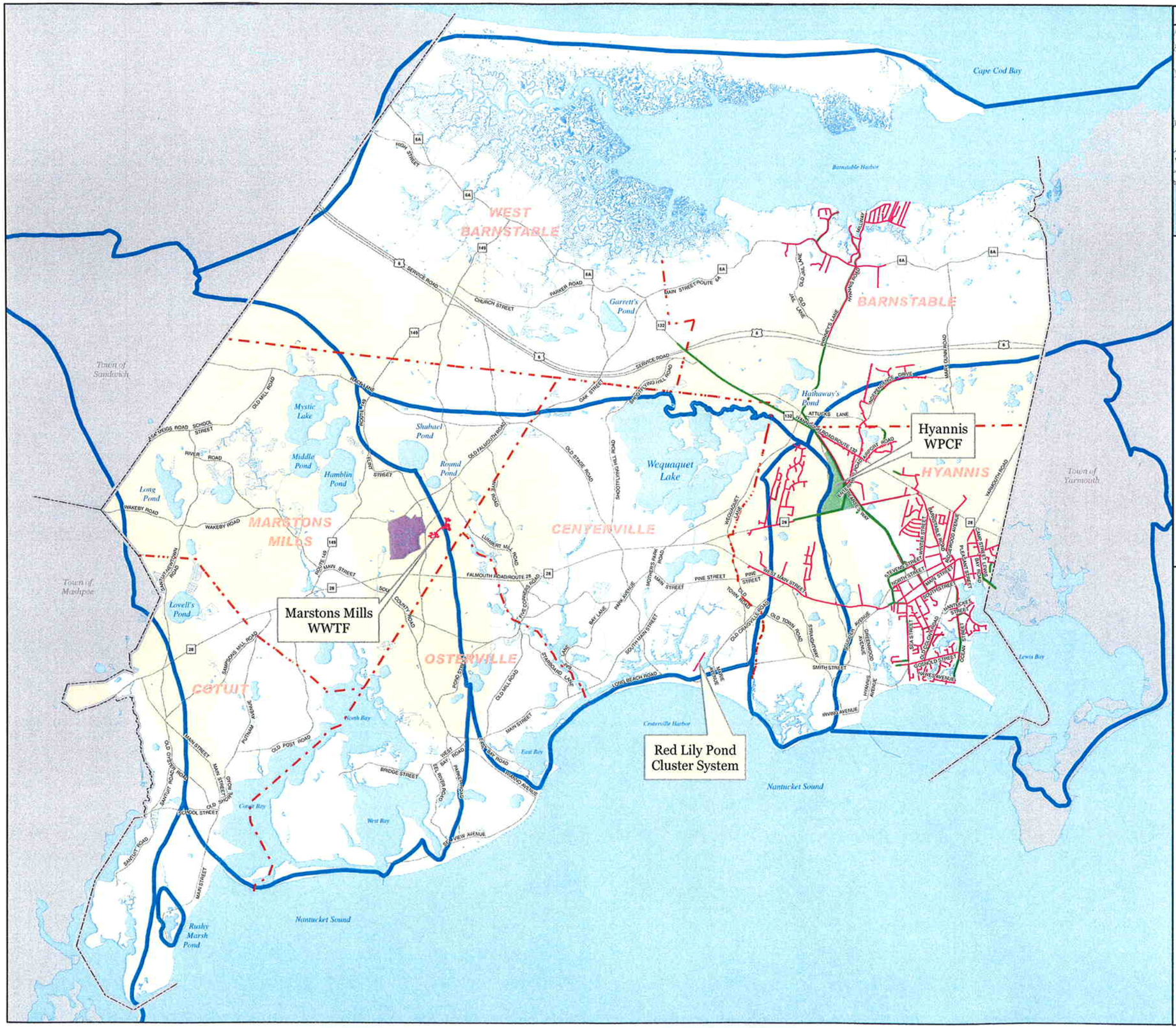
ABF	Aerated Biological Filters
ACEC	Areas of Critical Concern
ACRE	Applied Coastal Research and Engineering, Inc.
AOC	Area of Concern
AOP	Advanced Oxidation Processes
APCC	Association to Preserve Cape Cod
ATAD	Autothermal Thermophilic Aerobic Digestion
BAC	Biological Activated Carbon
BAF	Biologically Active Filters
BCDHE	Barnstable County Department of Health and Environment
BCP	Barnstable Comprehensive Plan
BMP	Best Management Practices
BNR	Biological Nitrogen Removal
BOD	Biological Oxygen Demand
BOH	Board of Health
CCC	Cape Cod Commission
CCWPC	Cape Cod Water Protection Collaborative
CEC	Contaminants of Emerging Concern
CFR	Code of Federal Regulation
CMR	Code of Massachusetts Regulations
CNR	Cyclical Nitrogen Removal
COD	Chemical Oxygen Demand
CWA	Clean Water Act
CWMP	Comprehensive Wastewater Management Plan
CZM	Coastal Zone Management
DBP	Disinfection By-Products
DCPC	District of Critical Planning Concern
DCWMP/DEIR	Draft Comprehensive Wastewater Management Plan and Draft Environmental Impact Report
DMF	Division of Marine Fisheries
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DPW	Department of Public Works
DRI	Development of Regional Impact
EDC	Endocrine Disrupting Compounds
EIR	Environmental Impact Report
eMLE	enhanced Modified Ludzack-Ettinger
ENF	Environmental Notification Form
ENR	Enhanced Nitrogen Removal
FAST	Fixed Activated Sludge Treatment
FCWMP/FEIR	Final Comprehensive Wastewater Management Plan and Final Environmental Impact Report
FFL	Falmouth Friendly Lawn

GAC	Granular Activated Carbon
GIS	Geographic Information System
gpd	gallons per day
gpd/im	gallons per day per inch-mile
gpd/sf	gallons per day per square foot
GWDP	Groundwater Discharge Permit Program
HAA	Haloacetic Acids
I/A	Innovative and Alternative
IFAS®	Integrated Fixed Film Activated Sludge
I/I	Infiltration/Inflow
LCP	Local Comprehensive Plan
MassDEP	Massachusetts Department of Environmental Protection
MBBR	Moving Bed Biofilm Reactors
MBR	Membrane Bioreactors
MCL	Maximum Contaminant Level
MEPA	Massachusetts Environmental Policy Act
MEP	Massachusetts Estuaries Project
MF	Microfiltration
MGL	Massachusetts General Law
mgd	million gallons per day
mg/L	milligrams per liter
MIEX	Magnetic Ion Exchange
MLE	Modified Ludzack-Ettinger
MLSS	Mixed Liquor Suspended Solids
MMMS	Marstons Mills middle School
MMR	Massachusetts Military Reservation
MSL	Mean Sea Level
NaOCI	Sodium Hypochlorite
N_2	Nitrogen Gas
NEPA	National Environmental Policy Act of 1970
NERR	National Estuarine Research Reserve
NF	Nanofiltration
NHESP	Natural Heritage and Endangered Species Program
NH_4	Ammonium Cation
NH_3-N	Ammonia Nitrogen
NO_3-N	Nitrate Nitrogen
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Units
OH	Hydroxyl
O&M	Operations & Maintenance

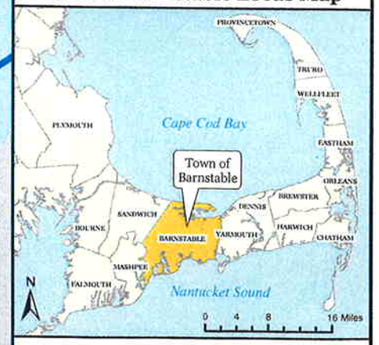
PAC	Powdered Activated Carbon
PALS	Pond and Lake Stewardship
POTW	Publicly Owned Treatment Works
PPCP	Pharmaceuticals and Personal Care Products
ppm	parts per million
psi	per square inch
PSTF	Privately-owned Sewage Treatment Facility
RAS	Return Activated Sludge
RBC	Rotating Biological Contactor
RO	Reverse Osmosis
ROW	Right-of-Way
RPP	Regional Policy Plan
RSF	Recirculating Sand Filter
SBR	Sequencing Batch Reactor
SCADA	Computer system that stands for: Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SMAST	School of Marine Science and Technology
STEG	Septic Tank Effluent Gravity
STEP	Septic Tank Effluent Pump
SWD	Solid Waste Division
TDS	Total Dissolved Solids
THM	Trihalomethane
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UCT	University of Capetown
UF	Ultrafiltration
ULPRO	Ultra Low Pressure Reverse Osmosis
UMass	University of Massachusetts
USDA	U.S. Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
VIP	Virginia Initiative Plant
WAS	Waste-Activated Sludge
WPA	Wetlands Protection Act
WPCD	Water Pollution Control Division
WPCF	Water Pollution Control Facility
WWTF	Wastewater Treatment Facility

ZOC Zone of Contribution

Chapter 1 Figures



Town of Barnstable Locus Map



Zones of Contribution to Public Water Supply

NOTE: this layer is a combination of the State Approved Zone II and the Town Approved GP and WP Overlay Districts.

- Marine Watersheds
- Sanitary Landfill
- Hyannis W.P.C.F.
- Existing Force Main
- Existing Sewer
- Fire District / Village Lines
- Major Roads
- Town Boundary
- Water Bodies

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Project Location
Figure 1-1

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1889

N W E S

Miles
0 0.25 0.5 1 1.5 2

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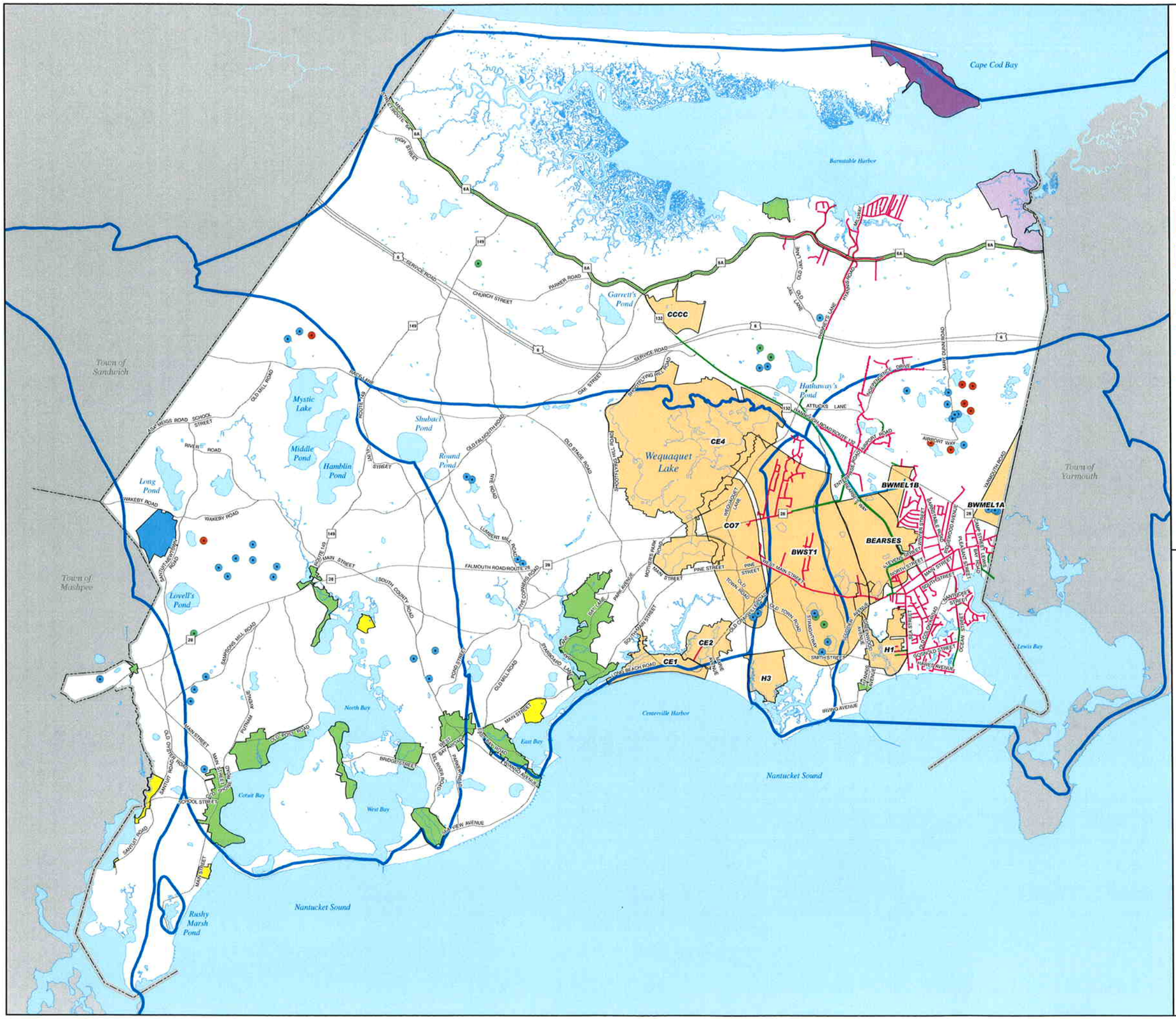
TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD

Chapter 2 Figures


Cape Cod Bay
Barnstable Harbor
Town of Sandwich
Town of Mashpee
Town of Yarmouth
Mystic Lake
Middle Pond
Hamblin Pond
Long Pond
Shubael Pond
Round Pond
Garrett's Pond
Hallaway's Pond
Wequaquet Lake
Lovell's Pond
Rushy Marsh Pond
North Bay
East Bay
West Bay
Cotuit Bay
Centerville Harbor
Lewis Bay
Nantucket Sound
CCCC
CE4
CE2
CE1
C07
H1
H3
BWMEL1A
BWMEL1B
BWST1
BEARSES
SERVICE ROAD
CHURCH STREET
OAK STREET
OLD STAGE ROAD
OLD FALMOUTH ROAD
FALMOUTH ROAD/ROUTE 28
MAIN STREET
WEST MAIN STREET
PINE STREET
SOUTH MAIN STREET
OLD TOWN ROAD
OLD STAGE ROAD
OLD KINGS HIGHWAY
OLD COLONY ROAD
OLD MILL ROAD
WAKEBY ROAD
SCHOOL STREET
SANDY NECK ROAD
SAMPSONS MILL ROAD
SOUTH COUNTY ROAD
OLD YARMOUTH ROAD
HIGHWAY
ROUTE 132
ATTUCKS LANE
HYANNIS-WEST BARNSTABLE ROAD/ROUTE 149
YARMOUTH ROAD
MAIN DRIVE
AIRPORT WAY
WEST BARNSTABLE ROAD
OCEAN AVENUE
SEASIDE AVENUE
IRVING AVENUE
SMITH STREET
SOUTH STREET
NORTH STREET
LEWIS BAY ROAD
BAY STREET
SANDY NECK ROAD
MAIN STREET
OLD POST ROAD
BRIDGE STREET
PARKER ROAD
RIVER ROAD
LOWELL ROAD
OLD WELL ROAD
STRAIGHTWAY
Wastewater Areas of Concern
Recommended
Wastewater Solutions
Connection to the Hyannis Water Pollution Control Facility
Single Unit Title V or Multiple Unit Title V
Composting Toilets
On-Site Title V or Composting Toilets
Area to Receive Town Water
Board of Health Solution
Marine Watersheds
Existing Sewer Force Main
Existing Gravity Sewer
Existing Vacuum Sewer
Existing Well
Proven Future Well
Proposed Future Well
Major Roads
Town Boundary
Water Bodies
TOWN OF BARNSTABLE
MASSACHUSETTS
Comprehensive Wastewater and Nutrient Management Plan
Wastewater Areas of Concern & Recommended Solutions From 2007 WWFP
Figure 2-1
SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1989
N
W
E
S
Miles
0 0.25 0.5 1 1.5 2
CWNMP_AOC_solutions_11x17.mxd J.A.B. 4/28/2010
TOWN OF BARNSTABLE
GEOGRAPHIC INFORMATION SYSTEMS UNIT
FIGURE PREPARED FOR STEARNS & WHELER GHD

Note: The phase numbering indicates a logical grouping and does not indicate a priority ranking

New Lake W-3 Pumping Station (optional) Construct, Phase 4

New Lake W-2 Pumping Station Construct, Phase 5

New Lake W-1 Pumping Station Construct, Phase 5

New LP-1 Pumping Station Construct, Phase 5

New LP-2 Pumping Station Construct, Phase 5

New Lincoln Rd Pump Station Construct, Phase 5

Mark's Path Pump Station Current Capacity: 300 gpm Upgrade, Phase 4

Vacuum Station Upgrade, Phase 9

Old Colony Pumping Station Current Capacity: 3300 gpm Upgrade, Phase 12

Main Street Pump Station Current Capacity: 435 gpm Upgrade to 650 gpm, Phase 2 Constrct New to 1300 gpm, Phase 10

Sea Street Pump Station Current Capacity: 200 gpm No Upgrade Required

Sea Street Beach Pump Station Current Capacity: 100 gpm No Upgrade Required

North
Northeast
Phinney's Lane Area
Great Marsh Rd Area
BWC West
BWC East
CO7 Northeast
CO7
Long Pond -N,W
Long Pond - S, E
BWB West
BWB East
BWA West
BWA East
CE1
CE2
H3
H1 West
H1 East
BW MEL 1B
BW MEL 1A
Bearse's Vacuum Area
Bearse's West
Bearse's Way/ Bacon Rd Area
Bearse's South

Legend

- Existing Pump Stations
- Proposed Pump Stations
- Buffer Tanks
- Existing Gravity Main
- Proposed Gravity Main
- Existing Vacuum Sewer
- Proposed Vacuum Sewer
- Existing Force Main
- Proposed Force Main
- Proposed Low Pressure Main
- Parcel Boundary
- Phase 1
- Phase 2
- Phase 3
- Phase 4
- Phase 5
- Phase 6
- Phase 7
- Phase 8 - Upgrade WPCF
- Phase 9
- Phase 10
- Phase 11
- Phase 12

1 inch = 2,000 feet

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Nutrient Management March 2010\PDFSewer Layout - phasing diagram\Fig 2-3.mxd

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Date: 3/2010 Project No. 81014

TOWN OF BARNSTABLE, MASSACHUSETTS

Implementation Phasing of Sewer Extensions Proposed in Draft November 2008 Memoranda

FIGURE 2-3 - Sewer Phasing Plan

Chapter 4 Figures



Note 1. Aerial photo taken on July 10, 2009.

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Hyannis WPCF Site Plan
Figure 4-1

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1939

N E S W

1 inch equals 80 feet

Feet
0 20 40 80 120 160

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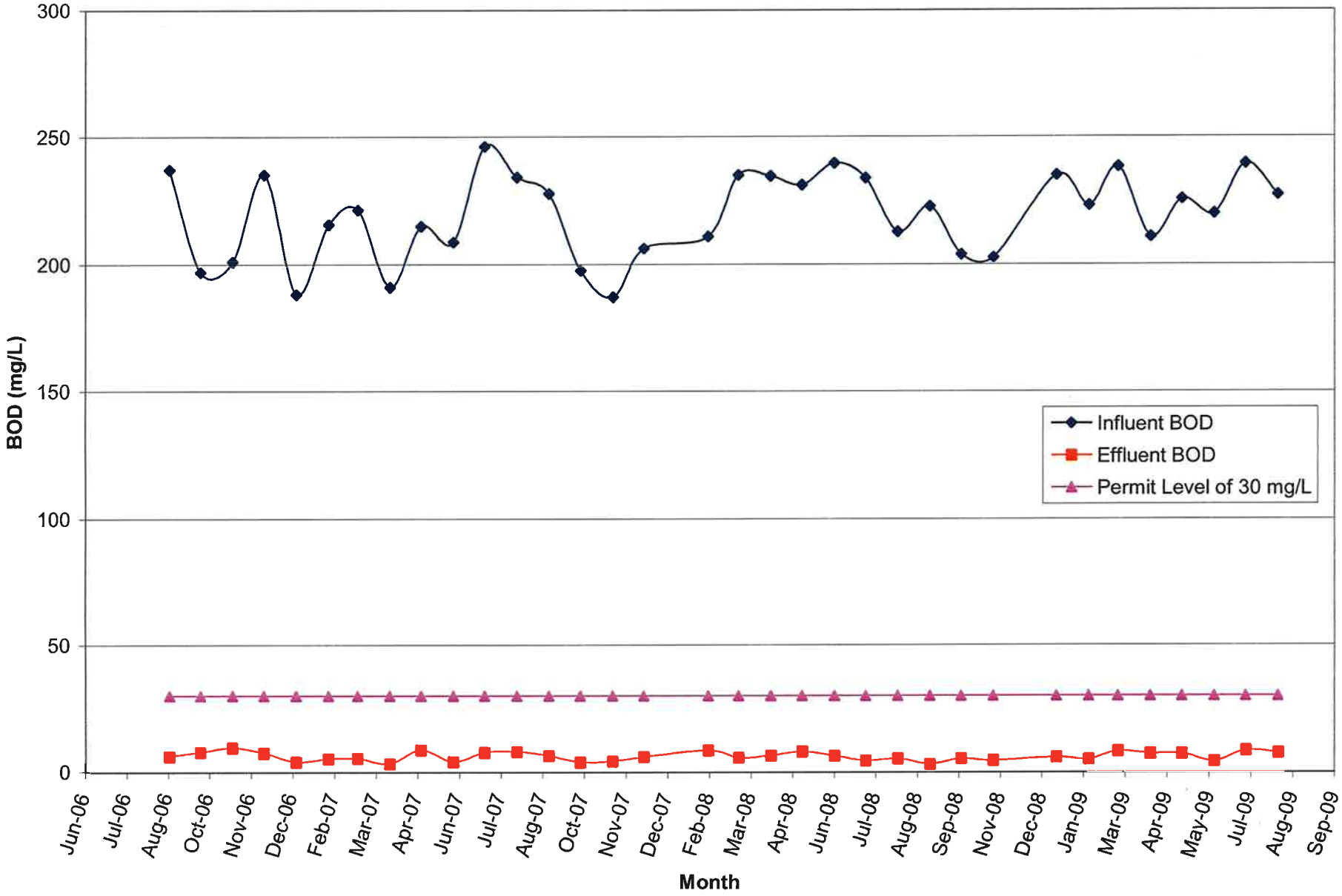
TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD



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Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

HYANNIS WPCF BOD CONCENTRATIONS

FIGURE 4-2

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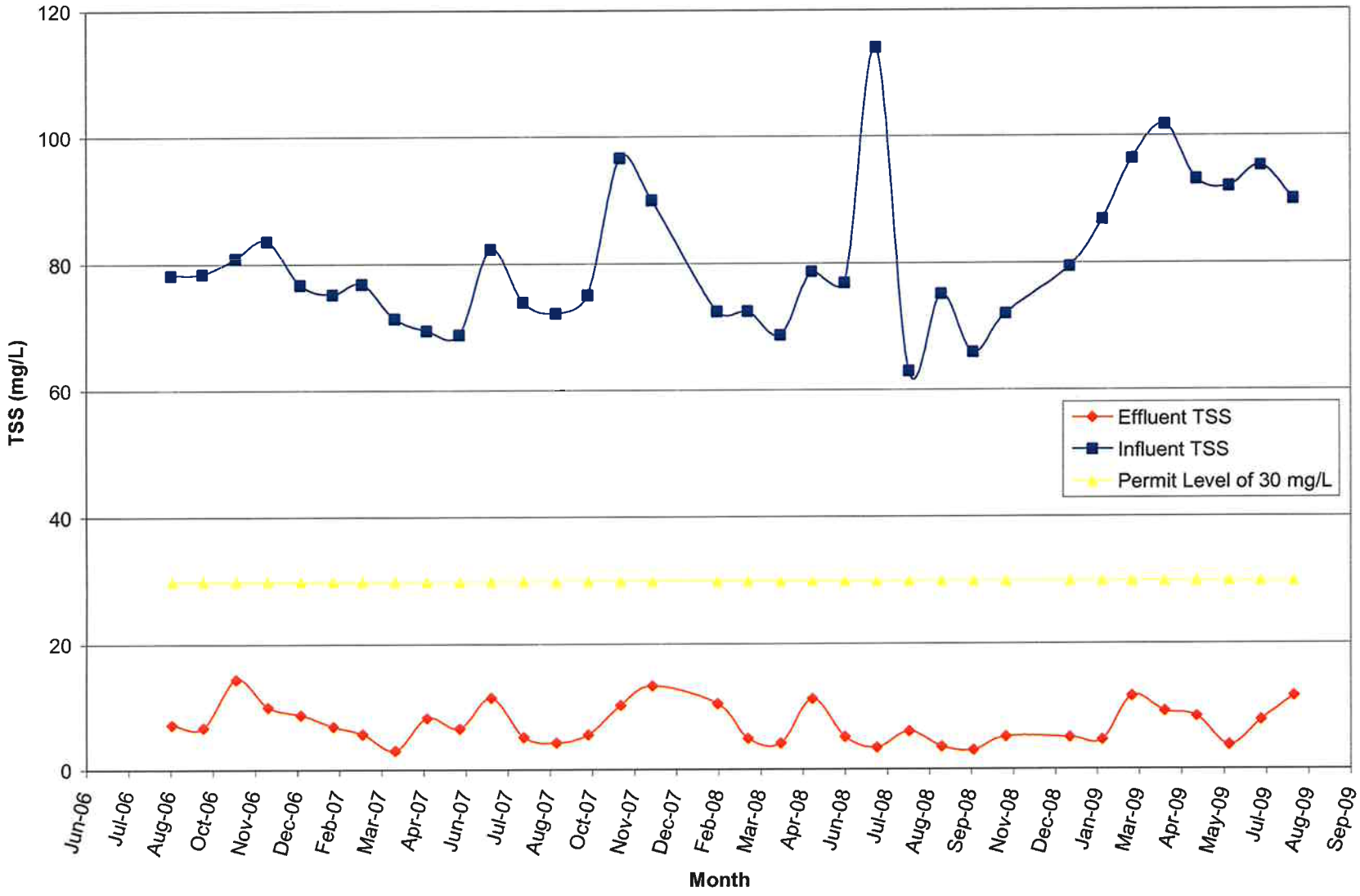

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Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

HYANNIS WPCF TSS CONCENTRATIONS

FIGURE 4-3

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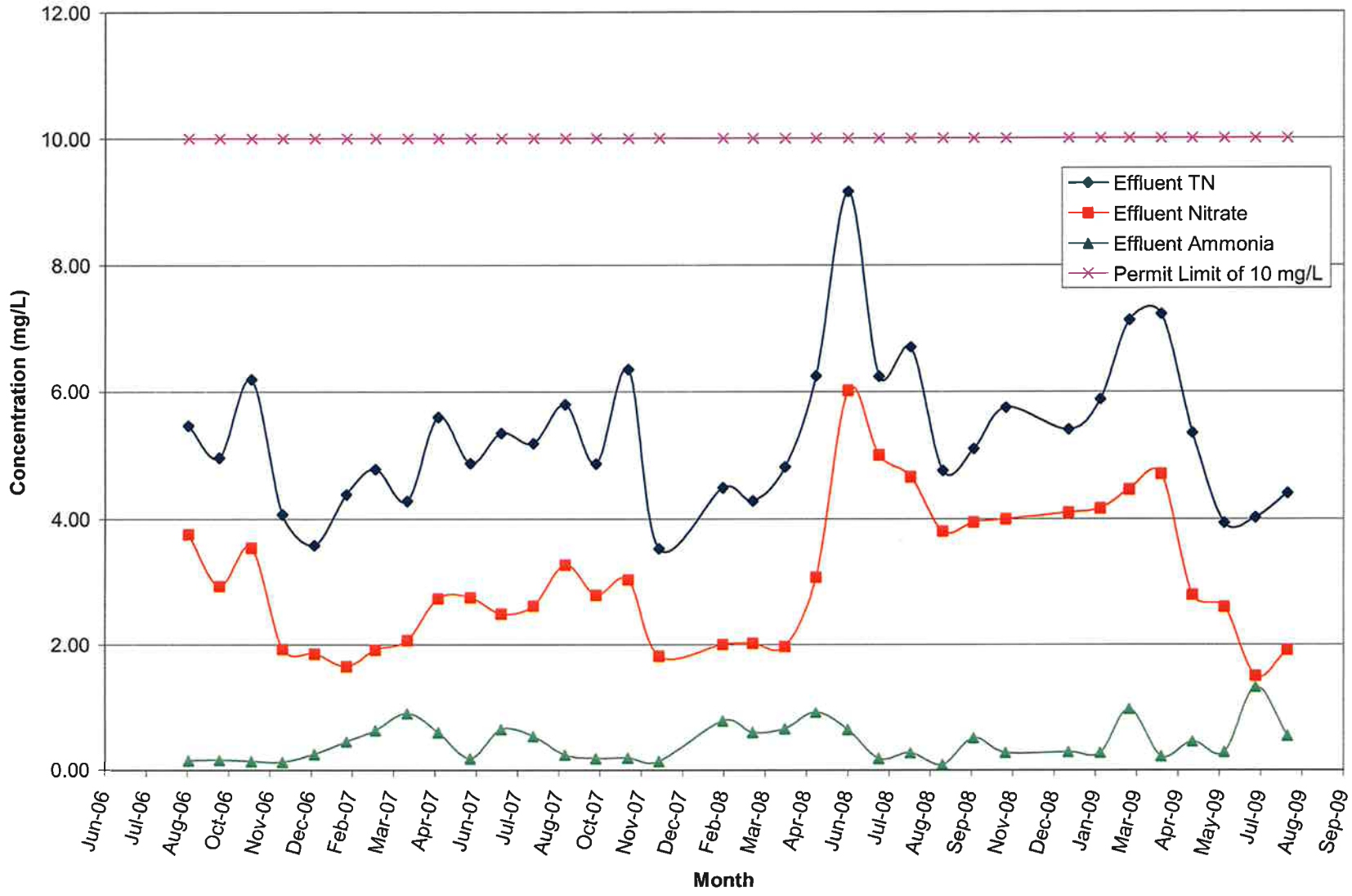

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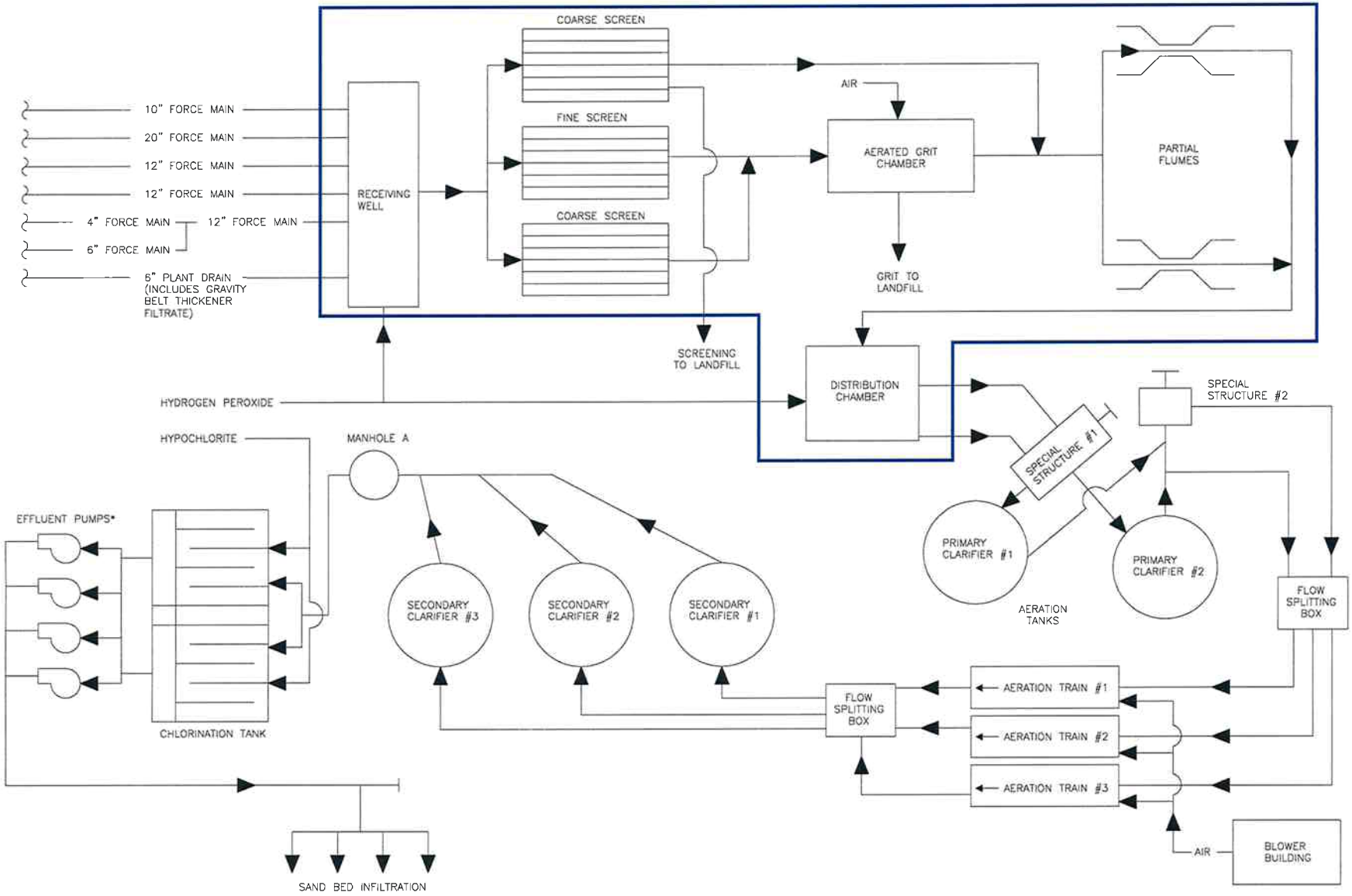
Comprehensive Wastewater and Nutrient Management Plan

HYANNIS WPCF EFFLUENT NITROGEN CONCENTRATIONS

FIGURE 4-4

PRETREATMENT BUILDING



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Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

Wastewater Flow Schematic for Hyannis WPCF

FIGURE 4-5

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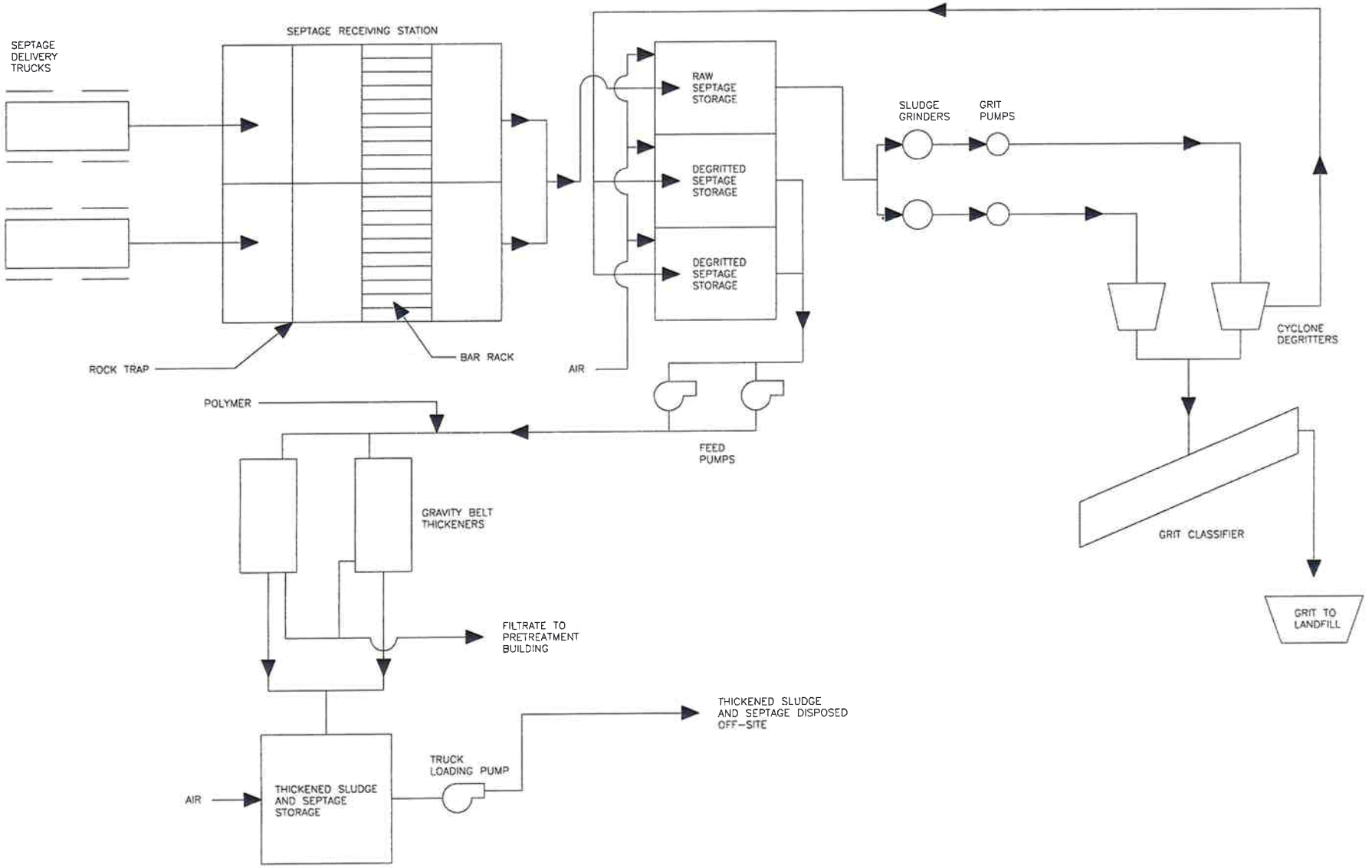

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Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

Septage Flow Schematic for Hyannis WPCF

FIGURE 4-6

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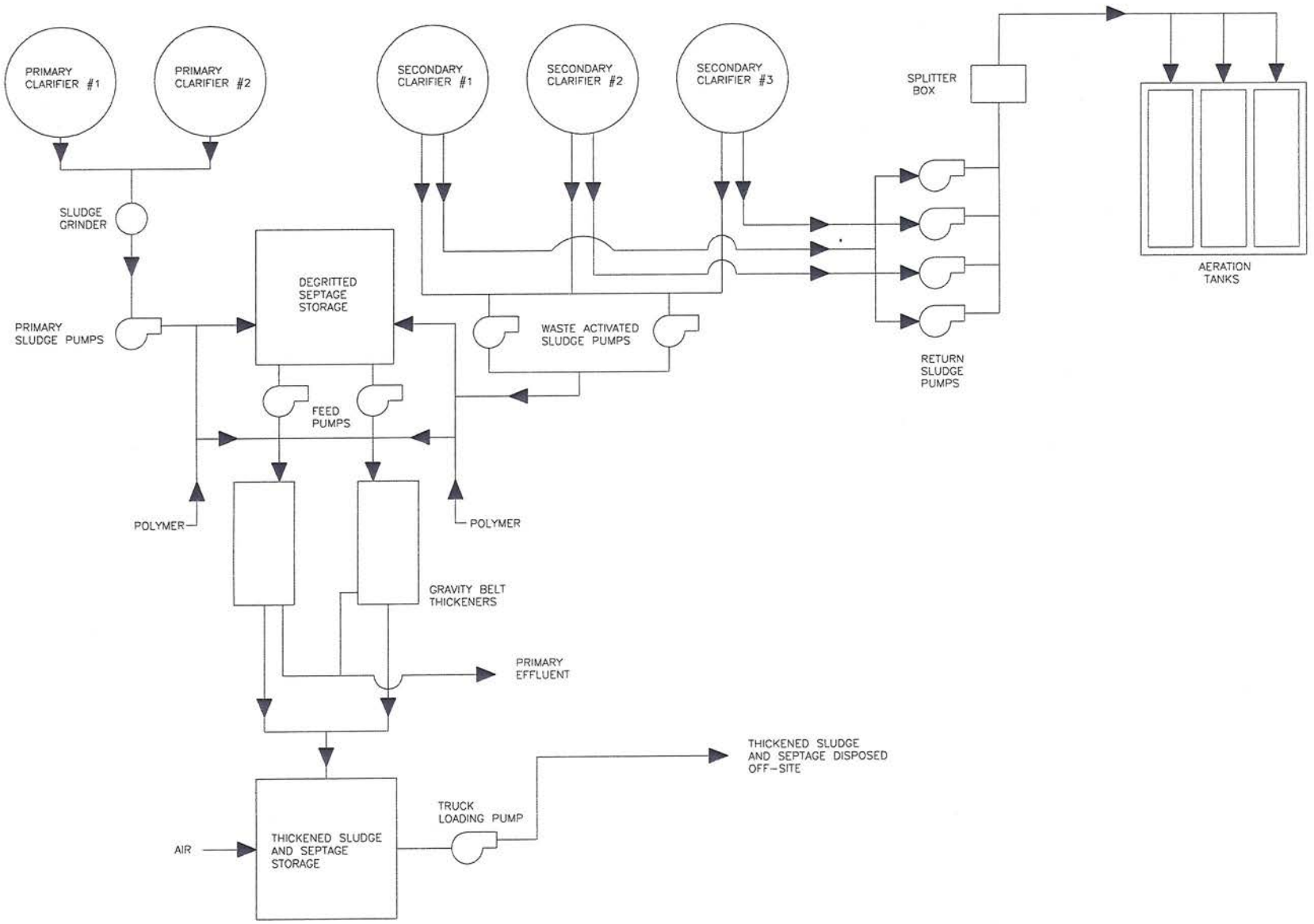

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Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

Sludge Flow Schematic for Hyannis WPCF

FIGURE 4-7

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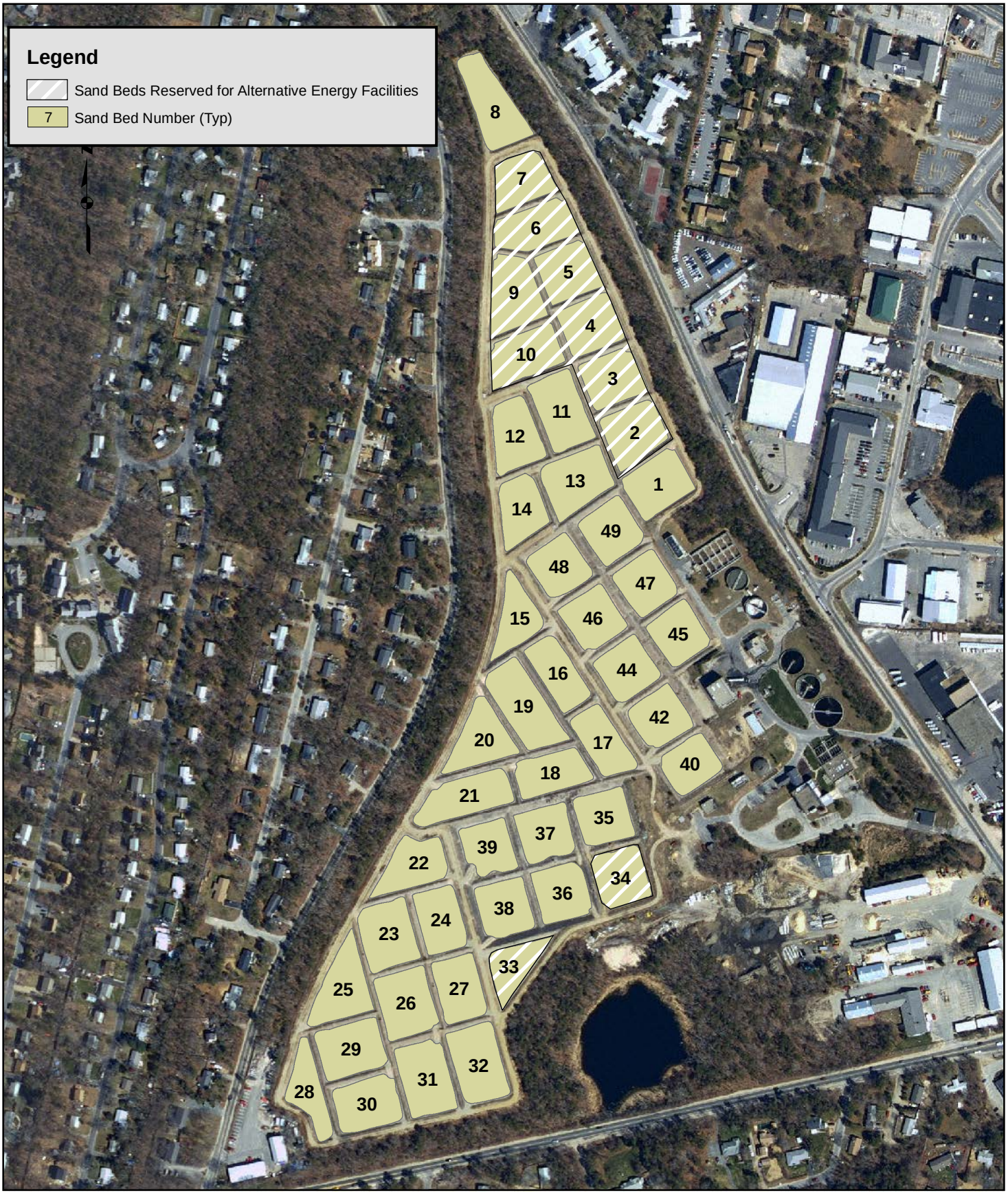

1 in = 380 ft

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Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

Sand Infiltration Bed Identification

FIGURE 4-8



1 in = 380 ft

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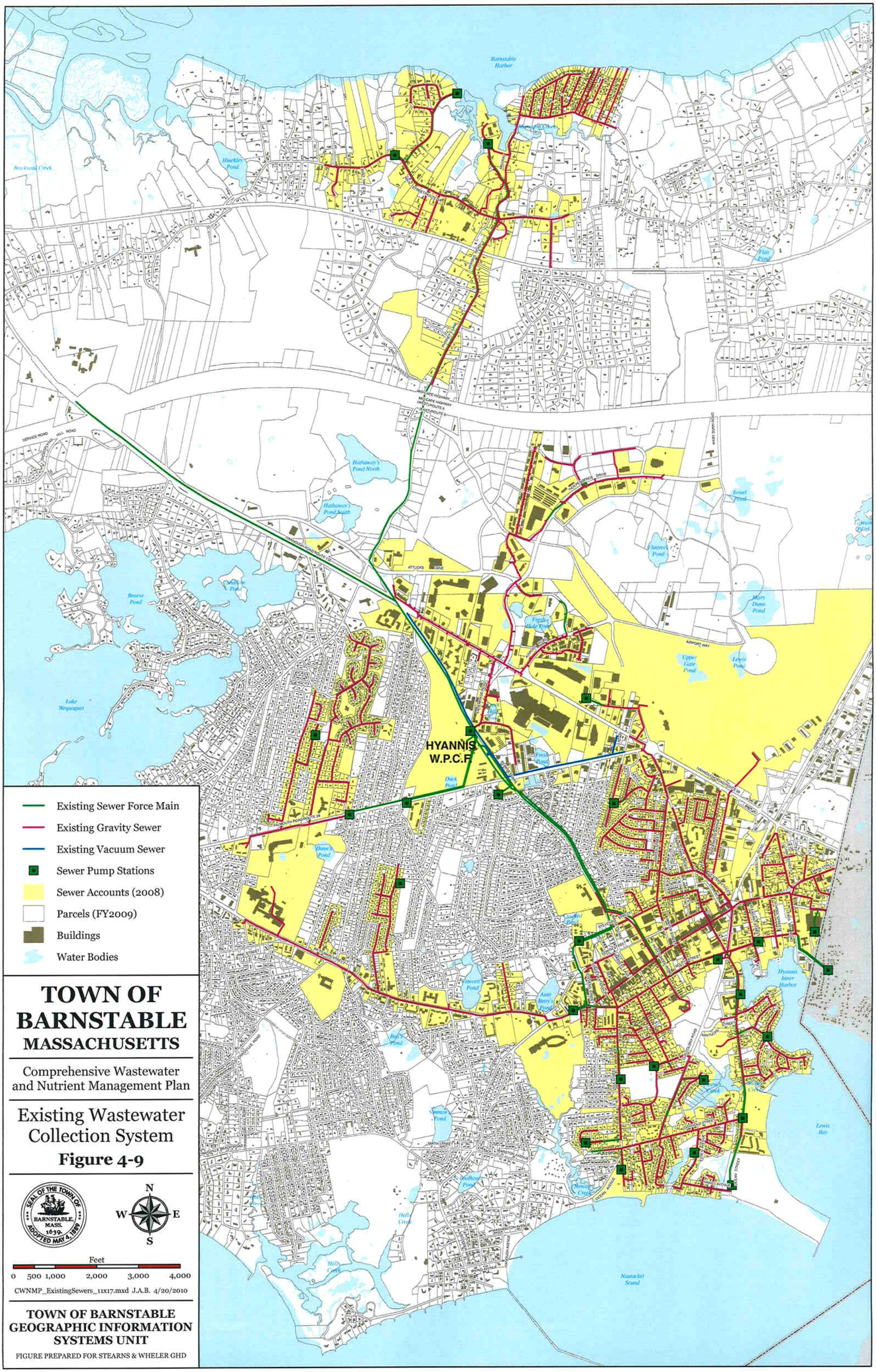
Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

Sand Infiltration Bed Identification

FIGURE 4-8



TOWN OF BARNSTABLE
MASSACHUSETTS

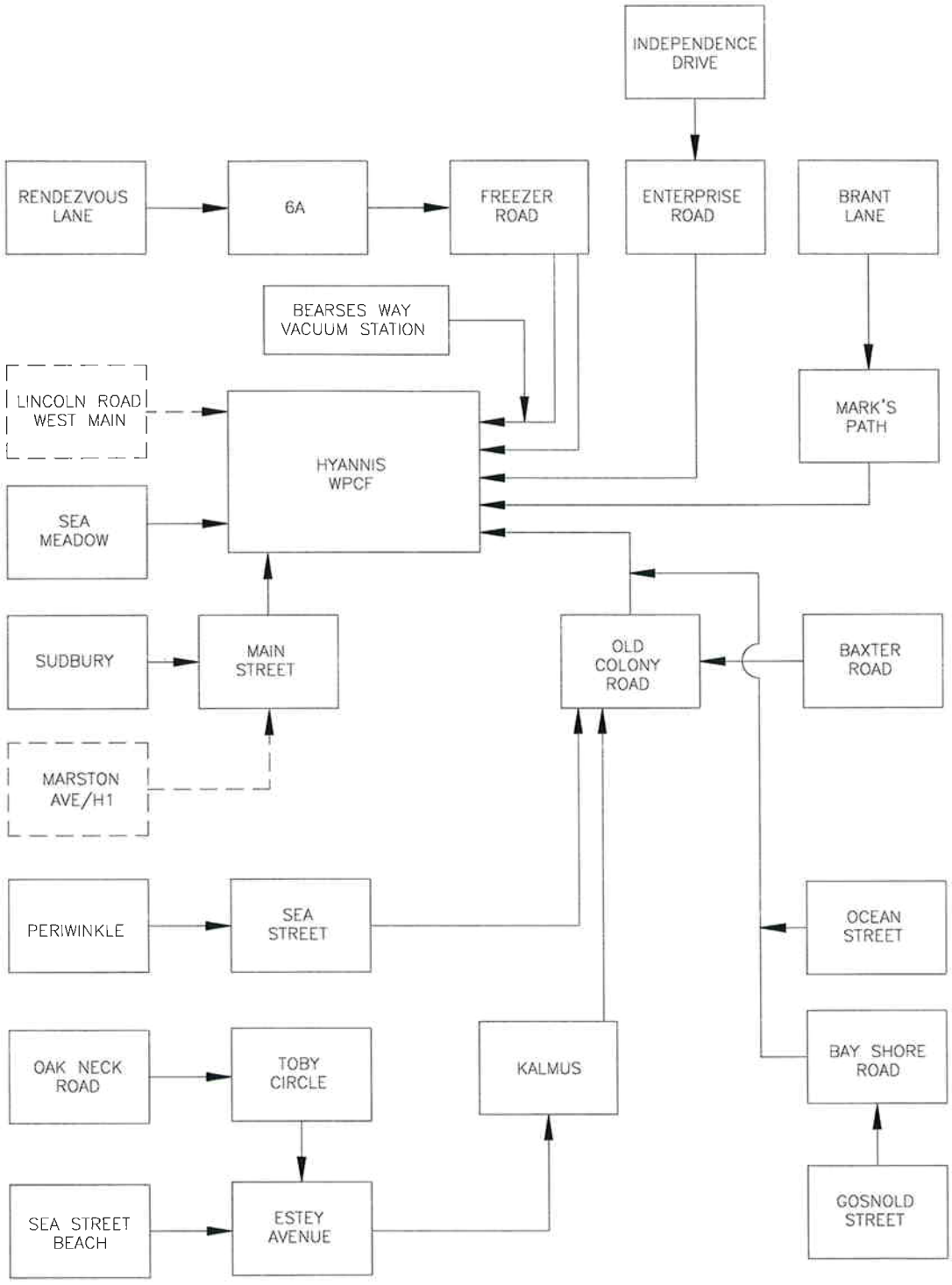
Comprehensive Wastewater and Nutrient Management Plan

Existing Wastewater Collection System
Figure 4-9

CWNMP_ExistingSewers_11x17.mxd J.A.B. 4/20/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD



- - - PUMP STATION AND FORCEMIAN UNDER CONSTRUCTION (2010)

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Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

Pump Station/ Forcemain Schematic

FIGURE 4-10

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TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Marstons Mills WWTF Site
Figure 4-11

N
W E
S

Feet
0 40 80 160 240 320

CWNMP_MMWWTF_8x11.mxd J.A.B. 4/28/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD

Aerial Photo Taken April 19, 2008

- Sewer Lines
- Treated Water Lines
- Leaching Facility
- Sewer Manholes
- Distribution Box
- Parcels

West Villages Elementary School

Marstons Mills WWTF

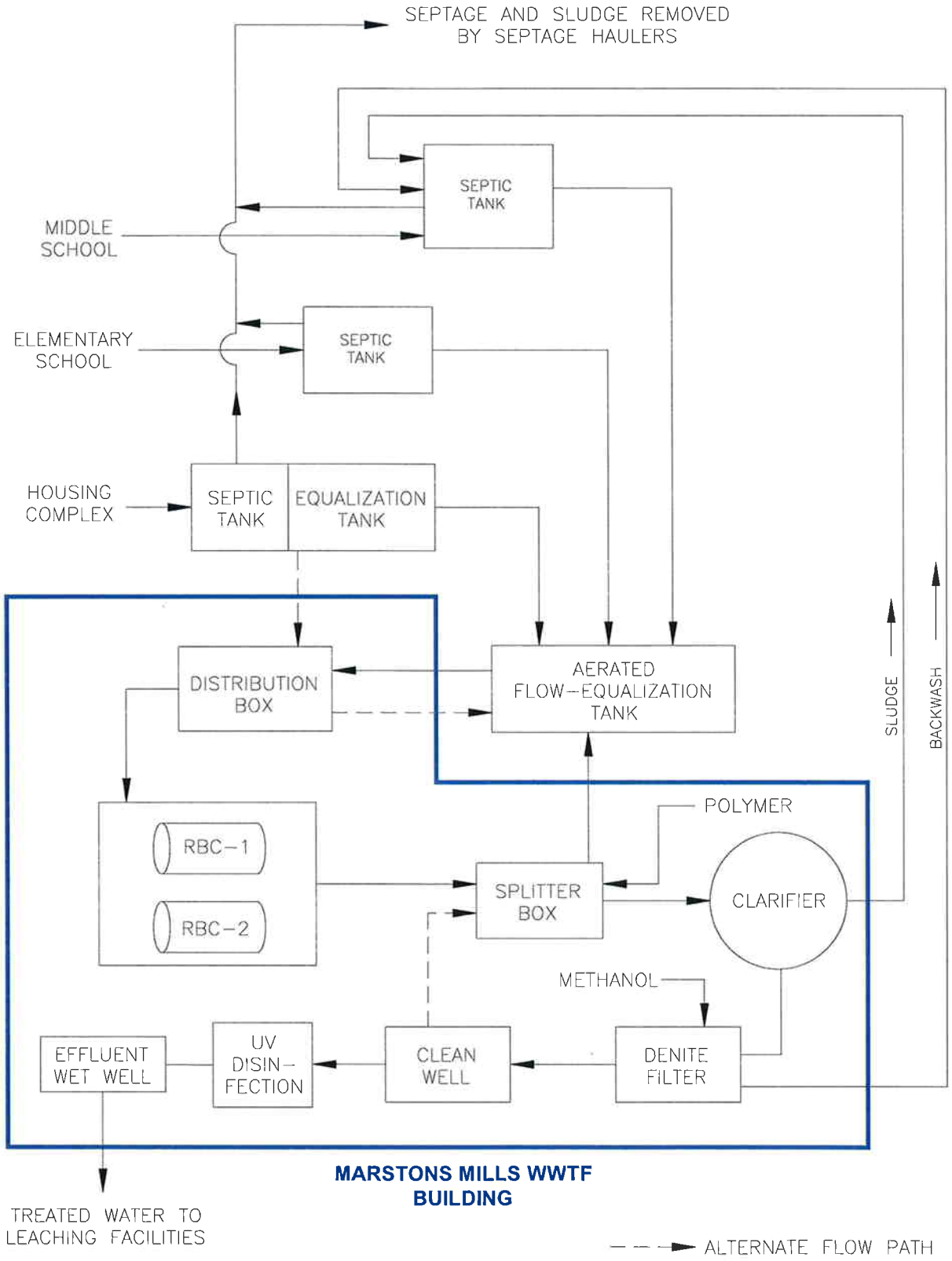
The Village At Marstons Mills

Horace Mann Charter School

Recharge Facilities (Typ)

Parcel lines on this map are only graphic representations of Assessor's tax parcels. They are not true property boundaries and do not represent accurate relationships to physical objects on the map such as building locations.

This map is for planning purposes only. It is not adequate for legal boundary determination or regulatory interpretation. This map does not represent an on-the-ground survey.



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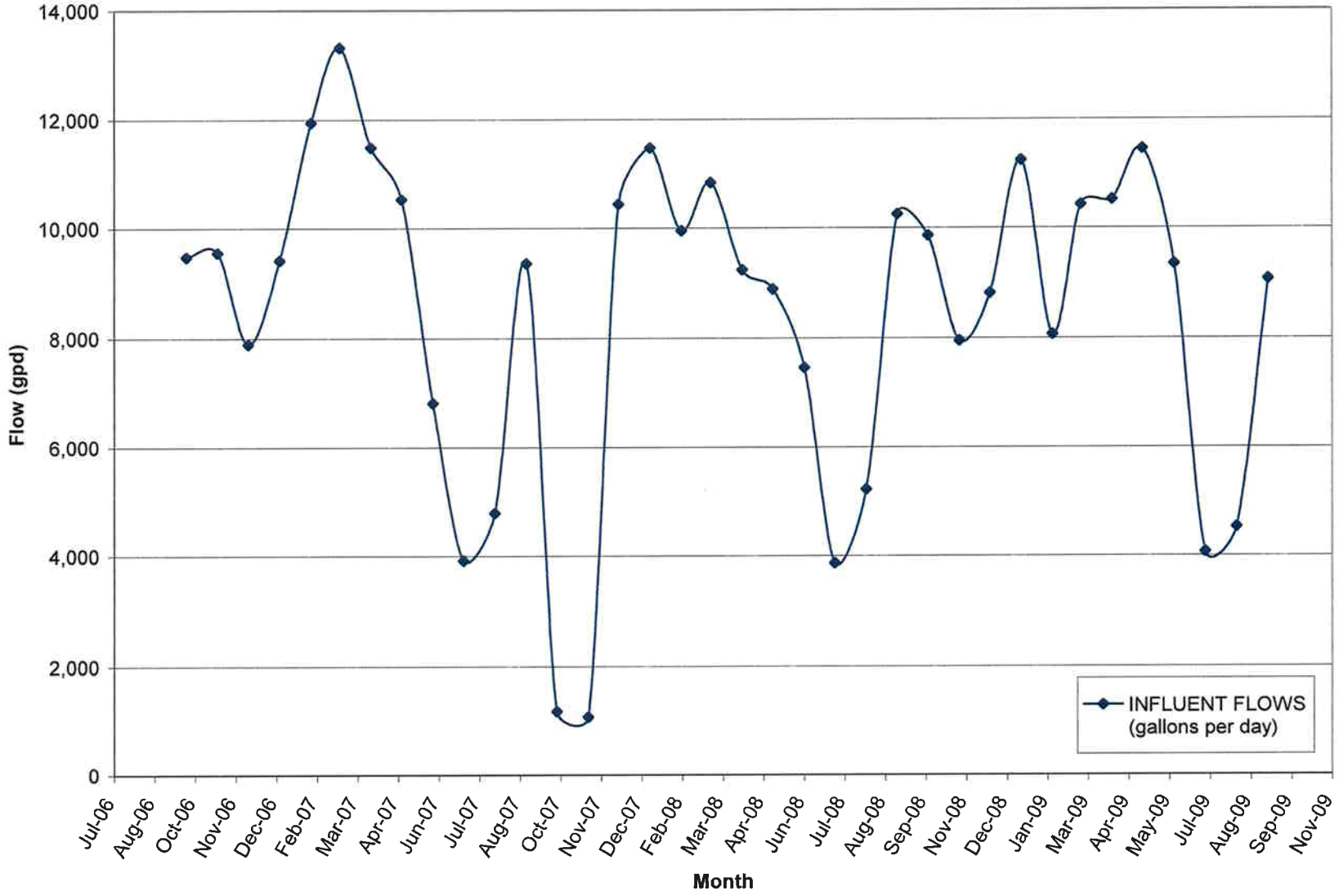
Location:I:\Jobs\80000\861247400 Barnstable\Figures\Report Figures 2_5_2010\F4-12_mxd

Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

MARSTONS MILLS WWTF FLOW SHEMATIC

FIGURE 4-12



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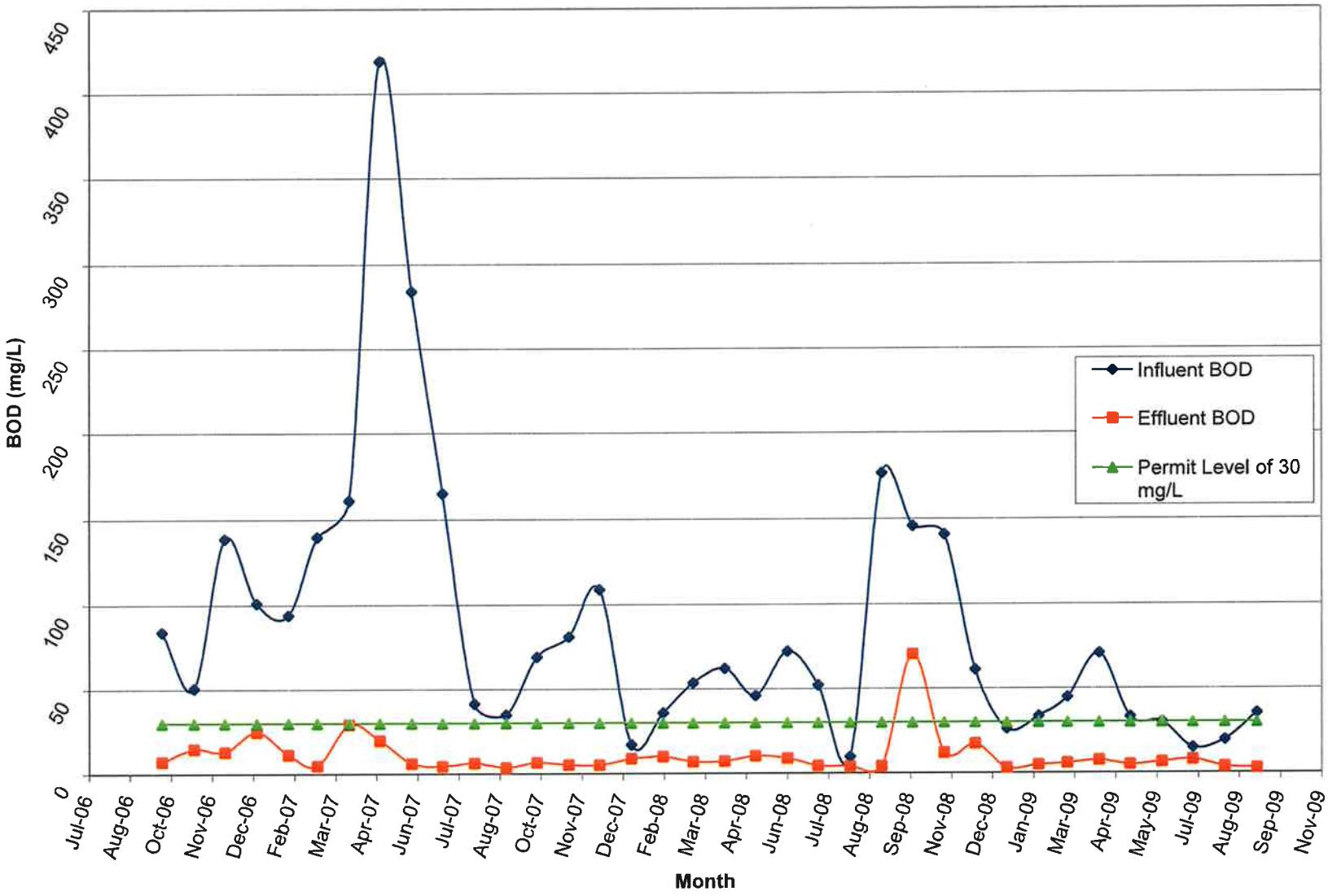
Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

MARSTONS MILLS WWTF INFLUENT FLOWS

FIGURE 4-13

Location: I:\Jobs\80000\861247400 Barnstable \Figures\Report Figures 3_17_2010\F4-132.mxd



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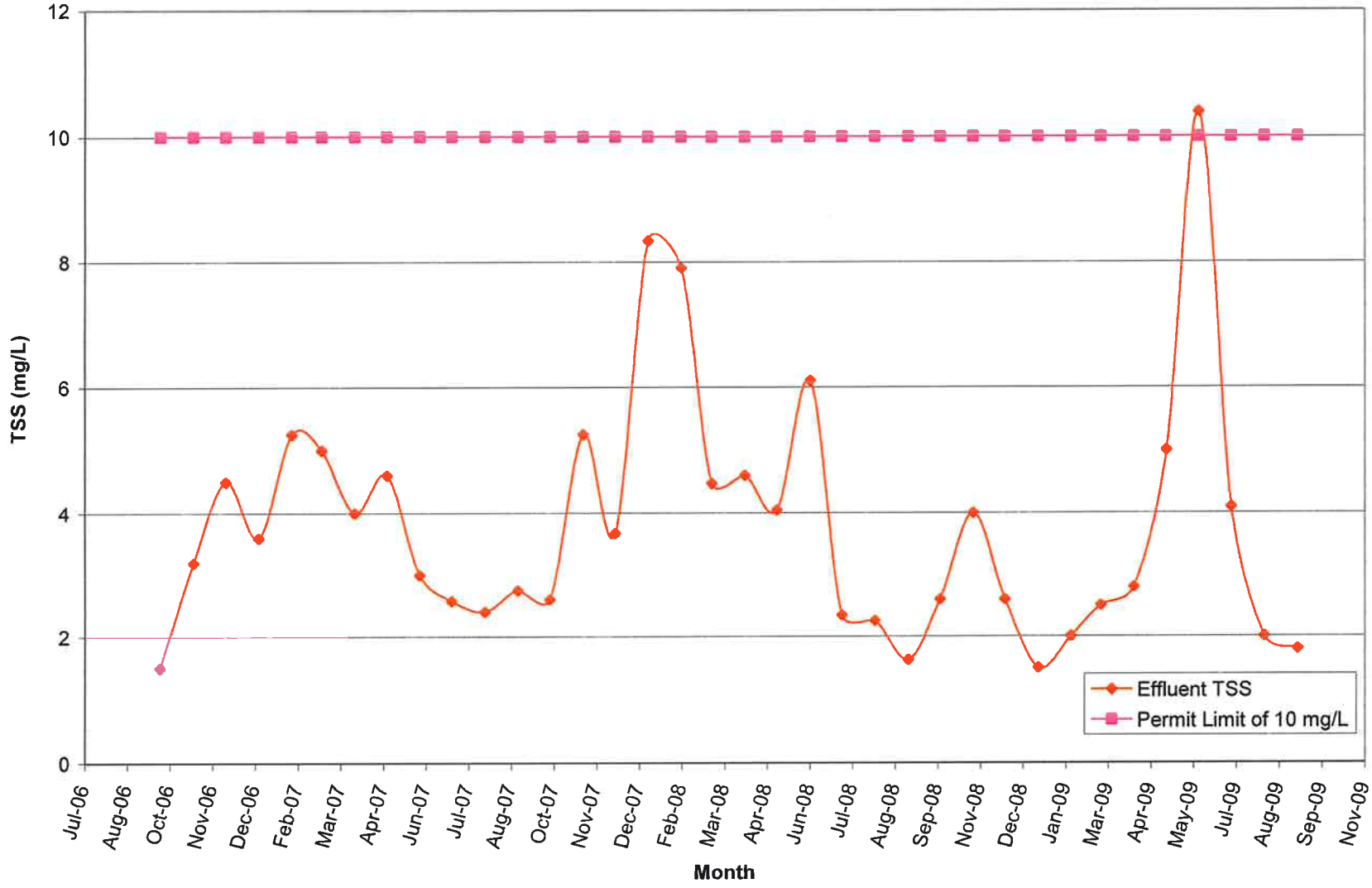
Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

MARSTONS MILLS WWTF INFLUENT AND EFFLUENT BOD CONCENTRATIONS

FIGURE 4-14

Location: I:\Jobs\80000\861247400 Barnstable \Figures\Report Figures 3_17_2010\F4-14.mxd



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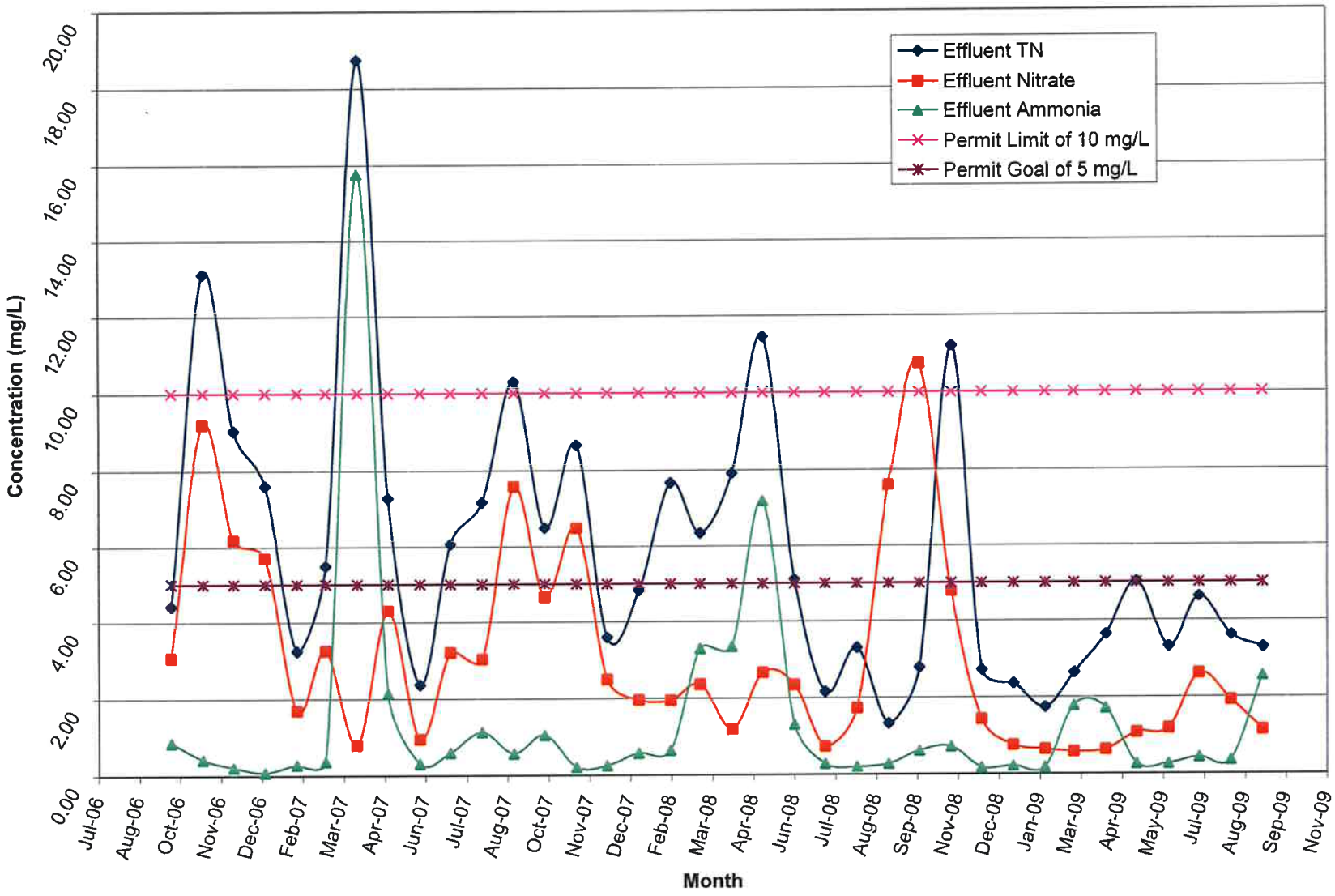
Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

MARSTONS MILLS WWTF EFFLUENT TSS CONCENTRATIONS

FIGURE 4-15

Location: I:\Jobs\80000\861247400 Barnstable \Figures\Report Figures 3_17_2010\F4-15.mxd



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Job No.: 861247400 Date: 03/17/2010

Town of Barnstable, Massachusetts

Comprehensive Wastewater and Nutrient Management Plan

MARSTON MILLS WWTF EFFLUENT NITROGEN CONCENTRATIONS

FIGURE 4-16

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Red Lily Pond Cluster System Site
Figure 4-17

N
W E
S

Feet
0 30 60 120 180 240

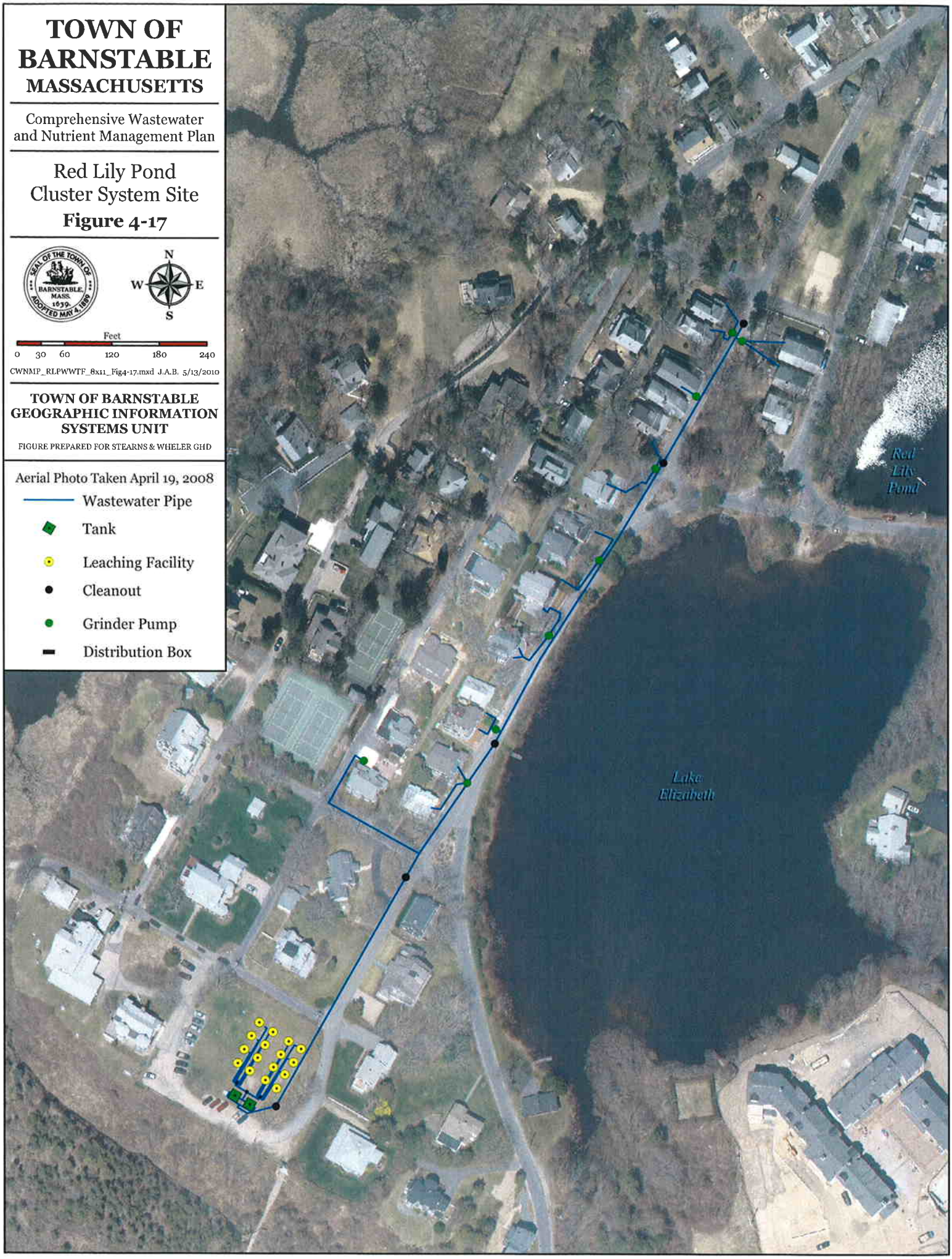
CWNMP_RLPWWTF_8x11_Fig4-17.mxd J.A.B. 5/13/2010

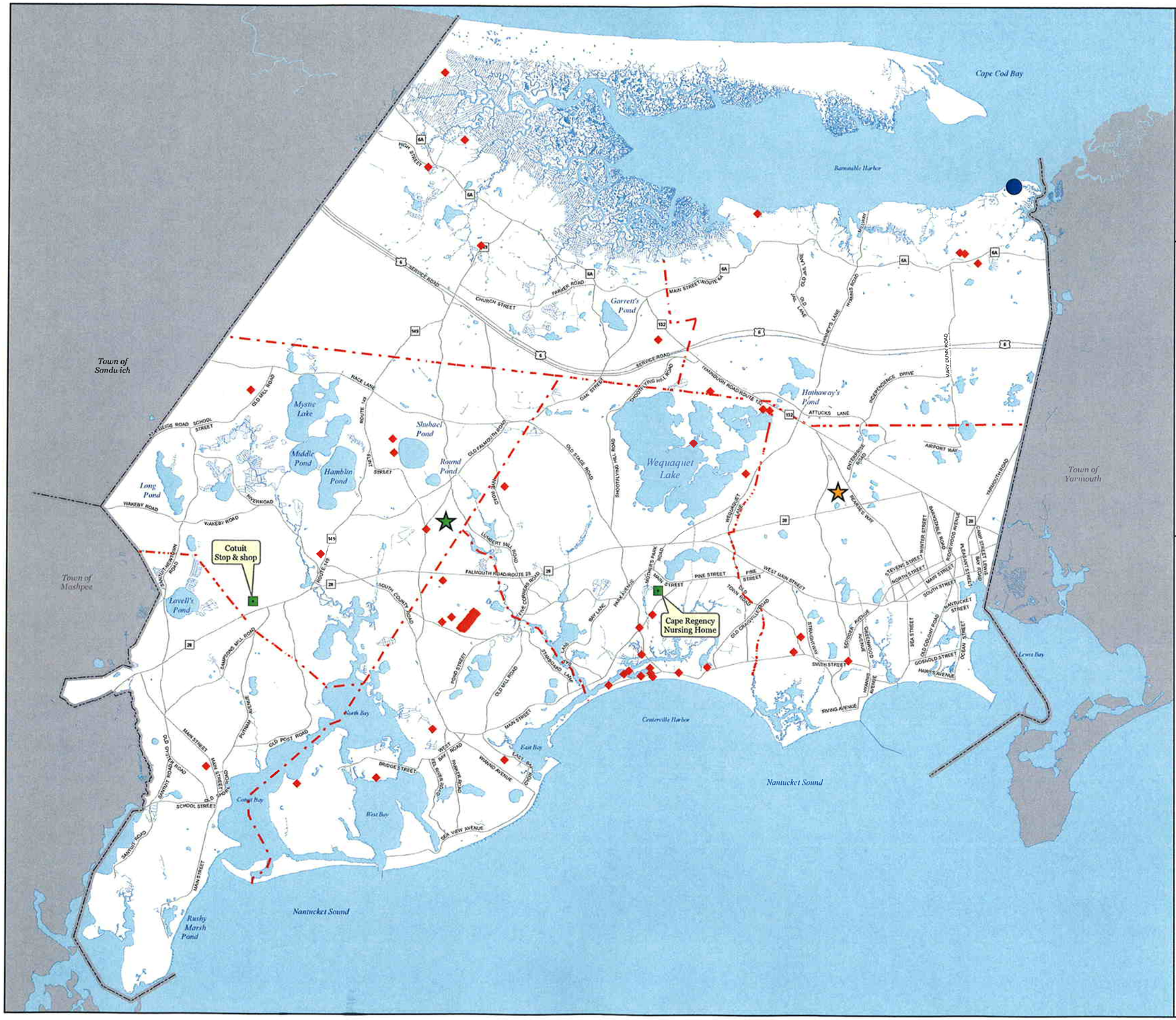
TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHEELER GHD

Aerial Photo Taken April 19, 2008

- Wastewater Pipe
- Tank
- Leaching Facility
- Cleanout
- Grinder Pump
- Distribution Box





Hyannis Water Pollution Control Facility

Marstons Mills Wastewater Treatment Facility

Private Small Wastewater Treatment Facilities

Cape Cod Village Condo Tight Tank

Individual Innovative / Alternative Systems

Major Roads

Fire District / Village Lines

Town Boundary

Water Bodies

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Locations of Existing Wastewater Treatment Systems Designed for Nitrogen Removal

Figure 4-18

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1889

N W E S

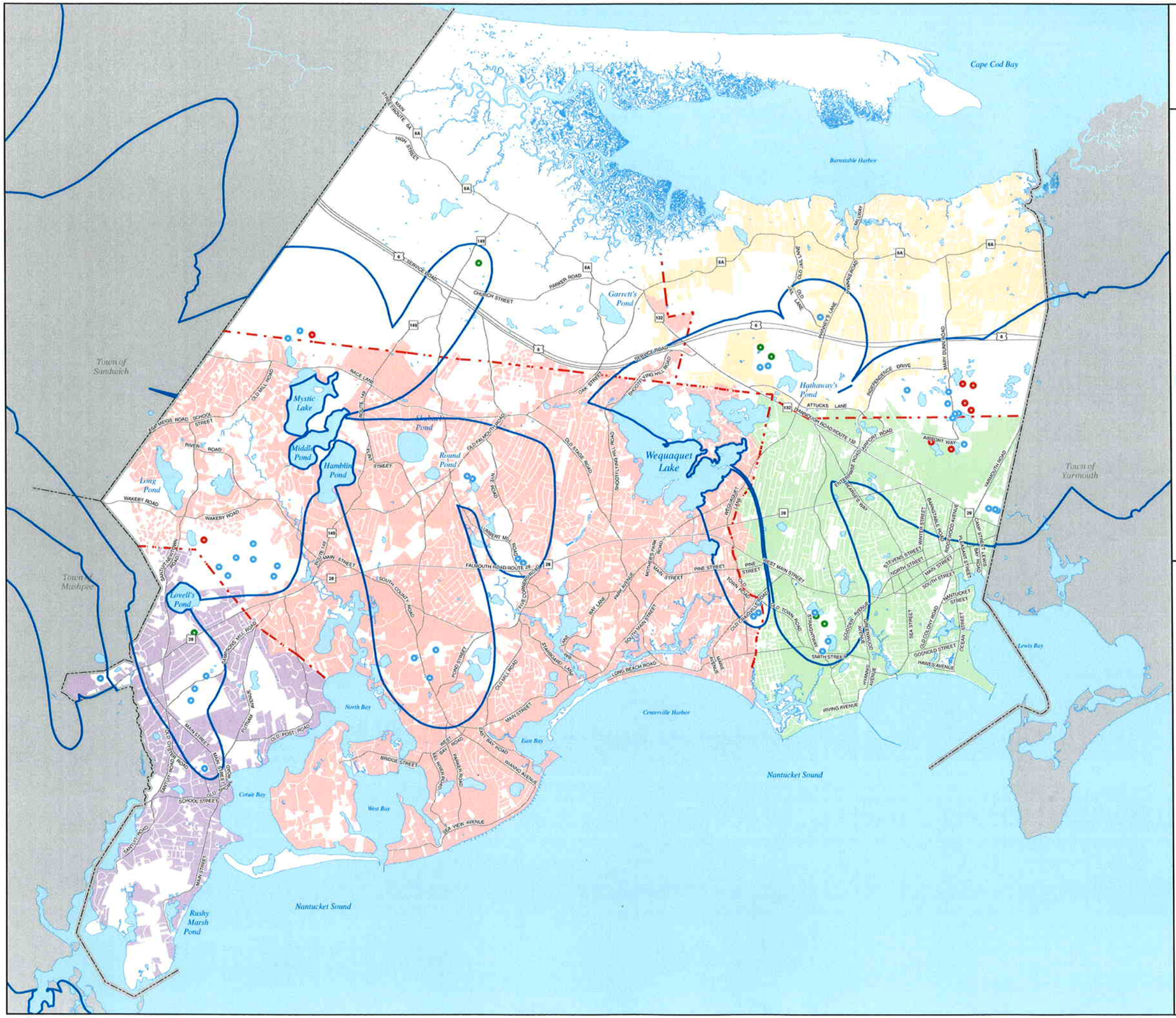
Miles

0 0.25 0.5 1 1.5 2

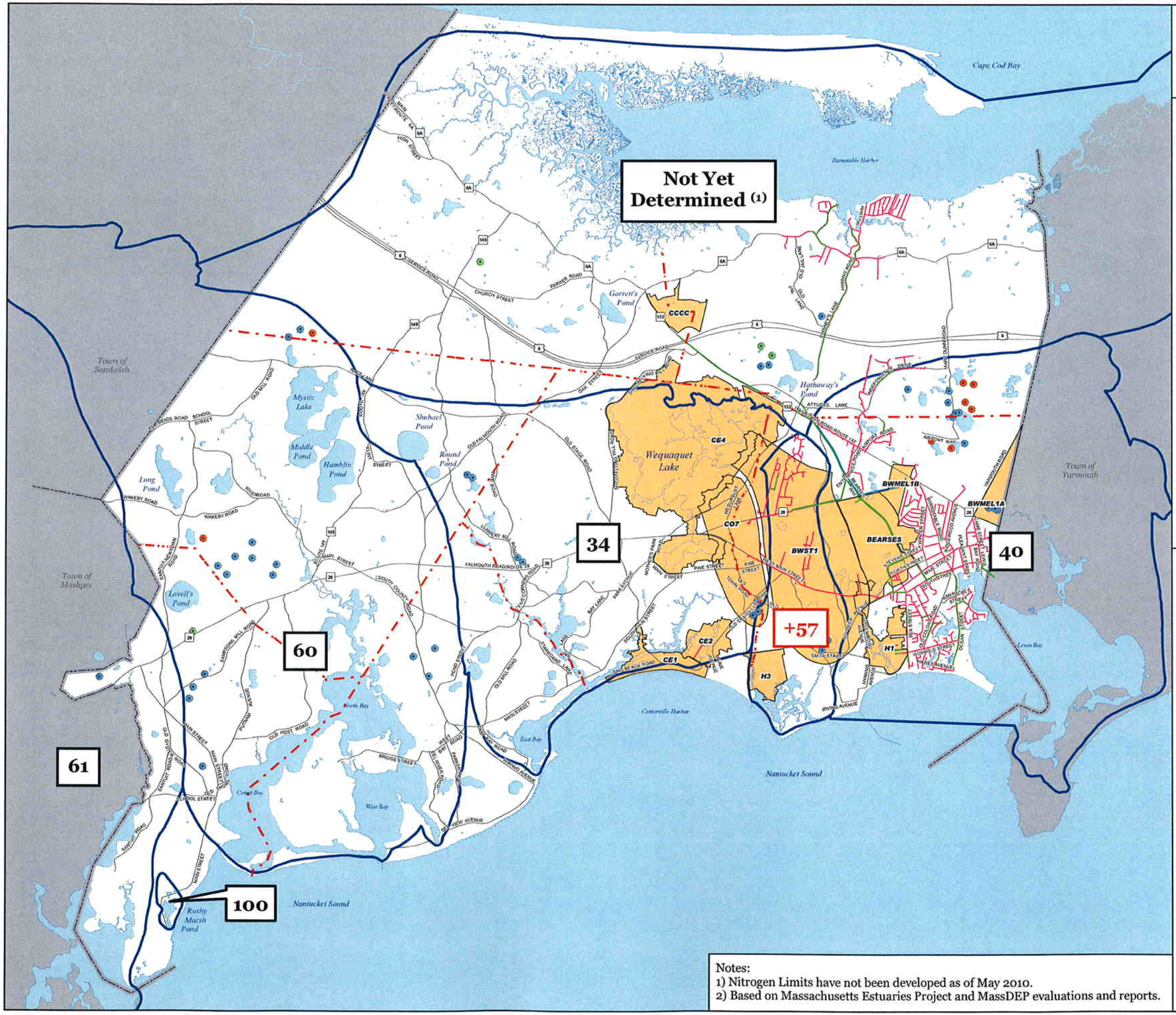
CWNMP_IA_Systems_11x17.mxd J.A.B. 7/27/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD


Cape Cod Bay
Barnstable Harbor
Town of Sandwich
Town of Mashpee
Town of Yarmouth
Garrett's Pond
Hathaway's Pond
Mystic Lake
Middle Pond
Hamblin Pond
Long Pond
Round Pond
Lovell's Pond
Rushy Marsh Pond
Wequaquet Lake
Centerville Harbor
North Bay
East Bay
West Bay
Cotuit Bay
Lewis Bay
Nantucket Sound
ROUTE 6
ROUTE 28
ROUTE 132
ROUTE 149
ROUTE 130
ROUTE 6A
SERVICE ROAD
MAIN STREET
OSTERVILLE-WEST BARNSTABLE ROAD
OLD STAGE ROAD
FALMOUTH ROAD
WAKEBY ROAD
OLD POST ROAD
SOUTH COUNTY ROAD
LONG BEACH ROAD
IRVING AVENUE
HYANNIS ROAD
MARY DUNN ROAD
ATTUCKS LANE
RACE LANE
OLD MILL ROAD
SCHOOL STREET
RIVER ROAD
PARKER ROAD
OAK STREET
PINE STREET
NORTH MAIN STREET
SOUTH MAIN STREET
OLD TOWN ROAD
OLD CRAIGVILLE ROAD
SEA VIEW AVENUE
BRIDGE STREET
MAIN STREET
OLD POST ROAD
SCHOOL STREET
SANDY NECK ROAD
MAIN STREET
OLD STAGE ROAD
SOUTH ROAD
OLD COLONY ROAD
SEA STREET
OCEAN STREET
HAWES AVENUE
GOSNOLD STREET
HIGHLAND AVENUE
SMITH STREET
WASHINGTON AVENUE
GREENWOOD AVENUE
HIGHLAND ROAD
WEST MAIN STREET
NORTH STREET
SOUTH STREET
HANCOCK STREET
CAMP STREET
LEWIS BAY ROAD
PLEASANT STREET
BARNSTABLE ROAD
OSTERVILLE AVENUE
ENTERPRISE ROAD
AIRPORT WAY
INDEPENDENCE DRIVE
PHINNEY'S LANE
OLD KINGS HIGHWAY
OLD COLONY ROAD
OLD STAGE ROAD
FALMOUTH ROAD
OLD MILL ROAD
OLD POST ROAD
OLD COLONY ROAD
OLD TOWN ROAD
OLD CRAIGVILLE ROAD
OLD KINGS HIGHWAY
OLD COLONY ROAD
OLD STAGE

Chapter 5 Figures



34 Percent Septic System Nitrogen Removal Suggested by MEP

+57 Percent Additional Nitrogen That Could Be Added (Suggested by MEP)

- Planned Sewer Extension
- Marine Watersheds
- Existing Sewer Force Main
- Existing Gravity Sewer
- Existing Vacuum Sewer
- Existing Well
- Proven Future Well
- Proposed Future Well
- Major Roads
- Fire District / Village Lines
- Town Boundary
- Water Bodies

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Existing Septic System Nitrogen Removal Needed To Meet the TMDLs (2)

Figure 5-1

N W E S

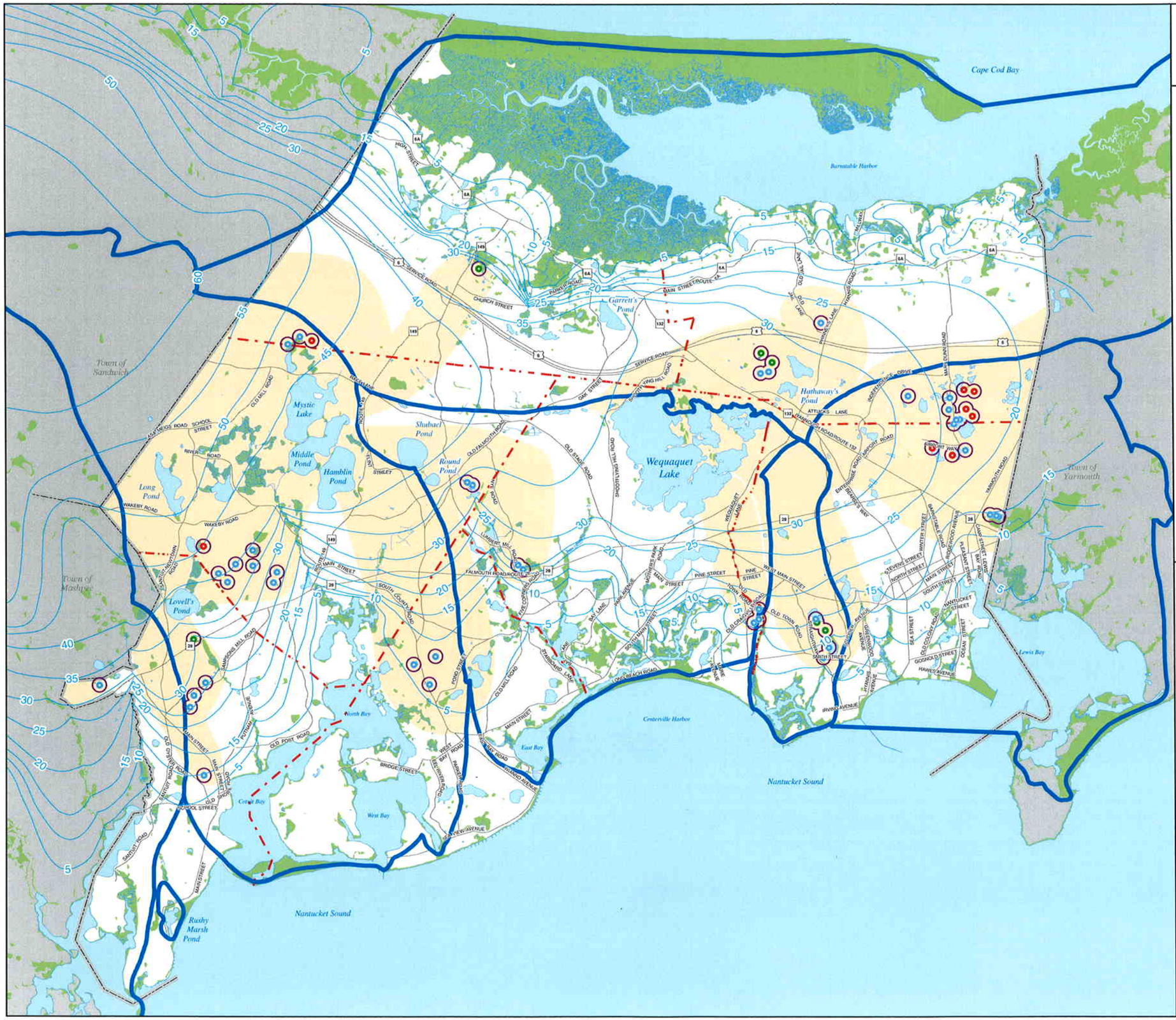
Miles

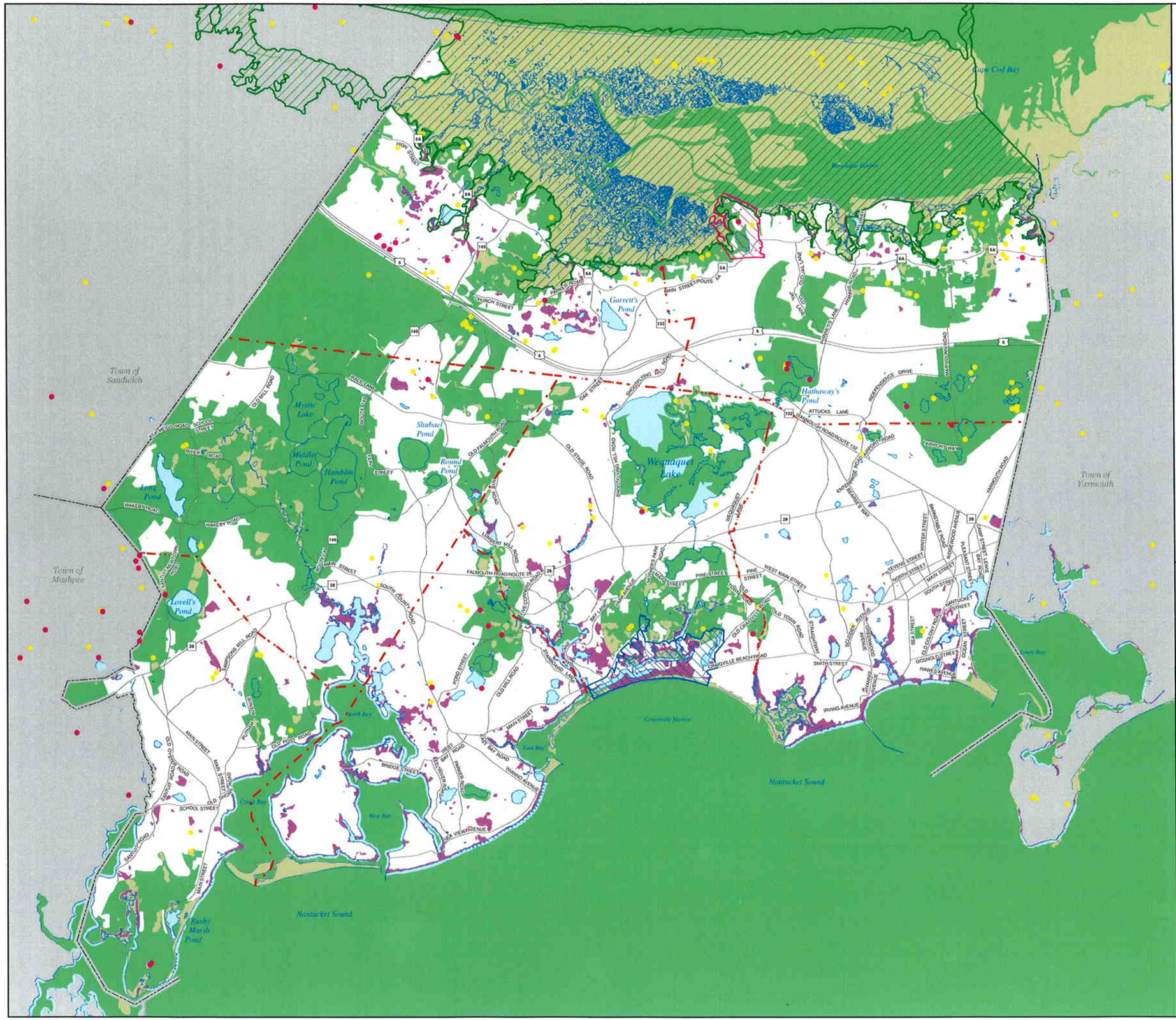
0 0.25 0.5 1 1.5 2

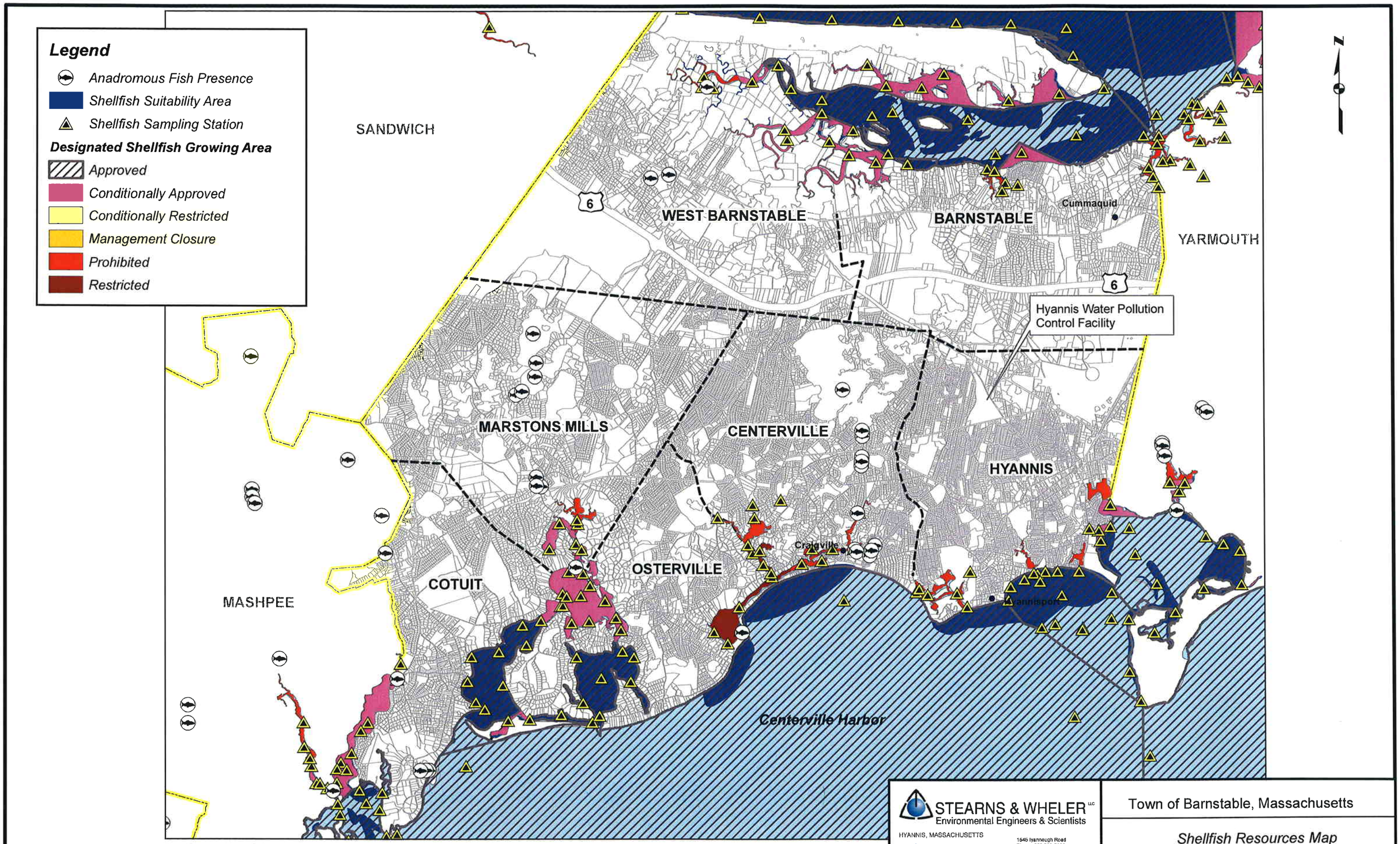
CWNMP_NitrogenRemoval_11x17_c.mxd J.A.B. 7/27/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD


Cape Cod Bay
Barnstable Harbor
Town of Sandwich
Town of Mashpee
Town of Yarmouth
Mystic Lake
Middle Pond
Hamblin Pond
Long Pond
Shubael Pond
Round Pond
Garrett's Pond
Wequaquet Lake
Hathaway's Pond
Lovell's Pond
Rushy Marsh Pond
North Bay
Centerville Harbor
East Bay
West Bay
Cotuit Bay
Lewis Bay
Nantucket Sound
Nantucket Sound
MAIN STREET/ROUTE 6A
SERVICE ROAD
CHURCH STREET
OAK STREET
WAKEBY ROAD
OLD POST ROAD
OSTERVILLE-WEST BARNSTABLE ROAD
FALMOUTH ROAD/ROUTE 28
YARMOUTH ROAD
HYANNIS-WEST BARNSTABLE ROAD/ROUTE 132
OLD STAGE ROAD
OLD KINGS HIGHWAY
SOUTH MAIN STREET
WEST MAIN STREET
PINE STREET
MAIN STREET
SCHOOL STREET
RIVER ROAD
ASHERS ROAD
SOUTH ROAD
OLD MILL ROAD
OLD FALMOUTH ROAD
LUMBERT MILL ROAD
SHOOTFLYING HILL ROAD
OLD TOWN ROAD
OLD COMMERCE ROAD
OLD YARMOUTH ROAD
OLD STAGE ROAD
OLD COLONY ROAD
OLD KINGS HIGHWAY
OLD BEAR'S WAY
OLD GRAFFAM ROAD
OLD TOWN ROAD
OLD COLONY LANE
OLD BARN LANE
OLD STAGE LANE
OLD COACH ROAD
OLD HYANNIS


Cape Cod Bay
Barnstable Harbor
Town of Sandwich
Town of Mashpee
Town of Yarmouth
Garrett's Pond
Hathaway's Pond
Wequaquet Lake
Mystic Lake
Middle Pond
Hamblin Pond
Shubael Pond
Round Pond
Long Pond
Lovell's Pond
Rushy Marsh Pond
Centerville Harbor
East Bay
West Bay
Cotchpee Bay
Lewis Bay
Nantucket Sound
MAIN STREET/ROUTE 6A
CHURCH STREET
PHINNEY'S LANE
ATTUCKS LANE
INDEPENDENCE DRIVE
MARYLAND ROAD
OAK STREET
SHOOTFLYING HILL ROAD
OLD STAGE ROAD
OLD FALMOUTH ROAD
RACE LANE
OLD MILL ROAD
OLD POST ROAD
SCHOOL STREET
WAKEBY ROAD
LOCUST STREET
LUMBERT MILL ROAD
FALMOUTH ROAD/ROUTE 28
SOUTH COUNTY ROAD
SAMPSONS MILL ROAD
OLD STURBRIDGE VILLAGE ROAD
MAIN STREET
OLD KINGS HIGHWAY
OLD COLONY ROAD
SANDY NECK ROAD
BRIDGE STREET
WEST BAY ROAD
WEST BAY ROAD
WIANNO AVENUE
SEA VIEW AVENUE
CRAIGVILLE BEACH ROAD
OLD TOWN ROAD
OLD STRAWBERRY HILL ROAD
SMITH STREET
IRVING AVENUE
OCEAN AVENUE
HAWES AVENUE
GOSNOLD STREET
OLD COLONY ROAD
SEA STREET
OCEAN STREET
MAIN STREET
SOUTH STREET
NANTUCKET AVENUE
PLEASANT STREET
CAMP STREET EXTENSION
OLD YARMOUTH ROAD
WEST MAIN STREET
PINE STREET
NORTH STREET
WINTER STREET
BARNSTABLE ROAD
ROBERTWOOD AVENUE
STEVENS STREET
OLD STRAWBERRY HILL ROAD
OLD TOWN ROAD
OLD GRAVELLY ROAD
CHAPMANS PARK ROAD
MAPLE AVENUE
OAK AVENUE
SCUDDER AVENUE
GREENWOOD AVENUE
ENTERPRISE ROAD
BEARSE'S WAY
AIRPORT ROAD
AIRWAY AVENUE
ROUTE 132
ROUTE 6
ROUTE 28
ROUTE 149
ROUTE 132
ROUTE 6A
ROUTE 6A
ROUTE 6A



Data Source: Mass GIS

*Note: Entire area is within Lobster Harvest zone

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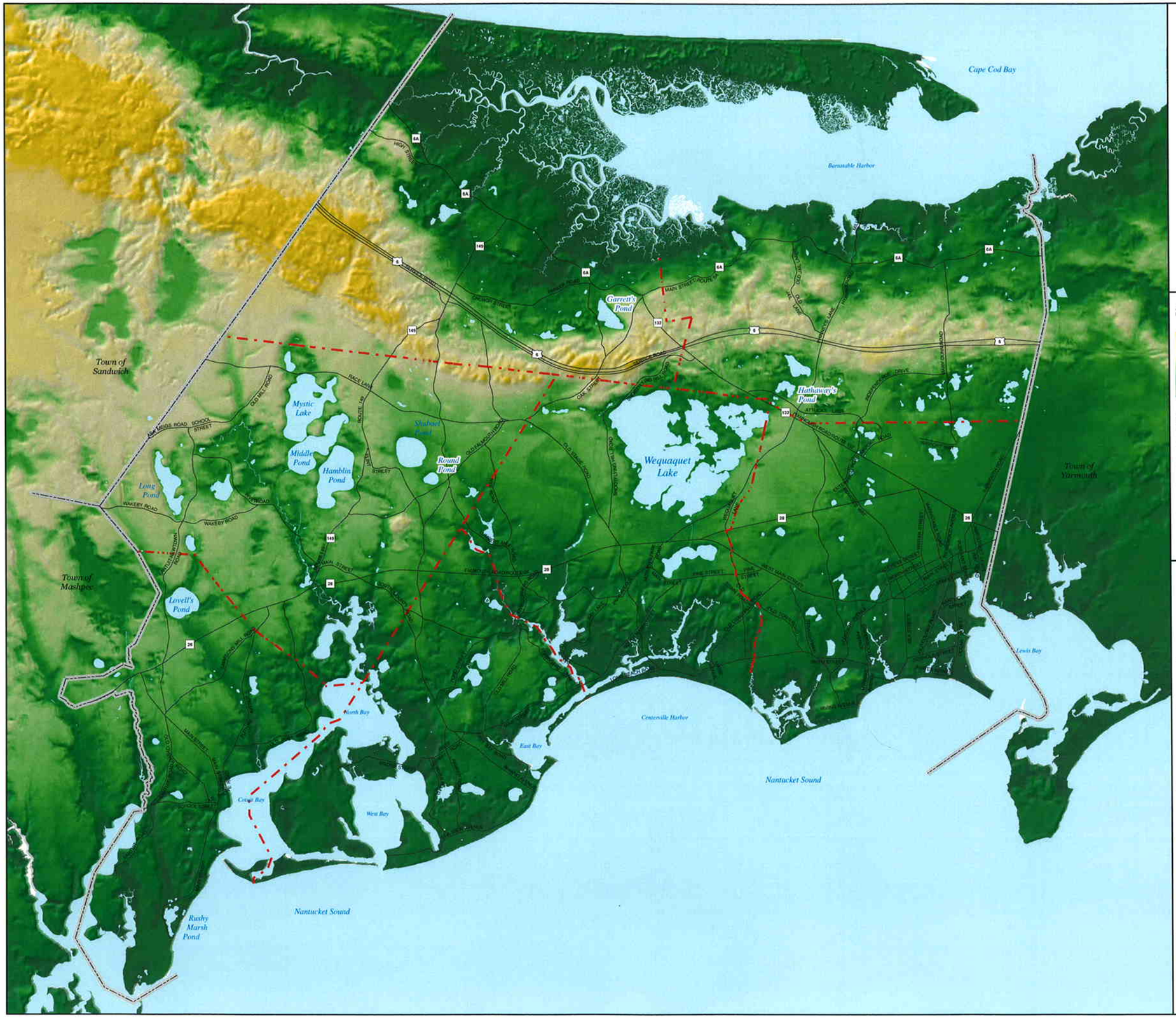
Date: 4/23/2010

Town of Barnstable, Massachusetts

Shellfish Resources Map

FIGURE 5-5



Surface Elevation

High Elevation (266 Ft.)

Low Elevation (0 Ft.)

SOURCE: Shaded relief and hillshade data obtained from MassGIS.

- Fire District / Village Lines
- Major Roads
- Town Boundary
- Water Bodies

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Topography
Figure 5-6

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1995

N
W E
S

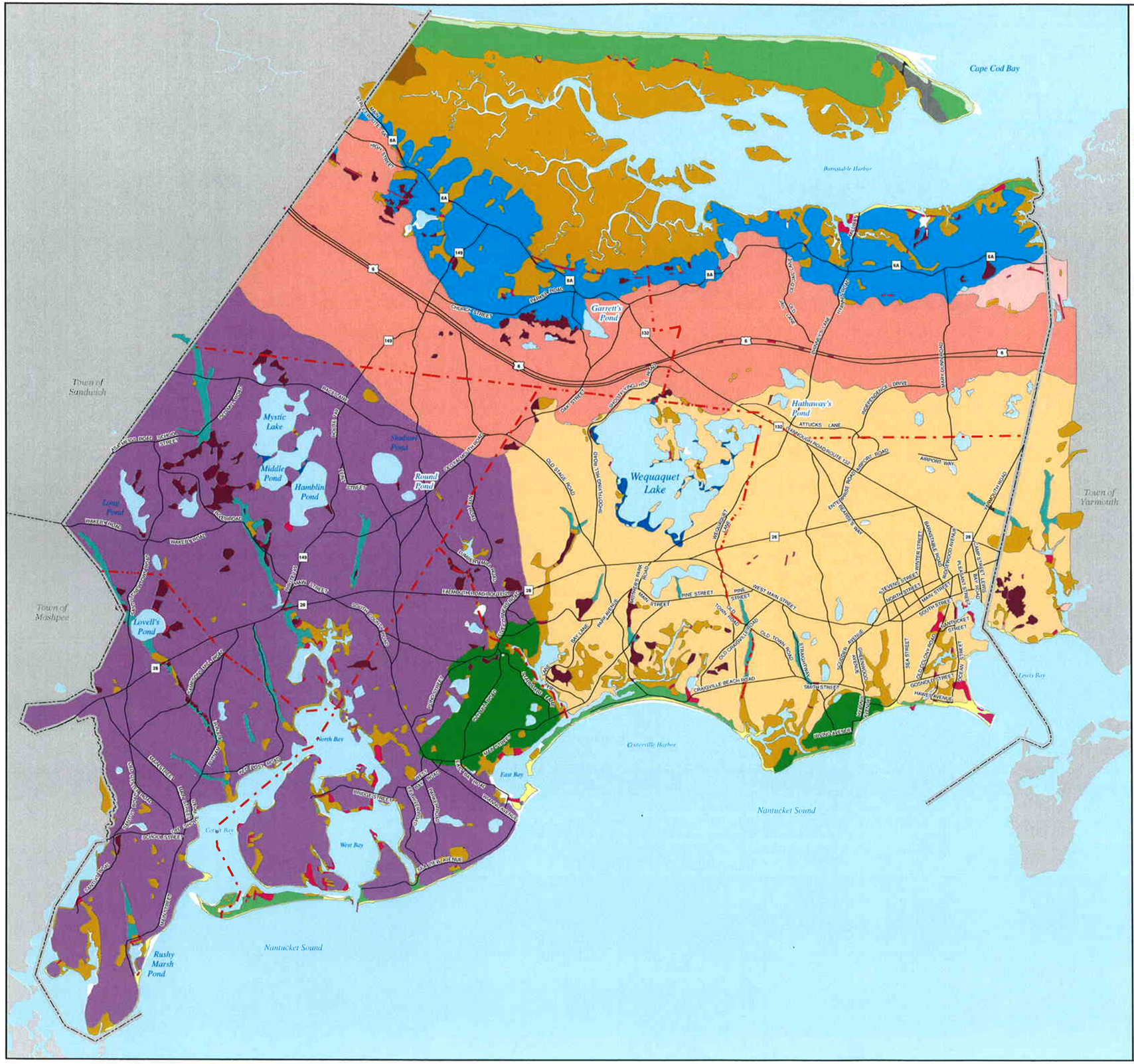
Miles

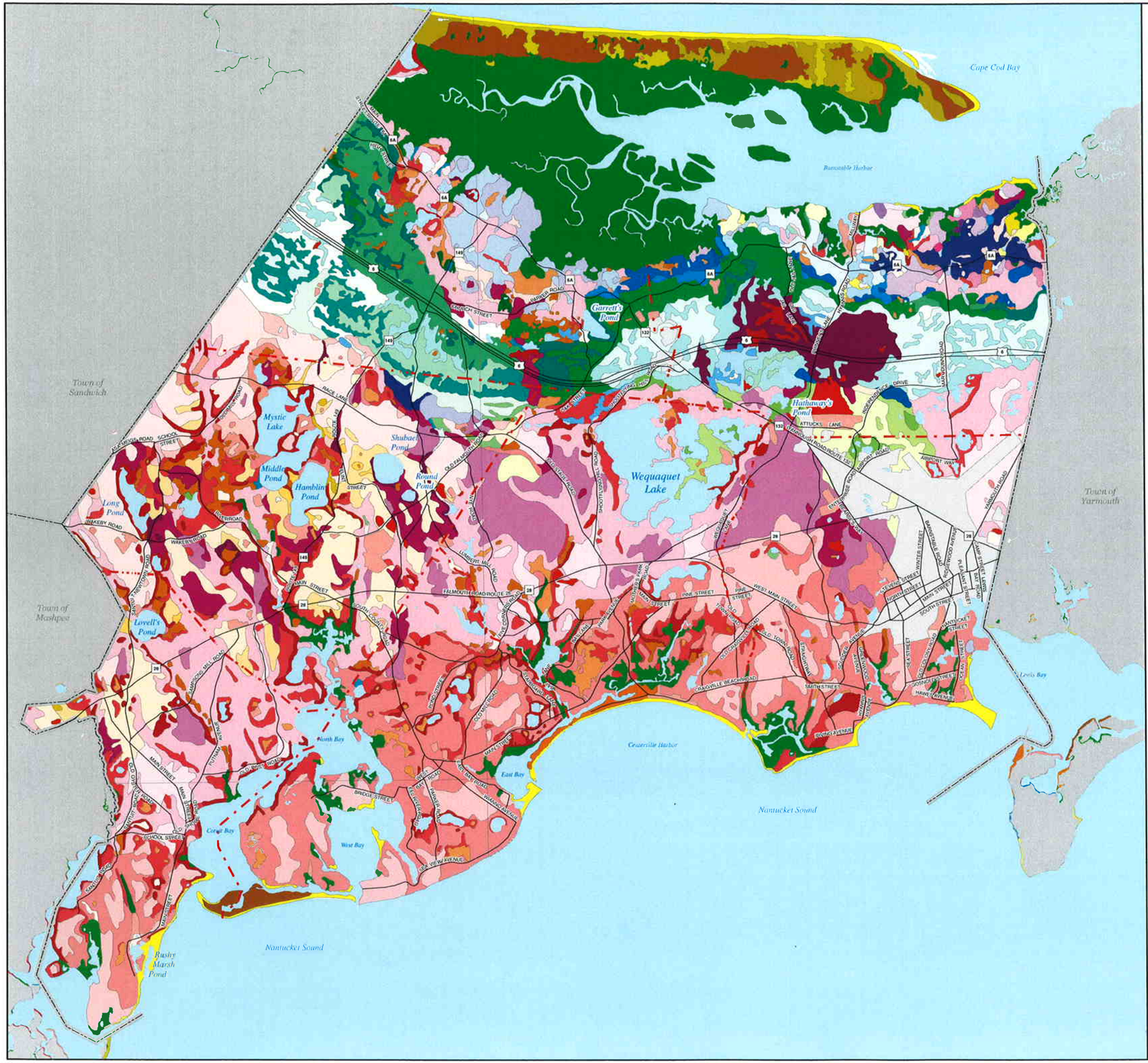
0 0.25 0.5 1 1.5 2

CWNMP_Topography_11x17.mxd J.A.B. 4/28/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD


Cape Cod Bay
Barnstable Harbor
Town of Sandwich
Town of Mashpee
Town of Yarmouth
Mystic Lake
Middle Pond
Hamblin Pond
Shubael Pond
Round Pond
Long Pond
Lovell's Pond
Rushy Marsh Pond
Garrett's Pond
Hathaway's Pond
Wequaquet Lake
North Bay
East Bay
Cotuit Bay
West Bay
Centerville Harbor
Lewis Bay
Nantucket Sound
Nantucket Sound
ROUTE 6
ROUTE 132
ROUTE 28
ROUTE 149
ROUTE 6A
ROUTE 130
ROUTE 151
ROUTE 149
ROUTE 28
ROUTE 28
ROUTE 28



Soils Key

- AmA - Amostown sandy loam
- BaB - Barnstable sandy loam
- BaC - Barnstable sandy loam
- BcC - Barnstable-Plymouth complex
- BdB - Barnstable-Plymouth complex
- BdC - Barnstable-Plymouth complex
- BfC - Barnstable-Plymouth-Nantucket complex
- BgC - Barnstable-Plymouth-Nantucket complex
- BlB - Belgrade silt loam
- BmA - Berryland mucky loamy coarse sand
- BoA - Boxford silt loam
- BoB - Boxford silt loam
- CcA - Carver loamy coarse sand
- CcB - Carver loamy coarse sand
- CdA - Carver coarse sand
- CdB - Carver coarse sand
- CdC - Carver coarse sand
- CdD - Carver coarse sand
- CoB - Carver-Hinesburg loamy coarse sands
- CoC - Carver-Hinesburg loamy coarse sands
- DeA - Deerfield loamy fine sand
- EaA - Eastchop loamy fine sand
- EaB - Eastchop loamy fine sand
- EaC - Eastchop loamy fine sand
- EnA - Enfield silt loam
- EnB - Enfield silt loam
- EnC - Enfield silt loam
- FmA - Freetown mucky peat
- FsA - Freetown & Swansea mucks
- FtA - Freetown coarse sand
- HeA - Hinckley sandy loam
- HeB - Hinckley sandy loam
- HkC - Hinckley gravelly sandy loam
- HkD - Hinckley gravelly sandy loam
- HnA - Hinesburg sandy loam
- HnB - Hinesburg sandy loam
- HnC - Hinesburg sandy loam
- HoC - Hooksan sand
- HoD - Hooksan sand
- HxC - Hooksan-Dune land complex
- ImA - Ipswich, Pawcatuck & Matunuck peats
- MaA - Maybid silt loam
- MeA - Merrimac sandy loam
- MeB - Merrimac sandy loam
- MeC - Merrimac sandy loam
- MeD - Merrimac sandy loam
- NaB - Nantucket sandy loam
- NaC - Nantucket sandy loam
- NsB - Nantucket sandy loam
- NsC - Nantucket sandy loam
- PeA - Pipestone loamy coarse sand
- PmB - Plymouth loamy coarse sand
- PmC - Plymouth loamy coarse sand
- PmD - Plymouth loamy coarse sand
- PsB - Plymouth loamy coarse sand
- PsC - Plymouth loamy coarse sand
- PsD - Plymouth loamy coarse sand
- PvC - Plymouth-Barnstable complex
- PvD - Plymouth-Barnstable complex
- PxD - Plymouth-Barnstable complex
- PyD - Plymouth-Barnstable-Nantucket complex
- ScA - Scitico silt loam
- SdA - Sudbury fine sandy loam
- Bh - Beaches
- Dm - Dumps, landfill
- Dn - Dune land
- Pg - Pits, sand & gravel
- Ud - Udipsamments, smoothed
- Ur - Urban land
- W - Water
- WS - Water

Source: soils data obtained from MassGIS in 2001. The data is based on the United States Department of Agriculture & National Cooperative Soil Survey soil survey of Barnstable County, Massachusetts, conducted in 1983. Information and explanations about the soil data displayed on this map may be found in the USDA Soil Conservation Service publication: Soil Survey of Barnstable County, Massachusetts, 1993.

- Fire District / Village Lines
- Major Roads
- Town Boundary
- Water Bodies

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Soils
Figure 5-8

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1685

N W E S

Miles

0 0.25 0.5 1 1.5 2

CWNMP_Soils_11x17.mxd J.A.B. 4/28/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD

DRAFT

Cape Cod Bay

Barnstable Harbor

Town of Sandwich

Town of Mashpee

Town of Yarmouth

Centerville Harbor

Nantucket Sound

Lewis Bay

Garrett's Pond

Mystic Lake

Middle Pond

Hamblin Pond

Long Pond

Shubael Pond

Round Pond

Wequaquet Lake

Hathaway's Pond

Lowell's Pond

North Bay

West Bay

Cotuit Bay

Bumby Marsh Pond

MAIN STREET/ROUTE 6A

SERVICE ROAD

CHURCH STREET

OLD KINGS HIGHWAY

OLD JAIL LANE

THANKFUL ROAD

MARY DUNN ROAD

INDEPENDENCE DRIVE

ATTUCKS LANE

WAKEBY ROAD

RACE LANE

OLD MILL ROAD

ASHMENS ROAD

SCHOOL STREET

RIVER ROAD

ROUTE 149

OLD STAGE ROAD

SHOOTFLYING HILL ROAD

OAK STREET

OLD FALMOUTH ROAD

FALMOUTH ROAD/ROUTE 28

MAIN STREET

SOUTH COUNTY ROAD

LONGBIT MILL ROAD

MEADOWS LANE

MOTHERS PARK ROAD

PINE STREET

WEST MAIN STREET

OLD TOWN ROAD

OLD CRAIGVILLE ROAD

SOUTH MAIN STREET

LOWER BEARSE ROAD

SEA VIEW AVENUE

IRVING AVENUE

SMITH STREET

SCUDDER AVENUE

GREENWOOD AVENUE

HINCKLEY ROAD

OSBORN AVENUE

HAWES AVENUE

OCEAN STREET

LIMEKILN STREET

SEA STREET

OLD COMMERCIAL STREET

STEVENS STREET

WINTER STREET

NORTH STREET

HIGH STREET

BARNSTABLE ROAD

RIDGEWOOD AVENUE

PLEASANT STREET

SAND STREET

LEWIS BAY ROAD

HYANNIS-WEST BARNSTABLE ROAD/ROUTE 132

AIRPORT ROAD

AIRPORT WAY

ENTERPRISE ROAD

BEARSE'S WAY

HUNTSMAN ROAD

SANDWICH ROAD

SAMPSONS MILL ROAD

PUTNAM AVENUE

OLD POST ROAD

OLD STAGE ROAD

OLD SCHOOL STREET

MAIN STREET

DRAFT

Special Flood Hazard Areas (SFHAs) Subject to Inundation by the 1% Annual Chance Flood

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood.

- Zone AE - Base Flood Elevations determined.
- Zone AO - Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined.
- Zone AH - Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
- Zone VE - Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

Other Flood Areas

- Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1%annual chance flood.

NOTE: The flood zones shown here represent the 2009 Preliminary Revised FEMA Flood Insurance Rate Maps. These maps are preliminary and have not yet been adopted. These are preliminary data that may be subject to appeal and may change before final adoption and cannot be used for making final determinations.

- Fire District / Village Lines
- Major Roads
- Town Boundary
- Shoreline
- Water Bodies (May be obscured)

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Flood Zones
Figure 5-9

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1989

N W E S

Miles

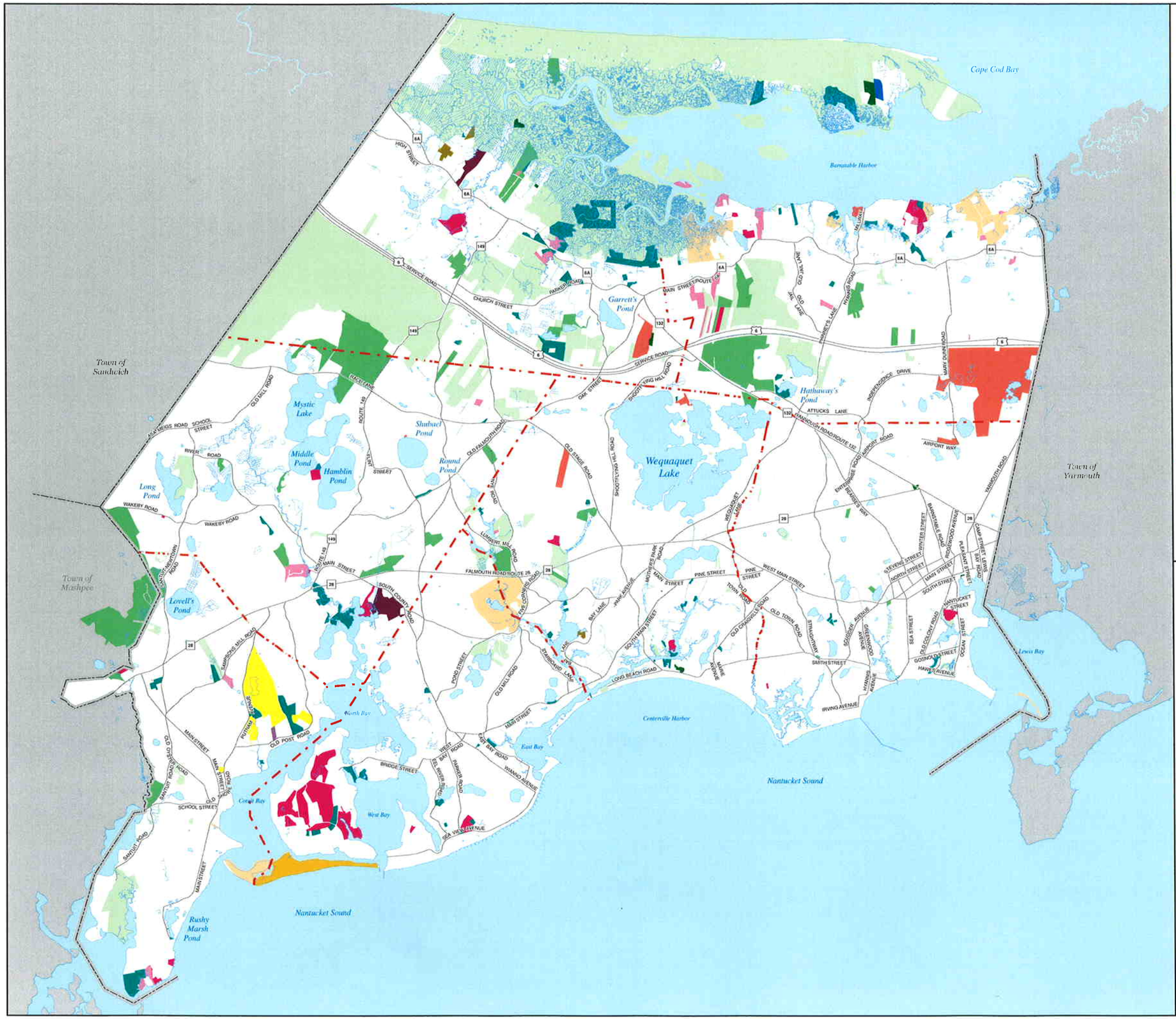
0 0.25 0.5 1 1.5 2

CWNMP_FloodZones_11x17.mxd J.A.B. 4/28/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD

DRAFT



Protected Open Space

- Town Conservation
- Town Land Bank
- Town CPA Open Space
- State Owned Protected Land
- Fire District with Conservation Restriction
- Barnstable Land Trust
- Mary Barton Conservation
- Massachusetts Audubon Society
- The Nature Conservancy
- Orenda Wildlife Land Trust
- Three Bays Preservation Inc.
- Compact of Cape Cod Conservation Trusts
- Trustees of Reservations
- Private Land with Conservation Restriction

NOTE: This data is not necessarily complete or definitive. This datawas compiled from sources including: Town of Barnstable FY 2010 Assessor records, Town of Barnstable Community Preservation Committee, Town of Barnstable Growth Management Dept., Town of Barnstable Attorney's Office, and Barnstable Land Trust.

- Fire District / Village Lines
- Major Roads
- Town Boundary
- Water Bodies

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Open Space
Figure 5-10

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1989

N W E S

Miles

0 0.25 0.5 1 1.5 2

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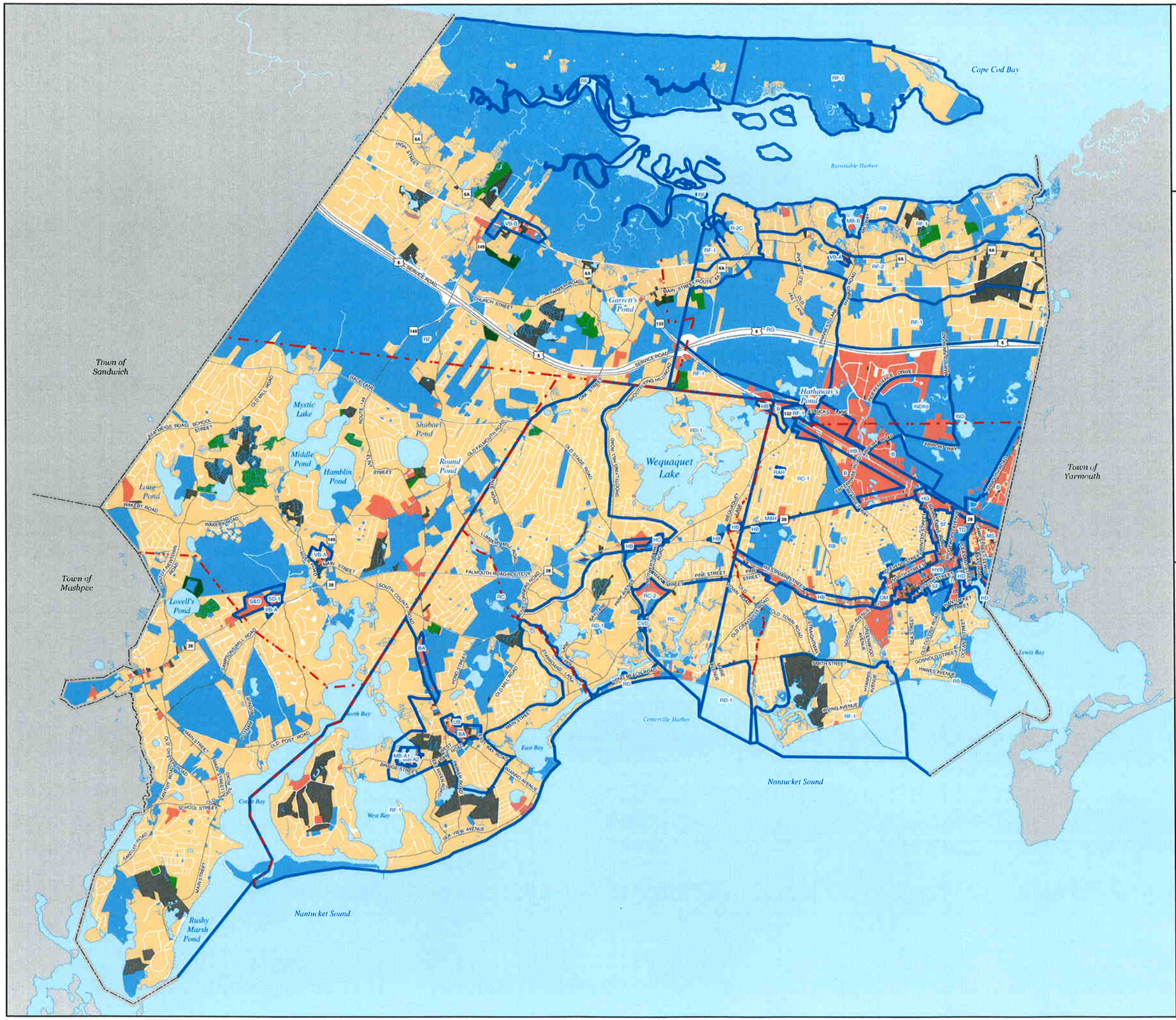
TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD



Land Use

- Residential
- Commercial
- Mixed Use
- Agricultural
- Recreational
- Tax Exempt

Land use categories summarized from FY 2010 Town of Barnstable Assessor's Database.

- Zoning Districts
- Fire District / Village Lines
- Major Roads
- Town Boundary
- Water Bodies

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Land Use
Figure 5-11

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1989

N W E S

Miles

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TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHEELER GHD

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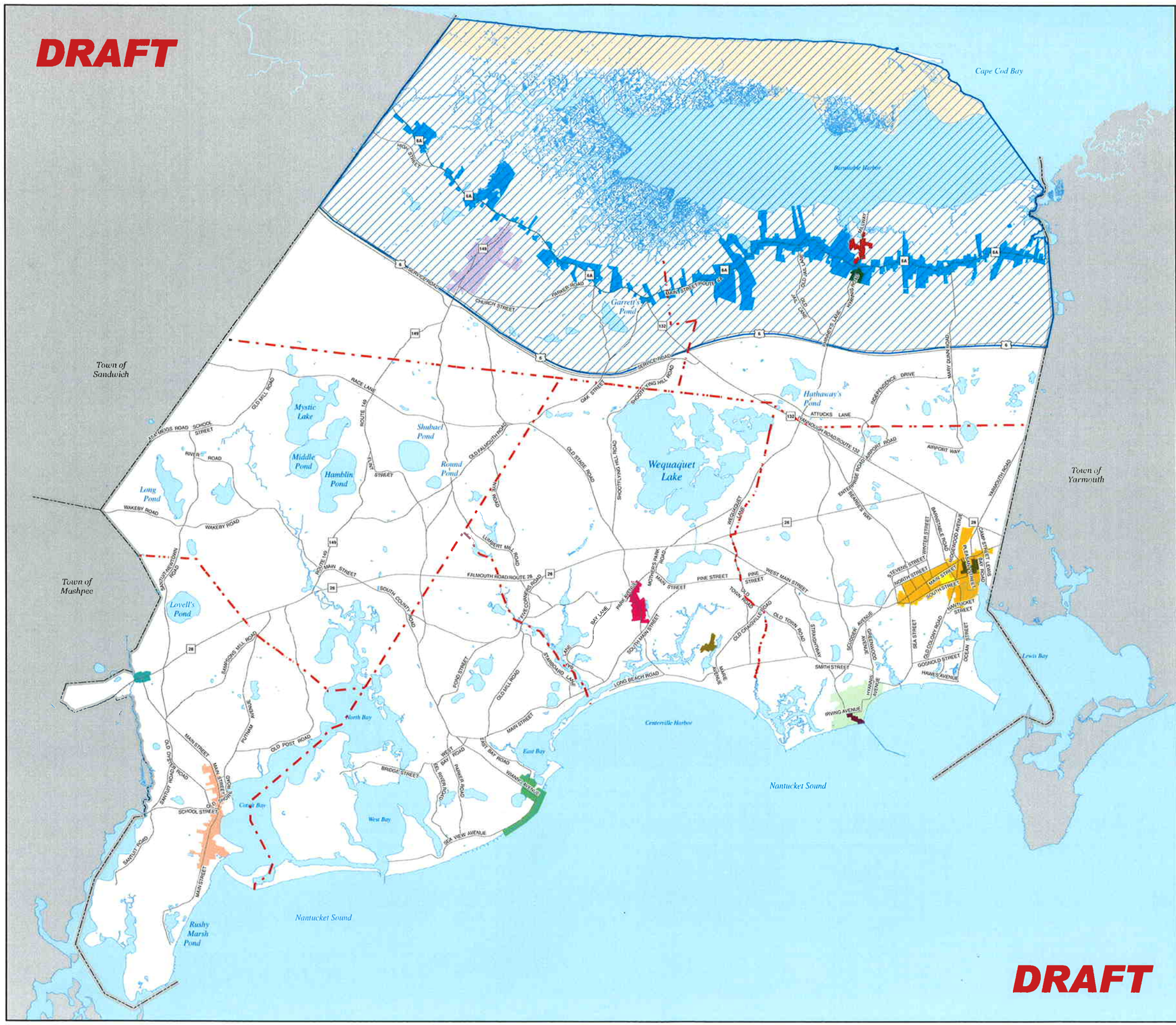

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National Register Historic Districts

- Old Kings Highway National Historic District
- Sandy Neck Cultural Resources District
- Barnstable Harbor Historic District
- Hyannis Road Historic District
- West Barnstable Historic District
- Santuit Historic District
- Cotuit Historic District
- Wianno Historic District
- Centerville Historic District
- Craigville Historic District
- Hyannisport Historic District
- Kennedy Compound National Historic Landmark
- Municipal Group Historic District
- Pleasant Street School Street Historic District

Local Historic Districts

- Old Kings Highway Local Historic District
- Hyannis Main Street Waterfront Historic District

- Fire District / Village Lines
- Major Roads
- Town Boundary
- Water Bodies

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Historic Districts
Figure 5-12

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1899

N W E S

Miles
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TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD

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Appendix 1-1

Town of Barnstable Wastewater Facilities Plan and Final Environmental Impact Report, Executive Summary and Table of Contents

EXECUTIVE SUMMARY
WASTEWATER FACILITIES PLANNING PROJECT

FINAL WASTEWATER FACILITIES PLAN AND FINAL ENVIRONMENTAL IMPACT REPORT

TOWN OF BARNSTABLE, MASSACHUSETTS

1.1 BACKGROUND

The Town of Barnstable (Town) is performing this Wastewater Facilities Planning Project (Project) to provide a comprehensive strategy for wastewater treatment and disposal issues for a 20-year planning period. The planning period design year is 2014 which is 20 years after the Project started in 1993 and 1994.

This Final Wastewater Facilities Plan and Final Environmental Impact Report documents the third of three major phases of the Project. The first phase was the Needs Assessment which was documented in the December 1993 Needs Assessment Report, and identified wastewater needs at several wastewater areas of concern (AOC) in Town and at the Hyannis Water Pollution Control Facility (WPCF). The second phase was the Identification and Screening of Alternative Solutions to meet the wastewater needs, and was documented in the February 1996 Alternatives Screening Analysis Report. The third phase is the Detailed Evaluation, Environmental Analysis, and Development of a Recommended Plan and was documented in the Draft Wastewater Facilities Plan and Draft Environmental Impact Report (Draft WWFP/EIR). This final Wastewater Facilities Plan and Environmental Impact Report has been prepared to address remaining issues of the Project and the Draft WWFP/EIR.

The Study is proceeding with a joint regulatory review process with the Massachusetts Executive Office of Environmental Affairs MEPA Unit and the Cape Cod Commission. The review process was initiated in 1987 when the Secretary of the Executive Office of Environmental Affairs (EOEA) required that the Town prepare an Environmental Impact Report as part of a Town Wastewater Facilities Plan (WWFP). The Town initiated the WWFP with the completion of a Needs Assessment Report and Alternatives Screening Analysis Report, and then filed a Notice of Project Change in March 13, 1996 for the review of these items and the establishment

of a Project scope for the third phase of the Project. Since then there has been interim implementation of several needed upgrades at the Hyannis WPCF and for several sewer repairs and short extensions as approved through additional NPC. These interim implementation projects and NPC are listed below:

1. **Design and Construction of a New Secondary Clarifier for the Hyannis WPCF.** This project dates to April 24, 1996 and the Secretary's Certificate on an NPC which approved a new secondary clarifier at the Hyannis WPCF. The Needs Assessment had identified the secondary clarifier capacity as a limiting factor in treatment capacity and performance. The project was constructed in 1997 and is currently operational.

2. **Design and Construction of Three Short Sewer Extensions.** These projects date to April 24, 1996 and the Secretary's Certificate on an NPC which approved the sewer extensions. These projects include:

- Sewer replacement and extension along Barnstable Road.
- Sewer replacement and extension along Bearses Way.
- Sewer extension along Corporation Street.

These projects are all complete and operational.

3. **Design and Construction of Aeration System and Biological Process Modifications at the Hyannis WPCF.** This project dates to September 15, 1997 and was the construction of modifications to the aeration system and biological nitrogen removal process at the Hyannis WPCF. The Secretary's Certificate on an NPC approved these modifications. This project was recommended in the Needs Assessment and included the following components:

- Conversion of the nitrogen removal process from a cyclical aeration process to a Modified Ludzack-Ettinger process.
- Construction of a new aeration blower building and installation of diffused aeration in the treatment process.
- Installation of new return activated sludge pumps.

The project is complete and the new nitrogen removal process is removing nitrogen to typical values of 5 to 7 mg/L.

4. **Design and Construction of Two Short Sewer Extensions.** These projects date to the September 15, 1997 NPC request and include:

- Sewer extension at Summerside Lane in Hyannis.
- Sewer repair at Center Street in Hyannis.

The projects are complete.

5. **Design and Construction of a Sewer Extension at Norris Street.** This sewer extension was approved with an NPC and includes a small sewer extension into the H1 AOC (Stewarts Creek). The extension is now complete.

6. **Town-wide Wastewater Facilities Planning NPC dated June 23, 2003 (EOEA #6553).** This NPC was filed because more than three years had elapsed since the previous Secretary's Certificate for this project. There was no proposed change to the project scope, but there was acknowledgement that the Massachusetts Estuaries Project had been initiated and nitrogen limits for the Town's coastal estuaries were scheduled to be completed in the next five to eight years.

As part of the NPC review, there was a decision to finish the Wastewater Facilities Plan (EOEA #6553) for the wastewater AOCs that were recommended for connection to the Hyannis WPCF, and to defer recommendation and implementation of the Title 5 technologies (individual and grouped septic systems) for the AOC in the western portion of the Town. The Town did not want to require Title 5 improvements in the western portion of the Town when the Massachusetts Estuaries Project could identify estuarine limits that would require advanced nitrogen removal that is not possible in Title 5 systems. At that time, the project scope for the Town's Nutrient Management Program was reviewed and there was broad agreement on this planning approach.

The Secretary's Certificate for this NPC is included in Appendix 1-3 of this document.

7. **Design and Construction of Future Improvements at the Hyannis WPCF.** These improvements were approved with an NPC and include the design of additional aeration and nitrogen removal process tankage; improvements to the Pretreatment Building and Primary Pump Building; and yard piping improvements. This project has been designed and approved for SRF loans and is scheduled for construction in 2007.

8. **Design and Construction of an Effluent Force Main and a Sewerage Force Main as Part of the Route 132 Road Reconstruction Project.** These improvements were approved with an NPC and include the design and construction of 2 force main systems to be constructed as part of the Route 132 Road Project. This project has been designed and approved for SRF loans and is scheduled for construction in late 2007 and 2008. The approval also allowed for an effluent recharge through sand filter beds at the 6.9-acre property purchased with sewer reserve funds and located adjacent to the Route 6/132 interchange, and 2 short sewer extensions in Hyannis.

There have been three main reports that have been produced and reviewed as part of this project as summarized below.

1. **The Needs Assessment Report** identified wastewater-related problems in over 20 Areas of Concern (AOC) and several problems at the Hyannis WPCF.

2. **The Alternatives Screening Analysis Report** identified and screened alternative technologies and solutions for these problem areas in the following major categories.

- Decentralized treatment and disposal alternatives
- Centralized wastewater treatment and effluent recharge alternatives
- Residuals management alternatives
- Collection system technologies
- Flow and loading reduction alternatives

These alternative technologies and solutions were screened to select the most feasible solutions for detailed evaluation. The most feasible ones were then evaluated in detail and the following AOC were identified for connection to the Hyannis WPCF.

- Long Beach Road Area (AOC Area CE1)

- Red Lily Pond Area (AOC Area CE2)
- Wequaquet Lake, Shootflying Hill Road Area, South of Route 132 and part of Phinneys Lane down to Pine Street (AOC Area CE4)
- Stewart's Creek and Greenwood Avenue Area; and H3, Hall's Creek (AOC Area H1)
- Hyannis Avenue (AOC Area H2)
- Area within the Zone of Contribution for Barnstable Water System well BWMEL1 (AOC Area BWMEL1A and B)
- Area within the Zone of Contribution of Barnstable Water System well BWST1 (AOC Area BWST1)
- Area within the Zone of Contribution managed by the C-O-MM Water District for Well CO7 (AOC Area CO7)
- Residential neighborhood area south of Route 28 along Bearses Way as identified by the Board of Health and based on high density of development (AOC Area Bearses Way).

The other AOC had recommended solutions that were not connected to the Hyannis WPCF such as Title 5 solutions (individual and grouped septic systems). As mentioned above, in June 2003, there was acknowledgement that the Massachusetts Estuaries Project had been initiated and nitrogen limits for the Town's coastal estuaries were scheduled to be completed in the next five to eight years. There was a decision to finish the Wastewater Facilities Plan for the wastewater AOCs that were recommended for connection to the Hyannis WPCF, and to defer recommendation and implementation the AOC in the western portion of the Town (the ones recommended for individual and grouped septic systems).

3. **The Draft Wastewater Facilities Plan and Draft Environmental Impact Report** presented the detailed evaluation of the alternatives and summarized the environmental evaluations to meet the state and regional environmental requirements. The Draft WWFP/EIR was the draft version of this Final Wastewater Facilities Plan and Final Environmental Impact Report.

The purpose of this Final Wastewater Facilities Plan and Final Environmental Impact Report is to summarize the detailed evaluations, and the environmental impact analysis; and present a recommended plan for the Town's wastewater facilities, addressing remaining issues and comments received from the submittal of the Draft WWFP/EIR.

1.2 RECOMMENDED PLAN

A. **Wastewater Collection System Extensions and Improvements.** Wastewater collection system extensions and improvements are recommended to collect the wastewater from the AOC's and convey it to the Hyannis WPCF. These extensions and modifications are briefly summarized below:

1. Extension to connect the Cape Cod Community College (CCCC) including:

    - Route 132 force main (FM) extension to be constructed during the Route 132 Reconstruction Project.
    - CCCC Pump Station and FM extension from Route 132, down Bearses Way to the Hyannis WPCF.

2. Main Street pump station (PS) and force main modifications to address capacity problems with the existing PS, force main, and down-stream collection system. A Notice of Project Change for the modifications was filed and approved because the Town plans to proceed with this project in early 2007 (before a full approval on the EIR is expected).

3. Collection System Extension to the Wequaquet Lake/Long Pond Area (Area CE4).

4. Collection System Extensions to the Stewarts Creek Area (Area H1).

5. Collection System Extensions to the Following Zone II drinking water protection areas including:

    - CO7 Zone II Area
    - BWST1A, B, and C Zone II Areas
    - BWMEL 1 A and B Zone II Areas

It is noted that the Wequaquet Lake/Long Pond Area (CE4) also includes a Zone II contributing area to the Barnstable Fire District Waster Department (BFD-WD) Wells.

6. Collection system extensions to the following coastal protection areas:

    - CEI Area at the Craigville Beach area

- CE2 Area at the Red Lilly Pond Area
- H3 Area at the Hyannis port area

7. Collection System extension to the densely developed areas along Bearses Way where there is much housing stock and many failed septic systems.

8. Old Colony Road pump station improvements to include:

   - New SCADA, pump controls and flow meters.
   - Further evaluations on the 10-inch force main to increase capacity and subsequent improvements.

9. South Street gravity line replacements to increase capacity.

10. West Main Street gravity line modification and replacements to increase capacity.

These extensions and modifications are all illustrated on Figure 7-2. A cost summary on these recommendations is provided in Table 7-3.

B. **Improvements at the Hyannis WPCF**. The following improvements as part of the Hyannis WPCF are recommended:

1. Aeration tank additions and improvements to the Primary Pump Building, Pretreatment Building, Septage Building, and to the yard piping. These improvements are already approved and scheduled for construction in 2007. This project will bring the treatment capacity of the Hyannis WPCF to 4.2 mgd.

2. Effluent facility additions to allow 0.5 mgd effluent recharge at the 6.9-acre site. These improvements are already approved and will begin permitting in the future. These facilities will include:

   - Modifications to the pump gallery
   - Effluent filtration and UV disinfection
   - Piping, valves and sand infiltration beds at the 6.9-acre site

3. Sludge Management improvements and addition of a new employee locker room including:

- Additional thickened sludge storage
- Additional waste activated sludge storage
- Addition of a 3rd sludge thickener
- Addition of a new employee locker and meeting room to replace the outdated existing one.

The locations of the new aeration tank and sludge management facility are illustrated on Figure 10-1. Costs for the Sludge Management improvements and employee locker room are summarized on Table 7-2. The wastewater flows that will be treated at the Hyannis WPCF from the various areas of the proposed collection system are summarized on Table 10-1 and will sum to slightly less than 4.2 mgd which is the capacity of the WPCF once the aeration tank addition is completed (planned in 2008 or 2009).

C. **Groundwater Monitoring Modifications and Implementation of an Adaptive Management Plan for the Effluent Recharge at the Hyannis WPCF Site.** A Groundwater Adaptive Management Plan has been developed to monitor for potential impacts to low elevation properties near the Hyannis WPCF from high groundwater events occurring naturally every 10 to 25 years in combination with an incremental increase to the groundwater elevation due to the groundwater recharge at the WPCF site. It is also developed to identify procedures that will be used if groundwater reaches specific elevations (threshold elevations) in a group of sentinel wells. If groundwater elevations reach elevation threshold levels, the following immediate actions will be implemented:

1. Verify the groundwater rise or potential impact, including:

   a. More detailed survey and site visit to verify the GIS elevations that been used to date.
   b. Possible correlation of groundwater rise to the WPCF recharge.
   c. Investigation of impacts from other possible water sources such as broken water mains or poor drainage.

d. Inquiries to adjacent property owners that may be impacted as to whether groundwater is entering any basement living space or if problems have been noted with operation of their septic systems.

If the threshold elevations are exceeded and the exceedances are believed to be due to Hyannis WPCF recharge at the site, the following correction action alternative evaluations will occur:

1. Evaluate various mitigation alternatives to address the high groundwater that may include the following:

a. Drainage improvements.
b. Wellpoint dewatering and recharge at an appropriate and permitted location.
c. More wide spread rotation of effluent recharge within the Hyannis WPCF sand filter beds.
d. Relocation of up to 0.5 mgd to the 6.9-acre site.
e. Property purchase of the affected property.
f. Evaluation, planning, approval, and implementation of additional remote effluent recharge locations.
g. Discontinuation of sewer connections to properties that want to be served by the sewer (sewer moratorium).

2. Prepare an evaluation report for submittal to MADEP summarizing the evaluations and recommended actions and timetable.

Also, as requested by the CCC, the AMP includes the creation of a Technical Advisory Group (TAG) to review groundwater monitoring and assessments. The TAG will be headed by Mark Ells, DPW Director, and include staff members from the MADEP, CCC, SMAST, USGS and the Town's DPW. This group may meet semi-annually.

1.3 PLANNED MITIGATION EFFORTS

Collection system extensions are planned in the road layouts to avoid impacts to animal habitats, wetlands, historic area or potential archeological sites. Construction in these areas will impact traffic (vehicle, pedestrian, and bicycle) in the roadways during construction. These impacts will be of short duration and construction will not be timed for the summer season to avoid traffic

congestion. Construction procedures for traffic control, erosion protection, dust control, noise prevention, and wetland protection will be implemented.

The collection system pump stations need to be located in low-elevation areas to be able to utilize gravity pipes that flow to a low area for collection and subsequent pumping. Wetland regulations and permitting will be followed to minimize impacts to any adjacent wetlands.

The Craigville Beach area (CE1 Area) is considered a barrier beach and state requirements (Executive Order 181) have the following stringent requirements for the construction of sewers on a barrier beach.

- All infrastructure must be protected from coastal flood hazards
- The sewers cannot promote additional growth on the barrier beach that would not have otherwise been allowed.

As a result, this collection system extension will be designed to withstand coastal flood hazards with pump stations that will not be flooded with a 100-year storm and all pipes and equipment suitably protected from wave action.

Also Town of Barnstable staff conducted a series of public meetings with citizens and Town Council representatives of Centerville (which includes AOC CE-1) in 2006. The meetings were broadly publicized, including direct mailings. Participants expressed their support for growth controls and a sewer-neutral regulation in the Craigville Beach area. The Town is considering several options that have sewer-neutral results to prevent growth on the barrier beach beyond the growth that is allowed by the current sanitary regulations of Title 5 State code as well as the Town's Board of Health bylaws. (A copy of Chatham's sewer regulation that takes a similar approach is attached in Appendix 10-1 and is being considered as a model for Barnstable's regulation).

The Town of Barnstable is in the process of updating its 1996 Local Comprehensive Plan (LCP). Upon completion, the LCP update will be submitted to the CCC for a determination of consistency with the Cape Cod Regional Policy Plan (RPP). The draft LCP update proposes to establish a "sewer neutral" policy for areas proposed to be connected to public sewers, similar to the Sewer Neutral Regulation adopted by the Town of Chatham. The growth neutral controls are planned to be in place before any sewers are implemented.

1.4 ONGOING WASTEWATER PLANNING EVALUATIONS

The Town has initiated its Nutrient Management Program which will include a large component on Wastewater Management to meet the new nutrient limits being developed by the Massachusetts Estuaries Project (MEP) as discussed in Chapter 1. The Nitrogen limit development work as well as the three years of water quality monitoring are the main components of Phase I of this program that has been on-going since 2002. The full Plan of Study for this planning program is attached in Appendix 1-7.

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EOEEA Certificate for Town of Barnstable Final Wastewater Facilities Plan/FEIR; May 18, 2007

The Commonwealth of Massachusetts
Executive Office of Energy and Environmental Affairs
100 Cambridge Street, Suite 900
Boston, MA 02114

DEVAL L. PATRICK
GOVERNOR
TIMOTHY P. MURRAY
LIEUTENANT GOVERNOR
IAN A. BOWLES
SECRETARY

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http://www.mass.gov/envir

RECEIVED
MAY 24 2007
By

May 18, 2007

CERTIFICATE OF THE SECRETARY OF ENERGY AND ENVIRONMENTAL AFFAIRS
ON THE
SPECIAL PROCEDURE: PHASE III –
FINAL WASTEWATER FACILITIES PLAN/FEIR

PROJECT NAME	: Area 5 Sewers/Wastewater Facilities Plan
PROJECT MUNICIPALITY	: Barnstable
PROJECT WATERSHED	: Cape Cod
EOEA NUMBER	: 6553
PROJECT PROPONENT	: Town of Barnstable
DATE NOTICED IN MONITOR	: April 11, 2007

As Secretary of Energy and Environmental Affairs, I hereby determine that the Phase III Wastewater Facilities Plan/Final Environmental Impact Report (FEIR) submitted on this project **adequately and properly** complies with the Massachusetts Environmental Policy Act (M.G.L. c. 30, ss. 61-62H) and with its implementing regulations (301 CMR 11.00).

I want to acknowledge the Town of Barnstable's significant efforts over many years to develop this comprehensive approach to wastewater management planning and groundwater resources management to guide the Town's efforts to address the immediate and longer term wastewater management needs. I also want to acknowledge the valuable help and guidance provided by the Cape Cod Commission (CCC), the Department of Environmental Protection (MassDEP), Coastal Zone Management (CZM), and the public throughout the MEPA Special Review process for this project. The Phase III Final Wastewater Facilities Plan/FEIR, together with the Town's Nutrient Management Program planning efforts, will bring us significantly closer to providing a sound basis for regional wastewater treatment and disposal decision-making that will benefit Cape Cod and the residents of the Town of Barnstable alike.

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PROJECT OVERVIEW

As described in the original September 1997 Environmental Notification Form (ENF), the project involved the sewering of Area 5 of the Town of Barnstable. The Secretary's Certificate on the ENF authorized the installation of the proposed sewers while the proponent prepared an EIR to address the need for a Sewer Master Plan including options for improving the Hyannis Water Pollution Control Facility (WPCF). The Certificate also required the Town to limit connections to only those sites with documented failing on-site septic systems until the MEPA process was completed. A scope for an EIR was established in the ENF Certificate issued June 1987. A Notice of Project Change (NPC) was filed in March 1996 that proposed to expand the project to include a comprehensive Town-wide wastewater facilities plan (WWFP) designed to quantify the Town's long-term wastewater treatment and water supply protection needs, and identify alternative approaches for meeting those needs through the 2014 planning period. A Special Review Procedure was established for this project, consisting of a Phase I - Needs Report, Phase II – Screening of Alternatives (Interim Report of the Wastewater Facilities Plan), and Phase III - Draft and Final Wastewater Facilities Plan/EIR. The Secretary's Certificate on the NPC (April 1996), adopted the proponent's proposed scope for a Wastewater Facilities Plan/Environmental Impact Report (WWFP/EIR) and provided for the establishment of a Citizens Advisory Committee (CAC) to provide input into the plan's development.

A second Notice of Project Change (2nd NPC) was filed in May 2003, that proposed to proceed with portions of the Scope for the Phase III – DEIR to provide sewering and advanced nitrogen removal for those Areas of Concern (AOCs) located in close proximity to the Hyannis WPCF. As described in the 2nd NPC, the Town proposed to wait until such time as the ongoing Massachusetts Estuaries Project (MEP) establishes appropriate nitrogen loading limits to determine appropriate treatment and discharge options for sewage flows from those AOCs located in the western and southwestern sections of Barnstable.

In February 2005, a third Notice of Project Change (3rd NPC) was filed with the MEPA Office that proposed to proceed with the construction of interim improvements to the Hyannis Water Pollution Control Facility (WPCF) that would enable the town to increase the wastewater flow capacity of the WPCF from 2.7 mgd to 4.2 mgd. Specifically, the proposed improvements to the WPCF include the addition of a third aeration tank, replacement of the existing grit removal system, and installation of a Supervisory Control and Data Acquisition (SCADA) system. The proposed facility modifications will result in approximately 6,000 sf of land alteration and approximately 8,000 sf of new impervious surface area.

The Town of Barnstable filed a fourth Notice of Project Change (4th NPC) on October 25, 2006 and proposed a number of comprehensive sewer construction activities in advance of the proponent's completion and submittal of the Draft and Final Wastewater Facilities Plan/EIR including: 1) construction of an 18" effluent force main within the Route 132 right-of-way from the Hyannis WPCF to the proponent's proposed effluent disposal site (McManus site) located near Exit 6 off Route 6, and construction of a sewer main from the Cape Cod Community College to the Route 132 effluent force main; 2) construction of the proposed McManus effluent disposal facility; and, 3) construction of two sewer extensions to limited areas in Hyannis (North Street, Pleasant Street).

The proposed force main construction was designed with the capacity to convey 1.3 mgd of treated wastewater effluent from the Hyannis WPCF to a new remote effluent disposal site located northwest of the Hyannis WPCF at the intersection of the Route 6 Mid-Cape Highway and Route 132 in Barnstable. The proponent has worked closely with MassDEP, MHD and others to coordinate its proposed effluent force main construction with the construction of the Route 132 Reconstruction Project (EOEA #13526). A Secretary's Certificate on the Route 132 Reconstruction Project was issued in June 2005 and determined that no further MEPA review was required.

In October 2006, a fifth Notice of Project Change/Phase I Waiver Request (5th NPC), was filed with the MEPA Office that proposed sewer construction activities in advance of the Town's completion and submittal of the Phase IV - Final Wastewater Facilities Plan/FEIR including; the construct ion of a new Main Street pump station to satisfactorily accommodate existing and projected future wastewater flows, and the replacement of existing force main within existing Town road right-of-ways to convey wastewater flows from the Old Colony Road pump station to the Hyannis WPCF. A Secretary's Certificate on the Main Street Pump Station Project was issued in February 2007 and determined that no further MEPA review was required.

FINAL RECOMMENDED WASTEWATER FACILITIES PLAN

The Town of Barnstable's Wastewater Facilities Plan (WWFP) proposes to extend new municipal sewers to ten wastewater areas of concern (AOCs) in Barnstable. These proposed new AOC sewer areas are located within or in close proximity to wellhead protection areas near to Lake Wequaquet, Long Pond, Red Lily Pond, Stewart's Creek, Hall's Creek, Willow Street, the Cape Cod Community College, and the Hyannis WPCF.

1. Cape Cod Community College
2. Long Beach Road area (CE1);
3. Red Lily Pond area (CE2);
4. Wequaquet Lake and Long Pond area (CE4);
5. Stewarts Creek and Greenwood Avenue areas (H1);
6. Halls Creek area (H3);
7. Bearses Way Residential neighborhood area (Bearses Way)
8. Area within Zone of Contribution (ZOC) of Barnstable Water Supply System well BWMEL1 (BWMEL1);
9. Area within Zone of Contribution (ZOC) of Barnstable Water Supply System well BWST1 (BWST1); and,
10. Area within Zone of Contribution (ZOC) of Centerville –Osterville Marston Mills (COMM) Water District for Water Supply System well CO7 (CO7).

The Long Beach Road area (CE1) is a barrier beach located in a coastal high hazard area within the velocity zone of the 100-year storm event. In response to comments received from CCC, CZM and others, the Town has committed to incorporate a system of check valves into the new sewer collection system for this area to minimize impacts in the event of a storm-related breach to the collection system.

The Final Wastewater Facilities Plan also includes a number of improvements to the Hyannis Water Pollution Control Facility's (WPCFs) buildings and piping, and effluent facility additions and sludge treatment processes, to be completed in 2007, that will enable the WPCF to increase its wastewater treatment capacity from 2.7 mgd to 4.2 mgd. The Town conducted a review of its groundwater modeling analysis subsequent to the issuance of the Secretary's Certificate on the 4th NPC, and concluded that the Hyannis WPCF site, together with the use of the 6.9 acre McManus site for groundwater discharge of up to 0.5 mgd, can accommodate up to 4.2 mgd of treated wastewater discharge to groundwater with no adverse effects on surrounding properties and groundwater resources.

As part of the Wastewater Facilities Plan, the Town of Barnstable developed an Adaptive Management Plan (AMP) to monitor the potential impacts to downgradient groundwater levels, water quality and private properties from the Hyannis WPCF's increased groundwater discharges. The Town has committed to create a Technical Advisory Group (TAG) comprised of representatives from the Barnstable Department of Public works (DPW), MassDEP, CCC, the School of Marine Science and Technology (SMSAT), and the United States Geologic Survey (USGS), to provide assistance to the Town to refine the scope of the AMP's groundwater monitoring plan and schedule. The TAG will evaluate existing monthly groundwater water level readings and water quality data, collected since the early 1990's from existing wells located downgradient of the WPCF and in the area associated with the regional groundwater divide between Vineyard/Nantucket Sound and Cape Cod Bay, and make recommendations regarding groundwater monitoring well locations and monitoring frequency.

The AMP will employ threshold groundwater elevations that will be used to trigger immediate corrective action alternatives to mitigate the high groundwater elevations resulting from the facility's increased groundwater recharge. As described in the FEIR, possible corrective action alternatives will include:

- relocation of discharges within the Hyannis WPCF site,
- dewatering and recharge at an appropriate location,
- relocation of 0.5 mgd of treated wastewater to the McManus wastewater discharge site,
- implementation of additional remote wastewater discharge locations,
- purchase of impacted property(s), and,
- institution of a sewer connection moratorium.

McManus Site

The Town has proposed to convey approximately 0.5 mgd of treated wastewater effluent from the Hyannis WPCF to a 6.9-acre portion of the 44-acre McManus site, located at the intersection of the Route 6 Mid-Cape Highway and Route 132, for subsurface disposal. The McManus effluent discharge site is located within a marine recharge area to Barnstable Harbor, the Wellhead Protection Area for Barnstable Fire District Wells (BFD) #3 and #4, and the recharge area for Lake Wequaquet, Shallow Pond and Hinckley Pond.

The McManus site was acquired in March 2002 for the purposes described in the Cape Cod Land Bank Acquisitions Program documentation, including the protection of public drinking water supplies, open space, and conservation land, the creation of walking trails and bicycling trails, and the creation of recreational areas. As part of the MEPA review of the 4th NPC submittal, the Town provided additional information to the MEPA Office indicating that prior to the purchase of the 44-acre McManus parcel in March 2002, the Town of Barnstable also acquired a use easement associated with a 6.9-acre portion of the McManus site for use as a groundwater discharge facility ("6.9-acre groundwater discharge easement area"). According to the proponent, this groundwater discharge easement area could accommodate the construction of a groundwater discharge facility to accept 0.5 mgd of treated wastewater effluent from the Hyannis WPCF. Based on a review of the information provided in the NPC4 submittal and additional information provided by the proponent pertaining to the 6.9-acre easement area, the Secretary's Certificate on the 4th NPC (January 20, 2006) found that the Town's proposed use of the 6.9-acre easement area for the disposal of treated wastewater effluent appeared to be consistent with the intended uses and activities described by the use easement documentation.

As described in the FEIR, the proposed groundwater discharge facility to be located within the 6.9-acre McManus easement area will be designed to be expandable to accommodate potential future increases in effluent discharges or groundwater from the Hyannis WPCF. The Town will need to submit a Notice of Project Change (NPC) to the MEPA Office for any future proposal to expand the 6.9-acre groundwater discharge easement area to include the use of any portion of the remainder 37.1-acre McManus site for wastewater effluent disposal. The NPC submittal will need to provide additional information to demonstrate the consistency of the proponent's proposed use of additional McManus site area for groundwater discharge with the intended Article 97 purposes and interests in land outlined in the Cape Cod Land Bank Acquisitions Program (Chapter 293 Act of 1998, and Chapter 127 Act of 1999). The Town of Barnstable will need to work closely with CCC, MassDEP and others to identify and complete any additional groundwater modeling and/or nutrient loading analysis that may be needed to determine the feasibility of increasing the proponent's McManus effluent discharge proposal beyond 0.5 mgd. Article 97 of the Massachusetts Constitution bespeaks the high value placed upon the preservation of existing open space lands, including lands subject to Conservation Restrictions. The goal of this policy is to ensure no net loss of Article 97 lands and interests in lands under the ownership and control of the Commonwealth and its political subdivisions. To further the Commonwealth's open space goals, the EOEA Article 97 Land Disposition Policy requires a demonstration that a proponent has explored alternatives to avoid and/or minimize the Article 97 disposition. The Town will need to propose adequate mitigation for any proposed use of Article 97 lands, and interests in lands, that are not in compliance with the intended Article 97 purposes and interests in land outlined in the Cape Cod Land Bank Acquisition Program.

Additional Effluent Reuse and Discharge Sites & Nutrient Management Program

The Town of Barnstable's Wastewater Facilities Plan also includes the identification of additional alternative remote sites that are potentially suitable for the disposal of treated wastewater effluent from its Hyannis WPCF. These sites will continue to be evaluated by the Town as potential future wastewater effluent recharge sites.

1. Cape Cod Community College (Site D);
2. Barnstable Airport Site (Site C);

3. Lorusso Site (Site E);
4. Cape Cod Hospital Abandoned Cranberry Bog Site (Site W1);
5. Makepeace Abandoned Cranberry Bog Site (Site W2);
6. Existing Hyannis WPCF Site (Site A)
7. Full McManus Site (Site B);
8. Country Farm Site;
9. Groundwater pumping from downgradient of Hyannis WPCF to remote location; and,
10. Tree Plantations downgradient of Hyannis WPCF.

In their comments, the CCC has suggested that the Town re-evaluate its prioritization of potential alternative effluent disposal sites to take into account the environmental constraints associated with the Barnstable Airport Site (Site C), and the Lorusso Site (Site E). Given the project's potential impacts to groundwater resources, drinking water supplies and Article 97 lands, I strongly encourage the Town of Barnstable to continue to explore opportunities to incorporate a mix of effluent disposal and reuse alternatives involving the McManus site at 0.5 mgd, together with use of one or more additional effluent disposal sites to accommodate the Town of Barnstable's future wastewater flows.

Sewering and Growth Management

Executive Order #385 requires that state and local agencies engage in protective and coordinated planning oriented towards resource protection and sustainable economic development. For reasons of both environmental protection and fiscal prudence, investments in public infrastructure should be carefully targeted toward those areas for which clear existing needs have been established and for areas where denser development is appropriate, thereby relieving development pressures on open space, agricultural lands, and other valuable natural resources. According to the information provided in the FEIR document, the Town has proposed to update its current Local Comprehensive Plan (LCP) to include a "sewer neutral" policy and to adopt appropriate regulations (similar to the Town of Chatham's Regulation of Sewer Flow, Article II, May 9, 2005) for controlling new future development requesting municipal sewer service and located in areas inside of the AOC's and the proposed new sewer areas. I encourage the proponent to consult with MassDEP and CCC in also developing growth-neutral policies and a strategy to prohibit and/or discourage future new development requesting municipal sewer service and located in areas outside the AOC's and the proposed new sewer areas.

Costs to Homeowners

The Town's WWFP will be constructed over several years and will cost an estimated $203, 000,000.00. As described in the FEIR, the average household costs (capital and O&M) for the proposed WWFP will be $28,800.00.

I find that the FEIR provides sufficient information to understand the environmental impacts of the project and potentially feasible alternatives to the project, that the project has avoided and mitigated environmental impacts to the greatest feasible extent, and that the state permitting agencies have adequate information on which to execute their Section 61 obligations. The proponent can resolve any remaining issues during the permitting process.

May 18, 2007
DATE

Ian A. Bowles, Secretary

Comments received:

05/11/07	Massachusetts Coastal Zone Management (CZM)
05/11/07	Massachusetts Department of Environmental Protection – SERO
05/09/07	Edward W. Marshall, Jr.
05/10/07	Hyannis Water Board
05/10/07	Gail T. Maguire
05/10/07	Pesce Engineering & Associates, Inc.
05/11/07	Natural Heritage and Endangered Species Program (NHESP)
05/11/07	Cape Cod Commission (CCC)

FEIR/Phase III - Final WWFP #6553
IAB/NCZ/ncz

Appendix 1-3

CCC DRI Decision on Town of Barnstable Wastewater Facility Plan; September 20, 2007

CAPE COD COMMISSION

3225 MAIN STREET
P.O. BOX 226
BARNSTABLE, MA 02630
(508) 362-3828
FAX (508) 362-3136
E-mail: frontdesk@capecodcommission.org

DATE: SEPTEMBER 20, 2007

TO: JOHN KLIMM, TOWN MANAGER
MARK ELLS, SUPERINTENDENT, DEPT OF PUBLIC WORKS

FROM: CAPE COD COMMISSION

RE: DEVELOPMENT OF REGIONAL IMPACT
CAPE COD COMMISSION ACT, SECTIONS 12 & 13

APPLICANT: TOWN OF BARNSTABLE
MAIN STREET
HYANNIS, MA 02601

PROPERTY OWNER: TOWN OF BARNSTABLE, MASSACHUSETTS

COMMISSION PROJECT#EOEA#6553/ BARNSTABLE WASTEWATER FACILITIES PLAN

PROJECT LOCATION: WATER POLLUTION CONTROL FACILITY
BEARSES WAY, HYANNIS, MA

DECISION OF THE CAPE COD COMMISISON

SUMMARY

The Cape Cod Commission (Commission) hereby approves, with conditions the application of the Town of Barnstable as a Development of Regional Impact (DRI) pursuant to Sections 12 and 13 of the Cape Cod Commission Act (Act), c.716 of the Acts of 1989, as amended, for the proposed Wastewater Facilities Plan. The decision is rendered pursuant to a vote of the Commission on September 20, 2007.

The Final Plan/DRI provides a proposed strategy for connecting areas of concern (AOCs) in the eastern portion of Town, identified in a 1993 Needs Assessment Report, to the municipal sewer system and addresses longstanding performance and disposal issues at the Hyannis Water Pollution Control Facility (WPCF). This Final Plan/DRI is the culmination of 13 years effort to provide a way forward to address immediate and long-term wastewater management needs at the WPCF and the portion of the Town of Barnstable that utilizes the WPCF. The development of the Final Plan included extensive coordination among and efforts by town officials, their consultants, regional, state and federal experts. Given the time to complete this effort all parties demonstrated flexibility to: include new information, incorporate evolving technologies and address regulatory changes along the way. The Final Plan/DRI provides solutions to the Town's immediate wastewater concerns, and provides the framework to address future needs, resource protection and restoration goals through the implementation of the Town's proposed Nutrient Management Program and Adaptive Management Plan.

PROJECT DESCRIPTION

The Final Plan/DRI provides a comprehensive 20-year strategy for wastewater treatment and disposal issues in the eastern portion of the Town of Barnstable. The planning period design year is 2014, which is 20 years after the project formally began in 1994.

The Barnstable Water Pollution Control Facility (WPCF) was initially sited and began operation in 1935 to serve downtown Hyannis. In 1979, the Facility was upgraded to secondary treatment with a design capacity of 4.2 million gallons per day (MGD). In the mid-1980s, prior to widespread sewering, it was discovered that treated effluent discharge causes water table mounding beneath the site that could have impacts to low lying properties and would spread the flow of effluent-altered groundwater to other water resources, such as nearby freshwater ponds and public drinking water supply wells. To address these concerns, the Town limited the wastewater discharge volume to 2.7 MGD for peak flow as a precaution and began its Wastewater Facility Planning process in 1987.

The Wastewater Facility Planning process included a number of steps that were coordinated through MEPA and Cape Cod Commission review and involved active discussion among all parties. The first phase, the identification of wastewater needs, included: 1) review of land use and demographics, including wastewater projections and areas with wastewater problems, 2)

development of a sub-regional groundwater model to help evaluate potential impacts of discharge from the WPCF, 3) development of town goals for wastewater treatment, and 4) potential upgrades in the WPCF and the sewer collection system. This first phase identified 24 Areas of Concern (AOCs) with wastewater issues to be addressed and was produced in December 1993.

The second phase of the Wastewater Facility Planning process, the alternatives screening analysis, which was produced in February 1996, identified four additional AOCs and reviewed potential solutions to address the issues for the AOCs.

During the course of developing the first two phases, a number of additional wastewater issues were identified that required attention. These were addressed mostly through Notices of Project Change between 1996 and 2006 and included:

- a review of wastewater issues at Cape Cod Community College,
- an initial evaluation of nitrogen loading within the watershed to the Three Bay estuary system,
- a pilot evaluation of wastewater injection wells,
- a review of potential satellite wastewater disposal locations at different locations throughout the town,
- upgrades of pump stations and sewer lines,
- upgrades of WPCF components, and
- changes in the process to await findings from the Massachusetts Estuaries Project.

Throughout these phases and subsequent efforts, the town coordinated with Commission and state staff. This coordination has also, in some cases, led to Commission staff providing technical assistance to assist the town with addressing issues. For example, the town utilized the County-sponsored US Geological Survey groundwater-modeling project to evaluate the potential impacts from a variety of discharge volumes at the 6.9-acre McManus site. This technical assistance combined with other technical efforts led to an approved discharge capacity of 0.5 MGD by the EOEA Secretary in his 2006 Certificate. The Certificate also allowed a plan to install force mains and sewers beneath the new Route 132 upgrade to connect the new site into the effluent discharge system.

The 2007 Final Wastewater Facilities Plan utilizes the insights from these past efforts and proposes a series of actions for moving forward. The water level issues at the WPCF are addressed through an assessment of groundwater level conditions at the WPCF. This assessment reviews water level data that has been collected over the past 15 years and concludes that the initial assessment, which constrained the site discharge to 2.7 MGD, overestimated the effect of the facility's discharge on water table levels. The FEIR proposes an adaptive management approach that would allow the discharge of up to 4.2 MGD of treated effluent at the WPCF through a water level monitoring program that contains contingencies to alter discharge locations, including use of the approved 6.9-acre site, if monitoring identifies concerns. This

proposed Adaptive Management Plan includes actions to monitor changes in water table levels from increasing treated-water recharge at the WPCF and identifies potential mitigation strategies from impacts should they occur in the future.

The Final Plan/DRI also proposes to provide sewering to 10 (ten) AOCs in the eastern portion of Town, that includes: 3 wellhead protection areas near and downgradient of the WPCF, areas near Lake Wequaquet, Long Pond, Red Lilly Pond, Long Beach Road, Stewart's Creek, Hall's Creek, and the Community College. The Plan acknowledges that sewering these areas will require consideration of regulatory changes, design issues, and public input. The plan also proposes a number of improvements at the WPCF are also recommended to increase the treatment capacity to 4.2 MGD and better treat sludge management. The Plan also acknowledges that the Town faces some additional wastewater-related issues for addressing nutrient loading to surface waters, both estuaries and freshwater ponds. The Plan includes a work plan for the Nutrient Management Plan that will actively address the assessment, screening and selection of wastewater alternatives to address the protection and/or remediation of these resources.

PROCEDURAL HISTORY

The Wastewater Facility Plan project has undergone regulatory review pursuant to section 11.26(7)(h)(6) of the Massachusetts Environmental Policy Act (MEPA) regulations beginning when the Secretary of Environmental Affairs scoped a Certificate on the initial Environmental Notification Form (ENF) in 1987. The Town filed a Notice of Project Change (NPC) in 1996 and opted to exercise a joint MEPA regulatory review with the Cape Cod Commission. The Town completed its Final Environmental Impact Report in March of 2007 and the Secretary, in his Certificate dated May 18, 2007, found that the Town's project adequately and properly compiles with MEPA and its implementing regulations. Over the last 13 years the Commission has received and reviewed 7 major MEPA submittals from the Town of Barnstable as indicated in the Table below. For each submittal, the document was reviewed, staff comments were prepared, some involving significant technical data and resource analysis, a joint public hearing was held, and Commission subcommittee comments were sent to the MEPA Office.

	Submittal	Public Hearing	Comment Letter
Environmental Notification Form (ENF)	Sept 1987	prior to Cape Cod Commission	
Notice of Project Change (NPC) 1st	March 1996	April 10, 1996	April 12, 1996
Notice of Project Change (NPC) 2nd	May 2003	***	June 12, 2003
Notice of Project Change (NPC) 3rd	Feb 2005	none	March 15, 2005
Notice of Project Change (NPC) 4th	Oct 2005	Nov 29, 2005	Dec 12, 2005
Notice of Project Change (NPC) 5th	Oct 2005	Nov 29, 2005	Dec 12, 2005
Draft Wastewater Facilities Plan (DEIR)	Nov 2006	Nov 12, 2006	Dec 12, 2006
Final Wastewater Facilities Plan, (FEIR)	March 2007	May 2, 2007	May 3, 2007

The content of each submittal is summarized below.

- 1987: Initial ENF Filing: To prepare a Sewer Master Plan
- 1996: 1st Notice of Project Change: To expand scope to include a Comprehensive Wastewater Facility Plan, setting the 2014 planning period and requiring three Phases of study including the Needs Assessment, Screening of Alternatives and the Draft and Final Plans.
- 2003: 2nd Notice of Project Change: To proceed with improvements to the Wastewater Facility Plan and defer wastewater alternative analysis for watersheds to nitrogen sensitive embayments until the Massachusetts Estuary Project establishes appropriate nitrogen loading limits.
- 2005: 3rd Notice of Project Change: To proceed with improvements of the Water Pollution Control Facility to increase its treatment capacity from 2.7 to 4.2 million gallons per day.
- 2006 4th Notice of Project Change: To allow additional improvements at the WPCF, install a force main along Route 132 to connect Cape Cod Community College to the WPCF, install two sewer extensions in Hyannis, and to develop sand filter beds with a capacity of 0.5 MGD at the 6.9-acre site adjacent to the McManus site located adjacent to Exit 6 on Route 6 north of the Hyannis Golf Course.
- 2006 5th Notice of Project Change: To allow the construction of a Main Street Pump facility and the limited replacement of force mains within Hyannis.
- 2007 Draft and Final Wastewater Facilities Plan: Described above on page 2.

MATERIALS SUBMITTED FOR THE RECORD

Chrono-logical #	**From the Applicant** Title	Date
1	Groundwater and Water Resource Protection Plan SEA Consultants	9/1/1985
2	Map of Zone 2 Recharge Area for Exisiting Water Supply Wells	3/2/1989
3	Update of Townwide Zones of Contribution of Public Supply Wells	9/1/1989
4	Hydrogeological and Water Quality Investigation on BWC Wells	3/1/1991
5	Report on Prolonged Pumping Test and Zone 2 Delineation at Test Well Site 8-90	11/1/1991
5a	Memo of Understanding between Mass Environmental Policy Act and the Cape Cod Commission	11/25/91
6	Technical Memorandum Three Dimensional Flow Model Construction and Calibration Town of Barnstable	1/22/1992
7	Map of Observed Water Table	6/1/1992
8	"Letter to Thomas Cambareri from Scott Potter, Geraghy & Miller re:	10/4/1992

	Response to November 10th Letter to Mark Ells from Mr. E. Eichner "	
9	Request for Statement of Qualifications to Perform a Wastewater Facilities Planning Study Town of Barnstable DPW	10/7/1992
10	Three Dimensional Flow model Construction and Calibration	10/22/1992
11	"Letter to Robert Cady from Thomas Mullen, Town of Barnstable re: Wastewater Facilities Plan DEP/BMF Project No. 20-1016-01 Groundwater Modeling and Related Services"	10/27/1992
12	"Letter to Thomas Cambareri from Mark Ells, Town of Barnstable re: Wastewater Facilities Plan DEP/BMF Project No. 20-1016-01"	11/9/1992
13	"Letter to Thomas Cambareri from Gisella M. Spreizer, Geraghy & Miller re: Ground-Water Flow Model Reports for Bourne and Sandwich, Ma"	4/1/1993
14	Letter to Robert Cady from Mark Ells. Town of Barnstable re: Wastewater Facilities Plan DEP/BMF Project No. 20-1016-01	4/7/1993
15	Groundwater Protection Overlay Districts	8/19/1993
16	Groundwater Conditions	9/1/1993
17	"ENF Well Supply Facility 5, Barnstable Fire District Water Department"	9/3/1993
18	"Map of Water Table of Wastewater Treatment Facility, Town of Barnstable"	9/13/1993
19	"Wastewater Facilities Plan Phase 1, Needs Assessment Report"	11/1/1993
20	"Wastewaters Facilities Plan Phase 1, Needs Assessment Report Town of Barnstable, "	11/1/1993
21	1994 Annual Report on BWC to Water Management Program Department of Environmental Protection	1/1/1995
22	Q & A about water quality in our town of Barnstable	10/19/1995
23	Town of Barns. Notice of Chg. EOEA #6553 Sewer Area 5 Project	3/13/1996
24	"Town of Barnstable, Comment Letter on EIR CCC#EIR96005/EOEA #6553"	4/9/1996
24a	Extension Agreement	4/12/96
25	Summary of Prioritized Sites for Evaluation in Phase III Modified Table 8-8	4/26/1996
26	Wastewater Facilities Plan DEP/BMF Project no. 20-1016-01 Revised Table 8-9	5/16/1996
27	"Wastewater Facilities Plan, Notice of Project Change EOEA #6553"	5/17/1996
28	Town of BWWFP Alternative Discharge Siting Effluent Mitigation Alternatives DEP/BMF Project No. 20-1016-1 Robert Cady	10/16/1996
29	Town of BWWFP Status of Area of Concern Evaluation DEP/BMF Project No. 20-1016-01 Robert Cady	10/17/1996
30	Progress Meeting Wastewater Facilities Plan Phase III Barnstable MA	10/23/1996
31	FAX: re Agenda for Barnstable Progress Meeting of 2/12/97	2/10/1997
32	"Town of Barns. Area 5 Sewer Project EOEA #6553 Town Wide Wastewater Facilities Plan, EIR, Notice of Project Change"	9/15/1997
33	Effluent Mitigation Alternatives Draft Summary	12/17/1997

33a	Extension Agreement	1/26/98
34	"Wastewater Facilities Plan, Cape Cod Commission March 18, 1998"	3/18/1998
35	"Wastewater Facilities Plan, Effluent Mitigation Options March 27, 1998"	3/27/1998
36	Fax with a meeting agenda 2/12/97 and Letter to Ron Lyberger re: Frequency and volume of effluent to be mitigated from the Hyannis WPCF	4/2/1998
37	"FAX: Draft Work Plan, Additional effluent mitigation evaluation Wastewater facilities report, Town of Barnstable"	6/15/1998
38	"Wastewater Facilities Plan, Effluent Mitigation Options April 8, 1998"	7/8/1998
39	Effluent Mitigation Screening and Evaluating of Potential Injection Well Sites - DRAFT	10/15/1998
40	"Minutes from 10/6/98 Meeting with DEP Wastewater Facilities Plan, Effluent Mitigation Alternatives"	10/20/1998
41	Draft Matrix of site evaluation for modeling of effluent disposal sites	11/13/1998
42	FAX re: Comments to Lake Wequaquet Protective Association re: Wastewater Facilities Plan progress	1/20/1999
43	Memo: Effluent Mitigation Alternatives	3/18/1999
44	Water Quality & Habitat Health of the Three Bays Estuarine System	10/1/2000
	Extension Agreement	1/29/01
45	Nutrient Management Planning Project- Project Scope	8/14/2001
46	Req.to add Norris St. to Cert.of Proj. Chg.	3/12/2002
	Extension Agreement	7/4/02
47	Attach. A Scope-Services-Compl. Of WWFP & EIR	3/19/2003
48	Meeting Agenda for Wastewater Facilities Plan	4/8/2003
49	Town of Barns. Notice of Chg.	5/12/2003
50	"Map, Figure 1 Town of Barnstable MA Effluent Mitigation Investigation benchmark Evaluation"	7/14/2003
51	"Lake Wequaquet, Long Pond and Cape Cod Community College Sewer Extension"	9/1/2003
52	Meeting Handouts on Local Comprehensive Plan Wastewater Facilities Plan/EIR including 2 maps of Wastewater Areas of Concern	3/29/2004
53	Notice of Project Change full report to EOEA for construction of interim improvements to the Hyannis WPCF	1/28/2005
54	"Town of Barnstable, Wastewater Capital Improvement Projects Program Schedule"	10/5/2005
55	"Town of Barnstable, Wastewater Facilities Plan, Summary of Environmental Review Process, Previous Evaluations and Reports, Related Town Wastewater Projects"	10/5/2005
56	Proposed Model Runs for Town of Barnstable	10/12/2005
57	Document Outline for Notice of Project Change for Proposed Approval and Implementation of an Effluent Force Main in the Route 132 ROW and Effluent Discharge at the McManus Site	10/12/2005
58	"Effluent Mitigation Evaluations, Wastewater Facilities Plan and USGS	10/12/2005

	Evaluations Model Review Meeting"	
59	Memo re: Outline for proposed Notice of Project Change for Phase I Waiver	10/12/2005
60	Nitrogen Loading Calculations for Barnstable Harbor	10/21/2005
61	"Notice of Project Change full report to EOEA for construction of interim improvements to the Hyannis WPCF, effluent discharge facility as well as three sewer extensions"	11/15/2005
62	"Wastewater Facilities Planning Study, NOPC Document, Town of Barnstable Volume 1 of 4"	11/15/2005
63	"Wastewater Facilities Planning Study, NOPC Document, Town of Barnstable Volume 2 of 4"	11/15/2005
64	"Wastewater Facilities Planning Study, NOPC Document, Town of Barnstable Volume 3 of 4"	11/15/2005
65	"Wastewater Facilities Planning Study, NOPC Document, Town of Barnstable Volume 4 of 4"	11/15/2005
66	"Letter to Stephen Prichard EOEA from Mark Ells, Barnstable DPW re: NOPC Barnstable Fire District Water Issues"	12/9/2005
67	"Draft Report on Infiltration Loading Tests to McManus Site Town of Barnstable, MA"	7/5/2006
68	"Draft Wastewater Facilities Plan And Draft Environmental Impact report and Notice of Project Change, Town of Barnstable Volume 1 of 4"	9/6/2006
69	"Draft Wastewater Facilities Plan And Draft Environmental Impact report and Notice of Project Change, Town of Barnstable Volume 2 of 4"	9/6/2006
70	"Draft Wastewater Facilities Plan And Draft Environmental Impact report and Notice of Project Change, Town of Barnstable Volume 3 of 4"	9/6/2006
71	"Draft Wastewater Facilities Plan And Draft Environmental Impact report and Notice of Project Change, Town of Barnstable Volume 4 of 4"	9/6/2006
72	"Letter to Stephen Prichard EOEA from Mark Ells, Barnstable DPW re: submitting DEIR and NPC"	10/16/2006
73	"Final Wastewater Facilities Plan and Final Environmental Impact Report Town of Barnstable, Volume 1 of 4"	3/7/2007
74	"Final Wastewater Facilities Plan and Final Environmental Impact Report Town of Barnstable, Volume 2 of 4"	3/7/2007
75	"Final Wastewater Facilities Plan and Final Environmental Impact Report Town of Barnstable, Volume 3 of 4"	3/7/2007
76	"Final Wastewater Facilities Plan and Final Environmental Impact Report Town of Barnstable, Volume 4 of 4"	3/7/2007
77	Plan of Study for Nutrient Management Program	11/1/2007

Chrono Logical #	**From State, Local and Public** Title	Date
1	"Letter from Cotuit Fire District, John Anderson to Trudy Coxes re Town of Barnstable Notice of Project Change EIR"	4/5/1996
2	"EOEA #6553 Notice of Project Change for Town of Barnstable Wastewater Facilities Plan, Barnstable"	4/11/1996
3	"Letter to Trudy Cox from Glenn Hass, MADEP, RE Barnstable Notice of Project Change Wastewater Mgmt Plan"	4/16/1996
4	MEPA Certificate on Notice of Project Change Wastewater Facilities Plan Area 5 Sewer Project	4/24/1996
5	"Letter to Mark Ells from Glenn Hass MADEP, re: Barnstable Wastewater Management Plan Site Screening- Phase III"	5/24/1996
6	Reclaimed Water Use The Massachusetts Approach	8/1/1996
7	MEPA Certificate on Notice of Project Change Wastewater Facilities Plan Area 5 Sewer Project	10/23/1997
8	MEPA Certificate on Notice of Project Change Wastewater Facilities Plan Area 5 Sewer Project	5/10/2002
9	MEPA Certificate on Notice of Project Change Wastewater Facilities Plan Area 5 Sewer Project	6/23/2003
10	MEPA Certificate on Notice of Project Change Wastewater Facilities Plan Area 5 Sewer Project	5/25/2005
11	Memo to Tom Cambareri from Brian Howes SMAST Technical Director MEP re Barnstable Wastewater Effluent Discharge McManus Site and Barnstable Marshes	11/11/2005
12	"CZM Memo to Robert Golledge from Susan Snow Cotter, Director CZM re EOEA #6554 Wastewater Facilities Plan Draft Environmental Impact Report and Notice of Project Change."	11/20/2006
13	"Letter to Secretary Golledge, from Johnathan Hobill MADEP re Barnstable NPC/DEIR Review"	12/1/2006
14	"Letter to MEPA Office from Robert Lawton, Town of Yarmouth re Draft Wastewater Facilities Plan"	12/16/2006
15	MEPA Certificate on Draft Wastewater Facilities Plan Area 5 Sewer Project	12/22/06
16	MEPA Certificate on Final Wastewater Facilities Plan Area 5 Sewer Project	5/18/07
17	Letter Keith Davidson	4/15/96
16	Letter V. Gale Klun	4/30/07

Chronological #	**From the Cape Cod Commission** Title	Date
1	"Town of Barnstable, Notice of Project Change Wastewater Facilities Plan-Environmental Impact Report Area 5 Sewer Project, EOEA #6553, CCC #EIR96005"	3/25/1996
2	Staff Report Town of Barnstable Wastewater Facilities Plan EOEA #6553	4/4/1996
3	"Letter Re: ""Re-evaluation of potential discharge sites for the Hyannis pollution and control facility"""	5/21/1996
4	Letter to Barnstable DPW Town of Barnstable Wastewater Facilities Plan Notice of Project Change	6/24/1996
5	Letter to EOEA re Barnstable Wastewater Facilities Plan CCC DRI Review #EIR96005 EOEA #6553	10/14/1997
6	"Development of Regional Impact Cape Cod Commission Act, Sections 12 and 13"	4/10/2003
7	"Fax Re: ""Conditions letter on Town of Barnstable NOPC"""	6/12/2003
8	"Town of Barnstable, Notice of Project Change Area 5 Sewers/Wastewater Facilities Plan/EIR EOEA #6553"	6/12/2003
9	Cape Cod Commission Comments on Barnstable CWMP DEIR	6/12/2003
10	"Town of Barnstable, Draft Wastewater Facilities Plan, Draft Environmental Impact Report, and Notice of Project Change (EOEA #6553)"	6/12/2003
11	"letter to EOEA Town of Barnstable Notice of Project Change, Area 5 Sewers/ Wastewater Facilities Plan/EIR"	6/12/2003
12	MEPA Meeting	10/5/2005
13	Subcommittee Meeting Handout notes	11/17/2005
14	Subcommittee notes	11/17/2005
15	Letter to EOEA Notice of Project Change, Area 5 Sewers/WWFP/EIR	12/12/2005
16	Staff Report	11/14/06
17	Hearing Notice and Minutes	11/14/06
18	Meeting Notice and Comment Letter on Draft EIR	11/21/06
19	Hearing Notice and Minutes	5/2/07
20	Comment Letter on Final EIR	5/3/07
21	Hearing Notice	6/28/07
22		
23	Draft Staff Report on Groundwater Monitoring Modifications and Implementation of an Adaptive Management Plan for the Effluent Recharge at the Hyannis WPCF Site	7/20/2007
24	Staff Report re Town of Barnstable Final Wastewater Facilities Plan, DRI	7/20/2007
25	Hearing Notice and Minutes	7/25/07
26	"Staff Report re: Town of Barnstable final Wastewater Facilities Plan, DRI"	7/25/2007

Chrono Logic #	Technical Information Title	Date
1	Hydrogeology And Hydrochemistry of a Sewage Effluent Plume in the Barnstable Outwash of the Cape Cod Aquifer, Master Thesis by Tom Cambareri	11/12/86
2	Cape Cod Comprehensive Regional Wastewater Management Strategy Development Project	6/1/2003
3	Meeting Minutes of USGS Groundwater Model Project with Cape Cod Commission	4/27/04
4	Enhancing Wastewater management on Cape Cod: Planning and Legal Tools	7/1/2004
5	Barnstable model Request	10/13/04
6	Barnstable Request for USGS Groundwater model runs S&W to Tom Cambareri	11/13/04
7	Effluent Disposal and reuse planning guidance document and Case Study Report, Stearns and Wheler	1/1/2005
14	Barnstable model Request	10/12/05
15	Figure showing flux to receptors at various loading rates BarnsSite B_flux.pdf	11/04/05
16	Figure showing particle cross section from Site B: BarnSiteBxs_fig.pdf	11/05/05
17	Barnstable Request for USGS Groundwater model runs S&W to Tom Cambareri	11/12/05
8	Barnstable Model Results: Barnstable Scenario: A	04/21/06
9	Barnstable Model Results: Barnstable Scenario: B and C	04/21/06
10	Barnstable Model Results: Barnstable Scenario: E and F	04/21/06
	Barnstable Model Results: Barnstable Scenario: D	05/27/06
11	Barnstable Model Results: Barnstable Scenario: G	05/27/06
12	Barnstable Model Results: Barnstable Scenario: F	05/27/06
13	Barnstable Model Results: Barnstable Scenario: H and I	06/23/06
18	Barnstable Model Results: Barnstable Scenario: new_5_27_ScenG	06/23/06
19	Barnstable Model Results 4.2 + 3.7 MGD	12/11/06
20	Spreadsheet of Water Quality Data from Monitoring Wells around the Water Pollution Control Facility 1990 to 2007	8/1/2007
21	Spreadsheet of Water Table Elevations from monitoring wells around the WPCF 1990 to 2007	8/1/2007

TO	FROM	EMAIL SUBJECT	DATE
Brian Dudley	Mark Giordano	Barnstable Facilities Plan	3/21/2003
Mark Ells & others	Mark Giordano	Public Notice Wastewater Facilities Planning	5/28/2003
Tom Cambareri	Mark Giordano	USGS modeling of Eastern Barnstable	6/17/2003
Tom Cambareri	Gage Muckleroy	Town of Barnstable - Draft for Nutrient Mgmt	8/11/2003
Tom Cambareri	Gage Muckleroy	Town of Barnstable - Draft for Nutrient Mgmt	8/11/2003
Tom Cambareri	Gage Muckleroy	Town of Barnstable - Draft for Nutrient Mgmt	8/12/2003
Tom Cambareri	Don Walter	Town of Barnstable Wastewater AOCs	3/18/2004
Tom Cambareri	Don Walter	Barnstable	4/19/2004
Mark Giordano	Tom Cambareri	Discharge Scenarios	5/19/2004
B Dupont	Don Walter	Barnstable runs	5/27/2004
Nate Weeks & others	Tom Cambareri	Barnstable WPCF	9/21/2005
Nate Weeks	Tom Cambareri	Additional Barnstable USGS Modeling	10/6/2005
Nate Weeks	Tom Cambareri	Additional Barnstable USGS Modeling	10/6/2005
Nate Weeks & others	Ron Lyberger	Town of Barnstable, Notice of Project Change Outline	10/17/2005
Tom Cambareri	Don Walter	USGS modeling and CCC issues related to effluent recharge	10/17/2005
Tom Cambareri	Don Walter	Results for Barnstable	10/19/2005
Nate Weeks & others	Tom Cambareri	Barnstable with attachment for REAL	10/21/2005
Nate Weeks & others	Tom Cambareri	Barnstable with attachment for REAL	10/21/2005
Nate Weeks & others	Tom Cambareri	Barnstable	10/21/2005
Ed Eichner & others	Scott Michaud	Effluent News - The Barnstable Patriot	10/24/2005
Nate Weeks	Tom Cambareri	USGS modeling and CCC issues related to effluent recharge	10/25/2005
Brian Howes	Ed Eichner	Barns Hbr N Loading	10/26/2005
Wu Xiaotong	Tom Cambareri	Barnstable	10/27/2005
Brian Howes	Ed Eichner	Barnstable Marshes	10/31/2005
Tom Cambareri	Don Walter	Additional Barnstable results	11/3/2005
Nate Weeks	Tom Cambareri	Barnstable	11/4/2005
Nate Weeks	Tom Cambareri	Barnstable	11/4/2005
Nicholas Zavalas	Nate Weeks	Town of Barnstable, Notice of Project Change Outline	11/9/2005
Mark Giordano	Nate Weeks	Barnstable maps	11/9/2005
Tom Cambareri	Mark Giordano	Effluent Mitigation Mtg 11/10 @ 4pm Town Hall	11/10/2005
Tom Cambareri	Mark Giordano	Effluent Mitigation Mtg 11/10 @ 4pm Town Hall	11/10/2005
Mark Giordano	Tom Cambareri	Effluent Mitigation Mtg 11/10 @ 4pm Town Hall	11/10/2005
Nate Weeks & others	Tom Cambareri	Effluent Mitigation Mtg 11/10 @ 4pm Town Hall	11/10/2005
Tom Cambareri	Mark Ells	Town comments of CCC staff report	11/17/2005
Brian Dudley	Nate Weeks	Barnstable Notice of Project Change & Water Supply Issues	11/18/2005
Nicholas Zavalas	Tom Cambareri	Barnstable NOPC	1/20/2006
Nate Weeks	Tom Cambareri	Barnstable	2/17/2006
Mark Ells & others	Tom Cambareri	Barnstable Groundwater Modeling	3/6/2006
Nate Weeks & others	Tom Cambareri	Mtg w/ Barnstable to review permitting issues for relocating GW	4/6/2006

Rona Lyberger	Mark Ells	Mtg w/ Barnstable to review permitting issues for relocating GW	4/6/2006
Nate Weeks & others	Rona Lyberger	Mtg w/ Barnstable to review permitting issues for relocating GW	4/6/2006
Nate Weeks & others	Brian Dudley	Mtg w/ Barnstable to review permitting issues for relocating GW	4/6/2006
Mark Ells & others	Tom Cambareri	Barnstable CWMP	8/16/2006
Greg Smith & others	Tom Cambareri	Barnstable Draft WWFP & EIR Mtg - 9/13	8/28/2006
Mark Ells & others	Tom Cambareri	Barnstable Facilities Meeting	9/8/2006
Greg Smith	Tom Cambareri	Barnstable Facilities MEPE Mtg in Boston	9/11/2006
Robert Butterw	Tom Cambareri	Barnstable Draft WWFP & EIR Mtg - 9/13	9/11/2006
Rona Lyberger	Brian Dudley	Barnstable Draft WWFP & EIR Mtg - 9/13	9/11/2006
Robert Butterw	Rona Lyberger	Barnstable Draft WWFP & EIR Mtg - 9/13	9/11/2006
Nate Weeks	Robert Butterw	Barnstable Draft WWFP & EIR Mtg - 9/13	9/11/2006
Robert Butterw	Robert Butterw	Barnstable Draft WWFP & EIR Mtg - 9/13	9/12/2006
Mark Ells & others	Robert Butterw	Barnstable Draft WWFP & EIR Mtg - 9/20	9/15/2006
Mark Ells & others	Robert Butterw	Barnstable Draft WWFP & EIR Mtg - 9/20	9/18/2006
Mark Ells & others	Robert Butterw	Barnstable Draft WWFP & EIR Mtg - 9/20	9/18/2006
Bill Hall	Robert Butterw	Barnstable Draft WWFP & EIR Mtg - 9/20	9/20/2006
Robert Butterw	Bill Hall	Barnstable Draft WWFP & EIR Mtg - 9/20	9/20/2006
Tom Cambareri	Mark Ells	Wastewater Plan	11/8/2006
Tom Cambareri	Mark Ells	Barnstable CWMP Mtg	11/27/2006
Mark Ells	Tom Cambareri	Barnstable CWMP Mtg	11/27/2006
Nate Weeks	Tom Cambareri	Looking for the lost Barnstable USGS model run	11/28/2006
Tom Cambareri	Mark Ells	Barnstable CWMP Mtg	11/29/2006
Mark Ells	Tom Cambareri	Barnstable CWMP Mtg	11/29/2006
Stephanie Osta	Tom Cambareri	Mark Ells	11/29/2006
Mark Ells & others	Tom Cambareri	Barnstable CWMP DEIR	12/1/2006
Tom Cambareri	Nate Weeks	Barnstable CWMP DEIR Mon. 11/11, 10-11 am	12/1/2006
Nate Weeks	Tom Cambareri	Barnstable CWMP DEIR Mon. 11/11, 10-11 am	12/1/2006
Tom Cambareri	Nate Weeks	Barnstable CWMP DEIR Mon. 11/11, 10-11 am	12/1/2006
Nate Weeks	Tom Cambareri	Barnstable CWMP DEIR	12/1/2006
Mark Ells & others	Tom Cambareri	Barnstable CWMP DEIR	12/1/2006
Mark Ells & others	Tom Cambareri	Barnstable CWMP DEIR	12/1/2006
Mark Ells & others	Tom Cambareri	Barnstable CWMP DEIR	12/4/2006
Mark Ells & others	Tom Cambareri	Barnstable CWMP DEIR	12/4/2006
Mark Ells & others	Tom Cambareri	Barnstable CWMP DEIR	12/4/2006
Nate Weeks & others	Tom Cambareri	Barnstable USGS model output	12/7/2006
Mark Ells & others	Tom Cambareri	Need for GIS plan - Coastal Resource Area include subembayments	12/10/2006
William Doherty	Tom Cambareri	Barnstable DEIR Letter	12/11/2006
Mark Ells & others	Tom Cambareri	Pdf 4.2 and 3.7 scenario	12/11/2006
Mark Ells & others	Tom Cambareri	Barnstable CWMP DEIR	12/11/2006
Nicholas Zavalas	Tom Cambareri	Barnstable CWMP DEIR	12/12/2006
Tom Cambareri	Mark Ells	Pdf 4.2 and 3.7 scenario	12/12/2006
Mark Ells & others	Tom Cambareri	Barnstable WWFP FEIR Comments	4/30/2007

Nate Weeks & others	Tom Cambareri	Barnstable WWFP FEIR Comments	5/1/2007
Tom Cambareri	Mark Ells	Barnstable WWFP FEIR Approval	5/2/2007
Mark Ells & others	Tom Cambareri	Barnstable WWFP FEIR Approval	5/2/2007
Tom Cambareri	Nate Weeks	Mtg w/ Mark Ells on Wed. June 6, 9:30am - Barnstable WWFP	5/24/2007
Nate Weeks & others	Tom Cambareri	Barnstable WWFP FEIR Approval	5/24/2007
Mastroianni, A.	Tom Cambareri	WPCF Monitoring Well Data	6/6/2007
Nate Weeks & others	Tom Cambareri	Hyannis WPCF data 2	6/6/2007
Nate Weeks & others	Tom Cambareri	Nutrient Management Plan	6/20/2007
Nate Weeks & others	Tom Cambareri	Thursday Mtg, July 18th, 1:30 pm	7/17/2007
Mark Ells & others	Tom Cambareri	Draft Staff Report	7/19/2007
William Doherty	Tom Cambareri	Barnstable WWFP DRI final plan/DRI Staff Report	7/20/2007
Mark Ells & others	Tom Cambareri	Any Comments on Draft	7/20/2007
Tom Cambareri et al	Andrea Adams	Materials	8/02/2007
Andrea Adams	Tom Cambareri	Barnstable WWFP	8/13/2007
Nate Weeks & others	Tom Cambareri	Barnstable WWFP DRI	8/13/2007
Mark Ells & others	Tom Cambareri	WWFP Meeting Dates	8/14/2007
Mark Ells & others	Tom Cambareri	Barnstable WWFP DRI	8/22/2007
Mark Ells & others	Tom Cambareri	Maps and table for AMP	8/24/2007
Mark Ells & others	Tom Cambareri	WWFP DRI Draft Decision	8/24/2007
Tom Cambareri	Nate Weeks	WWFP DRI Draft Decision	8/27/2007
Mark Ells & others	Tom Cambareri	Barnstable WWFP DRI	8/27/2007
Mark Ells & others	Tom Cambareri	WWFP DRI Draft Decision	8/27/2007
Mark Ells & others	Tom Cambareri	Barnstable WWFP DRI	8/28/2007

TESTIMONY

Public Hearing Minutes from April 10, 1996

Mr. David Shepardson of the Massachusetts Environmental Policy Act (MEPA) Unit presented introductory remarks and explained the history of the project.

Mr. Tom Mullen, Barnstable's Department of Public Works Director, asked about the process.

Mr. Richard Prince explained the Cape Cod Commission/MEPA process.

Ms. Gay Wells presented the Cape Cod Commission staff report.

Mr. Mark Ells made a presentation on Barnstable's Wastewater Facilities Plan. He also explained the public participation program and various studies connected to the Wastewater Facilities Plan.

Mr. Ron Lyberger, from the Department of Environmental Protection BMF, stated that his department is in general concurrence with the town about major issues.

Mr. Bob Schernig, Barnstable's Planning Director, stated that there had been substantial coordination between the development of the Local Comprehensive Plan and the Wastewater Facilities Plan.

Public Hearing Minutes for November 14, 2006

Mr. Mark Ells presented the project for the Town of Barnstable. Mr. Ed Eichner, a Cape Cod Commission Water Resources Scientist, presented the staff report. Ms. Elizabeth Taylor requested Mark's response to the staff recommendations. Mr. Ells responded they had only received the report the day before so they had a limited response at this time. He noted that many of the issues that were brought up they wish to resolve. He stated that in regards to the nutrient loading issue, there would be a net reduction because of the facility's ability to treat at a higher level than the on site systems. He stated that they would like to move forward without using the McManus site, however, they would like to know the scenarios. In relation to the Growth Incentive Zone, they will show in their plan how they can accommodate growth. In regard to the cost issues, they identified the costs to the best of their ability. Currently, they recover one hundred percent of their costs through a system where customers pay for the service. He noted that they may not have all the issues resolved in their plan, however, he hopes that this will not interfere with their approval.

Ms. Taylor inquired about the McManus and the community college sites and potential mounding and change in groundwater direction. Mr. Ells responded that what they saw in the USGS modeling was showed that smaller amounts in more sites helps to minimize the impact. However, it is more cost effective to use only one site. The only sites under consideration are the Hyannis Water Pollution Facility and the McManus site. If there is a need, they will look further into other sites, including the community college and possibly some bogs. Ms. Taylor inquired about the work on the bogs. Mr. Ells stated that this is in the preliminary thought stage and not included in this plan.

Mr. Richardson stated that he is grateful for all the work that has gone into this project. He is hoping that the town is comfortable with the Commission issues and hopes that two staffs can work well together. Mr. Ells and Mr. Eichner stated that they could.

Mr. Richard Andres inquired about why the map indicated that there were two North Bay Box 4s. Mr. Ells stated that this is the recharge area to the Three Bays area that extends into Mashpee and Sandwich. Mr. Eichner noted that the Commission funded a box model of the estuary. There are two box 4s because the watershed for North Bay is split.

Public Hearing Minutes for May 2, 2007

Mr. Mark Ells presented the Barnstable Wastewater Facilities Plan that is the subject of the Final Environmental Impact Report (FEIR). Mr. Thomas Cambareri, Water Resources Program Manager of the Cape Cod Commission presented the Commission staff report and reviewed each section of the proposed comment letter with the Subcommittee.

Mr. Paul Can, a resident of the Lake Wequaquet area, spoke in favor of the sewer extension to his neighborhood.

Mr. Jay Zavala inquired about mentioning in the Commission letter that there is uncertainty regarding including the Centerville study area in the appendix of the report. Mr. Cambareri stated that he is still unclear why this is in the report. Mr. Ells stated that they were requested to place it there.

Mr. Doherty emphasized that the Lorusso site and the airport site are not considered as back up sites. Mr. Cambareri noted the back up site is a 6.9 acre parcel of land that is adjacent to the golf course and the McManus site. He also noted that the Cape Cod Community College will be connected to the sewer.

Mr. Zavala inquired the concept of purchasing properties. Mr. Ells explained that it may be more cost effective to purchase low lying properties.

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Mr. Cambareri summarized the Cape Cod Commission staff report.
Mr. Ells introduced Mr. Weeks, from Stearns & Wheeler, and Ms. Saad, as a consultant and Barnstable Department of Public Works staff who were working on the project. Mr. Ells described the proposed Facilities Plan.
Mr. Zavala asked if the Nutrient Management Plan (Plan) had been revised in its entirety?
Mr. Cambareri said no. He said the Plan had undergone technical modifications to incorporate work that has been accomplished since 2001. Mr. Zavala said the Subcommittee should be provided with a version of the Nutrient Management Plan that showed where it had been changed. Mr. Cambareri said the tasks of the the Plan had remained the same since the 2001 version.

Mr. Harris asked how the Town evaluated wastewater treatment facility capacity versus Town population? Mr. Ells said the Town had looked at existing failed on-site septic systems when evaluating the capacity needs. He said this had been done using Town Geographic Information Systems (GIS) capability. Mr. Ells described his points using a color-coded GIS map, and noted the Town had looked at existing and projected flows in certain areas, including a build-out analysis. He said existing and projected flows in areas of concern were used, but also noted the Town was going to begin a larger effort once additional capacity studies are completed.

Mr. Harris asked if the Town had taken into account what to do if flow loading occurs more rapidly than the 20-year projections? Mr. Ells noted facility planning had begun in 1994, and the Town had used historical data and growth trends, including growth/development spikes and lulls to make capacity and flow projections. He noted the actual numbers seen in recent years were tracking the estimated projections made in the early years of facility planning. Mr. Ells said that based on this, the Town had increased confidence in the capacity numbers. At the same time, Mr. Ells said the Town was aware of the need to re-evaluate and adjust the capacity figures and the entire Facilities Plan, and the potential need for a new review. He noted the Facilities Plan discussed areas of planned sewer expansion. He said that expansion of sewers beyond these identified areas would need a new review by the Massachusetts Environmental Policy Act unit and the Cape Cod Commission.

Mr. Richardson said he felt the information provided was complete, in particular in that it recognized and anticipated the need for periodic re-evaluation. He asked how membership on the Technical Advisory Committee determined? Mr. Ells said the Technical Advisory Committee is typically made up of Barnstable Town and Commission staff. At the same time, he noted the process was a public one, and the documents were available to members of the public. As such, Mr. Ells said the meetings of the Technical Advisory Committee were public, and anyone could attend if they wished. Mr. Zavala noted that page 4 of the Certificate from Secretary of Environmental Affairs listed the Technical Advisory Committee members.

Mr. Doherty asked if the project might need an extension of the Commission's review timeframes in order to complete required documents that were currently in draft form? Mr. Cambareri said the draft Nutrient Management Plan and other documents would need to be updated, but he felt this could be accomplished within the Commission's timeframes, and no extension was needed.

Mr. Owen Carney asked when the Barnstable Harbor nutrient management study would be completed? Mr. Cambareri said it was part of the Massachusetts Estuaries Project (MEP). He said information from the study Mr. Carney was referring to would probably be part of the next group of studies released by the MEP. Mr. Ells said the Town of Barnstable was pushing the MEP to get the Harbor nutrient management study done in the next group of reports. He suggested additional request by members of the public to the DEP would also help.

Mr. Oliver Cipollini expressed concern over nutrient management, but noted that there were many constituents in addition to nitrogen that could be deemed "nutrients." As such, he said the Wastewater Facilities Plan should clearly define what it deemed to be nutrients. He asked whether the document took into account varied soil types, and full build-out, including growth in the number of condominiums? Mr. Cipollini asked how the effluent would be monitored? Mr. Doherty noted that the Faculties Plan had a monitoring protocol. He also noted Mr. Ells' comments regarding the build-out analysis, including facility capacity, flow and population.

Mr. Zavala noted that management systems typically would be in place for such a long-term effort regardless of personnel changes over that period. Mr. Richardson suggested the primary nutrients of concern related to nitrogen. Mr. Doherty concurred with Mr. Richardson, noting the key nutrient in groundwater was nitrogen.

Mr. Cambareri said the primary groundwater quality constituents or nutrients of concern were nitrogen and phosphorous. He said Barnstable County was working to implement a system to raise money and help towns work together to find solutions, but it was not intended to be a system of centralized, Cape-wide sewer infrastructure. In response to Mr. Cipollini's question about soil types, he said the studies were typically conservative, and picked worst-case soil types for nutrient management planning. He said the Facilities Plan also took account of specific soil types where appropriate.

Mr. Cipollini asked if the Town's plan would ties into the County's efforts? Mr. Doherty said yes. He also reiterated, however, that the County's efforts were not based on creation of a centralized sewer system. He also recognized that there could be many constituents deemed to be "nutrients," but noted that nitrogen and phosphorous were the two key ones in this case.

Mr. Andres asked for an explanation of the colored GIS map. Mr. Ells explained the map. He said the areas shown in orange were areas the Town intended to prioritize for sewering. He said this was based on areas that had high rates of failed on-site septic systems. He noted various data sources the Town had used to create the map. Mr. Ells said the Town came to the realization that based on the MEPA timeframe, utilization of the existing Barnstable Wastewater Treatment Plant was the best option, and that sewer should be extended to areas near in to that Plant.

Mr. Andres asked if Cape Cod Community College (College) had a public or private water supply? Mr. Ells said the College had public water flows that initially triggered the need for a Groundwater Discharge Permit. He said the Town had decided to provide sewer capacity to the College, and included it in the Facilities Plan because it had peak flows (Fall) when the Wastewater Treatment Plant was experiencing off-peak demand.

Mr. Andres expressed concern for possible failure of the wastewater transport pipes. Mr. Ells said the force mains will be constructed in a way that takes failures into account – with a redundant design. He noted the College currently has a large on-site wastewater discharge, which will be eliminated when the flow is treated at the Wastewater Treatment Plant.

Mr. Andres asked which local water district provided water to the College? Mr. Ells said he could check Town records and provide Mr. Andres with the information.

JURISDICTION

This project comes under the jurisdiction of the Cape Cod Commission pursuant to Section 2(d)(i) of the Cape Cod Commission Enabling Regulations Governing Review of Developments of Regional Impact, which requires projects subject to regulation under MEPA to undergo DRI Review.

FINDINGS

The Commission has considered the application of the Town of Barnstable for the proposed Wastewater Facility Plan. Based upon the consideration of the application and on the information presented in the public hearings and submitted for the record, the Commission makes the following findings pursuant to Sections 12 and 13 of the Act.

General

G1. The project is the Wastewater Facilities Plan for the town of Barnstable, as described in the Final Wastewater Facilities Plan / Final Environmental Impact Report of March 2007.

G2. The proposed project is consistent with Barnstable's zoning bylaws, as it is an existing wastewater treatment facility. The project is also consistent with the town's local comprehensive plan, provides wastewater infrastructure to the Hyannis Growth Incentive Zone for years 0-5 of the planned 20-year implementation of the GIZ and is not located in a District of Critical Planning Concern.

G3. The proposed project is consistent with Massachusetts State Revolving Loan regulations to provide infrastructure to existing development and provide wastewater capacity for denser development in Growth Centers. The FEIR also acknowledges that the town will adopt growth-neutral land use policies for controlling development and redevelopment in existing residential areas that will be provided new sewer services.

G4. As described in the Final EIR, the benefits of the Wastewater Facilities Plan include: protection of public health; improvement of the water quality to in the aquifer beneath the Water Pollution Control Facility and to nearby downgradient water supply wells; and an upgrade of the treatment plant's operating capacity and treatment efficiency to provide infrastructure for planned growth and infilling. The detriments are limited to construction activities and the long time frame it requires to implement the plan.

G5. This project was reviewed for consistency with the 2002 (revised) Regional Policy Plan.

Water Resources

WR1. The project affects the following water resources areas of the Town of Barnstable as defined by the Regional Policy Plan:

- Wellhead Protection Area (MPS 2.1.1.2A)
- Potential Public Water Supply Area (2.1.1.2.F)
- Fresh Water Recharge Area (2.1.1.2.B)
- Marine Water Recharge Area (2.1.1.2 C)
- Water Quality Improvement Area (2.1.1.2.E)

WR2. Applicable water resources minimum performance standards are:

MPS 2.1.1.2.C.2.: requires that development in estuary watersheds where critical nitrogen loads are exceeded or where there are documented water quality problems in the estuary to maintain or improve existing nitrogen loading.

MPS 2.1.1.2.E.2.: allows the use of public sewage treatment facilities within Wellhead Protection Areas to remediate existing problems. Requires treatment facilities to maintain hydrologic balance in the aquifer and demonstrate that there are no negative ecological impacts to surface waters.

MPS 2.1.2.2: requires all sewage treatment facilities to be designed to achieve tertiary treatment with denitrification and meet a maximum 5-ppm total nitrogen discharge standard in the effluent or at the downgradient property line.

WR3. The location of the Water Pollution Control Facility (WPCF) was initially selected in 1935. The Facility discharges treated effluent into the Sagamore Lens of the Cape Cod Aquifer and within the Wellhead Protection Areas, referred to under state wellhead protection regulations as Zone IIs, as well as estuary watersheds to Lewis Bay, Stewarts Creek, and Halls Creek, known under the Regional Policy Plan as Marine Water Recharge Areas.

WR4. Since the initial construction of the Facility, it has undergone a significant number of improvements and expansions. Through the improvements undertaken during the course of the development of the Final Plan, nitrogen removal has been incorporated into the treatment at the Facility. As a result of these improvements, effluent total nitrogen concentrations over the last three years (April 2004 to April 2007) averaged 4.95 ppm, while effluent nitrate-nitrogen concentrations averaged 2.48 ppm. Because the average effluent total nitrogen concentration is just under 5 ppm, MPS 2.1.2.2. is met by the current treatment processes at the Hyannis WPCF.

WR5. The Regional Policy Plan (MPS 2.1.1.2.E.2) allows and encourages the use of advanced wastewater treatment to remediate water quality impaired areas, provided the hydrologic balance of the aquifer is maintained and there are no negative impacts to surface waters. The Hyannis WPCF provides better wastewater treatment than occurs within standard Title 5 septic systems, so the better treatment at the WPCF has to be balanced with the accompanying movement of water and nutrients to discharge at the WPCF, potential impacts on resources around the WPCF,

and potential impacts/benefits at resources that have had septic loads and water volumes removed by connection to the sewer system. The Town proposes to address these Sewer Resource Benefit Assessments for each Areas of Concern through the Adaptive Management Plan and Nutrient Management Program.

WR6. The Facility Plan identifies 10 Areas of Concern for sewer connections to the Hyannis WPCF. These areas will address public health issues with failing septic systems near surface water bodies and reduce nitrogen loading in Wellhead Protection Areas. The proposed 4.2 MGD of flow at the WPCF addresses these areas, as well as providing wastewater capacity for future growth in the Hyannis area, including the Growth Incentive Zone. As identified in the Facilities Plan, the Town intends to address these areas through the phased implementation of the Nutrient Management Plan.

WR7. The allocation of existing and proposed future wastewater flow rates to the WPCF are shown in the table below (Table 10-1 from the FEIR):

FLOW SOURCES	**PROJECT MAXIMUM MONTH FLOWS (MGD) AT DESIGN YEAR 2014**
Current and Future Flows	
Existing flows at WPCF at 1993	2.1
Infilling along existing sewers (developed and undeveloped)	0.30
Bearses Way sewer extension	0.03
Route 28 and Corporation Street sewer extension	0.01
Independence Park	0.40
AOCs in H1, H3, CE1-3	0.47
AOCs in ZOCs	0.07
Infilling along proposed AOC sewers	0.05
Bearses Way AOC (50% of area)	0.20
Cape Cod Community College	0.03
Potential Expansion and Additional Infilling	
Growth along existing sewer lines not currently sewered	0.20
Gravel pit development	0.13
North of Kidd's Hill Road	0.10
TOTAL	**4.2**

WR8. MEPA approval of the 3rd Notice of Project Change allowed the town to defer the screening of management alternatives to reduce nitrogen loading to protect and restore marine water quality embayments to the completion of the Final Wastewater Facilities Plan. The assessment, screening and ultimate management scenarios will be completed under the Nutrient Management Plan. The purpose of the Nutrient Management Plan is to provide a listing of the steps needed for nutrient management planning in Barnstable. It will develop the recommended plan to mitigate the nutrient related problems in each watershed. This plan will include the scheduled implementation steps for new facilities, management structures, local regulations, and funding requirements.

WR9. The Nutrient Management Plan consist of the following phases:

Phase I Assessment of Monitoring and Nutrient Limit Targets

Prepare Water Quality Status and Monitoring Need Report

Phase II Nutrient Management Needs Assessment

Identify Nutrient Related Area of Concern and prepare a Nutrient and Wastewater Management Needs Assessment Report

Phase III Identification and Screening of Alternative Solutions

Prepare Nutrient and Wastewater Management Alternatives Screening Report

Phase VI Detailed Evaluation and Development of the Nutrient Management Plan

Submit the NMP and a DEIR for Public and Regulatory Review

Phase V Resolution of Remaining Issues and Project

Modify DEIR and submit it for regulatory and public review

Phase VI Environmental and Public Review Process

Description of public review process that starts at the beginning of the process and proceeds throughout the whole project. It includes the creation of a Citizens Advisory Committee, a Technical Advisory Committee and the implementation of a Public Participation Program including the coordination of meetings and submittal of regulatory review forms and notices.

WR10. The Town has made significant progress on the initial assessment phase of the Nutrient Management Plan. The Town is in its fourth year of participating on the Massachusetts Estuaries Project (MEP) in coordination with the staff from the School of Marine Science and Technology (SMAST) at UMASS Dartmouth, who are also the MEP project leads. The Town has coordinated an extensive group of volunteer monitors to obtain marine water quality samples from its embayments. Results from these samples will be combined with complementary water quality monitoring, watershed delineations, and sediment sampling to developed linked hydrodynamic, watershed nitrogen loading, and water quality models for all of Barnstable's estuary systems in order to produce MEP Technical Reports for each estuary. These Technical Reports will provide the Town with nitrogen thresholds or limits, which will subsequently be adopted as Total Maximum Daily Loads through a Massachusetts Department of Environmental

Protection process. TMDLs are official regulatory targets under provisions of the federal Clean Water Act.

WR11. The Town has received MEP Technical Reports for Shoestring Bay (as part of the Popponesset Bay System shared with Mashpee and Sandwich), Three Bays, Rushy Marsh, and Centerville River. The Lewis Bay report was submitted for MassDEP review in June 2007 and should be available for public review by the end of summer. MassDEP released the final TMDL for Popponesset Bay in April 2006, while the draft TMDLs for Three Bays and Centerville River were released in January 2007 and June 2007, respectively. The Rushy Marsh report was submitted to MassDEP in December 2005 and does not have a draft TMDL yet. The Barnstable Harbor report is the only remaining MEP report that the Town needs to have a comprehensive understanding of the nutrient management requirements to protect and restore coastal water quality in the Town of Barnstable.

WR12. The Regional Policy Plan (MPS 2.1.1.2.C.2) requires that development in estuary watersheds where critical nitrogen loads are exceeded or where there are documented water quality problems in the estuary to maintain or improve existing nitrogen loading. The publicly available MEP Technical Reports for Shoestring Bay, Three Bays, and Centerville River indicate that these estuary systems are impaired by excessive nitrogen. Potential solutions to address these impairments may involve the Hyannis WPCF. The balance between the potential benefits of improved nitrogen treatment at the WPCF and potential additional nitrogen loads to resources around the WPCF are included as part of the town's proposed Nutrient Management Plan.

WR13. The release of the MEP reports and the establishment of embayment-specific Total Maximum Daily Loads by MassDEP follow a formal public participation process with comment periods and public presentations on draft reports and TMDLs. Each step of the process presents the public with an opportunity to comment on the conclusions or requirements in the documents.

WR14. The Town has also partnered with Cape Cod Commission water staff to provide a comprehensive assessment of all the existing water quality data on fresh water ponds within the Town. The Commission water staff is also preparing a detailed water quality assessment on Lake Wequaquet. This assessment is similar to a previously completed study of the Indian Ponds (Hamblin, Mystic, and Middle) done by the Commission in 2006. The work on fresh water ponds is scheduled to be completed in 2007 and will be available for inclusion in the Nutrient Management Plan.

WR15. Site selection screening, groundwater modeling and nutrient analysis of Barnstable Harbor indicate that the 6.9-acre site, located adjacent to the McManus property along Route 132, is suitable to accept effluent discharge up to 0.5 million gallons per day. This rate of recharge, as shown by the current USGS groundwater model, does not result in treated effluent flow into Lake Wequaquet or the Barnstable Fire District (BFD) wells. Furthermore intended sewering of the Lake Wequaquet AOC will remove septic wastewater from the BFD supply well

Zone of Contribution. Effluent discharge exceeding 0.5 MGD at the 6.9-acre site may result in resource impairment to Lake Wequaquet and the nearby Barnstable Fire District Wells and would require further analysis and submittals to MEPA. Subsurface characterization of the 6.9-acre site only penetrated several feet into the water table.

WR16. Analysis of over 20 years of water level measurements taken from monitoring wells around the Hyannis Water Pollution Control Facility and recent observation during high groundwater level conditions of 2006 indicate that treated wastewater effluent can be discharged at the present 82.4-acre WPCF site at a higher rate than 2.7 MGD.

WR17. The MEPA certificate on the Final Plan finds that the discharge of treated effluent at the Hyannis Water Pollution Control Facility can reasonably approach 4.2 MGD contingent upon implementation of the Adaptive Management Plan. The Adaptive Management Plan describes an ongoing monitoring of water levels in the vicinity of the WPCF and identifies contingencies should unacceptable impacts of a higher discharge rate be identified. The Adaptive Management Plan contingencies include precluding further increases in discharge at the WPCF and use of off-site discharge locations such as the 6.9-acre site adjacent to the McManus property.

WR18. The baseline water level and water quality-monitoring program at the WPCF was established under a 1979 Groundwater Discharge Permit issued by the forerunner of MassDEP, the Department of Environmental Quality Engineering. Town officials have met with Commission staff to form a Technical Advisory Group and provided over 18 years of monitoring data to Commission water staff for review. Staff's compilation, review and interpretation of the monitoring data has led to a number of recommendations to expand the Adaptive Management Plan, into an Adaptive Management and Monitoring Plan (AMMP). These recommendations, which have been discussed and accepted by Town staff, should lead to an updated water level and water quality monitoring program that provides monitoring of the regional groundwater divide and provides for regular review of the data. The specific AMMP recommendations include:

1) automated water table monitoring with the use of data loggers,
2) the installation of a number of additional monitoring wells,
3) quarterly update of a master water quality spreadsheet/database,
4) monthly update of a water level data spreadsheet/database and
5) the compilation and submittal to the Commission of an annual report that also includes water quality data from public water supplies, ponds and streams.

WR19. The Adaptive Management and Monitoring Plan consists of the following components:

Introduction and Objectives
Technical Advisory Group
Initial Review and Preliminary Staff Review and Recommendations
1) Groundwater Quality

a. *Map of Monitoring Wells*
b. *Table of Monitoring Wells/Resources showing frequency*

2) *Water Levels*
   a. *Table showing Monitoring Wells for water level monitoring and frequency*
3) *Adaptive Management Action Plan*

WR20. Construction of sand-filter beds at the 6.9-acre site, located adjacent to the McManus property along Route 132, is estimated at $7.9 million. The implementation of the Adaptive Management and Monitoring Plan is designed to maximize the use of the rapid sand filter beds at the existing WPCF site, while avoiding any potential negative impacts to the resources and facilities around the WPCF. The 6.9 acre site will be used only if 4.2 MGD planned under the Final Plan cannot be discharged at the WPCF.

WR21. Groundwater modeling completed under a County-sponsored United States Geological Survey project indicates that increased recharge of treated effluent at the Hyannis Water Pollution Control Facility will enlarge the area of groundwater flow from the WPCF to effect additional receptors including the Mary Dunn Wells and Mill Creek to the east and the Craigville wells and Centerville River to the west. The Town has proposed to conduct analysis under the Nutrient Management Plan to evaluate the benefits of potential sewage collection and wastewater treatment to all resource areas potentially effected by increased WPCF discharge.

WR22. Recent research on Cape Cod and across the nation is focusing on emerging contaminants of concern in wastewater such as pharmaceuticals and personal care products. Additional information on potential presence of these compounds in the treated water effluent being discharged into the Wellhead Protection Areas is of interest to the town for present conditions and for future conditions as the increased discharge potentially impacts additional water resources.

WR23. The Massachusetts Department of Environmental Protection is in the process of revising it regulations for required disinfection of wastewater discharges within Zone II wellhead protection areas. Owing to the natural filtering conditions at the WPFC site, pathogens have not been identified as a concern to any of the downgradient public water supplies. The Commission supports the town's position that it should defer a decision to commit funds, estimated at $8.5 million, to include extra filtration and ultraviolet disinfection to address proposed MassDEP disinfection regulations.

WR24. Construction costs associated with the implementation of the Town's Wastewater Facility Plan are estimated at $203 million once the plan is fully implemented over a period of years. As described in the FEIR, the average household cost for the WWFP improvements and sewer expansion is $28,800.

CONCLUSION

Based on the findings above, the Cape Cod Commission hereby concludes the following:

- The probable benefits of the project outweigh the probable detriments as described in the Findings G4.
- The Wastewater Facilities Plan, as proposed, is consistent with the Commission's Regional Policy Plan (RPP) as described in Finding WR1 and Barnstable's Local Comprehensive Plan.
- The project is consistent with local zoning and development bylaws as described in Finding G1.
- The project is not located in a District of Critical Planning Concern.

The Commission hereby approves the application of the Town of Barnstable for the proposed Wastewater Facilities Plan as a Development of Regional Impact, provided the following conditions are met:

CONDITIONS

General

G1. This DRI decision is valid for 7 years. Local development permits may be issued pursuant hereto for a period of 7 years from the date of the written decision. The proposed project shall be constructed and implemented as described in the "Final Wastewater Facilities Plan" of March 2007.

G2. The applicant shall obtain all relevant state and local permits, as applicable, for the proposed project. The Town shall obtain a preliminary Certificate of Compliance from the Commission which states that conditions WR 1 through 7 of this decision have been met within 5 years of the of approval of the decision of the Cape Cod Commission on September 20, 2007.

G3. No development work, as the term "development" is defined in the Act, shall be undertaken until all appeal periods have elapsed or, if such an appeal has been filed, until all judicial proceedings have been completed.

G4. Failure to comply with all conditions stated herein, and with all related statutes and other regulatory measures, shall be deemed cause to revoke or modify this decision.

G5. The Nutrient Management Plan (Exhibit A) and the Adaptive Management and Monitoring Plan (Exhibit B) are attached to and incorporated into this decision by reference.

Water Resources

WR1. The town shall adopt the updated scope of the Nutrient Management Plan (Exhibit A). Any proposed changes to the Plan will be submitted Commission for review and approval.

WR2. The Nutrient Management Plan includes a proposed process for regulatory review including a joint MEPA/DRI review process starting with the submittal of an Environmental Notification Form. The town shall submit a preliminary schedule of the Plan's regulatory review to the Commission within two years of the date of this DRI decision.

WR3. As recommended and implemented through the Nutrient Management Plan, the town shall compare resource benefits with impacts of expanding sewer areas in order to provide additional definition, support, and prioritization for the sewering of each area. Adoption of the Nutrient Management Plan, completion of the required analyses, and implementation of steps to achieve hydrologic balance in the aquifer and demonstrate that there are no negative ecological impacts to surface waters will partially meet MPS 2.1.1.2.E.2. These Sewer Resource Benefit Assessments for each Areas of Concern shall be submitted for Cape Cod Commission review and approval prior to the preliminary sewer design report for each AOC.

WR4. The town shall adopt an expanded Adaptive Management and Monitoring Plan (Exhibit B) to monitor both water levels and water quality in the vicinity of the WPCF. The town shall implement recommendations for installing additional monitoring wells under the AMMP within one year of the date of this decision. Adoption of the Adaptive Management and Monitoring Plan and accompanying Nutrient Management Plan, follow through on the required analyses, and implementation of the steps to meet their intent will, when combined, fulfill MPS 2.1.1.2.E.2. Any proposed changes to the Adaptive Management and Monitoring Plan shall be submitted to the Commission for review and approval.

WR5. The town shall update the monitoring data generated from the Adaptive Management and Monitoring Program on a quarterly basis and prepare an annual Water level and Water Quality Monitoring Report. This annual report shall be submitted to the Commission for review and approval at the end of each calendar year. The Town shall schedule an annual meeting of the Technical Advisory Group within one month of the annual report submittal to the Commission to discuss the report's findings and any potential recommendations for adaptive strategies or monitoring modifications.

WR6. The Adaptive Management and Monitoring Plan includes contingencies for evaluating potential options for the review of effluent discharge sites that take advantage of enhanced natural attenuation of nutrients in surface water bodies. The Town and the Commission should work together to seek opportunities for conducting a pilot project for permitting of treated effluent discharge near appropriate surface water bodies to take advantage of natural attenuation and provide opportunities for maintaining water balance.

WR7. The current Massachusetts Department of Environmental Protection Groundwater Discharge Permit for the Water Pollution Control Facility is a 1990 draft that limits flow to 2.7 million gallons per day prior to treatment improvements and 4.2 MGD post improvements. The 2007 MEPA Certificate finds that the Town may now undertake activities that will approach a wastewater flow capacity of 4.2 MGD. The Town should submit a revised GWDP application to MassDEP within one year of the date of this decision. The Town should work to incorporate recommendations for monitoring that are described in the Adaptive Management and Monitoring Plan into the groundwater discharge permit. The revised GWDP application shall be submitted to the Commission for review and approval at the time of its submittal to MassDEP.

WR8. The Town shall submit its Groundwater Discharge Permit Application for the 6.9-acre site adjacent to the McManus property to the Commission for review and approval when it moves forward to implement use of the site.

WR9. The discharge of treated effluent at the WPCF shall not exceed 4.2 million gallons per day unless approved by the Commission. Further study under the Nutrient Management Plan and the Adaptive Management and Monitoring Program will be required to support flows higher than 4.2 MGD.

WR10. The town in implementing the Adaptive Management and Monitoring Program should conduct an assessment of Pharmaceutical and Personal Care products in the WPCF effluent and evaluate appropriate technologies to treat them if it is warranted.

WR11. The town in implementing the Adaptive Management and Monitoring Program should conduct an assessment of fate and transport of pathogens in the aquifer beneath the WPCF to address MassDEP disinfection concerns.

SUMMARY

The Cape Cod Commission hereby approves with conditions the application of the town of Barnstable for the Development of Regional Impact as outlined in this decision pursuant to Sections 12 and 13 of the Act, c 716 of the Acts of 1989, as amended for the proposed Barnstable Wastewater Facility Plan.

_____ _____

Robert Jones, Commission Chair Date

COMMONWEALTH OF MASSACHUSETTS

Barnstable, ss _____, 2007

Before me, the undersigned Notary Public, personally appeared

_____, in his capacity as Chairman of the Cape Cod Commission, whose name is signed on the preceding document, and such person acknowledged to me that he signed such document voluntarily for its stated purpose. The identity of such person was proved to me through satisfactory evidence of identification, which was personal knowledge of the undersigned.

_____

Notary Public

EXHIBIT A

OF CAPE COD COMMISSION DECISION

TOWN OF BARNSTABLE
NUTRIENT MANAGEMENT PLANNING PROJECT

PROJECT SCOPE

August 27, 2007

The purpose of the Nutrient Management Planning Project Scope is to provide a listing of the steps needed for nutrient management planning in Barnstable. The implementation of the Project will result in a recommended nutrient management plan for the Town of Barnstable that will mitigate the nutrient related problems in each watershed. This plan will include the scheduled implementation steps for new facilities, management structures, local regulations, and funding requirements. The objective of the Plan is to select the most appropriate nitrogen management plan for Barnstable based on a cost effectiveness analysis, analysis of non-monetary factors, and an environmental impact analysis. Listing these tasks allows Town departments, regional and state agencies, and public interest groups to understand the Nutrient Management Planning process, and efficiently provide input to the Project.

The Nutrient Management Plan was initially scoped as part of the Notice of Project Change in 2001 by Stearns and Wheler, Inc, the town's wastewater planning consultants. The Town has made significant progress on the assessment phase of the NMP and has budgeted funds under its State Revolving Loan to implement its subsequent Phases. The July 2007 revisions to the NMP scope under Cape Cod Commission DRI review provide an important update and incorporates the results of these cooperative efforts. Barnstable is in its 4th year of participating on the Massachusetts Estuary Project (MEP). The Town has coordinated an extensive group of volunteer monitors to obtain marine water quality samples from its embayments. Results from these samples will be combined with complementary water quality monitoring, sediment sampling, hydrodynamic and water quality modeling for all of Barnstable's estuary systems in

order to produce the MEP Technical Reports. The Town continues its work with the staff from the School of Marine Science and Technology (SMAST) at UMASS Dartmouth, who are also the MEP project leads. These Technical Reports will provide the town with nitrogen thresholds or limits, which will subsequently be adopted as TMDLs through a MassDEP process. TMDLs are official regulatory targets under provisions of the federal Clean Water Act.

The Project Scope is expected to have the following main uses:

- Budgeting and scheduling tool for nutrient management planning.
- Basis for the division of growth management planning tasks within the Town of Barnstable.
- Basis for professional agreements for the specialized consulting services needed for nutrient management planning.
- Low interest loan application for the State Revolving Fund (SRF) loan program.
- Development of an environmental review document for the Project through the joint Massachusetts Environmental Protection Act (MEPA) and Cape Cod Commission Development (CCC) review process.
- Development of public education materials throughout the Project.

PHASE I –ASSESSMENT OF MONITORING AND NUTRIENT LIMIT TARGETS.

This is the first phase of nutrient management planning, and it involves the assessment of the nutrient related health of coastal embayments and fresh water ponds. It is the phase when nutrient loading targets are identified for each embayment. These targets are a measure of the nitrogen assimilative capacity Total Maximum Daily Load (TMDL) of each embayment. It is the phase when the water quality of the fresh water ponds is measured and the need for phosphorus remediation in the ponds, and their watersheds, is determined. The main tasks are listed below and significant progress has been made on them.

To date, the Town has received MEP Technical reports for Shoestring Bay (as part of the Popponesset Bay System shared with Mashpee and Sandwich), Three Bays, Rushy Marsh, and Centerville River. The Lewis Bay report was submitted for MassDEP review in June 2007 and should be available for public review by the end of summer. The Rushy Marsh report was submitted to MassDEP in December 2005 and does not have a draft TMDL yet. The final TMDL for Popponesset Bay was released by MassDEP in April 2006, while the draft TMDLs for Three Bays and Centerville River were released in January 2007 and June 2007, respectively. The Barnstable Harbor report is the only remaining MEP report that the town needs to have a comprehensive understanding of the nutrient management requirements to protect and restore coast water quality in the town of Barnstable.

The release of the MEP reports and the establishment of embayment-specific Total Maximum Daily Loads by MassDEP follows a formal public participation process. Each step of the process presents the public with an opportunity to comment on the conclusions or requirements in the documents.

The Town has also partnered with Cape Cod Commission staff to provide a comprehensive assessment of all the existing data on fresh water ponds within the town. The Commission water staff are also preparing a detailed water quality assessment on Lake Wequaquet. This assessment is similar to a previously completed study of the Indian Ponds (Hamblin, Mystic, and Middle) done by the Commission in 2006. The work on fresh water ponds is scheduled to be completed in 2007.

A. Review Current and Past Monitoring of surface waters to assess future monitoring needs.

Estuary water quality monitoring has been conducted in order to provide adequate data for the preparation of the nitrogen thresholds in the MEP Technical Reports. TMDLs include a requirement for on-going water quality, eelgrass, and benthic habitat monitoring in order to ensure compliance with the nitrogen thresholds and protection of the resources. Definitive

guidance on what constitutes appropriate TMDL-compliance monitoring is being developed through discussions among MEP staff, towns, MassDEP, and SMAST.

Freshwater pond water quality monitoring has also been completed on a pond-specific, but limited, basis. With 184 ponds in town (CC Pond and Lake Atlas, 2003), this is a much larger effort and only selected ponds have been adequately sampled. The town has participated in a number of the SMAST/Cape Cod Commission PALS Snapshots, but data is limited to approximately 30 ponds. The Town Conservation Commission-funded review of pond water quality data that will be completed by the CCC in 2007 will evaluate the available data and provide suggestions for future monitoring and based upon the available data, characterize fresh water quality problems and offer recommendations for prioritization.

With the above status in mind, these steps will be undertaken:

1. Prepare a water quality-monitoring program for estuary TMDL compliance.

   - Review TMDLs and existing data, MEP reports, and ongoing monitoring programs.
   - Discuss current status of TMDL compliance monitoring with MassDEP and SMAST staff, especially concerning timing, extent of monitoring, and public reporting requirements.
   - Prepare a sampling plan to address compliance monitoring for estuaries based on MassDEP guidance
   - Recruit volunteers to perform the monitoring.
   - Provide needed monitoring equipment.
   - Select qualified analytical laboratory to perform the analyses.

2. Monitor and establish water quality priorities in fresh water ponds.

   - Review Cape Cod Commission review of Barnstable pond water quality data and any subsequent pond monitoring data
   - Discuss and establish monitoring goals and water quality thresholds for ponds.
   - Develop sampling plan to address impaired water quality.

- Recruit volunteers to perform the monitoring.
- Provide needed monitoring equipment.
- Select qualified analytical laboratory to perform the analyses.

B. Review current monitoring of public water supplies to assess status

- Review available MassDEP monitoring data from public water supplies
- Assess potential water quality issues of concern for individual wells or collectively of the town-wide system

C. Prepare Water Quality Status and Monitoring Need Report

1. Prepare this report to document the components of this phase.

2. Submit this report for environmental and public review as discussed in Phase 6.

PHASE II – NUTRIENT MANAGEMENT NEEDS ASSESSMENT

Phase II consists of the tasks to define the nutrient management needs of the Town. Needs will be defined by identifying the Town goals for nutrient management, evaluating the existing conditions, developing projections of the future conditions, and then comparing these goals and conditions to the water quality limitations of the Town's waters.

The purpose of the nutrient management needs assessments is to evaluate and define the nutrient management needs of the Town including other potential wastewater management needs previously identified in the Town's Wastewater Facility Plan and needs identified thorough the MEP Technical Reports, TMDLs, and freshwater pond assessments.

The main tasks of this phase are listed below:

A. Review, Describe, and Summarize Existing Conditions and Town Issues.
Including:

1. Nutrient management issues discussed in Phase I.

2. Town governmental issues including:

   - Town goals and objectives affecting nutrient management.
   - Local rules and regulations.
   - Growth management policies.
   - Affordable housing initiatives.
   - Fiscal constraints.
   - Institutional constraints.

3. Available technical data including:

   - Land use information from existing reports and town GIS files.

- Build out projections from existing reports.
- Areas of Town served by public and private water supplies.
- Zone of contribution (ZOC) delineations for public water supplies.
- Soils information and area of Town with high groundwater conditions.
- Areas of Town served by on-site systems, cluster treatment systems and the Hyannis WPCF.
- Performance of existing on-site nitrogen removal systems.
- Performance of Barnstable Middle School WWTF and all other public and private cluster and packaged treatment plants.
- Hyannis WPCF performance.
- Properties with septic system failures.

4. Previous and on-going projects related to nutrient management planning including:

- Town Wastewater Facilities Planning Study
- Recent and planned upgrades to Hyannis WPCF
- Stormwater remediation projects
- No-Discharge Area designation in Town's coastal areas
- Town DCPC and GIZ nomination efforts
- Land acquisition efforts
- Pond and embayment studies discussed in Phase I Report

B. Review And Summarize Regulatory Issues Affecting Nutrient Management Planning. Including issues related to:

- Watershed delineations to coastal embayments and freshwater ponds.
- Nitrogen standards for coastal waters.
- On-site systems and the nitrogen management aspects of the Title 5 regulations.
- Ocean Sanctuaries Act and the ability to discharge treated effluent through an ocean outfall.

- Wetland regulations.
- Groundwater standards and the discharge of treated effluent to the groundwater system.
- Drinking water standards and the ability to site an effluent discharge in Cape Cod's Sole Source Aquifer.
- Regulations pertaining to usage of nitrogen fertilizers.
- Privately owned wastewater treatment facilities.
- Septic systems owned and operated by community groups
- Collection and treatment of stormwater runoff
- Wastewater treatment and discharge requirements
- Coastal Zone Management (CZM), U.S. Corps of Engineers, and FEMA requirements on modifications to and remediation of coastal water bodies

C. Evaluate Summarize And Describe Future Conditions In Town. Including:

- Nutrient loadings and limitations presented in Phase I
- Findings of previous build out analysis
- Potential redevelopment in Hyannis
- Future wastewater flows and loadings with seasonal variation
- Proposed wastewater improvements at the Hyannis WPCF and proposed sewer extensions recommended as part of the wastewater facilities plan
- Proposed affordable housing projects
- Potential new public water supplies and the creation of new ZOC areas
- No action alternative (this is the future condition of the Town if nutrient management strategies are not implemented in the future)

D. Identify Nutrient Related Areas Of Concern And Prepare A Nutrient and Wastewater Management Needs Assessment Report.

1. Identify water bodies that currently or will exceed nutrient loading thresholds, including TMDLs and targets in the future.

2. Identify public water supplies with existing or future water quality concerns

3. Summarize the existing and future conditions for these areas to facilitate the evaluation of nutrient management and where applicable, wastewater management solutions in future phases.

4. Summarize the nutrient management needs of the Town.

5. Identify data gaps and additional information needed to proceed efficiently with the project.

6. Prepare the Nutrient Management Needs Assessment Report in accordance with State guidelines for nutrient management and wastewater management reports, and guidelines for projects funded by State Revolving Fund (SRF) loans. Summarize the analysis and findings of this project phase in the Needs Assessment Report.

PHASE III- IDENTIFICATION AND SCREENING OF ALTERNATIVE SOLUTIONS AND SITES

Phase III reviews, identifies, and develops solutions which may be feasible to meet the Town's nutrient management and wastewater management needs. These solutions are then summarized and screened to retain only the most feasible. Alternative wastewater treatment sites are also identified and screened to identify the most feasible sites that will balance costs, environmental impact and public acceptance. Feasible solutions (technical as well as management) and sites are then grouped into alternative scenarios for detailed evaluation in the next phase.

The purpose of the identification and screening of alternative solutions and sites is to identify nitrogen remediation solutions and then reduce the number of solutions to the most feasible ones for detailed evaluation. The Phase III identification and screening of alternatives may be specific to a particular watershed and its TMDL.

Significant progress has been made on the technical approaches to evaluate and resolve embayment specific and site-specific issues related to proposed sites for recharge of treated effluent. These approaches are described in the Technical Report Effluent Disposal and Reuse Planning Guidance that was prepared by the town under a County Wastewater Management Grant. The MEP reports and their accompanying models and the recently-updated USGS groundwater models will allow the town to test scenarios to see if they address the TMDLs and evaluate other potential impacts, such as changes in watershed boundaries. The benefits of these tools were recently demonstrated through findings from a County-funded USGS groundwater-modeling project, which allowed the town to evaluate the impact of different discharge volumes at the proposed McManus discharge location. This evaluation was paired with an evaluation of the potential impacts on Barnstable Harbor of the associated nitrogen loads completed by the MEP staff and an evaluation of potential phosphorus loading impacts on Lake Wequaquet. The Tasks evaluating alternatives will require evaluation of the changes in watershed boundaries from existing and proposed effluent recharge sites and the determination of net nutrient loads where both sewering to reduce loads and recharge of collected wastewater effluent will occur. Such analysis will demonstrate the benefits of potential sewage collection and wastewater

treatment to the impacts from existing septic systems on specific resources (coastal waters, fresh water ponds and drinking water wells).

The tasks of this phase are listed below.

A. Identify, Review and Summarize Alternative Solutions To Meet The Town's Nutrient and Wastewater Management Needs. Investigate the groups of technologies, opportunities and alternatives, including:

- Modification to Town Zoning and land use requirements
- Stormwater mitigation opportunities
- Fertilizer mitigation opportunities
- Individual on-site wastewater nitrogen removal technologies
- Community (cluster) wastewater nitrogen removal technologies
- Centralized wastewater treatment and nitrogen removal technologies
- Centralized wastewater collection and residual management technologies
- Wastewater flow and loading reduction opportunities
- Wastewater reuse opportunities
- Solutions to encourage greater nitrogen attenuation within watersheds
- Financing scenarios
- Infrastructure management scenarios
- Potential centralized discharge sites based on past Town evaluations

B. Screen The Alternative Solutions To Identify The Most Feasible Ones For Detailed Evaluation.

1. Prepare a screening methodology for solutions that can meet the needs identified in Phase II. The methodology will include a standard set of criteria to screen the technologies.

2. Prepare a screening matrix, which provides a side-by-side comparison of the various alternatives within a group that meets the specific needs in Phase II.

3. Select the most feasible alternatives for detailed evaluation.

C. Identify And Screen Potential Sites For Nutrient Management Facilities. Including wastewater treatment and discharge sites for cluster systems, centralized facilities and stormwater treatment and discharge sites.

1. Prepare a facilities site and screening methodology for regulatory and project review. The methodology will include a standard set of criteria to screen the sites.

2. Use the Town GIS to identify and tabulate information on potential sites.

3. Compare a screening matrix, which provides a side-by-side comparison for potential sites.

4. Visit the sites to form additional observations about the sites.

5. Meet with Land Bank representatives and other land preservation groups to explore possibilities of using preservation land for nitrogen management facilities.

6. Select the most feasible sites for detailed evaluation.

7. Identify subsurface or environmental investigations needed to demonstrate the feasibility and acceptability of particular sites for wastewater treatment and disposal facilities. Potential investigations include:

   - Wetland delineations
   - Endangered species survey
   - Archeological survey

- Test pit and percolation investigations
- Pump testing and hydraulic conductivity testing

D. Group Feasible Solutions And Sites Into Alternative Nutrient Management Scenarios.

1. Group the feasible solutions with the input of Town staff and Citizen Advisory Committee members.
2. Summarize the rational for grouping various feasible solutions into the nutrient management scenarios.

E. Prepare Nutrient and Wastewater Management Alternative Screening Report

1. Prepare this report to document the components of this phase.

2. Submit this report for environmental and public review as discussed in Phase 6.

PHASE IV – DETAILED EVALUATION AND DEVELOPMENT OF THE NUTRIENT MANAGEMENT PLAN

Phase IV provides a detailed analysis of costs and non-monetary factors for the alternative nutrient management scenarios. It also performs the environmental impact analysis for these alternative scenarios in accordance with State and Cape Cod Commission requirements. It presents the recommended nutrient management plan to mitigate the nutrient related problems in each waterbody. This plan will include the recommended implementation steps for new facilities, management structures, local regulations, and funding requirements, as well as recommended schedule for implementation.

The main tasks for this phase are listed below:

A. Additional Environmental Investigations and Modeling For Potential Nutrient Management Sites. Potential investigations include:

- Groundwater Modeling
- Nitrogen loading evaluations/comparison to estuary TMDLs and drinking water standards
- Phosphorus loading evaluations/comparison to freshwater pond thresholds
- Other drinking water contaminant evaluations
- Hydraulic surface water modeling/water balance evaluations
- Site assessments for enhanced natural nitrogen attenuation
- Wetland delineations
- Endangered species survey
- Archeological survey
- Test pit and percolation investigations
- Pump testing and hydraulic conductivity testing

B. Perform Present-Worth Evaluations Of Alternative Nutrient Management Scenarios.

1. Develop unit costs for capital and operational & maintenance (O&M) costs.

2. Develop capital costs for each alternative scenario.

3. Develop O&M costs for alternative scenario.

4. Perform a present-worth analysis to equate the capital cost and twenty years of O&M costs of each alternative scenario to a present worth cost. Compare present worth cost of the alternative scenarios to identify the most cost effective scenario. The purpose of this analysis is to develop a comparable cost for alternative scenarios that may have different cost structures. (One alternative scenario may have high capital cost but low O&M cost; while another alternative scenario could have low capital cost but high O&M cost.)

C. Perform Non-Monetary Evaluations Of The Alternative Scenarios.

1. Compare non-monetary factors of each scenario such as:

   - Anticipated public acceptance
   - Ease of implementation
   - Land area requirements
   - Energy use
   - Flexibility for changing requirements
   - Maintenance requirements and complexity of operations
   - Nutrient and other contaminant mitigation performance
   - Regulatory feasibility
   - Expected Growth

2. Develop a numerical rating system to quantify these non-monetary factors

D. Perform An Environmental Impact Analysis Of The Alternative Scenarios.

1. Perform an environmental impact analysis in accordance with the guidelines and regulatory procedures of the Cape Cod Commission and the Massachusetts Environmental Protection Act (MEPA) Office of the state.

E. Evaluate The Present-Worth Analysis With The Non-Monetary Evaluation and The Environmental Impact Analysis To Select The Most Appropriate Management Scenario.

1. Develop evaluation summaries for project team and regulatory review.

2. Select the most appropriate management scenario.

F. Develop And Present Recommended Nutrient Management Plan, and Prepare The Nutrient Management Plan And Draft Environmental Impact Report (DEIR).

1. Briefly summarize the previous evaluations and project phases.

2. Present the findings of any environmental investigations performed at the beginning of this phase.

3. Present a summary of the evaluations and analysis performed in this phase, including:

a. Present the wastewater management recommendations including:

i. Identify the recommended wastewater management approach for all areas of Town including:

- Areas to be served by sewers and advanced nitrogen removal at one or more new centralized wastewater treatment facility(s).
- Areas to be served by sewers and community (cluster) wastewater treatment facilities
- Areas to be served by on-site nitrogen removal systems serving individual homes or small groups of homes.
- Areas of Town that can continue to be served by Title 5 systems
- How each of these wastewater treatment technologies in these areas will address nutrient management thresholds and TMDLs.

ii. Present detailed description, O&M requirements, conceptual design, layout, design flows and loadings, and expected performance of all recommended wastewater management approaches including the following possibilities:

- Modification and expansion of the Hyannis WPCF
- New centralized treatment facility(s)
- New community (cluster) treatment facilities
- On-site nitrogen removal septic systems
- Standard Title 5 systems

iii. Present detailed description, conceptual design, design capacities, and O&M requirements of recommended effluent discharge facilities.

iv. Present detailed descriptions, conceptual design, O&M requirements and design capacities of recommended wastewater residuals management facilities including:

- Areas to be served by sewers and advanced nitrogen removal at the Hyannis WPCF

- Septage management facilities and managed pumping of septic tanks.
- Screenings, grit and biosolids management and disposal.

v. Capital and O&M costs for all recommendations.

b. Present recommendations for enhanced natural nitrogen attenuation within selected watersheds either through the restructuring of existing systems or creation of new systems.

c. Present pond remediation recommendations including:

- Prioritization of pond remediation projects.
- Detailed description of recommended remediation program, technology, and cost for each pond, including: evaluation of watershed controls, in-lake options and preferred treatment, opportunities for joint nitrogen and phosphorus removals, evaluation of potential decreased nitrogen attenuation due to better pond water quality, development of conservation commission application template for pond remediation projects, and evaluation of long term benefits of recommended remedial options.
- Capital and O&M costs for the pond remediation.

d. Present recommended institutional changes and management structures needed to operate and implement the nutrient management strategies recommended including:

- Changes in Town staffing
- Town departmental responsibility shifts
- Possible management district formation
- Possible inter-municipal agreements
- Capital and O&M costs for these management changes

e. Present fertilizer management recommendations including evaluation of the following options:

- Public education programs.
- Town regulations to monitor and control proper application of fertilizer.
- Development of specifications for approved fertilizers in town.
- Zoning changes to encourage smaller lawns and the disturbance of less natural ground cover.

f. Present stormwater management recommendations to manage and mitigate nutrient impacts from stormwater including:

- Prioritization and conceptual design of stormwater projects to mitigate impacts of stormwater discharges on estuaries and ponds.
- Zoning changes to minimize the creation of impervious surfaces and the production of stormwater.

4. Present recommended implementation schedule for implementing the management recommendations.

5. Recommend CIP budgeting needed for the implementation.

H. Submit The Nutrient Management Plan and DEIR For Regulatory and Public Reviews.

1. Prepare this report to document the components of this phase.

2. Submit this report for environmental and public review as discussed in Phase 6.

PHASE V – RESOLUTION OF REMAINING ISSUES AND PROJECT COMPLETION

This phase is needed to complete the Environmental Impact Review Process and finalize the Nutrient Management Plan. This phase includes the following tasks:

A. Resolve Remaining Issues. There maybe remaining issues to address, which will require the following tasks:

- Reinvestigate previous analyses as required
- Investigate additional alternatives and/or sites as required
- Develop additional information as required

B. Modify The DEIR To Prepare The Nutrient Management Plan and FEIR, and Submit It For Public and Regulatory Review. The DEIR will need to be modified to include any requested information to produce a FEIR. The FEIR will then be submitted to the regulatory agencies for review.

1. Prepare this report to document the components of this phase.

2. Submit this report for environmental and public review as discussed in Phase 6.

PHASE VI – ENVIRONMENTAL AND PUBLIC REVIEW PROCESS.

This phase is the creation and coordination of the environmental and public review process that proceeds throughout the whole project.

The environmental review process needs to follow the Cape Cod Commission/Massachusetts Environmental Policy Act (CCC/MEPA) Joint Review Process (CCC/MEPA, 1991) which typically uses public hearings after the submittal of each project document. The Town can also request a more formalized Joint Review Process described as "Special provisions for Major and Complicated Projects" and detailed in State Regulation 201CMR11.12. This review process requires regulatory review of each project document and can require additional review components as requested by the Town. Both environmental review processes require many regulatory meetings and public hearings to coordinate the flow of information to the various regulatory agencies.

The public review process is closely related to the environmental review process. It will contain additional items needed to properly disseminate information to the Town's community groups and to the Town Public. Proper public education is needed to ensure that the recommended plan will be approved by the Town Council and by the voters in any proposition 2½ override referendums.

The purpose of this phase is to create and coordinate an environmental and public review process which will inform project participants and the Town Public, and ensure that the recommended plan will be approved by the Town Council and Town Voters.

The main tasks of this phase are listed below:

A. Establish and Utilize a Citizens Advisory Committee. A Citizens Advisory Committee (CAC) is typically comprised of Town residents with diverse views that fairly represent all points of view. The purpose and function of the CAC include:

- Become knowledgeable about all aspects of the Project.
- Make recommendations to the Town and Town Decision Makers
- Represent members of the public that cannot attend public meetings.
- Investigate and develop recommendations on issues as they arise.

The CAC will meet periodically throughout the Project as desired by CAC members. Meeting notes will be maintained.

B. Establish and Utilize a Technical Advisory Committee. A technical Advisory Committee (TAC) is typically comprised of representatives of Town technical staff, representations from regulatory agencies, and professional staff from interested agencies. The Town has already assembled a Nutrient Management Team which is considered a TAC. The current representation of this group includes:

- Town Department of Public Works
- Town Health Department
- Town Conservation Department
- Town Planning Department
- Cape Cod Commission
- Massachusetts DEP
- Three Bays Preservation, Inc.

The TAC will meet regularly throughout he Project to be sure that technical issues are addressed. Meeting notes will be maintained.

C. Prepare and Conduct a Public Participation Program. A public participation program is needed to develop appropriate public education materials to inform the public of Project activities and findings. Public education tasks include:

- Provide public notification of all public meetings and hearings.
- Develop Project summaries before and after each major phase of the Project.

- Develop and distribute news bulletins to the press to keep project activities in the news.
- Maintain Project information dissemination booths at public libraries and other public locations. These tables will display information about the project as well as act as a distribution point for project summaries.
- Organize presentations to the Town citizen and public interest groups.
- Tape and air all CAC and public meetings on community television and/or through the town website
- Organize workshops with community groups to facilitate greater information exchange between Project team members and the public.

D. Prepare, Submit and Coordinate the Public Review of the Environmental Notification Form and Development of Regional Impact Document. The Environmental Notification Form (ENF) and Development of Regional Impact (DRI) document is the first Project Submittal of the Joint CCC/MEPA Review Process. The document briefly describes the main issues of the Project and presents a Project Scope that describes the major tasks to be accomplished by the Project. The ENF/DRI document will be based on the Plan of Study. The major tasks include:

1. Solicit comments form the regulatory agencies and other interested parties on the Plan of Study.

2. Prepare the ENF/DRI document for MEPA, CCC and public review.

3. Attend document review meetings and a public hearing.

4. Receive the MEPA Certificate and address public comments in a letter to the Secretary of the Executive Office of Environmental Affairs.

5. Modify the Plan of Study as needed to address the comments.

E. Coordinate the Public Review of the Other Project Documents

1. Coordinate the public review of the other project documents identified in previous phases including:

- Assessment of Monitoring and Nutrient Limit Targets.
- Nutrient Management Needs Assessment Report
- Nutrient and Wastewater Management Alternative Screening Report
- Nutrient Management Plan and Draft Environmental Impact Report (DEIR)
- Nutrient Management Plan and Final Environmental Notification Report (FEIR)

2. Attend review meetings and public hearings for these documents.

3. Receive the MEPA, CCC and other comments and address them in a letter.

F. Coordinate and Attend Meeting and Public Hearings.

PHASE VII – PROJECT MANAGEMENT AND FUNDING

A. Develop and Administer State Revolving Fund Loan Applications and Agreements.

B. Develop and Administer Contract Agreements for Specialized Services.

C. Provide overall Project Management and Coordination.

EXHIBIT B
OF CAPE COD DECISION ON

Adaptive Management and Monitoring Plan for the Effluent Recharge at the Hyannis WPCF Site

August 27, 2007
Draft

An Adaptive Management and Monitoring Plan has been developed to monitor water table fluctuations and trends caused by seasonal climatic variations and recharge of treated effluent at the Water Pollution Control Facility, and water quality. The purpose of the Adaptive Management and Monitoring Plan is to: 1) distinguish between changes in water table fluctuations caused by natural sources and those caused by WPCF discharge, 2) evaluate potential changes in the location of the regional groundwater divide resulting from increased discharge, 3) provide accurate documentation on the fate and transport of recharged components through the aquifer and 4) identify procedures that will be used if groundwater reaches specific elevations (threshold elevations) in a group of sentinel wells.

Technical Advisory Group: The Adaptive Management and Monitoring Program includes the establishment of a Technical Advisory Group (TAG) to regularly review monitoring data and recommend changes to the monitoring plan. The TAG will consist of members of the Town, their consultants, Cape Cod Commission Water Resource Program staff and others on an as needed basis to include MassDEP, USGS and SMAST. The technical advisory group shall meet at least once per year to review the on-going monitoring data to discuss and recommend any modifications or changes to the proposed AMMP and then.

Initial Review: The Barnstable Department of Public Works has conducted monthly measurements at monitoring wells around the WPCF since the mid 1980s. Over 18 years of water level and water quality data were provided to Commission Water Staff. Staff conducted an initial review and compiled a summary of water level and water quality data (see Appendix 1 for summary of wells reviewed). The AMMP is grouped into two sections based on this initial review: 1) Groundwater Quality and 2) Water Levels. The initial review included those items referenced in the MEPA Certificate:

1) Summary tables and graphs of water level data at each of the monitored wells including average, median, maximum and minimum and number of readings.

2) Summary table and graphs comparing water levels at each monitoring well to effluent discharge at the WPCF, precipitation and water levels at relevant USGS index wells and present r-squared values to evaluate their relationships.

3) Summary tables and graphs of water quality data at all the wells including effluent and influent to show average, median, maximum, minimum standard deviations and number of readings.

At present, Commission staff is working with the town to develop map of monitoring well locations to compliment the details included in this AMMP. A draft map is provided as a placeholder attachment (Figure 1).

1) Groundwater Quality

The objective of the groundwater quality monitoring program is to characterize and document changes in groundwater quality downgradient of the WPCF. Changes in water quality are to be expected from changes in effluent quality and increased volume of effluent discharge (see figures in Appendix 2). Changes to be expected are improvements from better overall treatment at the WPCF and an increase of the area of groundwater affected by increased volume of discharge.

An initial evaluation has been completed by Cape Cod Commission Water Resources Staff based on 18 years worth of data supplied by the Town. Based upon this preliminary review of the data, it is clear that the network of monitored wells should be altered: several monitoring well locations for water quality should be dropped and others should be added. A preliminary characterization of the monitoring well water quality data is included in Appendix 1. From the preliminary review, it is recommended that additional well information should also be added to the database, including: distance from WPCF, well screen depth below water table, depth to water, length of water column in the well and stratigraphy surrounding the well.

Recommended changes to the monitoring program include additional wells to characterize the existing plume area and wells to monitor an increased area potentially effected by the increased volume of discharge are shown on the attached Table 1. This monitoring program would supplement, but not replace standard monitoring regularly required under the MassDEP Groundwater Discharge Permit, such as influent and effluent monitoring. Follow-up with the

town on this initial evaluation will include discussion on staff recommendations of monitoring. The TAG may also want to consider additional monitoring programs for other compounds of concern such as total nitrogen, phosphorous, caffeine, drugs, pathogens, and estrogen mimics. These compounds concern a variety of receptors; the nutrients are important for surface waters (ponds, estuaries, and streams), while the caffeine, drugs, pathogens, and estrogen mimics are concerns for public water supplies.

The TAG will also consider the establishment of water quality thresholds for various compounds. Threshold and/or contingencies for consideration include, if trends in water quality at lateral monitoring points indicate an increase in effluent altered groundwater, additional monitoring points at a further distance from the WPCF will be added.

2) Water Levels

Water level monitoring is important because of the potential of WPCF discharge to impact low-lying properties and alter groundwater flow paths and impact drinking water wells, ponds, and estuaries. Specifically, it is important to monitor water levels around the WPCF to:

1) better manage the discharge among the 49 rapid infiltration beds as volume increases, 6.9-acre site, located adjacent to the McManus property along Route 132, in preparation of its potential use as a discharge site.

Water level information from 1990 to the present was evaluated by Commission staff. The relationship between water levels and discharge is readily discernable at only a few wells in close proximity to the WPCF. These wells include PT300-SE, C-2, 92-4, and 92-16. Staff recommend that these wells be adopted as the near-field monitoring wells for water levels and that appropriate water level thresholds for these wells be identified in the AMMP for effluent discharge management and groundwater divide monitoring (Table 2).

Staff also recommends well W7 as a groundwater divide monitoring location and several others that have yet to be identified.

Staff recommends that wells W4 and BA-3 be identified as far-field water level monitoring wells to evaluate the relationship to low-lying properties that have been identified in the FEIR as a

concern. The previously established thresholds for these wells should continue to be used until Town and Commission discussion of the water level relationships is completed.

3) Adaptive Management and Monitoring Plan.

If groundwater elevations reach elevation threshold levels, the following immediate actions will be implemented depending upon the degree and frequency and/or long term changes associated with low lying property concerns and/or the regional groundwater divide:

a. Verify the groundwater rise or potential impact, including:

   1) More detailed survey and site visit to verify the GIS elevations that have been used to date.

   2) Possible correlation of groundwater rise to the WPCF recharge.

   3) Investigation of impacts from other possible water sources such as broken water mains or poor drainage.

   4) Inquiries to adjacent property owners that may be impacted as to whether groundwater is entering any basement living space or if problems have been noted with operation of their septic systems.

If the threshold elevations are exceeded and the exceedances are believed to be due to Hyannis WPCF recharge at the site, the following correction action alternative evaluations will occur:

b. Evaluate various mitigation alternatives to address the high groundwater and changes in the groundwater divide that may include the following:

   1) Drainage improvements.

   2) Well point dewatering and recharge at an appropriate and permitted location.

3) More widespread rotation of effluent recharge within the Hyannis WPCF sand filter beds.

4) Relocation of up to 0.5 MGD to the 6.9-acre site.

5) Property purchase of the affected property.

6) Evaluation, planning, approval, and implementation of additional remote effluent recharge locations.

7) Discontinuation of sewer connections to properties that want to be served by the sewer (sewer moratorium).

c. Prepare an evaluation report for submittal to MADEP and the Cape Cod Commission summarizing the evaluations and recommended actions and timetable

Figure 1. Barnstable WPCF Adaptive Management and Monitoring Plan: Map of Monitoring Well Network showing DEP GWDP wells and others.

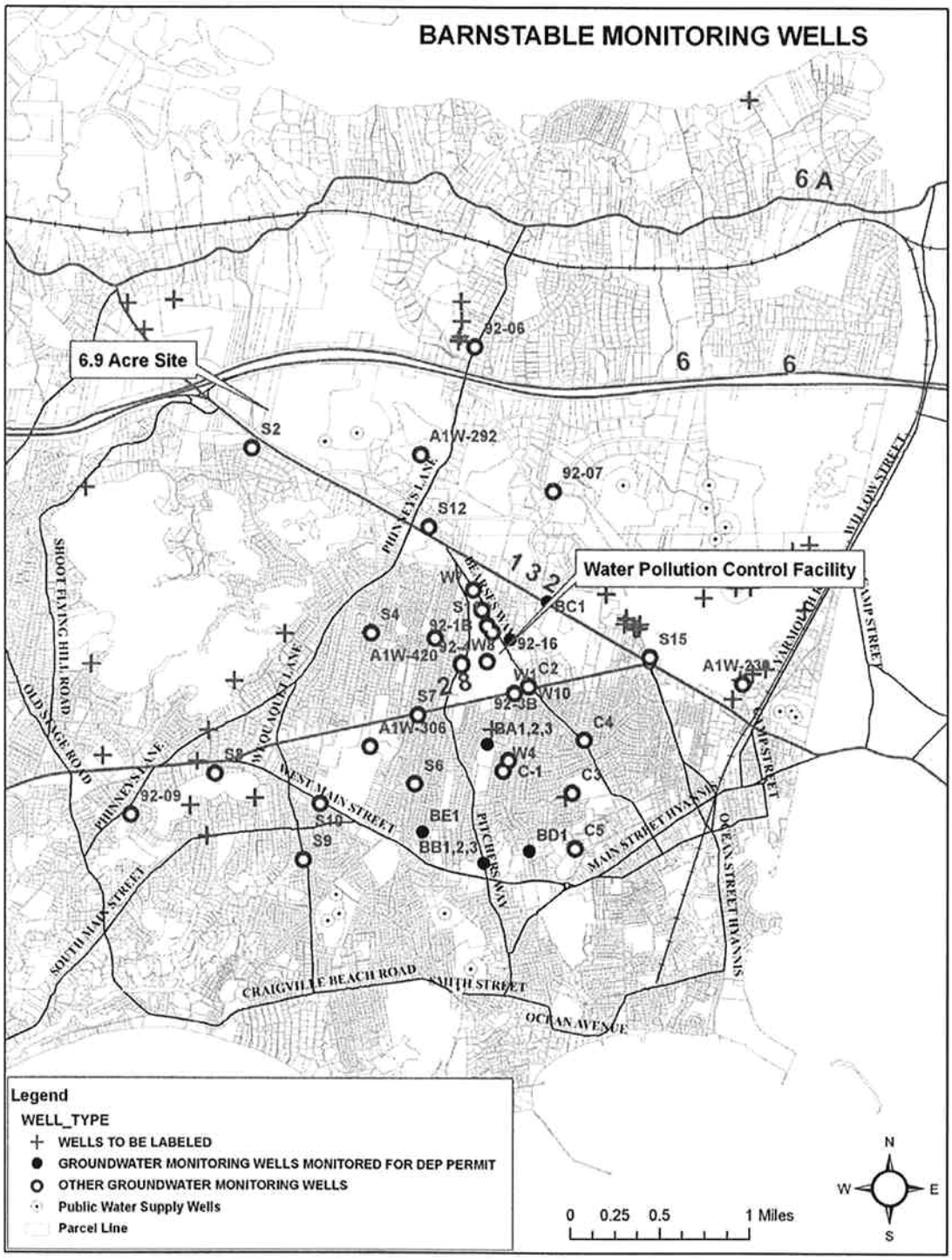


Table 1) Recommended Groundwater Quality Monitoring Plan

WELL/RESOURCE	LOCATION	DEPTH	RESOURCE	FREQUENCY
BA1	Expanded Plume	Deep	Water Supply	Quarterly
BA2	Expanded Plume	Inter	Water Supply	Quarterly
BA3	Background	Shallow	Urban Background	Can be Dropped
BB1	Expanded Plume	Deep	Water Supply	Quarterly
BB2	Background	Inter	Urban Background	Can be Dropped
BB3	Background	Shallow	Urban Background	Can be Dropped
BC	East Lateral	Inter	Water Supply	Quarterly
BD	Plume	Inter	Water Supply	Quarterly
BE	Background/W. Lateral	Inter	Urban Background	Quarterly
C1	Plume Core	Install Deep	Water Supply/SW	Quarterly
C2	Plume Core/Background	Install Deep	Water Supply/SW	Quarterly
C3	Plume Core	Install Supplement	WS/SW	Quarterly
C4	East Lateral	Install Supplement	WS/SW	Quarterly
C5	Plume Core	Deep	WS/SW	Quarterly
W7	North Upgradient	Install Supplement	Water Supply	Quarterly
AIW420	West Lateral	Install Supplement	Water Supply/SW	Quarterly
92-16	East Lateral	Install Supplement	Water Supply/SW	Quarterly
Stewards Creek	Downgradient SW	Stream flow	Surface Water	Quarterly
Duck Pond	Downgradient SW	Pond Water	Surface Water	Quarterly
4-Additional Wells	Lateral Control Points	Inter and Deep	Water Supply	Quarterly

Wells are to be measured for Water Level, Specific Conductance, Temperature, Dissolved Oxygen and sampled for Ammonia-N, Nitrate-N, Total Nitrogen, Phosphorous, chloride, copper, iron, manganese, sodium, sulfate, and annually monitoring for potassium, VOC, THM.

Additional Near-field wells should be considered to characterize additional compounds of concern.

Changes to the initial 9 – "B" series wells that were part of the 1980 Groundwater Discharge Permit will need concurrence by DEP.

Table 2. Recommended Water Level Monitoring Program

WELL	TYPE	OBJECTIVE	THRESHOLD (	FREQUENCY
PT300se	Near-field	Mound/Groundwater Divide	TBD	Data Logger
C2	Near-field	Mound / LLP*	33 ft	Data Logger
92-4	Near-field	Mound/ Groundwater Divide	TBD	Data Logger
W7	Near-field	Mound/ Groundwater Divide	TBD	Data Logger
92-16	Near-field	Mound / LLP/Divide	TBD	Data Logger
W4	Far Field	Mound/ LLP	26 ft	Monthly
BA3	Far-Field	Mound / LLP	TBD	Monthly

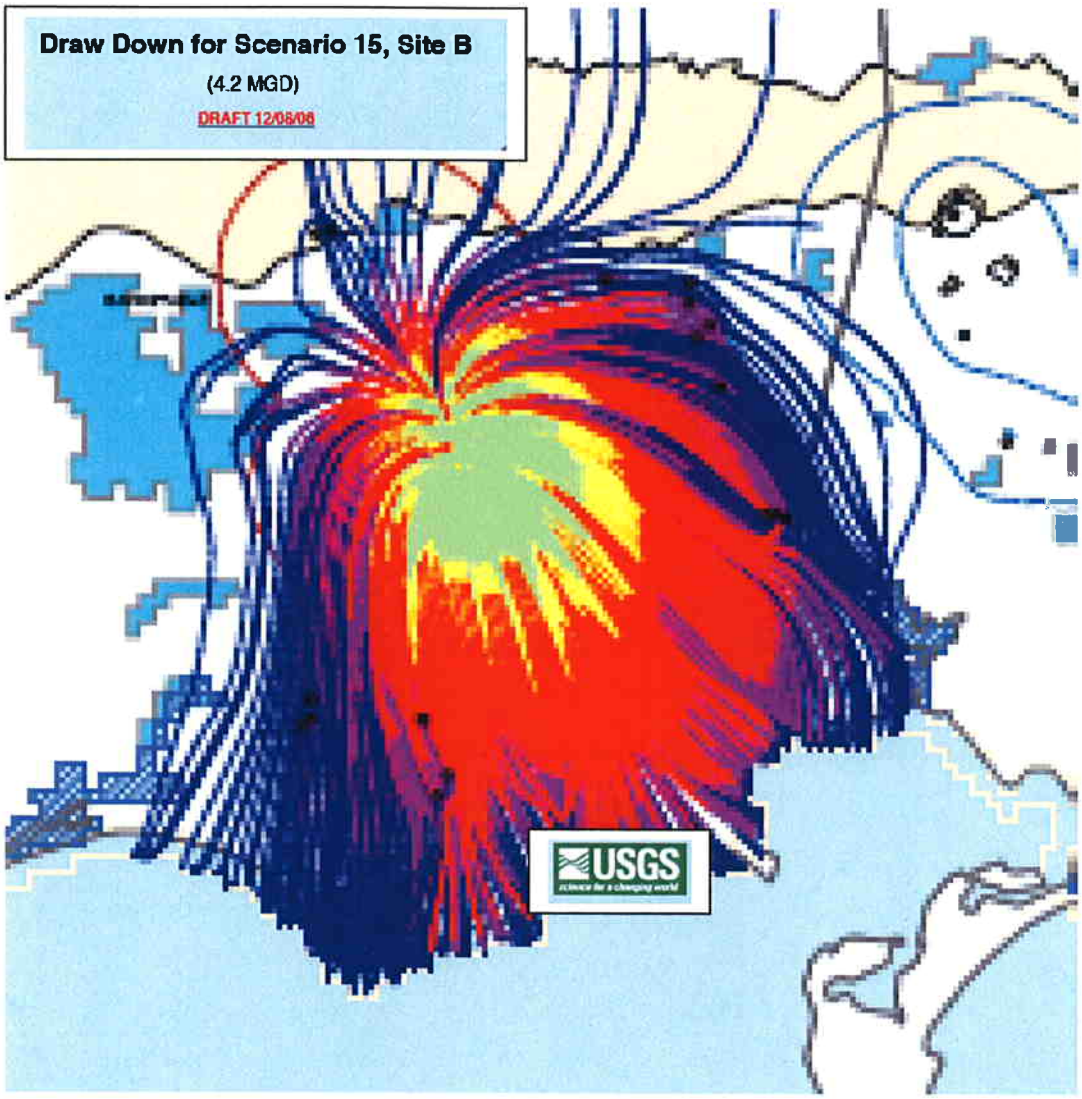
*Low Lying Property

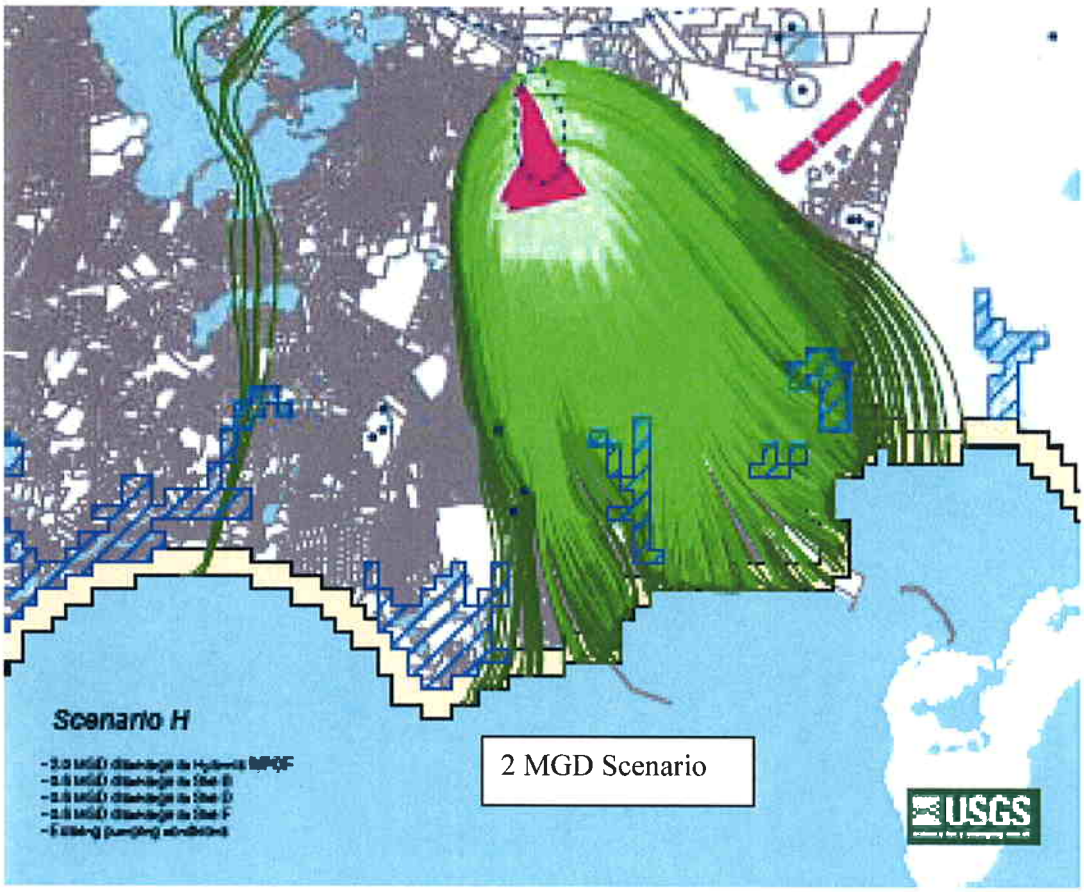
Staff will review and finalize these selections with the Town.

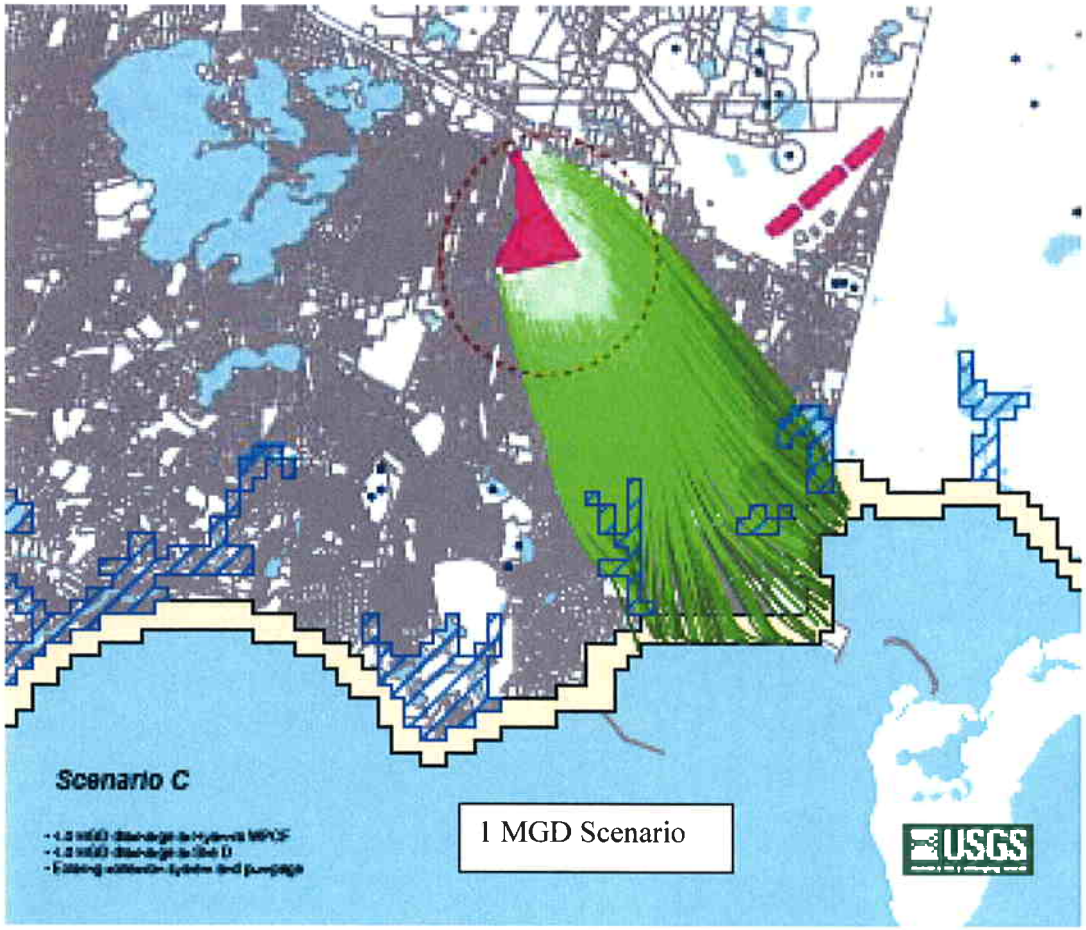
Appendix 1. Summary of Available Groundwater Quality Monitoring at the Hyannis WPCF

Well	Monitoring Location	Total Depth	Depth to H20	Depth of H2O	Year Installed	Period of Record	
BA-1	Plume	75	18	57	1979	1988+	Increase in Effluent plume character 1998+
BA-2	Plume	66	18	48	1979/1995	1988	Increase in Effluent plume character 1998+
BA-3	Plume	26	18	8	1979	1988+	Increase in Effluent plume character 1998+
BB-1	Plume	63	17	46	1979	1988+	Increase in Effluent plume character 2002++
BB-2	Background	43	17	26	1979	1988+	
BB-3	Background	25	17	8	1979	1988+	
BC	Background	66	31	35	1979	1988+	Run Off
BD	Plume	50	17	33	1979	1988+	Changes in oxidation state in 1995 & 2004
BE	Background	50	20	30	1979	1988+	
C1	Plume	75	12	63	1983*	1988-1993	Strong Plume Character
C2	Plume	42	11	31	1983*	1988-1997/2002-4	Run Off component
C3	Plume	58	18	40	1983	1988-1997	
C4	Plume	58	24	34	1983	1988-1997	
C5	Plume	45	6	39	1983	1988-1997	Strong Plume Character
W1	Plume	30	27	3	1978?	No data post 1994	Also Road Run Off
W4	Background	25	20	5	1978?	No data post 1994	
W5	Background	26	17	9	1978?	No data post 1994	
W7	Background	41	31	10	1978?	No data post 1994	
W8	Plume	43	33	10	1978?	No data post 1994	
W9	Background	Shallow		#VALUE!	1978?	No data post 1994	
W10	Background	Shallow		#VALUE!	1978?	No data post 1994	
92-1A	Plume	?			1992	1992,1996-1997	
92-1B	Plume	?			1992	1992,1996-1997	
92-2A	Plume	?			1992	1992,1996-1997, 2004	
92-2B	Plume	?			1992	1992,1996-1997, 2004	
92-4	Plume	?			1992	2002-2004	
92-16	Plume	?			1992	2002-2004	
PT300se	Plume	?			1992?	2004	

Appendix 2 – Selected Groundwater Particle Tracks from County Funded USGS Project




Scenario H
2 MGD Scenario
USGS


Scenario C
1 MGD Scenario
USGS

Appendix 1-4

Regional Wastewater Evaluations for Yarmouth and Barnstable

STEARNS & WHELER LLC
Environmental Engineers & Scientists

Technical Memorandum

To: David Young, P.E., CDM, Vice President
George Allaire, Town of Yarmouth DPW Director
Mark Ells, Town of Barnstable DPW Director

From: Nate Weeks, P.E.
Bill Hall Jr., P.E.
Andrew Ochs
Stearns & Wheler, LLC

Date: January 15, 2009

Subject: Regional Wastewater Evaluations for Yarmouth and Barnstable, Massachusetts
Summary of Task A Evaluations

BACKGROUND

The Town of Yarmouth is in the process of developing a Comprehensive Wastewater Management Plan to address nitrogen loading to its coastal estuaries. As part of this process, sewer needs and alternatives have been evaluated. One alternative is to connect a portion of flow from Yarmouth to the Hyannis Water Pollution Control Facility (WPCF), with treated water returned to Yarmouth for groundwater recharge. Stearns & Wheler has been tasked with evaluating the feasibility and costs associated with the transport of wastewater from Yarmouth to the Hyannis WPCF, treatment at this facility, and return of the treated water to Yarmouth. Three scenarios of varying flow contribution have been identified for evaluation.

Stearns & Wheler's tasks have been divided into two groups: Task A evaluations and Task B evaluations. The Task A evaluations are broad perspective evaluations to present initial findings, order of magnitude costs, and the identification of important issues that should be evaluated in further detail if desired by the Towns of Yarmouth and Barnstable. The Task B evaluations would have more detailed evaluations and cost development if requested by the two Towns.

The purpose of this memorandum is to outline the findings and costs of the Task A evaluation for the possible transport of wastewater from the Town of Yarmouth to the Hyannis WPCF for treatment and transport of the treated water back to Yarmouth.

SCENARIOS & EVALUATIONS

Three potential flow scenarios have been identified, as depicted in Table 1 below.

Table 1: Scenarios for Connection of Yarmouth Areas

Scenario	Pump Station	Areas Connected	Max Mo. Flow (MGD)
1	VP1	VS1	0.18
2	P1	VS1, PS1, GS1	0.30
3	P1	VS1, PS1, GS1, PS2.1, PS2.2, VS2, GS2	0.64

The source of the wastewater flows (pumpstations and areas connected) is depicted in the Town of Yarmouth Phase IV CWMP figure, included as Attachment A. As shown in Table 1, three scenarios exist for connection of Yarmouth areas to the Hyannis WPCF. The scenarios vary in their coverage and flow, encompassing either only a smaller section of western Yarmouth, or a significant portion of the west side of the Town. The flows depicted will have a varying impact on the Hyannis WPCF. All unit processes at the WPCF are currently capable of handling flows of this magnitude, but the capacity is currently allocated to sewer expansion in the Town of Barnstable. As such, treatment facility expansion at the Hyannis WPCF would be required regardless of the scenario chosen.

For each scenario, the costs have been developed for connection to the WPCF, with a treated water force main returning to Yarmouth for groundwater recharge. A sub-evaluation is completed for each scenario. The sub-evaluation develops costs for connecting a wastewater force main directly to the Hyannis WPCF as well as the costs for connecting a wastewater force main from Yarmouth to the existing gravity sewer closest to the Barnstable-Yarmouth border.

The shortest route to the Hyannis WPCF from the Yarmouth border is along State Routes 132 and 28, with a small portion on Bearse's Way (see Figure 1 attached). Installation along this busy stretch may cause difficulties. In addition, installation of piping in and around state roads requires special construction methods and materials, increasing the cost of installation in these areas. While there are no known restrictions to installing sewers in these roads (such as Mass. Highway prohibitions to cut the pavement after road reconstruction) at this time, this route should be investigated further as a more detailed design is developed.

Connection to the closest gravity sewer also has drawbacks. Recent evaluation of sewer capacity in the Town of Barnstable has shown severe limits to the capacity of existing gravity sewer near the Yarmouth border. In order to connect flows on the order proposed in the scenarios above, a complete rebuild of the sewer would be required to prevent surcharging. In addition, the pump station which receives this flow currently operates near full capacity and additional capacity is currently allocated to sewer expansion in Barnstable. This pump station would require significant upgrades to accommodate any flow from Yarmouth. As such, the evaluation for connection to the existing gravity system incorporates the costs for rebuilding the existing gravity sewer, upgrading the receiving pump station, and installing a new force main to the WPCF (see Figure 2 attached). The treated water force main could be installed in the same trench with the rebuilt gravity sewer and new wastewater force main. This route is less direct, but avoids installation in state roads.

The cost estimates are based on the installation of two wastewater force mains. Current Town of Barnstable practices dictate that two wastewater force mains should be installed to assist with startup flows and to allow operational flexibility. This has been the preferred method of installation and operation on all recent force main extensions in the Town of Barnstable. In general, only one force main will be in use at a given time, with the other serving as backup. As such, one force main is sized to accommodate the peak flow for each scenario, with an additional smaller force main installed as well to handle startup flows and provide a level of redundancy. The installation of dual force mains will assist in keeping velocities high in the force mains during startup to promote scouring and prevent sediment deposition and in limiting the residence time within the force main. The required force main lengths for each scenario are shown in Table 2 below.

Table 2: Force Main Distances – WPCF and Gravity Sewer Connections

	Connect Directly to WPCF	Connect to Existing Sewer
Primary Wastewater Force Main[1] (ft)	10,300	100
Secondary Wastewater Force Main[1] (ft)	10,300	100
Additional Pump Station Force Main (ft)	-	9,400
Treated Water Main[2] (ft)	9,800	13,100
Total Force Main Length (ft)	30,400	22,700

Notes:

1. From Yarmouth border only. Does not include force main in Yarmouth.
2. To Yarmouth border only. Does not include treated water main in Yarmouth.

Sewer Sizing

The wastewater and treated water force mains were sized to achieve the necessary velocities to prevent settling, as noted above. For the wastewater force mains, the velocity is maintained above 3 feet per second (fps) to prevent settling, while in the treated water force main 2 fps is maintained. Lack of settleable solids in the treated water allows for the lower value in the treated water main. TR-16 standards dictate that sewer systems (and thus force mains) should be design for peak flows. Thus, the maximum month flows displayed in Table 1 must be scaled to represent peak conditions. However, the relevant peaking factor depends on the total flow in question. TR-16 supplies peaking factors from average to peak flow over a wide range of total flow conditions. Average flows for each scenario are based on information provided by CDM. The average flows and relevant peaking factors are displayed in Table 3.

Table 3: Peak Flows and Pipe Sizing for Flow Scenarios

Scenario	1	2	3
Max. Mo. Flow (MGD)	0.18	0.30	0.64
Average Flow (MGD)	0.11	0.19	0.40
Average to Peak PF (TR-16)	5.4	5	4.4
Peak Flow (MGD)	0.59	0.93	1.8
Peak Flow (gpm)	410	650	1210
Pipe Size (in)	6	8	12
Velocity (fps)	4.7	4.1	3.5

The pipe sizes determined in Table 3 were used to estimate costs for the installation of the force mains for each scenario. For each scenario, one smaller pipe was included for a secondary wastewater force main, in agreement with good engineering practice, and one larger pipe was included to convey treated water (at a lower velocity). The pipe sizes for each scenario are shown in Tables 4.

Table 4: Force Main Sizes for Different Scenarios

Scenario	1	2	3
Primary Wastewater Force Main Size[1]	6 in.	8 in.	12 in.
Secondary Wastewater Force Main Size[2]	4 in.	6 in.	10 in.
Treated Water Main Size[3]	8 in.	10 in.	14 in.

Notes:

1. Sized to achieve 3 ft/s at peak flow.
2. Smaller wastewater force main to provide redundancy, assist with startup flows.
3. Sized to achieve 2 ft/s at peak flow.

WPCF Improvements

The Hyannis WPCF is currently undergoing an upgrade to its treatment processes which is expected to be complete by early 2009. This upgrade will expand the maximum month treatment capacity of the facility to 4.2 MGD. The heart of the upgrade is the installation of a new aeration tank, which expands the advanced secondary treatment process and nitrogen removal capabilities of the facility, which are the components that had been limiting the capacity of the overall facility. The new capacities of the various liquid stream unit processes are shown in Table 5 below.

Table 5: Capacities of Liquid Stream Unit Processes

Unit Process	Flow Condition	Capacity (MGD)
Grit Chambers	Peak	16.4
Parshall Flumes	Peak	15.6
Primary Clarifiers	Average	5.6
Secondary Treatment/Nutrient Removal	Max. Month	4.2
Secondary Clarifiers	Max. Month	4.8
Chlorination	Peak	13.8

While the current maximum month flow to the WPCF is approximately 2.5 MGD, wastewater facilities planning in the Town of Barnstable has resulted in the allocation of the additional flow capacity to several planned sewer extension areas within Barnstable. Thus, the connection of any portion of Yarmouth would require expansion of the Hyannis WPCF. This expansion would include an additional aeration tank to match the three existing. Each aeration tank provides approximately 1.4 MGD of treatment capacity under maximum month conditions. As such, none of the three scenarios considered would result in Yarmouth consuming the entire capacity of the upgrade.

However, as noted in Table 5, the current maximum month capacity of the secondary clarifiers is 4.8 MGD. Thus, although the current limiting factor can be upgraded by adding an additional aeration tank, the clarifiers would then become the limiting factor. While none of the scenarios for connecting flows from Yarmouth would result in total maximum month flows greater than 4.8 MGD, they would consume the remaining available capacity of the secondary clarifiers and necessitate an upgrade before additional Barnstable flows can be accommodated. The method for expanding the secondary clarification process

at the WPCF has not yet been determined. As such, costs developed in this memorandum do not incorporate costs associated with upgrading this unit process to meet flows beyond 4.8 MGD. Further investigation or negotiation will be required to determine a flow sharing agreement that accommodates the capacity of the clarification process. Other unit processes listed in Table 5 have sufficient capacity to accommodate the addition of Yarmouth flows, but Yarmouth may be responsible for some of the invested capital costs for the existing facilities.

In addition, the Hyannis WPCF will need to undergo a solids handling upgrade. This upgrade is planned for the time when the maximum month flow approaches 3.0 MGD, as the current solids handling capabilities do not reflect the upgraded maximum month capacity of the secondary treatment process. The design criteria of this upgrade may be altered depending on flow contributions from Yarmouth.

As part of the current upgrade, spare force main connections were installed in the headworks for future connections. Thus, if the force main is conveyed to the WPCF, there is an area for connection in place.

Once the wastewater has been treated at the Hyannis WPCF, the treated water is conveyed to a wet well and pump gallery that disperses treated water to the many sand beds on the site for groundwater recharge. Yarmouth's wastewater will be treated in conjunction with all other wastewater currently treated at the site and Yarmouth's share of the treated water will flow to a dedicated pump station to convey the water back to Yarmouth through the treated water force main. As such, the effluent quality will be similar to that which is currently achieved at the Hyannis WPCF. However, with a long treated water force main, there is potential for regrowth of bacteria in the pipe and exceedance of disinfection requirements at the discharge point in Yarmouth. The Town of Yarmouth should be prepared to make provisions for additional disinfection at the recharge site. These costs are not included in this evaluation. The costs are based on the installation of a dedicated pump station at the Hyannis WPCF to convey treated water back to Yarmouth. Further investigation may be performed in the future to determine if modifications to the pump gallery could alleviate the need for a separate pump station.

Capital Cost Estimating Methodology

In general, unit costs are used to estimate construction costs for items such as sewer piping, pump stations, excavation, backfill, mobilization, surface restoration, and other costs. Unit costs are developed based on a combination of the following:

- Schedule of values from recent pipeline construction jobs (water main, gravity sewer, force main and low pressure sewer) in Falmouth, Hyannis and other coastal areas in the Northeast.
- Past engineering experience for similar projects.
- Direct quotes from equipment manufacturers for selected items and other material costs.
- All costs reflect a December 2008 Engineering News-Record Cost Index of 8551.
- All capital costs include a 30% Contingency factor and a 30% Fiscal, Legal, and Engineering factor.

Costs for upgrades at the WPCF are based on the recent construction project of similar scope (installation of new aeration tank and blower) and similar engineering needs.

Sewer Capital Costs

The following is a list of unit cost items that have been included in developing the cost estimate, and a general identification, understanding and basis of these costs:

General Items -

1. *Sewer Testing* – a cost to the contractor to test the sewer for leaks and pressure in force main applications.

Sewer Items – Pipe and other appurtenance costs include:

1. *Gravity Mains* – a cost to excavate, install and backfill the gravity mains including pipe bedding. Costs rise as the size of the pipe installed and the depth of installation increases.

2. *Manholes* – cost to install manholes for gravity sewer service.

3. *Bypass Pumping* – a cost for the contractor to rent and operate bypass pumping equipment. Because the gravity sewer system is being replaced, the current system must be kept active

while the new pipes are being installed. When a portion of the existing system must be interrupted, bypass pumping will be required.

4. *Force Mains* – a cost to the contractor to excavate, install and backfill the force mains including pipe bedding required for the installation. Costs depend on the size of the pipe.

5. *Air Release / Flushing Manholes* – a cost to the contractor to install air release manholes at the high points in the force main and flushing manholes at the low points.

Trench and Restoration Items – Because all installation will be in a common trench (except in the immediate vicinity of the WPCF) one cost can be considered for trench excavation. The estimated trench width to install three pipes is 7 feet. Trench and restoration unit costs include:

1. *Control Density Fill* – a cost to install flowable fill required on state roads. Approximately 2.5 feet depth will be required in the trench for installation in state roads.

2. *Trench Base* – a cost to install trench sub-base prior to paving. Approximately 20" depth will be required on state roads, with 6" required on Town roads.

3. *Paving* – a cost to install paving for the full trench width. 7" is estimated for state roads, with 3-6" required on Town roads.

4. *Loam* – cost to install loam above trenches not located within the road.

5. *Police Detail* – a cost for police officers to direct traffic while the pipe is installed. Four officers per day are estimated for installation in the road, with two required when installed on the shoulder. 150 feet per day of trench is estimated due to the number of pipes being installed and the congested nature of the installation location.

6. *Directional Drilling* – Costs to directional drill and install piping beneath intersections. It is believed that this will be necessary for installation at the airport rotary and the intersection of Route 28 and Bearse's Way.

For the Task A sub-evaluations to connect to the closest gravity sewer, most existing gravity mains are increased by two sizes to accommodate the new flow, regardless of the scenario. For larger gravity

mains, the increase will be only one size. For instance, existing 8" sewer will be increased to 12", while existing 21" sewer will be increased to 24". This determination can be refined in the Task B evaluations with hydraulic modeling of the existing collection system to determine specific capacity requirements under each of the three scenarios.

WPCF Capital Costs

Costs for upgrades at the Hyannis WPCF are based on the recent construction that took place there that had a similar scope of work. In addition, upgrades to the solids handling facilities and installation of a treated water pump station would be required for full integration of flow from Yarmouth into the operations of the WPCF. The scope of work at the treatment facility is as follows:

- Construct new aeration tank
- Expand aeration building
- Install two new aeration blowers
- Upgrade sludge handling facilities
- Construct treated water pumping station
- Electrical additions/modifications
- Install yard piping and distribution box modifications
- Install new SCADA equipment

Of the items listed, the Town of Yarmouth would be expected to be fully responsible for the costs of the treated water pump station. For the other items, the flow from Yarmouth would only take up a portion of the capacity created. Costs for each scenario have been developed such that Yarmouth is only responsible for its proportion of the costs based on the flow contributed versus the capacity created by the project. As noted previously, costs for any upgrade to the secondary clarifiers is not included at this time, as no determination has been made as to the future upgrades necessary for this process.

No estimate is made for Yarmouth's use of capital facilities that are already installed, have excess capacity, and have significant value. These estimates would need to be completed through

discussions with the two Towns during the Task B evaluations. Upgrades to certain unit processes would not be required to accept flow from Yarmouth. However, Yarmouth will be utilizing a certain portion of the existing capacity, the value of which is yet to be determined. In the future, some discussion regarding or means of estimating the value of invested capital will need to take place and be incorporated before the full costs to Yarmouth for any WPCF upgrade can be determined in detail.

O&M Costs

There are three major additions to the operations and maintenance costs resulting from the addition of flow from Yarmouth:

- Additional power consumption
- Additional sludge disposal costs
- Additional maintenance of piping and treatment processes

The additional O&M costs do not reflect on-going operations and maintenance of the other facilities that would need to be shared with Yarmouth. Similar to the discussion on this subject in the capital costs section, no estimate is made for Yarmouth's portion of the O&M costs of the facilities that are already installed. **These estimates would need to be completed through discussions with the two Towns during the Task B evaluations.**

Power consumption and sludge disposal will be managed in a similar manner to the WPCF upgrade costs. Current power costs and sludge disposal costs are based on fiscal year 2008. Future sludge production quantities were scaled based on current values. Further investigation and negotiation at a later date will be required to precisely quantify the costs Yarmouth will be responsible for.

Cost Estimate Summaries

There are two aspects to the cost estimates for each scenario. The first is the wastewater and treated

water force mains from the Yarmouth border. The Town of Yarmouth is assumed to be responsible for the full cost of installation. As noted in the WPCF costs section above, the cost estimates for the WPCF upgrade have been adjusted based on the amount of flow that the Town of Yarmouth contributes. As noted in Table 1, this varies between 0.18 and 0.64 MGD on a maximum month basis. The addition of a new aeration tank will add 1.4 MGD to the overall plant capacity. Thus Yarmouth is responsible for between 12% and 43% of the total costs, depending on the scenario. The calculation is repeated for the sludge upgrade, which is forecast to increase the solids handling capacity to 5.5 MGD on a maximum month basis. The costs for each scenario using direct connection by force main as shown in Figure 1 are summarized in Table 6 below

Table 6: Sewer and WPCF Capital Costs for Direct Connection to WPCF[1]

Scenario	1	2	3
Wastewater Force Main Costs	$2.5 million	$2.8 million	$3.8 million
Treated Water Main Costs	$1.3 million	$1.5 million	$2.2 million
Trench Costs	$3.5 million	$3.5 million	$3.5 million
Total Force Main Costs	**$7.3 million**	**$7.8 million**	**$8.5 million**
Aeration Tank Costs	$600,000	$1.0 million	$2.2 million
Sludge Upgrade Costs	$40,000	$70,000	140,000
Yarmouth Share of WPCF Upgrade	12%	20%	43%
Effluent Pump Station Costs	$1.1 million	$1.6 million	$2.1 million
Yarmouth's Share of WPCF Costs	**$1.7 million**	**$2.7 million**	**$4.4 million**
Total	**$9.0 million**	**$11 million**	**$13 million**

Notes:
1. Costs estimated to 2 significant digits.

Table 7 summarizes the capital costs if the existing gravity collection system is rebuilt, and a new force main connects the Old Colony pumping station to the WPCF.

Table 7: Sewer and WPCF Capital Costs for Connection to Collection System[1]

Scenario	1	2	3
Wastewater Force Main Costs	$3.6 million	$3.6 million	$3.6 million
Treated Water Main Costs	$1.8 million	$2.0 million	$3.0 million
Gravity Sewer Rebuilding Costs	$1.3 million	$1.3 million	$1.3 million
Trench Costs	$1.5 million	$1.5 million	$1.5 million
Pump Station Upgrade Costs[2]	$4.1 million	$4.5 million	$4.9 million
Total Sewer Upgrade Costs	**$12 million**	**$13 million**	**$14 million**
Aeration Tank Costs	$600,000	$1.0 million	$2.2 million
Sludge Upgrade Costs	$40,000	$70,000	140,000
Yarmouth Share of WPCF Upgrade	12%	20%	43%
Effluent Pump Station Costs	$1.1 million	$1.6 million	$2.1 million
Yarmouth's Share of WPCF Costs	**$1.7 million**	**$2.7 million**	**$4.4 million**
Total	**$14 million**	**$16 million**	**$18 million**

Notes:
1. Costs estimated to 2 significant digits.
2. Details of the pump station and are uncertain and may include relocation to accommodate the future performing arts center.

As shown in Tables 6 and 7, preliminary cost estimates show that direct connection to the WPCF is less costly than rebuilding existing gravity sewer. These estimates can be refined in Task B when more detailed evaluation allows adjustment of the sizes of new gravity sewer.

Table 8 below summarizes the estimated operations and maintenance costs. Electrical costs represent a sharing of all power costs at the facility. While new power will be required to operate the new aeration tank, additional power will be consumed to operate other pieces of equipment at the site as well. Thus a straight line projection (based on flow) from current power consumption is utilized to predict

Yarmouth's share of future power costs. Labor and maintenance costs will have to be negotiated between the two towns.

Table 8: Yearly Electrical and Sludge Disposal Costs[1]

Scenario	1	2	3
Electrical Costs	$32,000	$53,000	$110,000
Sludge Disposal Costs	$16,000	$26,000	$56,000
Total	$48,000	$79,000	$170,000
Notes: 1. Costs estimated to 2 significant digits.			

Another method that should be considered to estimate O&M costs is the current sewer user rate. This is the rate charged by the Town of Barnstable to users for collection and treatment of wastewater. The current rate is $3.63 per 100 ft^3 for residential customers and varies slightly for other user types. This corresponds to a rate of approximately $4,900 per million gallons. Thus, the total cost per year for each scenario can be estimated based on the average flow, as shown in Table 9 below.

Table 9: Yearly Costs at Sewer Billing Rate[1]

Scenario	1	2	3
Average Flow (MGD)	0.11	0.19	0.40
Total Yearly Flow (MG)	40	69	146
Billing Rate ($/MG)	$4,900	$4,900	$4,900
Total Yearly Cost	$200,000	$340,000	$720,000
Notes: 1. Costs estimated to 2 significant digits.			

As shown in Tables 8 and 9, there is a significant difference between a projection based on current electrical and sludge disposal costs and a projection based on the full sewer billing rate. Further discussion between the two municipalities is recommended in the future to determine what structure any agreement on cost-sharing would take. This will allow more detailed study concerning the cost impacts of connecting flow from Yarmouth to the Hyannis WPCF.

SUMMARY OF FINDINGS AND RECOMMENDED NEXT STEPS

Direct connection to the Hyannis WPCF with force mains for wastewater treatment and treated water return is less expensive than connection to the closest portion of the existing gravity system. The capital costs range from $9 million to $13 million and the operating maintenance costs range from $0.048 million to $0.17 million per year based on current electricity and sludge disposal costs. If operations costs are based on the full sewer billing rate, the yearly costs to Yarmouth rise substantially.

These costs should be combined with the costs for the collection and recharge facilities needed in Yarmouth for each scenario to develop total regional scenario costs. The total regional scenario costs can be compared with costs for Yarmouth to treat the flows at new treatment facilities in Yarmouth to provide input on which treatment concept could be less expensive.

If the regional treatment concept appears to be less expensive, additional cost development should be pursued as part of the Task B evaluations.

Attachment A

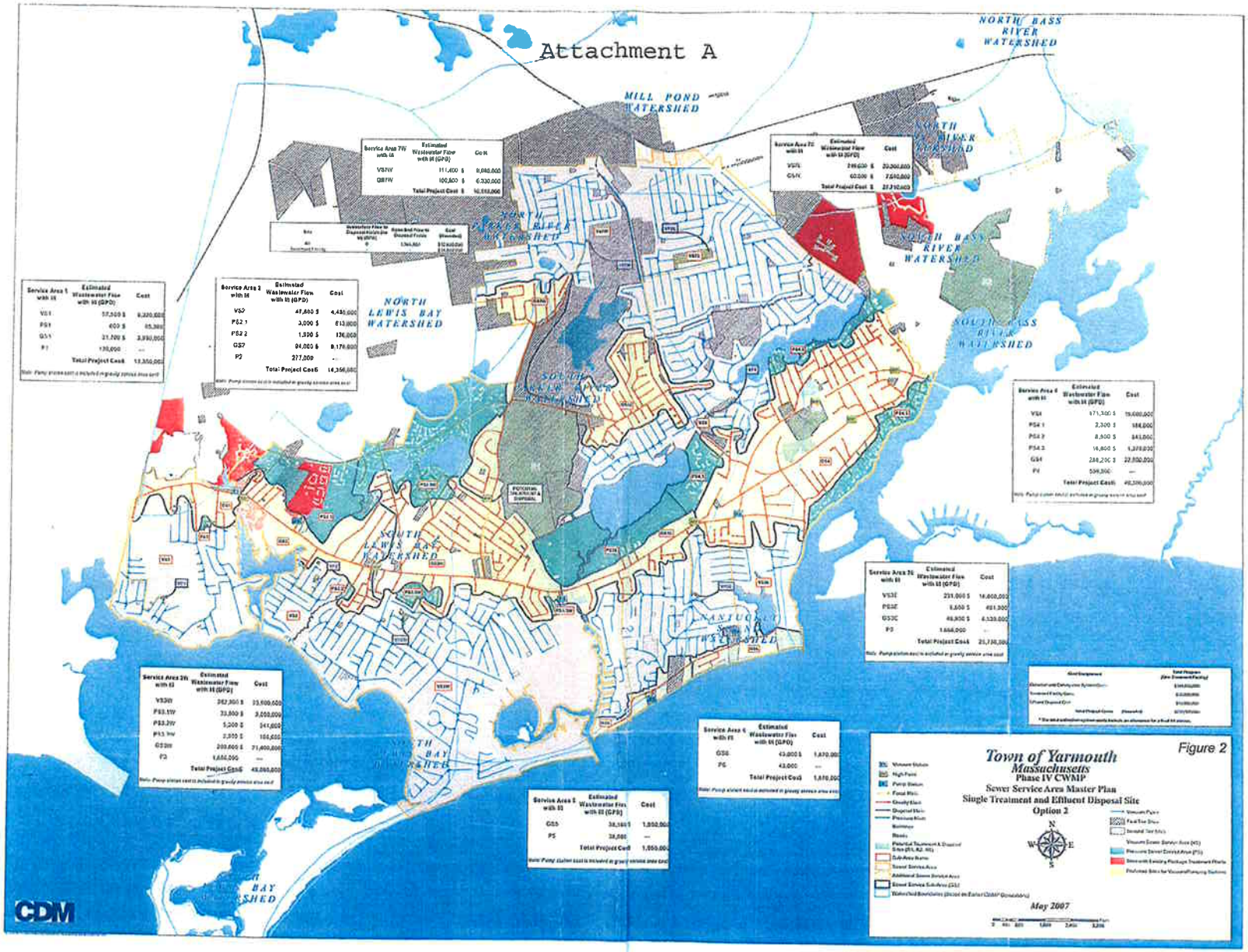
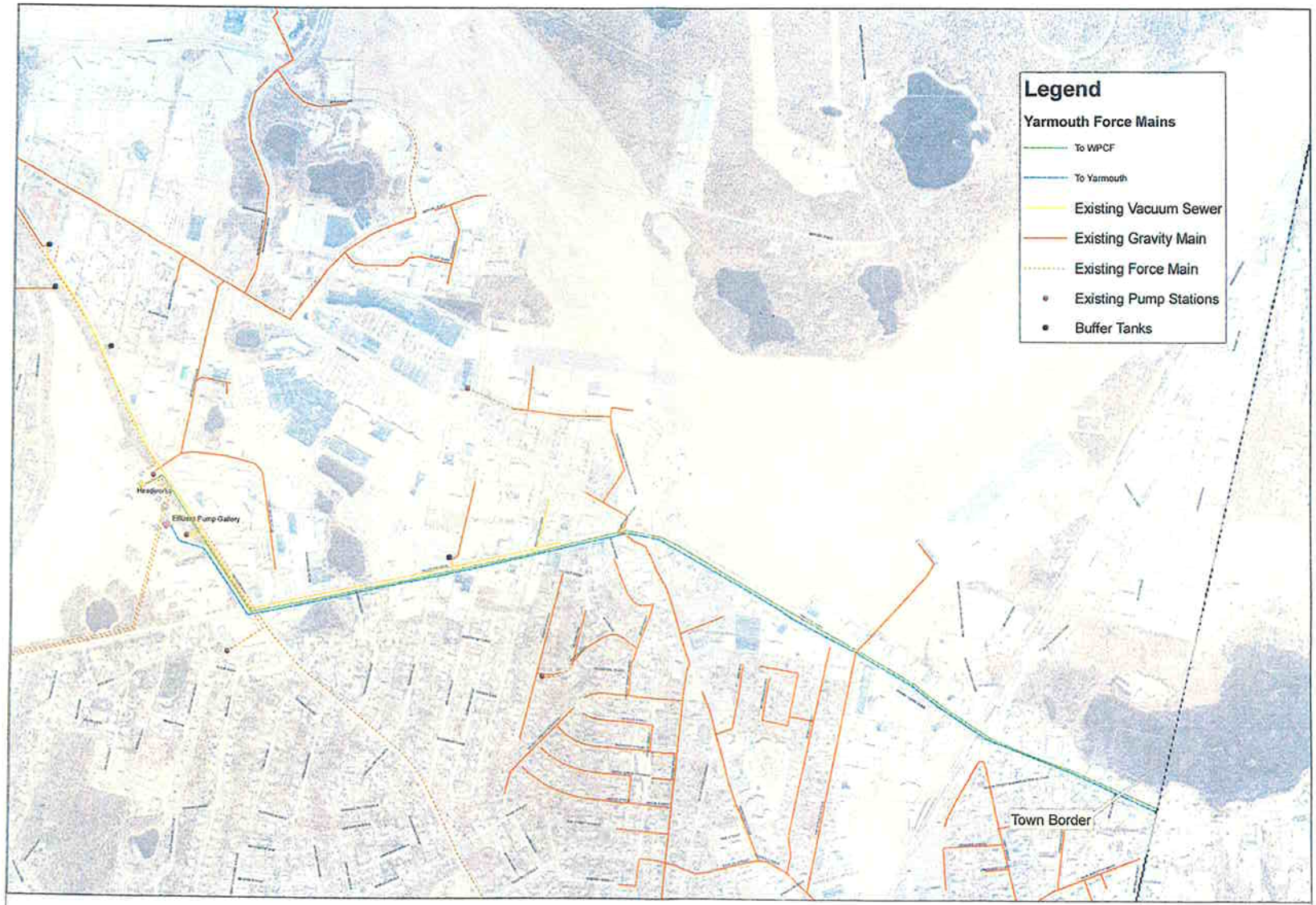
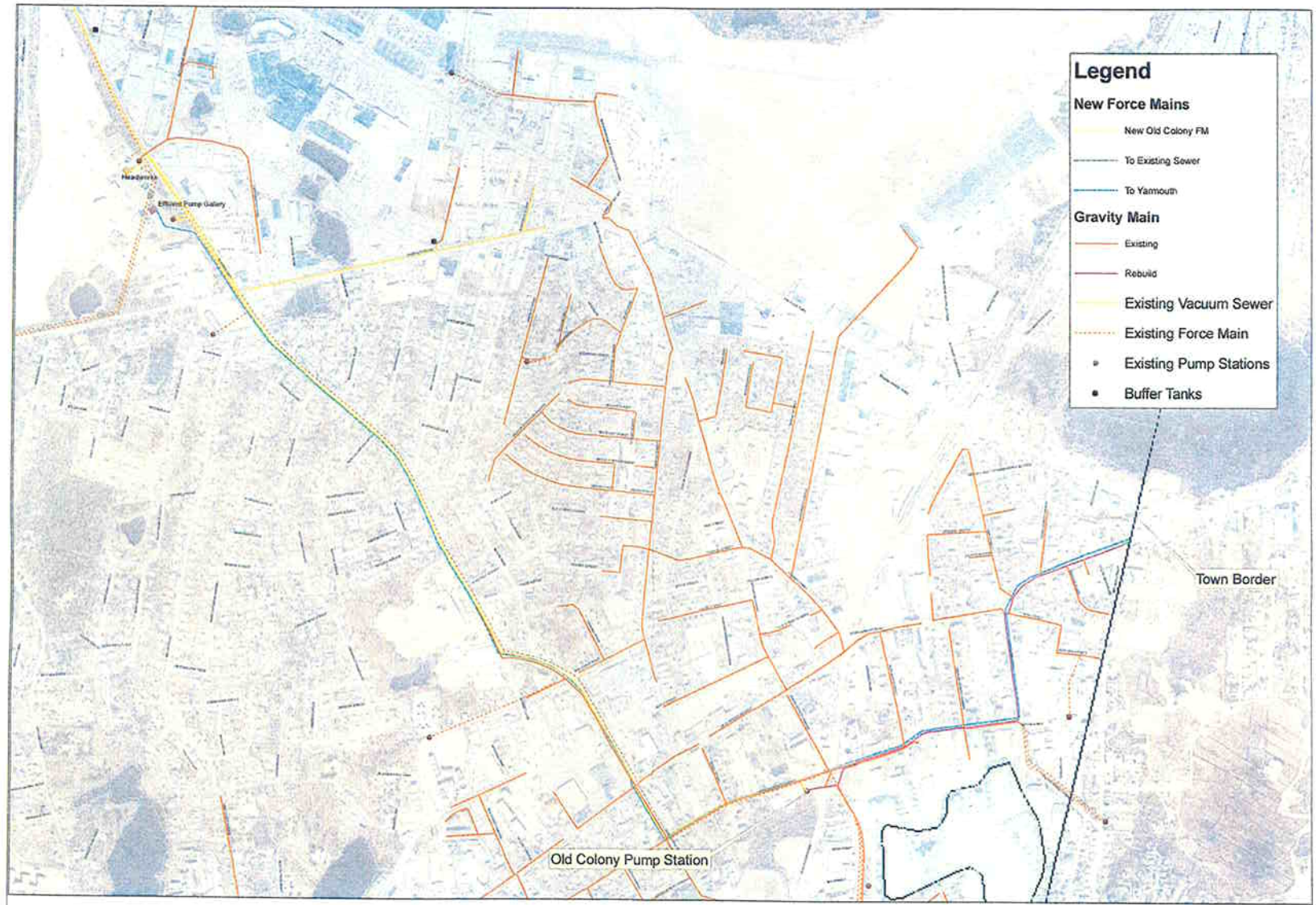


Figure 2


Legend
Yarmouth Force Mains
To WPCF
To Yarmouth
Existing Vacuum Sewer
Existing Gravity Main
Existing Force Main
Existing Pump Stations
Buffer Tanks
Effluent Pump Gallery
Town Border
0 250 500 1,000 1,500 2,000 Feet
1 inch equals 250 feet
STEARNS & WHELER
TOWN OF BARNSTABLE, MASSACHUSETTS
Yarmouth Sewer Area Connection
Direct Force Main Connection
FIGURE 1


Legend
New Force Mains
New Old Colony FM
To Existing Sewer
To Yarmouth
Gravity Main
Existing
Rebuild
Existing Vacuum Sewer
Existing Force Main
Existing Pump Stations
Buffer Tanks
Effluent Pump Gallery
Old Colony Pump Station
Town Border
0 250 500 1,000 1,500 2,000 Feet
1 inch equals 250 feet
STEARNS & WHEELER
TOWN OF BARNSTABLE, MASSACHUSETTS
Yarmouth Sewer Area Connection
Existing Collection System Connection
FIGURE 2

Appendix 1-5

Town of Barnstable Nutrient Management Project Scope, August 2008

TOWN OF BARNSTABLE
NUTRIENT MANAGEMENT PLANNING PROJECT

PROJECT SCOPE

August 14, 2001
(Updated August 25, 2008)

The purpose of the Project Scope is to provide a listing of the steps needed for nutrient management planning in Barnstable. Listing these tasks allows Town departments, regional and state agencies, and public interest groups to understand the Nutrient Management Planning process, and efficiently provide input to the Project. The Project Scope is expected to have the following main uses:

- Budgeting and scheduling tool for nutrient management planning.
- Basis for the division of planning tasks within the Town of Barnstable.
- Basis for professional agreements for the specialized consulting services needed for nutrient management planning.
- Low interest loan application for the State Revolving Fund (SRF) loan program.
- Development of an environmental review document for the Project through the joint Massachusetts Environmental Protection Act (MEPA) and Cape Cod Commission Development (CCC) review process.
- Development of public education materials throughout the Project.

Portions of this scope have been completed and the scope is annotated in parenthesis to state the Town's progress on these scope items.

PHASE I – ENVIRONMENTAL MONITORING AND MODELING, AND DEVELOPMENT OF NUTRIENT LIMIT TARGETS.

This is the first phase of nutrient management planning, and it involves the assessment of the nutrient related health of the coastal embayments and fresh water ponds. It is the phase when nutrient loading targets are identified for each embayment by UMass SMAST and the Massachusetts Estuaries Project (MEP). These targets are a measure of the nitrogen assimilative capacity (critical nitrogen loading limits) of each embayment. It is the phase when the water quality of the fresh water ponds is measured and the need for phosphorus remediation in the ponds, and their watersheds, is estimated. The nitrogen limits have now (August 2008) been set by the MassDEP for the Popponessett Bay, Three Bay, Centerville River and Lewis Bay Estuaries. The MEP is still working on the Barnstable Harbor limits. The Town is still working on water quality monitoring, and there is still a need to prioritize the remediation of several freshwater ponds. Updates and status are provided below in italics.

A. Perform Water Quality Monitoring of Coastal Embayments and Ponds.

1. Prepare a water quality-monitoring program for the coastal embayments, ponds and fresh water streams. *(This is completed by SMAST)*

- Review existing data, reports, previous water quality projects and ongoing monitoring programs.
- Prepare a Sampling and Analysis Quality Assurance Project Plan (QAPP) identifying all monitoring needs, resources, protocols, parameters, locations and transportation methodologies.
- Train volunteers to perform the monitoring.
- Provide needed monitoring equipment.
- Establish monitoring strategies, parameters, schedule, and locations.

2. Monitor the water quality in the Town's coastal embayments as detailed in the QAPP. *(This work continues for the estuaries)*

- Collect samples.
- Send samples to the SMAST laboratory for analysis.
- Compile and review data and summarize water quality trends.

- Prepare Technical and TMDL Reports. (The TMDL Report for Lewis Bay is still outstanding as well as the Technical and TMDL Reports for Barnstable Harbor.)

3. Monitor and establish water quality in fresh water ponds. *(This work continues)*

- Participate in the Ponds in Peril Program which will assist in sampling of many Barnstable ponds.
- Collect and analyze additional pond water quality samples as needed based on previously collected data and studies, and data collected through the Ponds in Peril Program.
- Send samples to a qualified laboratory for analysis.
- Compare and review data, and present water quality findings and trends.
- Prepare Pond Assessment Report. *(Completed by CCC)*

B. **Collect Additional Environmental Parameters.**

1. Collect and analyze embayment sediments to determine nitrogen loadings from this nitrogen source. *(SMAST task)*

2. Collect and analyze additional biological parameters from embayments to allow characterization of embayment health. Possible biological surveys include: *(SMAST task)*

- Eelgrass Survey
- Macrophite Survey
- Survey of benthic animal populations

3. Collect and analyze additional parameters (as needed) from ponds to allow characterization of pond health.

C. **Assess the Nutrient Related Health of the Coastal Embayments and Ponds.** *(This is completed for several embayments and some ponds)*

1. Integrate the available water quality data, aquatic plant surveys, benthic animal surveys and sediment surveys to assess the health of these water resources.

2. Compare existing water quality and biological parameter information with historic information including

- Eel grass coverage
- Macro algae data and observations
- Algae bloom data and observations
- Sediment types

3. Present various levels of environmental stress observed in the water bodies documenting if the waterbodies are currently stable or are changing in their ecological health.

D. **Perform Embayment Flushing Analysis and Hydrodynamic Model Development.** *(This work continues by SMAST for Barnstable Harbor)*

1. Determine the usefulness of the hydrodynamic model recently developed for the Three Bay System. Perform new hydrodynamic modeling for this area as needed.

2. Develop the Bathymetry for the coastal embayments using available information and new bathometric surveys as needed.

3. Measure the tidal fluctuation within the embayments with tide gages and velocity meters through one complete lunar cycle.

4. Develop a hydrodynamic model for the embayments based on the tidal fluctuation, bathometry and appropriate modeling techniques for the embayments.

E. **Develop Existing and Future Nitrogen Loadings to Coastal Embayments.** *(This work continues for Barnstable Harbor)*

1. Develop existing nitrogen loadings to the watershed groundwater system based on the following factors and concentrations:

- Existing land use.

- Water consumption data.
- Rainfall and evaporation rates for Barnstable.
- Nitrogen concentrations infiltrating from natural areas, golf courses, lawns, agricultural areas, landfills, impervious areas, and septic systems.
- Nitrogen loadings from wastewater treatment plant discharges.

2. Develop watershed nitrogen loadings for all significant nitrogen sources in the watershed. Typical sources include:

- Wastewater discharges
- Stormwater runoff from roads and roofs
- Infiltration from lawns, golf courses and agricultural areas
- Infiltrated nitrogen at the capped landfill site
- Infiltration from natural areas

3. Evaluate nitrogen attenuation factors and considerations for the watersheds based on watersheds characteristics (such as freshwater wetlands and bordering salt marshes) and actual water quality data from ponds, streams, and groundwater.

4. Develop nitrogen loadings to the coastal embayments based on loadings to the ground water system and the attenuation in the watersheds.

5. Develop future nitrogen loadings to the coastal embayments based on the following factors:

- Land use within the watersheds at the 20-year design condition as well as the build out condition.
- Similar factors, concentrations, and sources as listed for the existing nitrogen loading development.
- Nitrogen attenuation factors evaluated for the existing nitrogen loadings.

F. **Perform Water Quality Modeling.** *(This work continues for Barnstable Harbor)*

1. Develop and calibrate a water quality model to evaluate the mobilization and fate of total nitrogen in the embayment systems based on the hydrodynamic model and the following factors and considerations:

- Existing watershed nitrogen loadings.
- Time of travel from the watershed to the embayments.
- Nitrogen attenuation in the watersheds.
- Existing nitrogen loadings (and nitrogen sinks) from embayment sediments.
- Nitrogen uptake.
- Water column nitrogen measurements.
- Assessment of nutrient related health.

2. Run the Water Quality Model to understand and document the potential responsiveness of the modeled water quality to loading variations including:

- Future nitrogen loadings.
- Existing nitrogen loadings with portions of the wastewater loadings removed.
- Reduced loadings to meet desired water quality concentrations or standards.
- Modified sediment loading based on potential reductions of the watershed loadings.

3. Investigate potential water quality improvements if watershed nitrogen attenuation was maximized or promoted in modified pond or wetland systems.

G. **Develop Nitrogen Loading Targets.** *(This work continues for Barnstable Harbor)*

1. Develop nitrogen-loading targets for each embayment based on all of the components of this phase as well as CAC, TAC, regulatory, public and other input after review of preliminary findings.

2. Document the nitrogen loading targets in the nutrient loading assessment report (Technical and TMDL Reports). These are the loading targets that will be used in future nitrogen management evaluations to find cost effective nitrogen mitigation solutions.

H. **Prepare the Nutrient Loading Assessment Report. (Technical and TMDL Reports)** *(This work continues for Lewis Bay and Barnstable Harbor)*

1. Prepare reports to document the components of this phase.

2. Submit this report for review as discussed in Phase 6.

PHASE II – NUTRIENT MANAGEMENT NEEDS ASSESSMENT

Phase II consists of the tasks to define the nutrient management needs of the Town. Management needs will be defined by identifying the Town goals for nutrient management, evaluating the existing conditions, developing projections of the future conditions, and then comparing these goals and conditions to the water quality limitations of the Town's water bodies.

The purpose of the nutrient management needs assessments is to evaluate and define the nutrient management needs of the Town.

The main tasks of this phase are listed below:

A. **Review and Summarize Town Issues and Data.** Including:

1. Nutrient management issues developed and discussed in Phase I.

2. Town governmental issues including:

- Town goals and objectives affecting nutrient management.
- Local rules and regulations.
- Growth management policies.
- Affordable housing initiatives.
- Fiscal constraints.
- Institutional constraints.

3. Available technical data including:

- Water quality and other monitoring data.
- Land use information.
- Build out projections.
- Areas of Town served by public and private water supplies.
- Zone of contribution (ZON) delineations for public water supplies.
- Soils information and area of Town with high groundwater conditions.
- Areas of Town served by on-site systems, cluster treatment systems and the Hyannis WPCF.
- Performance of on-site systems and existing on-site nitrogen removal systems.
- Performance of Barnstable Middle School WWTF and all other cluster and packaged treatment plants.
- Hyannis WWPF performance.
- Properties with septic system failures.
- Geographic Information System (GIS) information.

4. Previous and on-going projects related to nutrient management planning including:

- Town Wastewater Facilities Planning Study
- Recent and planned upgrades to Hyannis WPCF
- Stormwater remediation projects
- No-Discharge Area designation in Town's coastal areas
- Town DCPC nomination efforts
- Land acquisition efforts
- Pond and embayment studies discussed in Phase I Report

B. **Review and Summarize Regulatory Issues Affecting Nutrient Management Planning.** Including issues related to:

- Watershed delineations to coastal embayments and freshwater ponds.
- Nitrogen standards for coastal waters.
- On-site systems and the nitrogen management aspects of the Title 5 regulations.
- Ocean Sanctuaries Act and the ability to discharge treated effluent through an ocean outfall.

- Wetland regulations.
- Groundwater standards and the discharge of treated effluent to the groundwater system.
- Drinking water standards and the ability to site an effluent discharge in Cape Cod's Sole Source Aquifer.
- Regulations pertaining to usage and possible moratorium on nitrogen fertilizers.
- Privately owned wastewater treatment facilities.
- Septic systems owned and operated by community groups
- Collection and treatment of stormwater runoff
- Wastewater treatment and discharge requirements
- Coastal Zone Management (CZM), U.S. Corps of Engineers, and FEMA requirements on modifications to and remediation of coastal water bodies

C. **Evaluate, Summarize, and Describe Existing Conditions in Town.** Including:

1. Nutrient loadings and limitations as presented in Phase I

2. Groundwater and water supply conditions including:

- Ground water levels
- Flow directions and watershed delineations
- Water quality
- Public water supply areas, Zone II delineations, and water quality
- Water usage and properties that use large flows of water exceeding 10,000 gallons/day
- Areas of Town that have many properties with private water supplies

3. Land use and demographics including:

- Populations
- Land use as recorded by the Tax Assessor's records
- Seasonal nature of land use
- Protected and/or environmentally sensitive areas

4. Wastewater treatment facilities.

- On-site systems
- Hyannis WPCF
- Marstons Mills Middle School WWTF and other cluster and packaged treatment facilities.

5. Soil characteristics

6. Stormwater flows and management systems

7. Town Landfill and water quality at the landfill site

D. **Identify the Goals and Objectives of the Town Related to Nutrient Management.** Including:

- Growth policy
- Residential development
- Commercial and economic development
- Affordable housing
- Transportation and traffic control
- Wastewater treatment and discharge
- Groundwater management
- Regulatory initiatives
- Fiscal/financial management
- Zoning

E. **Evaluate Summarize and Describe Future Conditions in Town.** Including:

- Nutrient loadings and limitations presented in Phase I
- Findings of previous build out analysis
- Potential redevelopment in Hyannis
- Future wastewater flows and loadings with seasonal variation
- Proposed wastewater improvements at the Hyannis WPCF and proposed sewer extensions recommended as part of the wastewater facilities plan

- Proposed affordable housing projects
- Potential new public water supplies and the creation of new ZOC areas
- No action alternative (this is the future condition of the Town if nutrient management strategies are not implemented in the future)

F. **Identify Nutrient Related Areas of Concern and Prepare Nutrient Management Needs Assessment Report.**

1. Compare the identified Town goals to the existing and projected future condition to identify areas in town that do not meet the goals at present, and/or will not meet the goals at the projected future conditions.

2. Identify watersheds that currently or will exceed nutrient loading thresholds and targets in the future.

3. Identify the nutrient management areas of concern which are the areas in Town that cannot meet the identified goals and the identified nutrient loading thresholds and targets.

4. Summarize the existing and future conditions for these areas to facilitate the evaluation of nutrient management solutions in future phases.

5. Summarize the nutrient management needs of the Town.

6 Identify data gaps and additional information needed to proceed efficiently with the project.

7. Prepare the Nutrient Management Needs Assessment Report in accordance with State guidelines for nutrient management and wastewater management reports, and guidelines for projects funded by State Revolving Fund (SRF) loans. Summarize the analysis and findings of this project phase in the Needs Assessment Report.

PHASE III - IDENTIFICATION AND SCREENING OF ALTERNATIVE SOLUTIONS AND SITES

Phase III reviews, identifies, and develops solutions which may be feasible to meet the Town's nutrient management needs. These solutions are then summarized and screened to retain only the most feasible. Alternative wastewater treatment sites are also identified and screened to identify the most feasible sites that will balance costs, environmental impact and public acceptance. Feasible solutions (technical as well as management) and sites are then grouped into alternative scenarios for detailed evaluation in the next phase.

The purpose of the identification and screening of alternative solutions and sites is to identify nitrogen remediation solutions and then reduce the number of solutions to the most feasible ones for detailed evaluation.

The tasks of this phase are listed below.

A. **Identify, Review and Summarize Alternative Solutions to Meet the Town's Nutrient Management Needs.** Investigate the following groups of technologies, opportunities and alternatives.

- Modification to Town Zoning and land use requirements
- Stormwater mitigation opportunities
- Fertilizer mitigation opportunities
- Individual on-site wastewater nitrogen removal technologies
- Community (cluster) wastewater nitrogen removal technologies
- Centralized wastewater treatment and nitrogen removal technologies
- Centralized wastewater collection and residual management technologies
- Wastewater flow and loading reduction opportunities
- Wastewater reuse opportunities
- Solutions to encourage greater nitrogen attenuation in the watersheds
- Financing scenarios
- Infrastructure management scenarios

B. **Screen the Alternative Solutions to Identify the Most Feasible Ones for Detailed Evaluation.**

1. Prepare a screening methodology for regulatory review. The methodology will include a standard set of criteria to screen the technologies.

2. Prepare a screening matrix which provides a side-by-side comparison of the various alternatives within a group.

3. Select the most feasible alternatives for detailed evaluation.

C. **Identify and Screen Potential Sites for Nutrient Management Facilities.** Including wastewater treatment and discharge sites for cluster systems, centralized facilities, and stormwater treatment and discharge sites.

1. Prepare a facilities site and screening methodology for regulatory and project review. The methodology will include a standard set of criteria to screen the sites.

2. Use the Town GIS to identify and tabulate information on potential sites.

3. Compare a screening matrix which provides a side-by-side comparison for potential sites.

4. Visit the sites to form additional observations about the sites.

5. Meet with Land Bank representatives and other land preservation groups to explore possibilities of using preservation land for nitrogen management facilities.

6. Select the most feasible sites for detailed evaluation.

7. Identify subsurface or environmental investigations needed to demonstrate the feasibility and acceptability of particular sites for wastewater treatment and disposal facilities. Potential investigations include:

- Wetland delineations

- Endangered species survey
- Archeological survey
- Test pit and percolation investigations
- Pump testing and hydraulic conductivity testing

D. **Group Feasible Solutions and Sites into Alternative Nutrient Management Scenarios.**

1. Group the feasible solutions with the input of Town staff and Citizen Advisory Committee members.

2. Summarize the rational for grouping various feasible solutions into the nutrient management scenarios.

E. **Prepare the Nutrient Management Alternative Screening Report**

1. Summarize the evaluations of Phase III.

2. Prepare this report as an interim report for public and regulatory review.

PHASE IV – DETAILED EVALUATION AND DEVELOPMENT OF THE NUTRIENT MANAGEMENT PLAN

Phase IV provides a detailed analysis of costs and non-monetary factors for the alternative nutrient management scenarios. It also performs the environmental impact analysis for these alternative scenarios in accordance with State and Cape Cod Commission requirements. It presents the recommended nutrient management plan to mitigate the nutrient related problems in each watershed. This plan will include the scheduled implementation steps for new facilities, management structures, local regulations, and funding requirements. The main tasks for this phase are listed below.

The purpose of this phase is to select the most appropriate nitrogen management plan for Barnstable based on a cost effectiveness analysis, analysis of non-monetary factors, and an environmental impact analysis.

The main tasks for this phase are listed below:

A. **Perform Subsurface and/or Environmental Investigations and Modeling for Potential Nutrient Management Sites.** Potential investigations include:

- Wetland delineations
- Endangered species survey
- Archeological survey
- Test pit and percolation investigations
- Pump testing and hydraulic conductivity testing

B. **Prepare a Methodology of the Planned Detailed Evaluation for Project and Regulatory Review.**

1. Describe the methodology and evaluation steps.

2. Prepare a timeline for regulatory and project team input.

3. Identify the evaluation criteria and how they will be used to rate the alternative.

C. **Perform Present-Worth Evaluations of the Alternative Nutrient Management Scenarios.**

1. Develop unit costs for capital and operational & maintenance (O&M) costs.

2. Develop capital costs for each alternative scenario.

3. Develop O&M costs for alternative scenario.

4. Perform a present-worth analysis to equate the capital cost and twenty years of O&M costs of each alternative scenario to a present worth cost. Compare present worth cost of the alternative scenarios to identify the most cost effective scenario. The purpose of this analysis is to develop a comparable cost for alternative scenarios that may have different cost structures. (One alternative scenario may have high capital cost but low O&M cost; while another alternative scenario could have low capital cost but high O&M cost.)

D. **Perform Non-Monetary Evaluations of the Alternative Scenarios.**

1. Compare non-monetary factors of each scenario such as:

- Anticipated public acceptance
- Ease of implementation
- Land area requirements
- Energy use
- Flexibility for changing requirements
- Maintenance requirements and complexity of operations
- Nitrogen mitigation performance
- Regulatory feasibility
- Expected Growth

2. Develop a numerical rating system to quantify these non-monetary factors

E. **Perform an Environmental Impact Analysis of the Alternative Scenarios.**

1. Perform an environmental impact analysis in accordance with the guidelines and regulatory procedures of the Cape Cod Commission and the Massachusetts Environmental Protection Act (MEPA) Office of the state.

F. **Evaluate the Present-Worth Analysis With the Non-Monetary Evaluation and the Environmental Impact Analysis to Select the Most Appropriate Management Scenario.**

1. Develop evaluation summaries for project team and regulatory review.

2. Select the most appropriate management scenario.

G. **Develop and Present the Recommended Nutrient Management Plan, and Prepare the Nutrient Management Plan and Draft Environmental Impact Report (DEIR).**

1. Briefly summarize the previous evaluations and project phases.

2. Present the findings of any subsurface or environmental investigations performed at the beginning of this phase.

3. Present a summary of the evaluations and analysis performed in this phase.

4. Present fertilizer recommendations including the following possibilities:

- Public education programs.
- Town regulations to monitor and control proper application of fertilizer.
- Development of specifications on the approved types of slow release nitrogen fertilizer to be used in Town.
- Zoning changes to encourage smaller lawns and the disturbance of less natural ground cover.

5. Present stormwater management recommendations to manage and mitigate nutrient impacts from stormwater including:

- Prioritization and conceptual design of stormwater projects to mitigate remaining stormwater discharges.
- Zoning changes to minimize the creation of impervious surfaces and the production of stormwater.

6. Present the wastewater management recommendations including:

a. Identify the recommended wastewater management approach for all areas of Town including:

- Areas to be served by sewers and advanced nitrogen removal at one or more new centralized wastewater treatment facility(s) in the western portion of Barnstable.
- Areas to be served by sewers and community (cluster) wastewater treatment facilities
- Areas to be served by on-site nitrogen removal systems serving individual homes or small groups of homes.
- Areas of Town with minimal nitrogen sensitivity that can be served by non-nitrogen removal Title 5 systems

b. Present detailed description, O&M requirements, conceptual design, layout, design flows and loadings, and expected performance of all recommended wastewater management facilities including the following possibilities:

- Modification and expansion of the Hyannis WPCF
- New centralized treatment facility(s) in the western part of Barnstable
- New community (cluster) treatment facilities

c. Present detailed description of approved on-site nitrogen removal systems to serve individual homes or small groups of homes; and the operations, maintenance, and management requirements associated with these systems.

d. Present detailed description of Title 5 systems (non-nitrogen removal systems) to serve areas of Town with minimal nitrogen sensitivity, and the operations, maintenance, and management requirements associated with these systems.

e. Present detailed description, conceptual design, design capacities, and O&M requirements of recommended effluent discharge facilities.

f. Present detailed descriptions, conceptual design, O&M requirements and design capacities of recommended wastewater residuals management facilities including:

- Areas to be served by sewers and advanced nitrogen removal at the Hyannis WPCF
- Septage management facilities and managed pumping of septic tanks.
- Screenings, grit and biosolids management and disposal.

g. Capital and O&M costs for all recommendations.

7. Present watershed modification recommendations to create wetlands and other fresh water environments where greater nitrogen attenuation can occur in the watershed to minimize nitrogen loading to coastal embayments.

8. Present pond remediation recommendations including:

- Prioritization of pond remediation projects.
- Detailed description of remediation program and technology for each pond.
- Identification of septic system discharges that need to be relocated to distances greater than 300 feet from freshwater ponds, streams and rivers.
- Capital and O&M costs for the pond remediation.

9. Present the institutional changes and management structures needed to operate and implement the nutrient management strategies recommended including:

- Changes in Town staffing
- Town departmental responsibility shifts
- Possible management district formation
- Possible inter-municipal agreements
- Capital and O&M costs for these management changes

10. Present the implementation schedule for implementing the recommendations.

11. Recommend CIP budgeting needed for the implementation.

H. **Submit the Nutrient Management Plan and DEIR for Regulatory and Public Reviews.**

PHASE V – RESOLUTION OF REMAINING ISSUES AND PROJECT COMPLETION

This phase is needed to complete the Environmental Impact Review Process and finalize the Nutrient Management Plan. This phase includes the following tasks:

A. **Resolve Remaining Issues.** There maybe remaining issues to address which will require the following tasks:

- Reinvestigate previous analyses as required
- Investigate additional alternatives and/or sites as required
- Develop additional information as required

B. **Modify the DEIR to Prepare the Nutrient Management Plan and FEIR, and Submit it for Public and Regulatory Review.** The DEIR will need to be modified to include any requested information to produce a FEIR. The FEIR will then be submitted to the regulatory agencies for review.

PHASE VI – ENVIRONMENTAL AND PUBLIC REVIEW PROCESS

This phase is the creation and coordination of the environmental and public review process that proceeds throughout the whole project.

The environmental review process needs to follow the Cape Cod Commission/Massachusetts Environmental Policy Act (CCC/MEPA) Joint Review Process (CCC/MEPA, 1991) which typically uses public hearings after the submittal of each project document. The Town can also request a more formalized Joint Review Process described as "Special provisions for Major and Complicated Projects" and detailed in State Regulation 201CMR11.12. This review process requires regulatory review of each project document and can require additional review components as requested by the Town. Both environmental review processes require many regulatory meetings and public hearings to coordinate the flow of information to the various regulatory agencies.

The public review process is closely related to the environmental review process. It will contain additional items needed to properly disseminate information to the Town's community groups and to the Town Public. Proper public education is needed to ensure that the recommended plan will be approved by the Town Council and by the voters in any proposition 2½ override referendums.

The purpose of this phase is to create and coordinate an environmental and public review process which will inform project participants and the Town Public, and ensure that the recommended plan will be approved by the Town Council and Town Voters.

The main tasks of this phase are listed below:

A. **Establish and Utilize a Citizens Advisory Committee.** A Citizens Advisory Committee (CAC) is typically comprised of Town residents with diverse views that fairly represent all points of view. The purpose and function of the CAC include:

- Become knowledgeable about all aspects of the Project.
- Make recommendations to the Town and Town Decision Makers
- Represent members of the public that cannot attend public meetings.
- Investigate and develop recommendations on issues as they arise.

The CAC will meet periodically throughout the Project as desired by CAC members. Meeting notes will be maintained.

B. **Establish and Utilize a Technical Advisory Committee.** A technical Advisory Committee (TAC) is typically comprised of representatives of Town technical staff, representations from regulatory agencies, and professional staff from interested agencies. The Town has already assembled a Nutrient Management Team which is considered a TAC. The current representation of this group includes:

- Town Department of Public Works
- Town Health Department
- Town Conservation Department
- Town Planning Department
- Cape Cod Commission
- Massachusetts DEP
- Three Bays Preservation, Inc.

The TAC will meet regularly throughout the Project to be sure that technical issues are addressed. Meeting notes will be maintained.

C. **Prepare and Conduct a Public Participation Program.** A public participation program is needed to develop appropriate public education materials to inform the public of Project activities and findings. Public education tasks include:

- Provide public notification of all public meetings and hearings.
- Develop Project summaries before and after each major phase of the Project.

- Develop and distribute news bulletins to the press to keep project activities in the news.
- Maintain Project information dissemination booths at public libraries and other public locations. These tables will display information about the project as well as act as a distribution point for project summaries.
- Organize presentations to the Town citizen and public interest groups.
- Prepare one or more video(s) which can be shown on cable television or loaned to community schools or groups.
- Organize workshops with community groups to facilitate greater information exchange between Project team members and the public.

D. **Prepare, Submit and Coordinate the Public Review of the Environmental Notification Form and Development of Regional Impact Document.** The Environmental Notification Form (ENF) and Development of Regional Impact (DRI) document briefly describes the main issues of the Project and presents a Project Scope that describes the major tasks to be accomplished by the Project. The ENF/DRI document will be based on the Plan of Study.

E. **Coordinate the Public Review of the Other Project Documents.**

1. Coordinate the public review of the other project documents identified in previous phases including:

- Water Quality and Nutrient Loading Assessment Report
- Nutrient Management Needs Assessment Report
- Nutrient Management Alternatives Screening Analysis Report
- Nutrient Management Plan and Daft Environmental Impact Report (DEIR)
- Nutrient Management Plan and Final Environmental Notification Report (FEIR)

2. Attend review meetings and public hearings for these documents.

3. Receive the MEPA, CCC and other comments and address them in a letter.

F. **Coordinate and Attend Meetings and Public Hearings.**

PHASE VII – PROJECT MANAGMENET AND FUNDING

A. **Develop and Administer State Revolving Fund Loan Applications and Agreements.**

B. **Develop and Administer Contract Agreements for Specialized Services.**

C. **Provide Overall Project Management and Coordination.**

Appendix 2-1

Draft Memorandum on Sewer Phasing Evaluation and Implementation Schedule, November 2008

STEARNS & WHELER LLC
Environmental Engineers & Scientists

MEMORANDUM

To: Mr. Mark Ells - Town of Barnstable
Mr. Jack Harris – Town of Barnstable

From: Jeff Gregg - Stearns & Wheler
Andy Ochs - Stearns & Wheler

Date: November 26, 2008

Re: Draft Sewer Phasing Evaluation and Implementation Schedule

DRAFT

Purpose

The purpose of this memorandum is to outline the tasks as identified in the Scope of Services dated November 27, 2007, and provide the Town recommendations on an approach to sewer implementation related to the 2007 Facilities Plan.

This evaluation is for planning and phasing purposes only. Survey, additional flow data, and other information are required to complete detailed design and costing for the areas referenced in this memo. The Town should perform a detailed user count for each area Area of Concern (AOC) as part of design.

The Areas of Concern that are to be considered in the sewer implementation schedule are listed below. The AOCs are shown in Figure 1.

- BEARSE'S
- BWMEL1A
- BWMEL1B
- BWST1 (BWC, BWB, BWA as shown on map)
- CE1
- CE2
- CE4
- CO7
- H1
- H3

The following tasks are discussed herein:

- Task 1 – Development of a preliminary sewer implementation schedule for the AOCs listed above
- Task 2 – Evaluation of bottlenecks, preliminary pumping station reviews, and preliminary costs
- Task 3 – Comparison of original costs (adjusted for 2008) for Areas H1 and CE4 with updated costs in Task 2
- Task 4 – Town Review Meeting
- Task 5 – Development of a detailed sewer implementation schedule

This document is developed based on our review with the Town and incorporates input on prioritized areas and the desire to maximize users in the near term without building new pumping stations. Planning level costs have been provided, however they do not reflect updates to Area H1 costs prepared within the last month. The summary of each task is included below.

Task 1 – Initial Sewer Implementation Schedule

As part of this task, Stearns & Wheler reviewed the various AOCs and worked to prioritize those areas meeting the following criteria, based on input from the Town DPW Director and Staff:

1. Maximize the number of connections to the existing system, while minimizing the impact to capacity.
2. Prioritize sewer service to areas of CE4 and H1, preferably within 10 years as requested by the Town.
3. Provide sewer service to condominiums on Old Strawberry Hill Road in area CE-4. The Town has identified this as a priority.
4. Provide a preliminary schedule to address the AOCs identified above.

For the purposes of developing the phases, the original AOCs are broken up as follows:

- CE4 (North, Northeast, Great Marsh Rd Area, Phinney's Lane Area, Long Pond-NW, Long Pond-SE)
- H1 (East, West)
- Bearse's (Vacuum Area, West, Bearse's Way/Bacon Rd Area, South)

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- BW MEL 1B (Vacuum, other)
- BWA (East, West)
- BWB (East, West)
- BWC (East, West)
- CO7 (Northeast, other)

These subdivided AOCs are shown on Figure 1.

As part of the Facilities Plan's recommended alternative, the WPCF is currently undergoing an upgrade to increase the allowable maximum month flow to 4.2 mgd. The Facilities Plan allocated flows from certain AOCs (or portions of AOCs) that would make up this total. Table 1 is adapted from Table 10-1 of the facilities plan.

TABLE 1
WPCF Flow Allocation

FLOW SOURCES	MAX. MONTH FLOW CONTRIBUTED (MGD)
Existing flows at WPCF in 1993	2.1
Infilling along existing sewers	0.30
Bearse's Way sewer extension	0.03
Route 28 and Corporation Street sewer extension	0.01
Independence Park	0.40
AOCs H1, H3, CE1, CE2, CE4	0.47
Parts of AOCs BWA, BWB, BWC, CO7, BW MEL 1A, BW MEL 1B	0.07
Infilling along proposed AOC sewers	0.05
Bearse's Way AOC (50% of area)	0.20
Cape Cod Community College	0.03
Growth along existing sewer lines not currently sewered	0.20
Gravel pit development	0.13
North of Kidd's Hill Road	0.10
TOTAL	4.2

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After these areas are connected, the WPCF would have to be expanded before the collection system could be extended. Based on the AOCs earmarked for connection and the goals noted above in Table 1, an initial phasing plan identified how the Town might approach sewering areas identified in that Table. The following preliminary implementation schedule is intended only to identify where one AOC (or portion thereof) might fall relative to another within the initial constrains set by the Town. The specifics regarding what section of an AOC might be sewered are discussed later:

1. Connection of Area H1 east of Stewarts Creek and Northeast CE4 on Old Strawberry Hill Road
2. Small expansions in BWB
3. Expansion of sewer in Bearse's AOC
4. Connection of CE4 north, BWC West, and CO7 Northeast.
5. Connection on H1 West and the remainder on CE4.
6. Connect CE1, CE2, H3
7. Upgrade the WPCF
8. Then connection of the remaining AOCs:
    a. CO7
    b. BWA (southern most BWST1)
    c. BEARSE'S
    d. BWMEL1A and 1B

In establishing this prioritization of the areas, several areas in the existing collection system require review (as identified in Task 2). The areas that require a review and/or upgrade are the Mark's Path Pumping Station (PS), Old Colony PS, Main St. PS, and a possible new pumping station on West Main Street (at the intersection of Lincoln Road).

Task 2 – Connection Considerations

Based on the preliminary phasing plan in Task 1, the following modifications to the H1 and CE4 preliminary design and Facilities Plan sewer layouts are identified. These modifications and other considerations are modeled based on existing information using SewerCAD to identify potential sewer "bottlenecks" and needs for possible pumping station improvements as part of any sewer implementation plan.

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1. Area H1 proposed Marston Avenue PS force main would connect to the new Main Street PS, instead of the lower end of Sea Street sewer as proposed in the H1 preliminary design.

2. West Main Street sewer accepting flow from the Long Pond area and southern portions of Wequaquet Lake area. The CE4 preliminary design noted that this flow may be routed to the Main Street PS, but that surcharging would occur. The impact of the surcharging was modeled to determine if this was a viable option.

3. Old Strawberry Hill Road sewer accepting flow from the northern portions of Lake Wequaquet area. The flow from this area was originally slated for an individual pump station near Huckins Neck Road as part of the CE4 preliminary design and connecting to FMs along Route 132.

4. At the direction of the Town, address properties not indentified for connection, located between Wequaquet Lake and Long Pond (between Richardson Road on the west to the intersection of Route 28 and West Main Street to the east).

In addition the following other considerations are examined:

1. The schedule of the two Main Street PS improvements (upgrade of existing facility to 650 gpm and construction of a new facility capable of pumping upto 2200 gpm).
2. Possible upgrade of the Old Colony PS.
3. Upgrade of the Mark's Path PS.
4. Construction of a new pumping station near the intersection of Lincoln Road and West Main Street, near West Elementary School.

In order to refine the preliminary implementation schedule developed in Task 1, SewerCAD is used to evaluate the impact of various parts of the AOCs when connected to the existing collection system. Flow data is based on information developed as part of the Preliminary Designs for CE4 and H1; in addition to AOC flows as developed for the Barnstable Facilities Plan are used. Flows are applied on an average basis spread throughout each area of the AOC. Thus, more detailed or updated flow analyses are required for detailed design. The boundaries and/or phasing, described in this memorandum, will be revised based on any findings that result from a parcel by parcel flow analysis.

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The SewerCAD model provides an estimation of potential surcharging under peak flow conditions. This condition is created when the peak flow from the estimated users and any pumping stations that tie into a particular section of sewer main discharge at the same time. Therefore, it tends to predict a worst case scenario; however it provides a reasonable planning tool to identify potential trouble spots. The model will not predict the impacts of blockages, buildup of oil and grease or I/I (beyond available estimates) on the system.

The model was used to evaluate three major connection areas:

1. West Main St. Connections
2. Mark's Path PS
3. Old Colony PS / Downtown Hyannis sewers

The following describes the various options considered for each of these areas.

West Main St. Connection

The Main Street PS is currently being upgraded to a capacity of 650 gpm. This interim upgrade is expected to be completed in 2009. Any additional connections to this pumping station are contingent upon the completion of the on-going WPCF improvements. The available capacity at the station allows for gravity and low pressure connections in a relatively small portion BWB. These connections must be completed while leaving the necessary capacity of 33,000 gpd as originally identified by the Hyannis Growth Incentive Zone (GIZ) planning. The following options identify the connection of areas that result in exceeding the 650 gpm capacity of the upgraded Main Street PS.

We looked at two options for connecting AOCs located along West Main St.

- Connect areas to existing gravity sewer with flow going to Main St. PS.
- Cut existing sewer at Lincoln Rd and construct a new Lincoln Rd PS

The options are based on the connection of available gravity connections to the West Main Street sewers. This includes gravity and low pressure sewer on Lincoln Road and the surrounding area in BWB West, gravity and low pressure sewer in BWB East and Bearse's East, and several short extensions in BWA. After these connections are made, routing the flow from other planned pumping stations to the

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West Main St. stretch of sewer was considered in order to estimate the impact on of the Main Street PS when connecting flow from several outlying AOCs.

Option 1: Connect four of the CE 4 pumping stations (LP1-*Long Pond NW* and 2- *Long Pond SE*, Lake W1 - *Great Marsh Road Area*, and Lake W2-*Phinney's Lane Area*) and AOCs CE1 and CE2, BWA west, H3, BWA east, BWB west and H1 West to existing the West Main Street infrastructure. This results in:

a. Surcharging in more than half the existing pipes in the West Main Street sewer.
b. Total flow to the Main Street PS under this condition would be 2,400 gpm, larger than the estimated future capacity of 2,200 gpm for a new station.

Result: The Main St. PS must be expanded in the future to handle this additional flow and major reconstruction of the West Main Street sewer.

Due to the capacity constraints in the West Main Street gravity sewer and the necessity of a large new pumping station at West Main Street, this option is not recommended. Some other means of collecting flow from the AOCs in the southern and western portions of the planning area must be considered. Option 2 is considered below.

Option 2: In order to address the concerns about the capacity of the West Main Street gravity sewer and the large flows to the Main St. PS, the construction of a Lincoln Road PS is proposed. Under this option, the new Lincoln Rd pumping station would receive flow from the four CE4 pumping stations identified in option 1 (LP 1 and 2, Lake W1 and 2) and flow from pump stations in AOCs CE1 and CE2, BWA West, and H3. Expansion of gravity and low pressure sewer would also add contributions from BWB west. The existing West Main Street sewer west of the new Lincoln Rd pumping station would be connected here and may have a section reconstructed to address any potential surcharging issues. The existing sewer east of Lincoln Road will continue to the Main Street PS, as will pumping stations in AOCs BWA east, BWB east, and H1 West. This results in:

c. Surcharging of two pipes directly upstream of the Lincoln Road PS. Note that this surcharging is small compared to the total amount of flow in this area. These sections may be reconstructed under this option in order to connect to the pumping station.

d. Total estimated peak flow to Lincoln Road PS is 1,500-1,700 gpm.

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e. No surcharging is likely to occur in pipes flowing to Main Street PS.

f. Total estimated peak flow to Main Street PS is 1,100-1,300 gpm and could allow for additional redevelopment in this area. Alternatively, the connection of BWA to the Main Street PS would exceed the estimated design flow and the future plans for this station would need to be revised to reflect this additional demand.

Based on this analysis, without the construction of a new Main Street PS and the construction of an intermediate pumping station at Lincoln Road, no additional flow can be connected to the West Main Street sewer main from the surrounding AOCs save for some small gravity extensions in BWB east and west. Option 2 is recommended – without the construction of a Lincoln Rd pumping station a large percentage of the West Main St. sewer would need to be rebuilt, and the size of the Main St. PS would grow substantially. This would significantly hinder the Town's ability to connect AOCs CE1, CE2, CE4, and H3.

Mark's Path PS

The current Mark's Path PS capacity is 300 gpm (per WPCF pumping station data, and also listed as 330 gpm on design drawings). Based on this capacity and the existing flow in the area, the following areas could likely be connected without upgrading the pump station – CE4 North East, and the stretch of Old Strawberry Hill Road between the existing sewer and Phinney's Lane in BWC West.

Further connections beyond those listed above will require an upgrade to the Mark's Path PS based on pump capacity only. The WPCF Staff has identified that there may be other issues associated with the Mark's Path PS that may limit its current capacity; however detailed evaluation of the condition of that station or other improvements that may be necessary at that facility are not identified as part of this evaluation.

Gravity and low pressure sewer covering BWC East, extension of gravity and low pressure sewer to achieve full coverage of BWC West, and connection of CO7 Northeast would require an upgrade to the existing pump station.

In addition, flow may be added to Mark's Path from other pumping stations. The four options listed below are for additional flow that would be routed by force main to an upgraded Mark's Path PS

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1. Under this option CE4 North and the Phinney's Lane area sub-AOCs would be connected to the Mark's Path PS. This would eliminate some of the flow proposed to go to Lincoln Road. This results in:

    a. One slightly surcharged pipe.

    b. Total peak flow to Mark's Path PS of approximately 800 gpm. This is above the current capacity of 300 gpm. Requiring construction of a new pumping station at Mark's Path.

    c. Velocity in the existing force main would be above acceptable levels. Installation of a new force main would be required.

2. Connect only the Phinney's Lane area of CE4 (PS Lake W-2), to Mark's Path PS. CE4 North would have its own pumping station (Lake W-3), near Huckin's Neck Road. This pumping station would tie into the exiting 4" or 6" force main running in Iyannough Road. This results in:

    a. No surcharging of existing sewer to Mark's Path.

    b. Total flow to Mark's Path PS of approximately 550 gpm. This is above the current capacity of 300 gpm. Requiring construction of a new pumping station at Mark's Path.

    c. A pumping station must be constructed to handle flow from CE4 North.

3. Connect only CE4 North to Mark's Path PS. The low pressure sewer can be routed such that no pumping station is required. This results in:

    a. No surcharging in existing sewer.

    b. Total flow to pumping station of approximately 600 gpm. This is also above the current capacity of Mark's Path. Requiring construction of a new pumping station at Mark's Path.

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c. Eliminates need to build a pumping station near Huckin's Neck Road.

d. May alter some of the low pressure pipe sizes (and thus cost estimates) for the Lake Wequaquet preliminary design.

4. Do not connect CE4 north or Phinney's Lane area to Mark's Path PS. This results in:

a. Increased flow to Lincoln Road PS or Main Street PS.

b. A pumping station must be constructed to handle the flow from CE4 North as in option 2.

c. Total flow to Mark's Path PS of approximately 450 gpm. This still requires an upgrade to the Mark's Path PS.

Under any of the above conditions, the Mark's Path PS would require an upgrade. Discussions with Town WPCF staff indicate that it would be desirable to replace that station with a station without submersible pumps. Station could be converted to a wet pit/dry pit or possibly a suction lift type station; however site constraints will make improvements difficult and expensive. The current wet well is approximately twenty-five feet deep, and is contained on a small parcel in a largely residential neighborhood. There is little available area on this site for any new structure or to stage construction. The Town will have to weigh the constraints on upgrading Mark's Path versus the cost incurred by building or upgrading of other stations.

If Mark's Path PS improvements are feasible, it is recommended that either option 3 or 4 above be pursued. Either option can be accommodated in the scheduling included in Task 4 below. Options 3 and 4 limit the size of any new pumping station at Mark's Path, eliminates any pipe surcharging, and allows for continued use of the existing force main. Instead, the flow can be accounted for in new infrastructure to be built at Lincoln Rd and elsewhere. Which of these two options is ultimately pursued will depend on the conclusions as to the fate of CE-4 North as part of the Lake Wequaquet final design effort.

Old Colony Area Connection Options

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The following options would occur after the upgraded Main Street PS is connected to new 8-inch force main. This alleviates some of the pressure on the Old Colony PS, as it will no longer be receiving flow from the Main Street PS.

1. Under this option, additional flow to the Old Colony PS would be from proposed gravity and low pressure systems from the Bearse's AOC. This option also includes the removal of flow from Main Street PS as this will be connected directly to the WPCF. This results in:

    a. Additional minor surcharging of one pipe, which occurs as a result of gravity and low pressure tie-ins.

    b. Total flow to Old Colony PS of approximately 2,900 gpm, less than the current capacity of 3,300 gpm.

2. Under this option, additional flow to Old Colony PS would be from proposed gravity and low pressure in the Bearse's AOC, as well as flow from BW MEL 1A. This results in:

    a. Surcharging in the entire length of the existing sewer (Camp St., Lewis Bay Rd., South St., etc.) from the BW MEL 1A connection point to Old Colony PS.

    b. Total flow of approximately 3,500 gpm to the Old Colony PS. This exceeds the current capacity of 3,300 gpm.

It is recommended that extension of gravity and low pressure sewer in Bearse's AOC be pursued after the Main St PS is directly connected to the WPCF, taking advantage of existing infrastructure. However, capacity issues prevent the connection of BW MEL 1A without an upgrade of both the Old Colony PS and the existing collection system. As such the expansion of sewers in BW MEL 1A is a very expensive option by itself, but may be attractive if grouped with other projects in the area. Developments in concert with the Town of Yarmouth may affect the ultimate fate of the flows from BW MEL 1A.

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Task 3 – Cost Comparison to Prior Reports

There are two AOCs for which more detailed reports have already been prepared for the Town. These are Areas CE-4 by Tighe and Bond (2003) and Area H1 by Stearns & Wheler (2004).

The Wequaquet Lake and Long Pond (CE-4) report recommended Alternative #3 and estimated construction costs for this alternative were developed and tied to a construction cost index (ENR Index) value of 6578. As part of this task, these costs have been updated using ENR of 8602 for November 2008.

The above identified report presented the **total estimated construction costs** for Area CE-4 in 2003 and this estimate has been updated for the year 2008. As part of this task, costs were also re-evaluated for the recommended alternative. This was completed using the same cost factors used to estimate costs for other AOCs as part of this memorandum. The current estimate of the total project cost is presented below. Note that the current **total estimated project cost** includes costs for engineering and administrative items not included in the original report. This current estimate also considers a slightly higher contingency than that carried in 2003 to remain consistent with the cost estimates for other AOCs. Differences between the unit prices used for the original estimate and those used for this memorandum also account for the difference in costs.

Also, some minor modifications have been made to the previous plan. The current price estimate eliminates the need for a new pumping station in CE4 North. This area is now proposed to tie by low pressure to gravity sewer on Old Strawberry Hill Road and ultimately reach the Mark's Path PS. The current estimate does include the costs for constructing the new Lincoln Road PS and for the upgrade or construction of a new pumping station at or near Mark's Path. While these pieces of infrastructure do not fall within the bounds area CE4, they are vital for conveying the flow from these areas to the WPCF.

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TABLE 2
CE4 Cost Estimates

2003 ESTIMATE	2003 CONSTRUCTION ESTIMATE (UPDATED) (1)	CURRENT TOTAL PROJECT COST ESTIMATE (3)	CURRENT TOTAL PROJECT COST ESTIMATE WITH ADDITIONAL PS UPGRADES(2,3)
$17.8 million	$22 million	$44 million	$54 million

Notes:
1. Updated based on ENR value only.
2. This cost includes Mark's Path and Lincoln Road Pump Station work as sewer construction in CE4 is contingent on those upgrades.
3. Project Costs include fiscal, legal, engineering (design and construction) and contingency.

The Stewarts Creek (Area H1) report recommended Alternative #4 and total estimated project costs (ENR Index value of 7107) were developed as part of that report. As part of this task, these costs were updated to the current ENR of 8602. In addition, a revised estimate was developed that included some minor additional costs for fiscal, legal, engineering and administrative items not carried in the original area H1 report. These were higher in the current estimate in order to be consistent with the planning-level nature of this memorandum and the costs developed for other AOCs. As such, planning level estimates for other areas were developed because they have not undergone detailed survey and flow characterization.

The current estimate is less than the facilities plan estimate because a small portion of sewer was converted to gravity instead of being low pressure. Also, under the current plan, the force main from the Marston Avenue Pumping Station will run north on Marston Avenue and tie directly the to the existing West Main Street sewer. While this distance is slightly further than originally planned, a small cost savings is seen due to the ability to install both the gravity main and the force main in a single trench. These estimates are shown below:

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TABLE 3
H1 Cost Estimates

2004 TOTAL PROJECT COST ESTIMATE	2004 TOTAL PROJECT COST ESTIMATE (UPDATED) [1]	2007 FACILITIES PLAN TOTAL PROJECT COST ESTIMATE	CURRENT TOTAL PROJECT COST ESTIMATE
$5.8 million	$7.1 million	$7.5 million	$7.1 million

Note:
1. Updated based on ENR value only.

Tasks 5 – Costs and Proposed Implementation Schedule.

Based on the preliminary schedule developed in Task 1 and the proposed changes evaluated in Task 2, the following phased implementation plan is proposed. The phasing is based on two main periods – extensions that can be made with the WPCF at current capacity and extensions that require a further expansion. This follows the recommendations of Table 10-1 in the Facilities Plan submitted March 2007 (see Table 1, this memo). After the current WPCF upgrade is completed, the maximum month capacity of the facility will be 4.2 mgd on a maximum month basis. This allows for the connection of the following areas:

- H1
- CE4
- CE1
- CE2
- H3
- 70,000 gpd from CO7, BWA, BWB or BWC
- 200,000 gpd from Bearse's AOC
- Other growth areas not relevant to this evaluation

After sewers in the areas noted are constructed, the WPCF will have to undergo further expansion before additional sewer extensions can be completed. After the upgrade of the WPCF, the following connections can be completed, either in their entirety or the balance after connecting the areas above:

- CO7
- BWA
- BWB
- BWC

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- Bearse's AOC
- BW MEL 1A
- BW MEL 1B

As such, the proposed phasing will connect properties located within each identified AOC, while attempting to maximize connections in the near term without new pump stations, while adhering to the regions allocated for connection according to the facilities plan. This results in twelve sewer phases.

The cost estimate amounts shown in the table below are an order of magnitude estimate that represents each phase's total project (capital) cost. Costs are based on November 2008 ENR Index of 8602. The approximate number of connections for each phase is noted as well. Connections are based on a per parcel rather than a per user basis. However, for parcels that contained a significant number of buildings (based on 2005 aerial photography), such as a condo development, each building was counted individually. For phases that include rehabilitation of existing infrastructure such as pumping station upgrades, this cost is included in the total. As was noted above, these costs are for planning purposes only and could change upon more detailed evaluation in preliminary/final design. Note that force main sizes for any proposed pump stations listed below will be determined as part of preliminary design for that project.

Figure 2 (attached) depicts the proposed phasing in detail. The detailed phasing elements are as follows:

Phase 1 – Utilize existing pumping station capacities (Years 1-3)

1. Construct gravity and low pressure sewer in H1 East
2. Construct gravity and low pressure sewer in CE4 Northeast and in and around Old Strawberry Hill Rd in BWC West.

Phase 2 – Utilize capacity in upgraded Main St. PS (Years 2-3)

1. Connect Main St. PS to WPCF with dedicated force main. Complete upgrade to 650 gpm pump station.
2. Construct gravity and low pressure sewer on Pontiac St, Woodland Avenue, and Dunn's Pond Road in BWB.

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Phase 3 – Extend gravity connections to Old Colony PS (Years 3-5)

1. Construct gravity and low pressure sewer in the Bearse's Way and Bacon Road area in Bearse's AOC. Note that this can be constructed because the flow from Main Street now has a dedicated force main instead of being pumped to Old Colony.

Phase 4 – Upgrade Mark's Path PS (Years 4-7)

1. Upgrade Mark's Path PS to at least 450 gpm. This value will increase depending on the fate of flow form CE4 North.
2. Construct gravity and low pressure sewer in BWC West and CO7 Northeast.
3. Construct low pressure sewers in CE4 North connecting to either a dedicated pump station near Huckins Neck Rd or to Mark's Path. This may be revised based on decisions made concerning the Lake Wequaquet sewers.

Phase 5 – Construct Lincoln Road PS (Years 5-10)

1. Construction new Lincoln Rd PS with capacity of 1600 gpm or as needed depending on other areas that will connect to this PS. Cut existing West Main Street gravity sewer. Construct gravity sewer traveling west along Main Street from Straightway to Lincoln Road. Existing sewer in this stretch will be abandoned.
2. Construct gravity and low pressure sewer and pumping station in H1 West. Capacity is now available at the Main St. PS as some flow has been diverted to the Lincoln Rd. PS
3. Construct gravity and low pressure sewer and pumping station LP-1 in Long Pond north and west areas in CE4.
4. Construct gravity and low pressure sewer and pumping station LP-2 in Long Pond south and east areas in CE 4.
5. Construct gravity and low pressure sewer and pumping station Lake W-1 in Great Marsh Road area of CE4.
6. Construct gravity and low pressure sewer and pumping station Lake W-1 in Great Marsh Road area of CE4.

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Phase 6 – Connect Additional AOCs earmarked for connection before WPCF Upgrade (Years 10-13)

1. Construct gravity and low pressures sewers and pumping stations in CE1, CE2, and H3. Flow will ultimately arrive at the Lincoln Rd PS.

Phase 7 – Upgrade vacuum station pumps and extend vacuum service (Years 13-15)

1. Upgrade vacuum station pumps
2. Construct vacuum sewer in vacuum area of Bearse's AOC.

Phase 8 – Upgrade WPCF (Years 15-17.5)

1. Upgrade the WPCF for additional flows per the facilities plan or for additional flows as determined necessary at that time.

Phase 9 – Make additional gravity and low pressure connections (Years to be determined)

1. Construction gravity and low pressure sewers in BWB West, CO7 and the northern section of BW MEL 1B. These connections can be made without any additional pumping stations.

Phase 10 – Replace Main St PS (Years to be determined)

1. Construct new Main St. PS with capacity of 1300 gpm or as needed based on flows at the time.
2. Construct gravity and low pressure sewer in Bearse's South and West and in BWB east to connect to existing gravity sewer.

Phase 11 – Complete BWST1 sewering (Years to be determined)

1. Construct gravity and low pressure sewers in BWA West, BWA East, and BWB East. BWA West will send flow to the Lincoln Rd PS while BWB East and BWA East will send flow to the new Main St. PS.

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Phase 12 – Upgrade Old Colony PS (Years to be determined)

1. Upgrade Old Colony PS to 3,500 gpm or as necessary based on flows at the time.
2. Rehabilitate existing sewers to allow for increased flow from BW MEL 1A
3. Construct gravity and low pressure sewer and pumping station in BW MEL 1A.

Table 4 below shows the estimated costs and connections for each phase or subphase as described above. There is some uncertainty as to the total costs and connections as full parcel level flow estimates were not included.

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TABLE 4
Sewer Phasing

PHASE	SUB-PHASE	AREA OR PUMP STATION[1]	ESTIMATED COST ($ MILLIONS) [2]	ESTIMATED # OF CONNECTIONS [3]	TIME FRAME
1	1	H1-East	3-4	120-140	Within 10 year period
	2	Part of BWC West, CE4 Northeast	2-3	110-130	
2	1	Parts of BWB	1-3	70-90	
3	1	Bearse's Way/Bacon Rd Area	7-9	275-325	
4	1	Upgrade Mark's Path PS	2-4	n/a	
	2[4]	BWC West, CO7 Northeast, CE4 North	19-23	550-650	
5	1	Construct Lincoln Rd PS	7-9	n/a	
	2	Great Marsh Rd, Phinney's Lane, Long Pond NW and SE	22-28	450-500	
6	1	CE1, CE2, H3	17-21	500-600	Years 10-13
7	1	Bearse's – Vacuum Area	2-4	90-110	Years 13-15
8	1	Upgrade WPCF	TBD	n/a	Years 15-17.5
9	1	BW MEL 1B, BWB West, CO7	12-16	575-675	To Be Determined
10	1	Construct New Main St. PS	3-5	n/a	
	2	Bearse's West, Bearse's South	4-6	180-220	
11	1	BWB East, BWA West, BWA East	30-35	1000-1200	
12[5]	1	Upgrade Old Colony PS and rehab existing sewer	10-14	n/a	
	2	BW MEL 1A	8-10	120-150	

Notes:

1. General areas are identified here. Detailed description is provided in the text below. Figure 2 displays the phasing.
2. Costs are based on November 2008 ENR of 8602. Where an upgrade of existing infrastructure is noted, these costs are included.
3. Connections were estimated on a per parcel basis. However, in instances where there were condominiums or similar developments, each building on the parcel was included in the connection count.
4. CE4 north depending on fate of Lake Wequaquet final design
5. Phase 12 contains significantly more commercial connections than other phases.

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In addition to the phasing description and summary table above, Figures 3-6 show the AOC connectivity and phasing in flow chart form. Also, Tables 5 and 6 attached show the two main efforts for the sewer implementation plan. Table 5 shows the approximate costs and connections for phases 1-7 before the next WPCF upgrade. Table 6 shows the full build-out costs in comparison to those estimated as part of the Facilities Plan submitted in 2007.

This sewer phasing plan meets the requirements of the facilities plan while maximizing connections in the near term without additional pumping stations and prioritizes the connections of areas CE4 and H1. The proposed phasing is based on the current status of design efforts for those two areas, and may change based on the ultimate determination as to how to handle flows in the Lake Wequaquet area. The phasing (and especially expansion of sewers to use existing pump stations) is based on previously determined flow data. The areas proposed for interim connections may be reordered or boundaries redrawn as part of the final design effort in these areas.

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Table 5 - Phases 1-7 Costs and Connections

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		Phases 1-7[1]			
AOC	SubArea	Connections	Collection Cost	PS/FM Cost	Total Cost
H-1		220			$7,100,000
	H-1 East	*130*	*$3,700,000*		*$3,700,000*
	H-1 West	*90*	*$2,300,000*	*$1,100,000*	*$3,400,000*
BWA					
	BWA East				
	BWA West				
H3		250	*$6,300,000*	*$1,400,000*	$7,700,000
CE2[2]		170	*$4,800,000*	*$2,000,000*	$6,800,000
CE1		140	*$4,300,000*	*$1,400,000*	$5,700,000
CO7		80			$2,500,000
	Northeast[3]	*80*	*$2,500,000*		*$2,500,000*
	Balance				
CE4		1020			$46,000,000
	Long Pond -S,E[4]	*90*	*$3,600,000*	*$1,900,000*	*$5,500,000*
	Long Pond -N,W[5]	*100*	*$5,400,000*	*$2,500,000*	*$7,900,000*
	Great Marsh Rd Area	*150*	*$5,100,000*	*$800,000*	*$5,900,000*
	Phinney's Lane Area	*140*	*$5,700,000*	*$1,300,000*	*$7,000,000*
	North	*440*	*$17,000,000*		*$17,000,000*
	Northeast	*100*	*$2,300,000*		*$2,300,000*
BWC		100			$2,900,000
	East				
	West[6]	*100*	*$2,900,000*		*$2,900,000*
BWB		80			$2,000,000
	East				
	West	*80*	*$2,100,000*		*$2,100,000*
Bearse's		390			$12,000,000
	West				
	Vacuum	*100*	*$2,900,000*	*$300,000*	*$3,200,000*
	BW/Bacon Rd Area	*290*	*$8,500,000*		*$8,500,000*
	South				
BW MEL 1B		30			$1,100,000
	Vacuum	30	*$1,100,000*		*$1,100,000*
	Balance				
BWMEL1A					
Additional Items					
New Main St. PS					
New Lincoln Rd PS				*$3,200,000*	$3,200,000
Upgraded Mark's Path PS				*$3,200,000*	$3,200,000
Upgraded Old Colony PS					
Total					$100,000,000

Notes:
1. Sewer Coverage based on facilities plan, updated from March 2008 ENR of 8109 to 8602 for November
2. Pump station sized to accept from from CE1, H3
3.Includes small portion of BWC West, see note 6
4. Pump station sized to accept flow from CE2
5. Pump station sized to accept flow from Great Marsh Rd and Phinney's Lane areas
6. Small portion connection via CO7 northeast

Table 6 - Full Buildout Costs and Connections - Current Estimate and Facilities Plan

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		Phases 1-12[7]				Facilities Plan Estimate[8]	
AOC	SubArea	Connections	Collection Cost	PS/FM Cost	Current Total Cost	Facilities Plan Connections	Facilities Plan Total
H-1		220			$7,100,000	200	$8,400,000
	H-1 East	*130*	*$3,700,000*		*$3,700,000*		
	H-1 West	*90*	*$2,300,000*	*$1,100,000*	*$3,400,000*		
BWA		790			$22,000,000	600	$20,000,000
	BWA East	*360*	*$8,600,000*	*$1,700,000*	*$10,300,000*		
	BWA West	*430*	*$10,300,000*	*$1,800,000*	*$12,100,000*		
H3		250	*$6,300,000*	*$1,400,000*	$7,700,000	100	$6,700,000
CE2[1]		170	*$4,800,000*	*$2,000,000*	$6,800,000	200	$6,700,000
CE1		140	*$4,300,000*	*$1,400,000*	$5,700,000	100	$5,000,000
CO7		500			$14,000,000	500	$17,000,000
	Northeast[2]	*80*	*$2,500,000*		*$2,500,000*		
	Balance	*420*	*$11,400,000*		*$11,400,000*		
CE4		1020			$48,000,000	1200	$45,000,000
	Long Pond -S,E[3]	*90*	*$3,600,000*	*$4,000,000*	*$7,600,000*		
	Long Pond -N,W[4]	*100*	*$5,400,000*	*$2,500,000*	*$7,900,000*		
	Great Marsh Rd Area	*150*	*$5,100,000*	*$800,000*	*$5,900,000*		
	Phinney's Lane Area	*140*	*$5,700,000*	*$1,300,000*	*$7,000,000*		
	North	*440*	*$17,000,000*		*$17,000,000*		
	Northeast	*100*	*$2,300,000*		*$2,300,000*		
BWC		240			$6,700,000	200	$6,700,000
	East	*140*	*$3,800,000*		*$3,800,000*		
	West[5]	*100*	*$2,900,000*		*$2,900,000*		
BWB		580			$19,000,000	500	$18,300,000
	East[6]	330	*$8,800,000*	*$3,200,000*	*$12,000,000*		
	West	250	*$7,200,000*		*$7,200,000*		
Bearse's		590			$17,000,000	400	$11,600,000
	West	170	*$3,700,000*		*$3,700,000*		
	Vacuum	100	*$2,900,000*	*$300,000*	*$3,200,000*		
	BW/Bacon Rd Area	290	*$8,500,000*		*$8,500,000*		
	South	30	*$1,500,000*		*$1,500,000*		
BW MEL 1B		40			$1,500,000	100	$1,700,000
	Vacuum	30	*$1,100,000*		*$1,100,000*		
	Balance	10	*$400,000*		*$400,000*		
BWMEL1A		140	*$5,500,000*	*$3,900,000*	$9,400,000	200	$8,400,000
Additional Items							
New Main St. PS				*$3,200,000*	$3,200,000		
New Lincoln Rd PS				*$8,500,000*	$8,500,000		
Upgraded Mark's Path PS				*$3,200,000*	$3,200,000		
Upgraded Old Colony PS				*$12,700,000*	$12,700,000		
Total					$193,000,000		$156,000,000

Notes:
1. Pump station sized to accept from from CE1, H3
2.Includes small portion of BWC West, see note 6
3. Pump station sized to accept flow from CE2
4. Pump station sized to accept flow from Great Marsh Rd and Phinney's Lane areas
5. Small portion connection via CO7 northeast
6. Pitcher's PS sized to accept flow from BWA east
7. Requires upgrade of WPCF, updated from March 2008 ENR of 8109 to November 2008 ENR of 8602
8. Updated from June 2006 ENR of 7700 to November 2008 ENR of 8602

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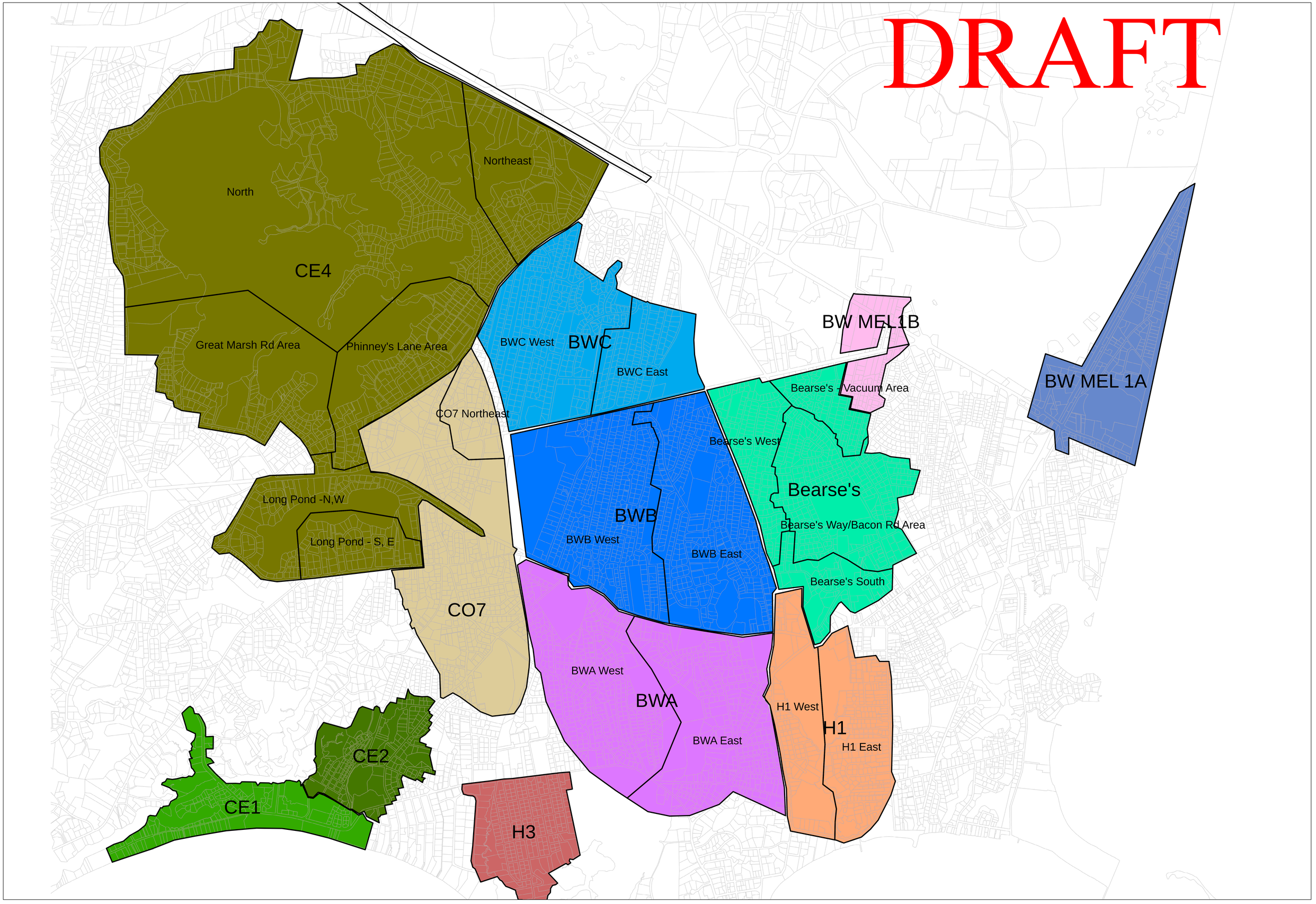

1 inch equals 625 feet

STEARNS & WHELER LLC
Environmental Engineers & Scientists
HYANNIS, MASSACHUSETTS
1545 Iyannough Road
Phone: 508 362-5656
Fax: 508 362-5664
Web: steamswheler.com

Date: 11/20/2008 Project No. 81014

TOWN OF BARNSTABLE, MASSACHUSETTS

Sewer Phasing Plan

AOC Division Map

FIGURE 1

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Legend

- Proposed Pump Station
- Proposed Low Pressure Main
- Proposed Gravity Main
- Proposed Vacuum Sewer
- Proposed Force Main
- Existing Pump Stations
- Buffer Tanks
- Existing Vacuum Sewer
- Existing Gravity Main
- Existing Force Main
- Phase 1
- Phase 2
- Phase 3
- Phase 4
- Phase 5
- Phase 6
- Phase 7
- Phase 8 - Upgrade WPCF
- Phase 9
- Phase 10
- Phase 11
- Phase 12

North

Northeast

Great Marsh Rd Area

Phinney's Lane Area

BWC West

BWC East

CO7 Northeast

Bearse's - Vacuum Area

BW MEL 1B

BW MEL 1A

Bearse's West

Bearse's Way/Bacon Rd Area

Long Pond -N,W

Long Pond - S, E

BWB West

BWB East

CO7

Bearse's South

BWA West

BWA East

H1 West

H1 East

CE2

CE1

H3

New Lake W-3 Pumping Station (optional)
Construct, Phase 4

New Lake W-2 Pumping Station
Construct, Phase 5

New Lake W-1 Pumping Station
Construct, Phase 5

New Lincoln Rd Pump Station
Construct, Phase 5

New LP-1 Pumping Station
Construct, Phase 5

New LP-2 Pumping Station
Construct, Phase 5

Mark's Path Pump Station
Current Capacity: 300 gpm
Upgrade, Phase 4

Vacuum Station
Upgrade, Phase 9

Main Street Pump Station
Current Capacity: 435 gpm
Upgrade to 650 gpm, Phase 2
Constrct New to 1300 gpm, Phase 10

Sea Street Pump Station
Current Capacity: 200 gpm
No Upgrade Required

Old Colony Pumping Station
Current Capacity: 3300 gpm
Upgrade, Phase 12

Sea Street Beach Pump Station
Current Capacity: 100 gpm
No Upgrade Required

1 inch equals 625 feet

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Web: steamswheler.com
Date: 11/20/2008 Project No. 81014

TOWN OF BARNSTABLE, MASSACHUSETTS

Sewer Phasing Plan

Proposed Implementation Phasing

FIGURE 2

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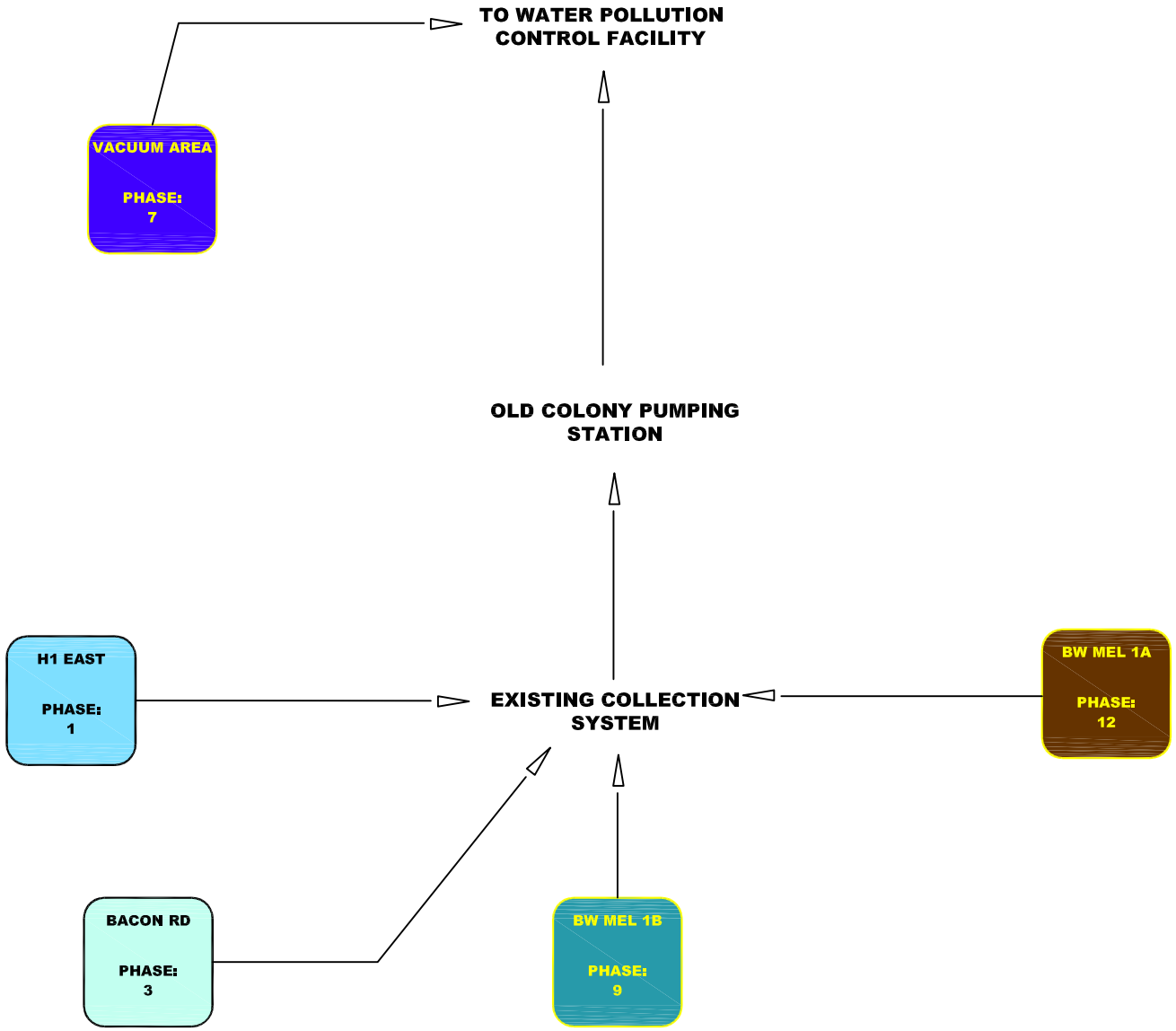

Figure 3: ***Old Colony PS Connections***

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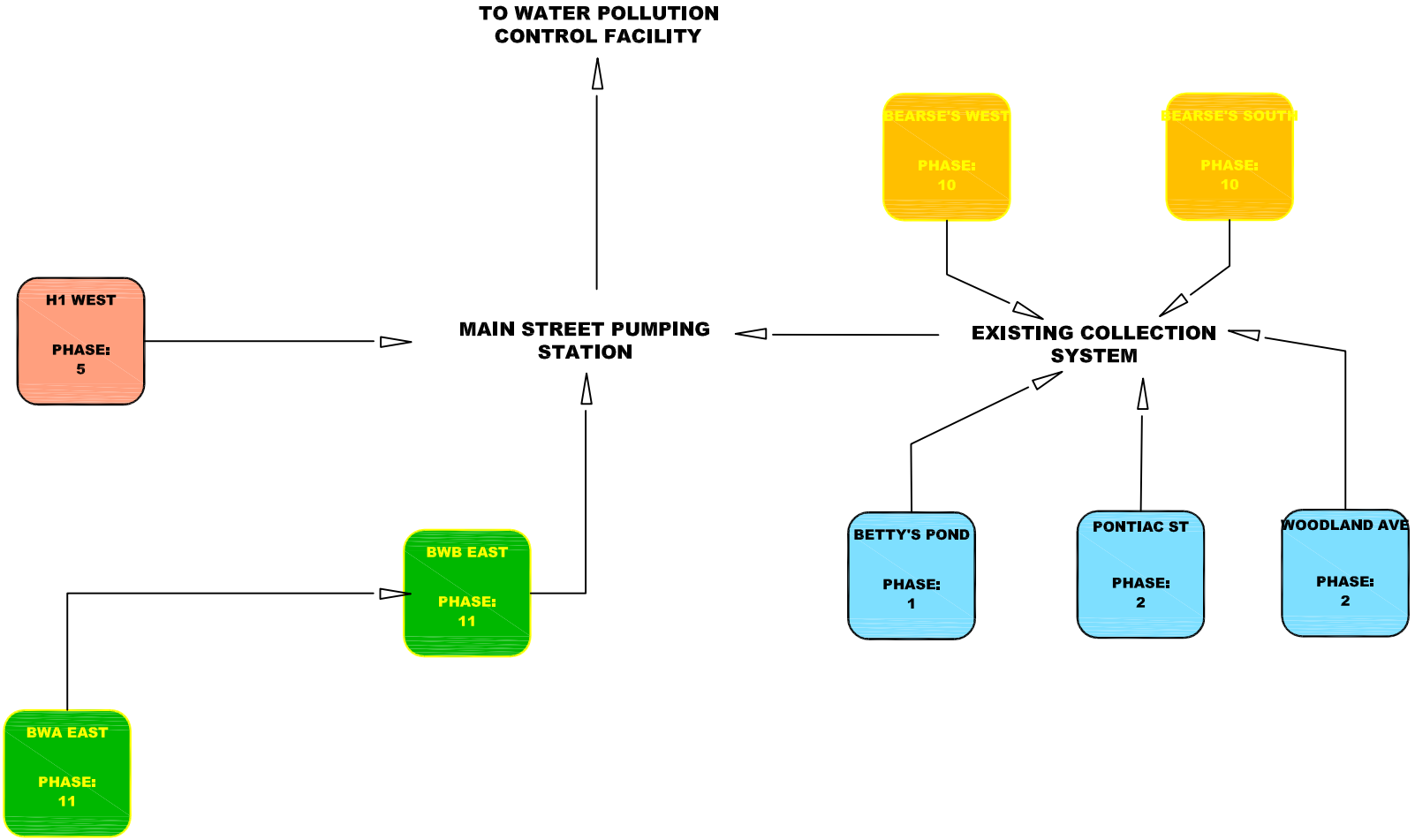

Figure 4: ***Main Street PS Connections***

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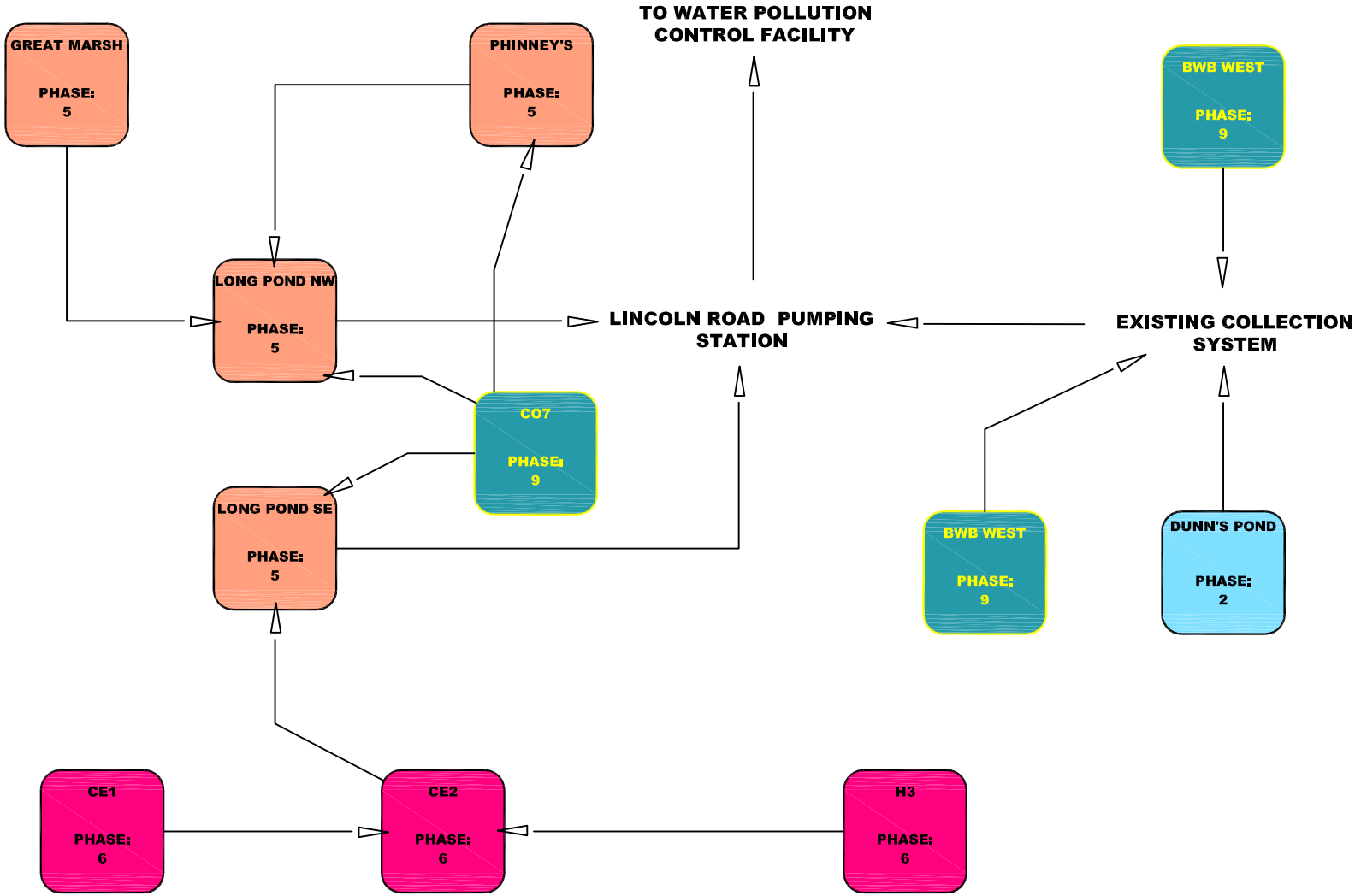

Figure 5: ***Lincoln Road PS Connections***

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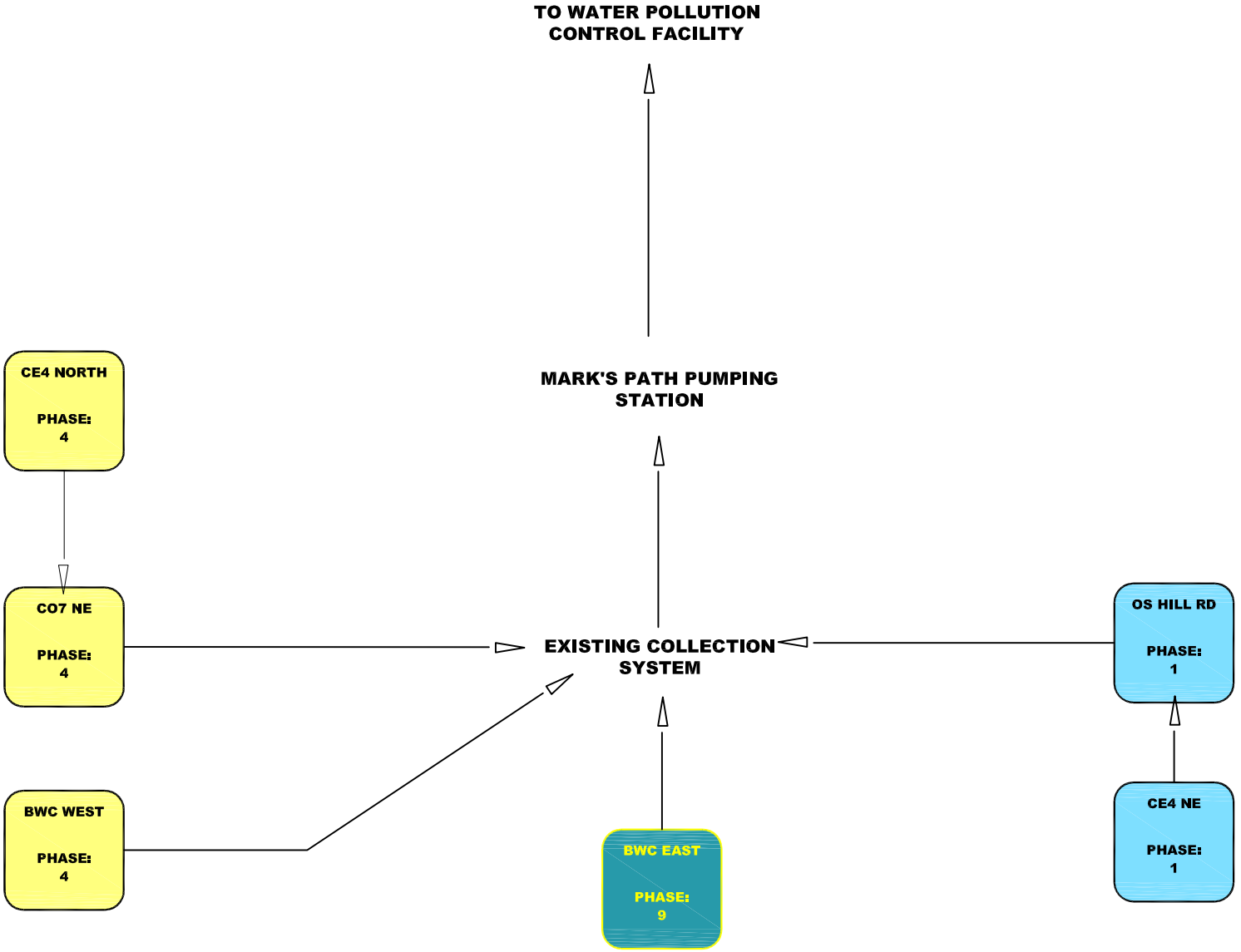

Figure 6: ***Mark's Path PS Connections***

Appendix 2-2

Hyannis WPCF Groundwater Discharge Permits: 1980 and 1990 Draft

1980 GROUNDWATER DISCHARGE PERMIT

Discharge Permit

The Commonwealth of Massachusetts

Water Resources Commission

Division of Water Pollution Control

110 Tremont Street, Boston 02108

OFFICE OF THE DIRECTOR

April 30, 1980

H. Lester Sherman, Jr., Chairman
Water Pollution Control Department
Post Office Box 314
Hyannis, Massachusetts 02601

Re: Subsurface Discharge
Permit 0-21
Hyannis WWTP
Barnstable

Dear Mr. Sherman:

In response to your application submitted on behalf of the Town of Barnstable for a permit to discharge into the ground a treated effluent from an on-site wastewater treatment facility on Bearses Way in Hyannis designed to treat wastes from the Village of Hyannis, after due public notice and no objections to the issuance of the permit having been received, I am therefore issuing the permit effective this date.

Very truly yours,

Thomas C. McMahon
Director

TCM/WAS/rew

cc (w/enclosure):

Abraham Michaels, Superintendent, Department of Public Works, New Town Hall, Main Street, Hyannis 02601
Paul T. Anderson, Regional Environmental Engineer, Department of Environmental Quality Engineering, State Hospital, Lakeville 02346
Mr. Peter Churchill, Whitman & Howard, Inc., 45 William Street, Wellesley 02181
Ms. Donna L. B. D'Amore, Camp Dresser & McKee Inc., One Center Plaza, Boston 02108

RECEIVED
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MAY 15 1980
DEPT. OF PUBLIC WORKS
TOWN OF BARNSTABLE
BY

The Commonwealth of Massachusetts
Water Resources Commission
Division of Water Pollution Control
110 Tremont Street, Boston 02108

OFFICE OF THE DIRECTOR

DISCHARGE PERMIT

Name and Address of Applicant: Town of Barnstable, Water Pollution Control Department, 397 Main Street, (P.O. Box 314), Hyannis, Massachusetts 02601

Application No. 0-21

Date of Application February 28, 1978

Permit No. 0-21

Date of Issuance April 30, 1980

Date of Expiration April 30, 1985

AUTHORITY FOR ISSUANCE

Pursuant to authority granted by Chapter 21, Sections 26-53 of the Massachusetts General Laws, as amended, the following permit is hereby issued to:

Town of Barnstable, Water Pollution Control Department, (hereinafter called the "permittee") authorizing discharges from an on-site wastewater treatment facility on Bearses Way, Hyannis, designed to treat wastes from the Village of Hyannis with discharge to the ground, such authorization being expressly conditional on compliance by the permittee with all terms and conditions of the permit hereinafter set forth.

This permit shall become effective on the date of the Director's signature and shall expire on April 30, 1985.

Thomas C. McMahon, Director
Division of Water Pollution Control

4/30/80
Date

I. SPECIAL CONDITIONS

A. Effluent Limits

The permittee is authorized to discharge into the ground from the wastewater treatment facilities for which this permit is issued a treated effluent whose characteristics, within one month after start-up of the facilities and continuing thereafter, shall not exceed the following values:

Effluent Characteristic	Monthly Average	Weekly Average	Maximum Day
Flow, Cu, M/day (MGD)	4.2	-	-
Biochemical Oxygen Demand 5-day, 20°C	30	45	50
Total Suspended Solids (mg/l)	30	45	50
Settleable Solids (ml./l.)	-	0.1	0.3
Total Coliform Bacteria (#/100 ml.)	1000	2000	2000
Chlorine Residual, (mg/l)	1.0	-	-

a) The pH of the effluent shall not be less than 6.0 nor greater than 9.0 at any time, unless these values are exceeded due to natural causes or as a result of the approved treatment processes.

b) The total chlorine residual of the effluent shall not result in any demonstrable adverse effect on the groundwater or violate any water quality standard which has been or may be promulgated. Upon promulgation of any such standard, this permit may be revised or amended in accordance with such standards, the permittee being so notified.

c) The discharge shall not cause a violation of the water quality standards of the receiving waters.

d) The monthly average concentration of BOD and total suspended solids in the discharge shall not exceed 15 percent of the monthly average concentrations of BOD and total suspended solids in the influent into the permittee's wastewater treatment facilities.

e) When the effluent discharged for a period of 90 consecutive days exceeds 80 percent of the permitted flow limitation, the permittee shall submit to the permitting authorities projected loadings and a program for maintaining satisfactory treatment levels consistent with approved water quality management plans.

B. Monitoring and Reporting

1) The permittee shall monitor and record the quality and quantity of discharge at the sampling station immediately following the chlorine contact chamber according to the following schedule and other provisions:

Parameter	Minimum Frequency of Analysis	Sample Type
Flow	✓ daily	Daily Avg., Max., Min.
BOD	2 x wk.	24 hr. - Comp.
TSS and Total Solids	2 x wk.	24 hr. - Comp.
Settleable Solids	1 x d	Grab
Total Coliform	2 x wk.	Grab
pH	1 x d	Grab
Chlorine Residual	1 x d	Grab
Total Phosphorus as P	1 x month	24 hr. - Comp.
Nitrates as N	1 x month	24 hr. - Comp.
DO	1 x d	Grab
NH_3 as N	1 x month	24 hr. - Comp.

2) The locations of nine(9) observation wells in the vicinity of the treatment facility are shown on the map and described in the tabulation appended to and made a part of this permit. The permittee shall monitor, record and report the quality of water in the observation wells according to the following schedule and other provisions:

Chloride	1 x monthly
Copper	1 x monthly
Iron	1 x monthly
Manganese	1 x monthly
Nitrate-Nitrogen	1 x monthly
Sodium	1 x monthly
Sulfate	1 x monthly
pH	1 x monthly

3) Any grab sample or composite sample required to be taken less frequently than daily shall be taken during the period of Monday through Friday inclusive. Eight hour composites and grab samples shall be taken between 8:00 a.m. and 6:00 p.m.

4) The permittee shall submit all reports on an acceptable form, properly filled in and signed, on the fifteenth of every month, beginning 30 days after start-up of the permitted facilities, to the Regional Engineer, DWPC, P.O. Box 537, N. Pembroke 02358 and to the Regional Environment Engineer, DEQE, State Hospital, Lakeville 02346

II. GENERAL CONDITIONS

1)

a) All discharges authorized herein shall be consistent with the terms and conditions of this permit. The discharge of any pollutant more frequently than, or at a level in excess of, that identified and authorized by this permit shall constitute a violation of the terms and conditions of this permit. Such a violation may result in the imposition of civil and/or criminal penalties as provided for in Section 42 of the State Act. Facility modifications, additions, and/or expansions that increase the plant capacity must be reported to the Director, and this permit then modified or reissued to reflect such changes. No change in the facility discharge that will result in new or increased discharges of pollutants from such treatment system may be made unless reported to and approved by the Director. This permit may be modified accordingly. In no case are new connections, increased flows, or significant changes in influent quantity or quality permitted that will cause violation of the effluent limitations specified herein.

2) After notice and opportunity for a hearing, this permit may be modified, suspended, or revoked in whole or in part during its term for cause including, but not limited to, the following:

a) Violation of any terms or conditions of the permit;

b) Obtaining a permit by misrepresentation or failure to disclose fully all relevant facts; and

c) A change in conditions or the existence of a condition which requires either a temporary or permanent reduction or elimination of the authorized discharge.

3) The permittee shall permit the Director, and other duly authorized Division personnel upon the presentation of proper credentials:

a) To enter upon permittee's premises where an effluent source is located or in which any records are required to be kept under the terms and conditions of this permit;

b) To have access to and copy any records required to be kept under the terms and conditions of this permit;

c) To inspect any monitoring equipment or monitoring method required in this permit; or

d) To sample at any intake, wastewater treatment facility, and/or discharge.

4) In the event of any change in control or ownership of facilities from which the authorized discharges originate, the permittee shall notify the succeeding owner or controller of the existence of this permit by letter, a copy of which shall be forwarded to the Director. Succeeding owners or controllers shall be bound by all the conditions of this permit, unless and until a new or modified permit is obtained.

5) All waste collection, control, treatment, and disposal facilities shall be operated in a manner consistent with the Division's "Rules and Regulations for Operation and Maintenance of Sewerage Systems and Waste Treatment Facilities," as most recently amended, and the Division of Environmental Health's "Manual of Procedure - Sewage Treatment Plants with Subsurface Sewage Disposal, "as most recently amended, which regulations are hereby incorporated into and made a part of this permit. The permittee shall at all times maintain in good working order and operate as efficiently as possible any facilities or system of control installed or utilized to achieve compliance with the terms and conditions of this permit.

6) The issuance of this permit does not convey any property rights in either real or personal property, or any exclusive privileges; nor does it authorize or relieve the permittee of any liability for any injury to private property or any invasion of personal rights; nor any infringement of Federal, State, or local laws or regulations; nor does it waive the necessity of obtaining any local assent required by law for the discharge authorized herein.

7) This permit shall be subject to such monitoring requirements as may be reasonably required by the Director, including the installation, use, and maintenance of monitoring equipment or methods (including, where appropriate, biological monitoring methods). The permittee shall provide the Director with periodic reports on the proper reporting form of monitoring results obtained by a permittee pursuant to the monitoring requirements contained herein. The permittee shall maintain records of all information resulting from any monitoring activities required herein. Any records of monitoring activities and results shall include for all samples:

a) The date, exact place and time of sampling;

b) The dates and times analyses were performed;

c) Who performed the sampling and analyses;

d) The analytical techniques/methods used, including sampling, handling, and preservation techniques; and

e) The results of each such analysis. Any records of monitoring activities and results including all original strip chart recordings for continuous monitoring instrumentation and calibration and maintenance records, shall be retained for a minimum of three years. This period shall be extended during the course of any unresolved litigation regarding the discharge of pollutants by the permittee or when requested by the Director.

8) All information and data provided by an applicant or a permittee identifying the nature and frequency of a discharge shall be available to the public without restriction. All other information (other than effluent data) which may be submitted by an applicant in connection with a permit application or which may be furnished by a permittee in connection with required periodic reports shall also be available to the public unless the applicant or permittee is able to demonstrate that the disclosure of such information or particular part thereof to the general public would divulge methods or processes entitled to protection as trade secrets in accordance with the provisions of M.G.L., c.21, § 27 (7). Where the applicant or permittee is able to so demonstrate, the Director shall treat the information or the particular part (other than effluent data) as confidential and not release it to any unauthorized person. Such information may be divulged to other officers, employees, or authorized representatives of the Commonwealth or the United States Government concerned with the protection of public waters or water supplies.

9) All reports and communications required hereunder are to be made or sent to the Director of the Division of Water Pollution Control.

10) The provisions of this permit are severable, and the invalidity of any condition or subdivision thereof shall not make void any other condition or subdivision thereof.

11) Reporting and Monitoring

a) Quality Control

The permittee shall calibrate and perform maintenance procedures on all monitoring and analytical instrumentation at regular intervals to ensure accuracy of measurements or shall ensure that both activities will be conducted. Samples shall be representative of the volume and quality of effluent discharged over the sampling and reporting period.

1) The permittee shall provide the above records and shall demonstrate the accuracy of the flow measuring device upon request of the Director. The permittee shall identify the effluent sampling point used for each discharge.

2) The permittee shall analyze any additional samples as may be required by the Director to ensure analytical quality control.

3) If this permittee monitors any pollutant more frequently than is required by this permit, he shall also provide the results of such monitoring to the Director.

b) Sampling and Analysis

The sampling, preservation, handling, and analytical methods used must conform to the following approved test procedures. However different but equivalent methods are allowable if they receive the prior written approval of the Director.

1) Standard Methods for the Examination of Water and Wastewaters, 13th Edition, 1971, American Public Health Association, New York, New York 10019;

2) A.S.T.M. Standards, Part 23, Water; Atmospheric Analysis, 1970; American Society of Testing and Materials, Philadelphia, Pennsylvania 19103; or

3) Methods for Chemical Analysis of Water and Wastes, April 1971, Environmental Protection Agency Water Quality Office, Analytical Quality Control Laboratory, 1014 Broadway, Cincinnati, Ohio 45268.

c) Reporting

The results of the above mentioned requirements shall be reported as required in Special Condition B. The permittee shall include in this report any previously approved non-standard methods used. Permanent elimination of a discharge should be brought to the attention of the Director within 15 days by a special written notification. A written report should be submitted if there have been any modifications in the waste collection, treatment, and disposal facilities; changes in operational procedures; or other significant activities which alter the nature and frequency of the discharge or otherwise concern the conditions of this permit.

12) Certification of Reports

All reports shall be signed by the chief operator of the treatment facility and

a) In the case of corporation, by a principal executive officer of at least the level of vice president, or his duly authorized representative, if such representative is responsible for the overall operation of the facility from which the discharge described in the permit originates;

b) In the case of a partnership, by a general partner;

c) In the case of a sole proprietorship, by the proprietor;

d) In the case of a municipal, State, or other public facility, by either a principal executive officer or ranking elected official.

13) Oil Discharges

There shall be no discharge of harmful quantities of oil, as defined pursuant to the Massachusetts Water Quality Standards, including (1) any subsequent amendments or revisions made thereto, or (2) any more restrictive limitations which may be imposed otherwise by law or regulation. The authorization of this permit does not preclude the institution of any legal action nor relieve the permittee from any liabilities, penalties, or responsibilities established by Section 311 of the Federal Act, by Massachusetts General Laws c. 21, §§ 27 (14), and 42 as amended, and the Massachusetts Rules for the Prevention and Control of Oil Pollution in the Waters of the Commonwealth by any subsequent amendments thereto, or by any superseding Federal or State legislation.

14) Other Materials

Other materials ordinarily produced or used in the operation of this facility, which have been specifically identified in the application, may be discharged at the maximum frequency and maximum level identified in the application, provided:

a) They are not

1) Designated as toxic or hazardous under provisions of the Massachusetts General Laws c. 21, §§ 57, 58 and the Division of Water Pollution Control Hazardous Waste Regulations

2) Known to be hazardous or toxic by the permittee, except that such materials may be discharged in certain limited amounts with the written approval of, and under special conditions established by the Director or his designated representatives, if the substance will not pose any imminent hazard to the public health or safety;

b) The discharge of such materials will not violate applicable water quality standards; and

c) The permittee is not notified by the Director to eliminate or reduce the quantity of such materials entering the watercourse.

15) Solids Disposal

Collected screenings, sludges, and other solids removed from liquid wastes shall be disposed of in such a manner as to prevent entry of such materials or leachate therefrom into navigable waters or their tributaries.

16) Non-Compliance

In the event the permittee is unable to comply with any of the conditions of this permit, due, among other reasons, to:

a) Breakdown or maintenance of waste treatment equipment (biological and physical-chemical systems including, but not limited to, all pipes, transfer pumps, compressors, collection ponds or tanks from the segregation of treated or untreated wastes, ion exchange columns, or carbon adsorption units),

b) Accidents caused by human error or negligence, or

c) Other causes, such as act of nature,

the permittee shall provide the Director with the following information in writing within five days after commencement of such occurrence:

1) Cause of non-compliance;

2) A description of the non-complying discharge including its impact upon the receiving waters;

3) Anticipated time the condition of non-compliance is expected to continue, or if such condition has been corrected, the duration of the period of non-compliance;

4) Steps taken by the permittee to reduce and eliminate the non-complying discharge; and

5) Steps to be taken by the permittee to prevent reoccurrence of the condition of non-compliance.

The permittee shall take all reasonable steps to minimize any adverse impact to navigable waters resulting from non-compliance with any effluent limitation specified in this permit, including, such accelerated or additional monitoring as necessary to determine the nature and impact of the non-complying discharge.

Nothing in this permit shall be construed to relieve the permittee from civil or criminal penalties for non-compliance, whether or not such non-compliance is due to factors beyond his control, such as equipment breakdown, electric power failure, accident, or natural disaster.

17) Emergency Action - Electric Power Failure

The permittee shall indicate in writing to the Director within 30 days of the effective date of this permit that, in the event the primary source of electric power fails, the permittee will provide an alternative source of power for the operation of its treatment facilities in accordance with a schedule to be established by the Director which will become part of this permit. The alternate power supply, whether from a generating unit located at the plant site or purchased from an independent source of electricity, must be separate from the existing power source used to operate the waste treatment facilities. If a separate facility located at the plant site is to be used, the permittee shall certify in writing to the Director when the facility is completed and prepared to generate power.

18) Bypasses

The diversion or bypass of any discharge from waste treatment facilities utilized by the permittee to maintain compliance with the terms and conditions of this permit is prohibited, except

1) Where unavoidable to prevent loss of life or severe property damage, or

2) Where excessive storm drainage or runoff would damage any facilities necessary for compliance with the terms and conditions of this permit.

The permittee shall immediately notify the Director in writing of each such diversion or bypass in accordance with the procedure specified above for reporting non-compliance.

19) Reapplication

If the permittee desires to continue to discharge after the expiration of this permit, it shall reapply on the application forms then in use at least 180 days before this permit expires.

20) Definitions

For purposes of this permit, the following definitions shall apply:

Director	Director of the Massachusetts Division of Water Pollution Control
Division	Massachusetts Water Resources Commission Division of Water Pollution Control Third Floor 110 Tremont Street Boston, Massachusetts 02108
Mean	The mean value is the arithmetic mean unless used for fecal or total coliform, which would be geometric mean.
Grab Sample	An individual sample collected in a period of less than 15 minutes.
Composite Sample	A sample consisting at a minimum of grab samples taken hourly during the period specified in the section on Monitoring and Reporting and combined proportional to flow, or a sample continuously collected proportional to flow over that same time period.
Monthly Average	The average of a minimum of twelve composite samples taken on twelve separate days, or at least one grab sample per day, taken on twelve separate days, as required for the parameter being reported within a calendar month.
Instantaneous Maximum	A value not to be exceeded in any grab sample.
Average	The arithmetic mean of values taken at the frequency required for each parameter over the specified period. For total and/or fecal coliforms, the average shall be computed as the geometric mean.
Federal Act	The Federal Water Pollution Control Act, as amended, (P. L. 92-500)

Incompatible Pollutant	Any pollutant, other than biochemical oxygen demand, suspended solids, pH, fecal coliform bacteria, or additional pollutants identified in the permit, which the treatment works was not designed to treat and does not remove to a substantial degree.

The following abbreviations, when used, are defined below:

Cu. M/day or M^3/day	Cubic meters per day
mg/l	milligrams per liter
ug/l	micrograms per liter
kgpd or kg/day	kilograms per day
Temp. ^oC	temperature in degrees Centrigrade
Temp. ^oF	temperature in degrees Fahrenheit
TNFR or TSS	total nonfilterable residue or total suspended solids
DO	dissolved oxygen
BOD	five-day biochemical oxygen demand unless otherwise specified
TKN	total Kjeldahl nitrogen as nitrogen
NH_3-N	ammonia nitrogen as nitrogen
lb/day	pounds per day
Total P	total phosphorus as phosphorus
COD	chemical oxygen demand
TOC	total organic carbon
Surfactant	surface-active agent

pH	a measure of the hydrogen ion concentration
PCB	polychlorinated biphenyl
CFS	cubic feet per second
MGD	million gallons per day
Oil & Grease	hexane extractable material
Total Coliform	total coliform bacteria
Turb.	turbidity measured in Jackson Candle Units (JTU)
Fecal Coliform	total fecal coliform bacteria
ml/l	milliliter(s) per liter
ml	milliliter(s)
SU	standard units
NO_3-N	nitrate nitrogen as nitrogen
NO_2-N	nitrite nitrogen as nitrogen
NO_2&NO_3	combined nitrite and nitrate nitrogen as nitrogen
Cl_2	total residual chlorine

1990 DRAFT GROUNDWATER DISCHARGE PERMIT

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
Department of Environmental Protection
Division of Water Pollution Control
One Winter Street, Boston, Mass. 02108

Brian Donahoe
Director

RECEIVED
DEPT. OF PUBLIC WORKS
TOWN OF BARNSTABLE
BY_____

2155

November 6, 1990

NOV 14 1990

Thomas J. Mullen, Superintendent
Department of Public Works
Town of Barnstable
Hyannis, MA 02601

Dear Mr. Mullen:

The attached draft groundwater discharge permit is, as you will notice, very similar to one we sent you Sept.13, 1989. At this time, we intend to issue the permit which has been held in abeyance for far too long.

In answer to some of your comments regarding the original draft, please consider the following:

1. The eventual flow of 4.2 mgd for the facility is based upon current knowledge of hydraulics and physical limitation of the site. If further study indicates greater or lesser capacity, the next groundwater permit can reflect that figure. Permits are only issued for five years, and assuming the schedule on the draft is adhered to, construction of an improved facility would not be completed until this permit expires, and a new one is pending.

2. If you have suggestions regarding the appropriate monitoring wells to be used in the permit, please indicate those you feel are suitable.

3. The plant uses chlorine for disinfection of the effluent at the present time. This is primarily because the discharge is not subsurface but to sand beds which can produce an aerosol effect. If other methods of disinfection are preferable to the town, they can be incorporated into a subsequent permit, after study and recommendation.

4. The implementation schedule included in the permit was developed in conjunction with the Bureau of Municipal Facilities and represents a realistic approach for the Town. If the Town disagrees, they have the right to appeal the permit upon issuance. The town if required to prepare an environmental impact report for the MEPA office, but MEPA has determined that we can issue a groundwater discharge permit prior to completion of an EIR.

Original on Recycled Paper

5. The permit contains specific water quality parameters to which the discharge must conform. The permit does not require that an upgradient well meet class I standards- that is not within the purview of this permit process.

In summary, please consider that the permit is issued for only a five year period.

The requirements are not final and unchangeable, and in fact, the permit may be revised/modified at any time for just cause.

If you have any further questions regarding the draft permit please call Clinton Watson of my staff at 617-292-5693.

Very truly yours,

Brian Donahoe

Brian Donahoe
Director

cc: DEP/DWPC, SERO
Board of Health, Town Hall, 397 Main St., Hyannis, MA 02061
DEP/BMF, Boston, Atttn: Bob Cady

BD/CW/yg
wp2/mullen

DRAFT
FOR REVIEW ONLY

DISCHARGE PERMIT

Name and Address of Applicant: Town of Barnstable, Water Pollution Control Facility, DPW, 367 Main St., Hyannis, MA 02601

Application No.: 0-21

Date of Application: 2-06-84

Permit No.: _____

Date of Issuance: _____

Date of Expiration: _____

AUTHORITY FOR ISSUANCE

Pursuant to authority granted by Chapter 21, Sections 26-53 of the Massachusetts General Laws, as amended, the following permit hereby issued to:

Town of Barnstable, Department of Public Works

(hereinafter called "the permittee"), authorizing discharges from an on-site wastewater treatment facility on Bearses Way, Hyannis, to the ground, such authorization being expressly conditional on compliance by the permittee with all terms and conditions or the permit hereinafter set forth.

This permit shall become effective on the date of the Director's signature and shall expire on _____.

DRAFT
FOR REVIEW ONLY

Brian Donahoe, Director
Division of Water Pollution Control

Date

I. SPECIAL CONDITIONS

A. Effluent Limits

The permittee is authorized to discharge into the ground from the wastewater treatment facilities for which this permit is issued a treated effluent whose characteristics, within one month after start-up of the facilities and continuing thereafter, shall not exceed the following values:

1. Prior to treatment system improvements:

Effluent Characteristic	Discharge Limitations
Flow, million gallons per day	2.7 mgd
Biochemical Oxygen Demand, 5 day 20°C	30 mg/l
Total Suspended Solids	30 mg/l
Settleable Solids	0.1 ml/l
Fecal Coliform Bacteria	200/100 ml
Chlorine Residual	1.0 mg/l
Total Dissolved Solids	1000 mg/l
Chlorides	250.0 mg/l
Nitrate Nitrogen	15.0 mg/l
Total Nitrogen	15.0 mg/l

2. After treatment system improvements:

Effluent Characteristic	Discharge Limitations
Flow, million gallons per day	4.2
Biochemical Oxygen Demand, 5 day 20°C	30 mg/l
Total Suspended Solids	30 mg/l
Settleable Solids	0.1 ml/l
Fecal Coliform Bacteria	200/100 ml
Chlorine Residual	1.0 mg/l
Total Dissolved Solids	1000 mg/l
Chlorides	250.0 mg/l
Nitrate Nitrogen	10.0 mg/l
Total Nitrogen	10.0 mg/l

(a) The pH of the effluent shall not be less than 6.5 nor greater than 8.5 at any time.

(b) The discharge of the effluent shall not result in any demonstrable adverse effect on the ground water or violate any water quality standard that has been promulgated.

(c) The monthly average concentration of BOD and total suspended solids in the discharge shall not exceed 15 percent of the monthly average concentrations of BOD and total suspended solids in the influent into the permittee's wastewater treatment facilities.

(d) When the effluent discharged for a period of 90 consecutive days exceeds 80 percent of the permitted flow limitation, the permittee shall submit to the permitting authorities projected loadings and a program for maintaining satisfactory treatment levels consistent with approved water quality management plans.

B. Monitoring and Reporting

1) The permittee shall monitor and record the quality and quantity of effluent at the sampling station immediately following the chlorine contact chamber according to the following schedule and other provisions:

Parameter	Minimum Frequency of Analysis	Sample Type
Flow	Daily	Daily Avg., Max., Min.
BOD	2 x weekly	24 hour composite
TSS and Total Solids	2 x weekly	24 hour composite
Settleable Solids	1 x daily	Grab
Fecal Coliform	2 x weekly	Grab
pH	1 x daily	Grab
Chlorine Residual	1 x daily	Grab
Total Phosphorous as P	1 x monthly	24 hour composite
Nitrate Nitrogen	2 x monthly	24 hour composite
NH3 as Nitrogen	2 x monthly	24 hour composite
Total Nitrogen	2 x monthly	24 hour composite
Dissolved Oxygen	1 x daily	Grab
Chloride	2 x weekly	Grab
Total Dissolved Solids	2 x weekly	24 hour composite
Sodium	2 x weekly	Grab
Total Volatile Organic Compounds (EPA Method #624)	1 x weekly	Grab

2) The permittee shall monitor and report the quality of ground water in existing monitoring wells BA-1,2,3;BB-1,2,3,; BC-11; BD-1 and BE-11(as shown on the accompanying map) according to the following schedule and other provisions:

Specific Conductance	1 x monthly
Ammonia Nitrogen	1 x monthly
Chloride	1 x monthly
Copper	1 x monthly
Iron	1 x monthly
Manganese	1 x monthly
Nitrate-Nitrogen	1 x monthly
Sodium	1 x monthly
Sulfate	1 x monthly
pH	1 x monthly
Total Phosphorus	1 x annually
Total Trihalomethanes (EPA Method #624)	1 x annually
Total Volatile Organics (EPA Method #624)	1 x annually
MBAS	1 x annually
Static Water Level	1 x monthly

3) Any grab sample or composite sample required to be taken less frequently than daily shall be taken during the period of Monday through Friday inclusive. Eight hour composites and grab samples shall be taken between 8:00 a.m. and 6:00 p.m. All composite samples shall be taken over the operating day.

The permittee shall submit all reports on an acceptable form, properly filled and signed, on the fifteenth day of every month, beginning thirty days after the issuance of this permit, to the Regional Director, Department of Environmental Protection, Southeast Regional Office, Lakeville Hospital, Lakeville, MA 02346 and to the Director, Department of Environmental Protection, Division of Water Pollution Control, One Winter Street, Boston, MA 02108.

C. Implementation Schedule

1) The permittee shall engage a registered professional engineer by December 30, 1990 to prepare engineering plans to improve effluent quality from the wastewater treatment system to meet the discharge limitations listed in A.2 "Effluent LImits" above.

2) By September 1, 1992, the permittee shall submit for review a preliminary engineering report detailing improvements to the existing treatment system necessary to meet the effluent limits contained in A-2 above. This preliminary engineering report shall provide detailed information on reasons for selecting the proposed method for treatment plant improvements, the costs associated with such improvements, steps which must be taken to secure money for the improvements and a complete project schedule.

3) By September 1, 1993, the permittee shall submit for approval final plans and specifications for improvements to the existing treatment system necessary to meet the effluent limits contained in section A-2 above.

4) By December 30, 1993, the permittee shall begin construction of the improvements to the existing treatment system in accordance with the approved plans and specifications.

5) By December 30, 1995, the permittee will have completed all necessary improvements to the treatment system to meet effluent limits as shown in A-2 above and to attain operational level.

6) Should the completed facility be incapable of meeting the effluent limits specified in paragraph A-2 above or if the Division determines that additional treatment is necessary to protect downgradient public water supplies, the permit will be modified to include, as appropriate, new effluent limits and/or and implementation schedule for additional facilities.

p-barnst
SPS #9

PART II GENERAL PERMIT CONDITIONS

The following conditions apply to all permits:

1 No discharge authorized in the permit shall result in a violation of the Massachusetts Surface Water Quality Standards (314 CMR 4.00) or the Massachusetts Ground Water Quality Standards (314 CMR 6.00), or any amendments thereto. Upon promulgation of any amended standard, this permit may be revised or amended in accordance with such standard and 314 CMR 2.10 and 3.12 or 5.12. For purposes of determining compliance with ground water quality standards, a violation of the ground water quality standards, and the discharge permit, will be determined to occur when any parameter measured in any downgradient well exceeds the applicable criteria listed in 314 CMR 6.06. In those cases where it is shown that a measured parameter exceeds the applicable criteria listed in 314 CMR 6.06 at the upgradient monitoring well, a violation of the ground water quality standards and the discharge permit will be determined to occur when it is shown that a measured parameter in any downgradient well exceeds the level of that same measured parameter in the upgradient well for the same sampling period.

2 Duty to comply. The permittee shall comply at all times with the terms and conditions of the permit, 314 CMR, the State Act and all other applicable state and federal statutes and regulations.

3 Standards and prohibitions for toxic pollutants. The permittee shall comply with effluent standards or prohibitions established under Section 307(a) of the Federal Act for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.

4 Proper operation and maintenance. The permittee shall at all times properly operate and maintain all facilities and equipment installed or used to achieve compliance with the terms and conditions of the permit, and in accordance with 314 CMR 12.00.

5 Duty to halt or reduce activity. Upon reduction, loss, or failure of the treatment facility, the permittee shall, to the extent necessary to maintain compliance with its permit, control production or discharges of both until the facility is restored or an alternative method of treatment is provided. It shall not be a defense for a permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of the permit.

6 Power Failure. In order to maintain compliance with the effluent limitations and prohibitions of this permit, the permittee shall either:

(a) provide an alternative power source sufficient to operate the wastewater control facilities; or

(b) halt, reduce or otherwise control production and/or all discharges upon the reduction, loss, or failure of the primary source of power to the wastewater control facilities.

7 Duty to mitigate. The permittee shall take all reasonable steps to minimize or prevent any adverse impact on human health or the environment resulting form non-compliance with the permit.

8 Duty to provide information. The permittee shall furnish to the Director within a reasonable time any information which the Director may request to determine whether cause exists for modifying, revoking and reissuing, or terminating the permit, or to determine whether the permittee is complying with the terms and conditions of the permit.

9 Inspection and entry. The permittee shall allow the Director or his authorized representatives to:

(a) Enter upon the permittee's premises where a regulated facility or activity is located or conducted, or where records required by the permit are kept;

(b) Have access to and copy, at reasonable times, any records that must be kept under the conditions of the permit;

(c) Inspect at reasonable times any facilities, equipment, practices, or operations regulated or required under the permit; and

(d) Sample or monitor at reasonable times for the purpose of determining compliance with the terms and conditions of the permit.

10 Monitoring. Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity. Monitoring must be conducted according to test procedures approved under 40CFR Part 136 unless other test procedures are specified in the permit.

11 Record keeping. The permittee shall retain records of all monitoring information including all calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by the permit, and all records of all data used to complete the application for the permit, for a period of at least three (3) years from the date of the sample, measurement, report or application. This period may be extended by request of the Director at any time.

Records of monitoring information shall include:

(a) The date, exact place, and time of sampling or measurements;
(b) The individual(s) who performed the sampling or measurement:
(c) The date(s) analyses were performed;
(d) The individual(s) who performed the analyses;
(e) The analytical techniques or methods used; and
(f) The results of such analyses.

12 Prohibition of bypassing: Except as provided in 314 CMR 3.19(13), bypassing is prohibited and the Director may take enforcement action against a permittee for bypassing, unless the discharge is to a surface water and:

(a) The bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;
(b) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if the permittee could have installed adequate backup equipment to prevent a bypass which occurred during normal periods of equipment downtime or preventive maintenance; and
(c) The permittee submitted notice of the bypass to the Director:
1. In the event of an anticipated bypass at least ten (10) days in advance, if possible; or
2. In the event of an unanticipated bypass as soon as the permittee has knowledge of the bypass and no later than twenty-four (24) hours after its fist occurrence.

13 Bypass not exceeding limitations. The permittee may allow a bypass to occur which does not cause effluent limitations to be exceeded, but only if necessary for the performance of essential maintenance or to assure efficient operation of treatment facilities.

14 Permit actions. The permit may be modified, suspended, or revoked for cause. The filing of a request by the permittee for a permit modification, reissuance, or termination, or a notification of planned changes or anticipated non-compliance does not stay any permit condition.

15 Duty to reapply. If the permittee wishes to continue an activity regulated by the permit after the expiration date of the permit, the permittee must apply for and obtain a new permit. The permittee shall submit a new application at least one hundred and eighty (180) days before the expiration date of the existing permit, unless permission for a later date has been granted by the Director.

continued

16 Property rights. The permit does not convey any property rights of any sort or any exclusive privilege.

17 Other laws. The issuance of a permit does not authorize any injury to persons or property or invasion of other private rights, nor does it relieve the permittee of its obligation to comply with any other applicable Federal, State and local laws and regulations.

18 Oil and harzardous substance liability. Nothing in the permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties to which the permittee is or may be subject under Section 311 of the Federal Act, and M.G.L.c.21E.

19 Removed substances. Solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters shall be disposed in a manner consistent with applicable Federal and State laws and regulations including, but not limited to, the State and Federal Acts, the Massachusetts Hazardous Waste Management Act, M.G.L.c.21C, and the federal Resource Conservation and Recover Act, 42 U.S.C. s.6901, et seq. 310 CMR 19.00 and 30.000, and other applicable regulations.

20 Reporting requirements.

(a) Monitoring reports. Monitoring results shall be reported on a Discharge Monitoring Report (DMR) at the intervals specified elsewhere in the permit. If the permittee monitors any pollutant more frequently than required by the permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the DMR.

(b) Compliance schedules. Reports of compliance or non-compliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of the permit shall be submitted no later than fourteen (14) days following each schedule date.

(c) Planned changes. The permittee shall give notice to the Director as soon as possible of any planned physical alterations or additions to the permitted facility or activity which could significantly change the nature or increase the quantity of pollutants discharged. Unless and until the permit is modified, any new or increased discharge in excess of permit limits or not specifically authorized by the permit constitutes a violation.

(d) Anticipated non-compliance. The permittee shall give advance notice to the Director of any planned changes in the permitted facility or activity which may result in no-compliance with permit requirements.

(e) Twenty-four (24) hour reporting. The permittee shall report any non-compliance which may endanger health or the environment. Any information shall be provided orally within twenty-four (24) hours from the time the permittee becomes aware of the circumstances. A written submission shall also be provided within five (5) days of the time the permittee becomes aware of the circumstances. The written submission shall contain a description of the non-compliance, including exact dates and times, and if the non-compliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the non-compliance.

The following shall be included as information which must be reported within twenty-four (24) hours:

1. Any unanticipated bypass which exceeds any effluent limitation in the permit.
2. Violation of a maximum daily discharge limitation for any of the pollutants listed by the Director in the permit to be reported within twenty-four (24) hours.

(f) Other non-compliance. The permittee shall report all instances of non-compliance not reported under 314 CMR 3.19(20)(a), (b) or (e) at the time monitoring reports are submitted. The reports shall contain the information listed in 314 CMR 3.19(20)(e).

(g) Toxics. All manufacturing, commercial, mining, or silvicultural dischargers must notify the Director as soon as they know or have reason to believe:

1. That any activity has occurred or will occur which would result in the discharge of any toxic pollutant listed in 314 CMR 3.16 which is not limited in the permit, if that discharge will exceed the highest of the following notification levels:

a. One hundred micrograms per liter (100 ug/l);
b. Two hundred micrograms per liter (200 ug/l) for acrolein and acrylonitrile; five hundred micrograms per liter (500 ug/l) for 2,4-dinitrophenol and for 2-methyl-4,6-dinitrophenol; and one milligram per liter (1 mg/l) for antimony;
c. Five (5) times the maximum concentration value reported for that pollutant in the permit application; or

2. That they have begun or expect to begin to use or manufacture as an intermediate or final product or byproduct any toxic pollutant which was not reported in the permit application.

(h) Indirect dischargers. All Publicly Owned Treatment Works shall provide adequate notice to the Director of the following:

1. Any new introduction of pollutants into the POTW from an indirect discharger which would be subject to Sections 301, or 306 of the Federal Act if it were directly discharging those pollutants; and

2. Any substantial change in the volume or character of pollutants being introduced into the POTW by a source introducing pollutants into the POTW at the time of issuance of the permit.

3. For purposes of 314 CMR 3.00, adequate notice shall include information on the quality and quantity of effluent introduced into the POTW, and any anticipated impact of the change on the quantity or quality of effluent to be discharged from the POTW.

(i) Information. Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application or in any report to the Director, it shall promptly submit such facts or information.

21 Signatory requirement. All applications, reports, or information submitted to the Director shall be signed and certified in accordance with 314 CMR 3.14 and 5.11.

22 Severability. The provisions of the permit are severable, and if any provision of the permit, or the application of any provision of the permit to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of the permit, shall not be affected thereby.

23 Reopener clause. The Director reserves the right to make appropriate revisions to the permit in order to establish any appropriate effluent limitations, schedules of compliance, or other provisions which may be authorized under the State or Federal Acts in order to bring all discharges into compliance with said statutes.

24 Approval of plans and specifications for treatment works. All discharges and associated treatment works authorized herein shall be consistent with the terms and conditions of this permit and the approved plans and specifications. Any modification to the approved treatment works shall require written approval of the Director or the Department.

25 Transfer of Permits.

(a) RCRA facilities. Any permit which authorized the operation of a RCRA facility which is subject to the requirements of 314 CMR 8.07 shall be valid only for the person to whom it is issued and may not be transferred.

(b) Transfers by modification. Except as provided in 314 CMR 3.19(25)(a) and (c) a permit may be transferred by the permittee to a new owner or operator only if the permit has been modified or revoked and reissued or a minor modification made to identify the new permittee.

(c) Automatic transfers. As an alternative to transfers under 314 CMR 3.19(25)(b), any permit may be automatically transferred to a new permittee if:

1. The current permittee notifies the Director at least thirty (30) days in advance of the proposed transfer date in 314 CMR 3.19(25)(c)2.

2. The notice includes a written agreement between the existing and new permittees containing a specific date for transfer of permit responsibility, coverage, and liability between them; and

3. The Director does not notify the existing permittee and the proposed new permittee of his intent to modify or revoke and reissue the permit. A modification under 314 CMR 3.19(25) may also be a minor modification. If this notice is not received, the transfer is effective on the date specified in the agreement mentioned in 314 CMR 3.19(25)(c)2.

26 Permit Fees.

(a) Any permittee, other than a public entity, required to obtain a surface water or ground water discharge permit pursuant to M.G.L. c.21, s.43 and 314 CMR 3.00 and 5.00, shall be required annually to obtain an inspection certificate from the Division, and submit the information and fee associated therewith in accordance with 314 CMR 2.12.

Appendix 2-3

Marstons Mills WWTF Groundwater Discharge Permit, March 2010

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY & ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION

GROUNDWATER DISCHARGE PERMIT

Name and Address of Applicant: ***Town of Barnstable, 617 Bearse's Way, Hyannis, Massachusetts 02601.***

Date of Application:	***August 1, 2008***
Application/Permit No.	***576-2***
Date of Issuance:	***March 2, 2010***
Date of Expiration:	***March 2,, 2015***
Effective Date:	***March 2, 2010***

AUTHORITY FOR ISSUANCE

Pursuant to authority granted by Chapter 21, Sections 26-53 of the Massachusetts General Laws, as amended, 314 CMR 2.00, and 314 CMR 5.00, the Massachusetts Department of Environmental Protection (the Department) hereby issues the following permit to: Town of Barnstable (hereinafter called "the permittee") authorizing discharges from the Horace Mann Charter School, 730 Osterville – West Barnstable Road, Marstons Mills, Massachusetts (school with a population of 1,751 and a 30 unit affordable housing development) on-site wastewater treatment facility to the ground, such authorization being expressly conditional on compliance by the permittee with all terms and conditions of the permit hereinafter set forth.

Brian A. Dudley
Bureau of Resource Protection

March 2, 2010
Date

I. SPECIAL CONDITIONS

A. Effluent Limits

The permittee is authorized to discharge into the ground from the wastewater treatment facilities for which this permit is issued a treated effluent whose characteristics shall not exceed the following values:

Effluent Characteristics	Discharge Limitations
Flow	42,900 GPD
Oil and grease	15 mg/l
Total Suspended Solids (TSS)	10 mg/l
Total Nitrogen ($NO_2 + NO_3 + TKN$)	10 mg/l
Nitrate-Nitrogen	10 mg/l
Biochemical Oxygen Demand, 5-day @20°C (BOD_5)	30 mg/l
Turbidity	5 NTU
Fecal Coliform	200 colonies / 100 ml

a) The pH of the effluent shall not be less than 6 nor greater than 9 at any time or not more than 0.2 standard units outside the naturally occurring range.

b) The discharge of the effluent shall not result in any demonstrable adverse effect on the groundwater or violate any water quality standards that have been promulgated.

c) The monthly average concentration of BOD and TSS in the discharge shall not exceed 15 percent of the monthly average concentrations of BOD and TSS in the influent into the permittee's wastewater treatment facility.

d) When the average annual flow exceeds 80 percent of the permitted flow limitations, the permittee shall submit a report to the Department describing what steps the permittee will take in order to remain in compliance with the permit limitations and conditions, inclusive of the flow limitations established in this permit.

B. Monitoring and Reporting

1) INFLUENT:

The permittee shall monitor and record the quality of the **influent** waste stream to the facility according to the following schedule and other provisions:

Parameter	Minimum Frequency of Analysis	Sample Type
BOD_5	Monthly	24-Hour Composite
Total Suspended Solids	Monthly	24-Hour Composite
Total Solids	Monthly	24-Hour Composite
Ammonia Nitrogen	Monthly	24-Hour Composite

EFFLUENT:

The permittee shall monitor and record the quality and quantity of **effluent** at the effluent pump chamber to the leaching area according to the following schedule and other provisions:

Parameter	Minimum Frequency of Analysis	Sample Type
Flow	Daily	Meter reading
pH	Daily	Grab
UV Intensity	Daily	Continuous
Total Suspended Solids	Weekly	24-Hour Composite
Total Solids	Monthly	24-Hour Composite
Oil & Grease	Monthly	Grab
BOD_5	Weekly	24-Hour Composite
Nitrate Nitrogen	Weekly	24-Hour Composite
Total Nitrogen (NO_2 + NO_3 + TKN)	Weekly	24-Hour Composite

Turbidity	Continuous	Meter reading
Fecal Coliform	2 / Week	Grab
Total Phosphorus[2] (as P)	Quarterly	Grab
Orthophosphate[2] (as P)	Quarterly	Grab
Volatile Organic Compounds[1]	2 x Annually	Grab

[1]USEPA Method #624
[2]After one full year of monitoring the Total Phosphorus and Orthophosphate results, the Department may determine, upon the request of the permittee, that the frequency of monitoring may be reduced if, in the judgment of the Department, the results of the sampling indicate that existing phosphorus levels will not adversely impact downgradient receptors.

2) The permittee shall sample the upgradient monitoring well: GWMW# 8 and the downgradient monitoring wells GWMW# 5, GWMW# 6, GWMW# 4, GWMW# 3 and GWMW# 2 as shown on a plan titled "Existing Site Plan, Marstons Mills Middle School, Barnstable, Massachusetts" dated August, 2003, submitted by Stearns & Wheler, LLC. Labels identifying each monitoring well's identification in accordance with the above-referenced approved plan shall be affixed to the steel protective casing of each monitoring well.

The permittee shall monitor, record and report the quality of water in the monitoring wells according to the following schedule and other provisions:

Parameter	**Frequency of Analysis**
Static Water Level[1]	Monthly
pH	Monthly
Total Nitrogen (NO_2+NO_3+TKN)	Quarterly
Nitrate-Nitrogen	Quarterly
Total Phosphorus (as P)[3]	Quarterly
Orthophosphate (as P)[3]	Quarterly
Volatile Organic Compounds[2]	Annually

[1]Static Water Level shall be expressed as an elevation and shall be referenced to the surveyed datum established for the site. It shall be calculated by subtracting the depth to

the water table from the surveyed elevation of the top of the monitoring well's PVC well casing/riser.
[2]USEPA Method #624
[3]After one full year of monitoring the Total Phosphorus and Orthophosphate results, the Department may determine, upon the request of the permittee, that the frequency of monitoring may be reduced if, in the judgement of the Department, the results of the sampling indicate that existing phosphorus levels will not adversely impact downgradient receptors.

3) Any grab sample or composite sample required to be taken less frequently than daily shall be taken during the period of Monday through Friday inclusive. All composite samples shall be taken over the operating day.

The permittee shall submit all monitoring reports within 30 days of the last day of the reporting month. Reports shall be on an acceptable form, properly filled and signed and shall be sent to the Department of Environmental Protection, Southeast Regional Office, 20 Riverside Drive, Lakeville, MA 02347, and to the Director of Watershed Permitting, Department of Environmental Protection, Watershed Permitting Group, One Winter Street, Boston, MA 02108, and to the Board of Health, P.O. Box 534, Hyannis, MA 02601. Submission of monitoring reports in electronic format is available through eDEP and serves as data submission to both the Regional and Boston offices. To register for electronic submission go to:
http://www.mass.gov/dep/service/compliance/edeponlf.htm

C. Supplemental Conditions

1. The permittee shall notify the Department at least thirty (30) days in advance of the proposed transfer of ownership of the treatment works for which this permit is written. Said notification shall include a written agreement between the existing and new permittees containing a specific date for transfer of permit, responsibility, coverage and liability between them.
2. A staffing plan for the treatment works shall be submitted to the Department once every two years and whenever there are staffing changes. The staffing plan shall include the following components:
   a) The operator(s)'s name(s), operator grade(s) and operator license number(s);
   b) The number of operational days per week;
   c) The number of operational shifts per week;
   d) The number of shifts per day;
   e) The required personnel per shift;
   f) Saturday, Sunday and holiday staff coverage;
   g) Emergency operating personnel
3. The permittee is responsible for the operation and maintenance of all sewers, pump stations, and treatment units for the permitted facility, which shall be operated and maintained under the direction of a properly certified wastewater operator.
4. The permittee shall contract to have any and all solids and sludges generated by the treatment works for which this permit is issued removed off site by a properly licensed

waste hauler for disposal at an EPA/DEP approved facility. The name and license number of the hauler along with the quantity of wastes removed and the date(s) of removal shall be reported by the permittee in writing to the Department.

5. Operation and maintenance of the proposed facility must be in accordance with 314 CMR 12.00, "Operation and Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Discharges", and, 257 CMR 2.00, "Rules and Regulations for Certification of Operators of Wastewater Treatment Facilities.
   a. The facility has been rated (in accordance with 257 CMR 2.00), to be a Grade 4 facility. Therefore, the permittee shall provide for oversight by a Massachusetts Certified Wastewater Treatment plant operator (Chief Operator) Grade 4 or higher. The permittee will also provide for a backup operator who shall possess at least a valid Grade 3 license.
   b. The date and time of the operator's inspection along with the operator's name and certification shall be recorded on the required monthly monitoring reports.
6. If the operation and maintenance of the facility is to be contracted to a private concern, the permittee shall submit a copy of the contract, consistent with what is required by the approved Operation & Maintenance manual and signed only by the contractor, to the appropriate MassDEP Regional Office for review and approval ninety (90) days **prior** to the start up of the facility. Along with the contract, a detailed listing of all contract operation obligations of the proposed contractor at other facilities shall also be submitted. The permittee shall not begin operation of the treatment facility until the Department approves the contract.
7. All tests or analytical determinations to determine compliance with permit standards and requirements shall be done using tests and procedures found in the most recent version of *Standard Methods for the Examination of Water and Wastewater* and shall be performed by a Massachusetts certified laboratory.
8. The permittee shall notify the Department, in writing, within thirty (30) days of the following events:
   a. Any interruption of the treatment system operation, other than routine maintenance.
   b. Final shutdown of the treatment system.

D. Appeal Rights

This Permit is an action of the Department. Any person aggrieved by this action may request an Adjudicatory Hearing. A request for a hearing must be made in writing and postmarked within thirty (30) days of the Permit issuance date. Under 310 CMR 1.01(6)(b), the request must state clearly and concisely the facts, which are the grounds for the request, and the relief sought.

The Hearing request along with a valid check payable to the Commonwealth of Massachusetts in the amount of one hundred dollars ($100.00) must be mailed to:

Commonwealth of Massachusetts
Department of Environmental Protection
P.O. Box 4062
Boston, MA 02211

The request will be dismissed if the filing fee is not paid, unless the appellant is exempt or granted a waiver as described below. The filing fee is not required if the appellant is a city or town (or municipal agency), county, or district of the Commonwealth of Massachusetts, or a municipal housing authority. The Department may waive the adjudicatory hearing filing fee for a person who shows that paying the fee will create an undue financial hardship. A person seeking a waiver must file, together with the hearing request as provided above, an affidavit setting forth the facts believed to support the claim of undue financial hardship.

II. GENERAL PERMIT CONDITIONS

The following conditions apply to all individual and general permits:

(1) No discharge authorized in the permit shall cause or contribute to a violation of the Massachusetts Surface Water Quality Standards (314 CMR 4.00) or any amendments thereto. Upon promulgation of any amended standard, this permit may be revised or amended in accordance with such standard and 314 CMR 2.10 and 3.13 or 5.12. Except as otherwise provided in 314 CMR 5.10 (3)(c), 310 CMR 5.10(4)(a)2 and 314 CMR 5.10(9), no discharge authorized in the permit shall impair the ability of the ground water to act as an actual or potential source of potable water. Evidence that a discharge impairs the ability of the ground water to act as an actual or potential source of potable water includes, without limitation, analysis of samples taken in a downgradient well that shows one or more exceedances of the applicable water quality based effluent limitations set forth in 314 CMR 5.10. In those cases where it is shown that a measured parameter exceeds the applicable water quality based effluent limitations set forth in 314 CMR 5.10 at the upgradient monitoring well, evidence that a discharge impairs the ability of the ground water to act as an actual or potential source of potable water is deemed to exist if a measured parameter in any downgradient well exceeds the level of that same measured parameter in the upgradient well for the same sampling period. . A statistical procedure approved by the Department shall be used in determining when a measured parameter exceeds the allowable level.

(2) Duty to comply. The permittee shall comply at all times with the terms and conditions of the permit, 314 CMR 5.00, M.G.L. c. 21, §§ 26 through 53 and all applicable state and federal statutes and regulations.

(3) Standards and prohibitions for toxic pollutants. The permittee shall comply with effluent standards or prohibitions established under § 307(a) of the Federal Act, 33 U.S.C § 1317(a), for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.

(4) Proper operation and maintenance. The permittee shall at all times properly operate and maintain all facilities and equipment installed or used to achieve compliance with the terms and conditions of the permit, and the regulations promulgated at 314 CMR 12.00 entitled "Operation and Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Discharges, and 257 CMR 2.00, Rules and Regulations for Certification of Operators of Wastewater Treatment Facilities".

(5) Duty to halt or reduce activity. Upon reduction, loss, or failure of the treatment facility, the permittee shall, to the extent necessary to maintain compliance with its permit, control production or discharges or both until the facility is restored or an alternative method of treatment is provided. It shall not be a defense for a permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of the permit.

(6) Power Failure. In order to maintain compliance with the effluent limitations and prohibitions of this permit, the permittee shall either:

(a) provide an alternative power source sufficient to operate the wastewater control facilities; or

(b) halt, reduce or otherwise control production and/or all discharges upon the reduction, loss, or failure of the primary source of power to the wastewater control facilities.

(7) Duty to mitigate. The permittee shall take all reasonable steps to minimize or prevent any adverse impact on human health or the environment resulting from non-compliance with the permit.

(8) Duty to provide information. The permittee shall furnish to the Department within a reasonable time as specified by the Department any information which the Department may request to determine whether cause exists for modifying, revoking and reissuing, or terminating the permit, or to determine whether the permittee is complying with the terms and conditions of the permit.

(9) Inspection and entry. The permittee shall allow the Department or its authorized representatives to:

(a) Enter upon the permittee's premises where a regulated facility or activity is located or conducted, or where records required by the permit are kept;

(b) Have access to and copy, at reasonable times, any records that must be kept under the conditions of the permit;

(c) Inspect at reasonable times any facilities, equipment, practices, or operations regulated or required under the permit; and

(d) Sample or monitor at reasonable times for the purpose of determining compliance with the terms and conditions of the permit.

(9A) The permittee shall physically secure the treatment works and monitoring wells and limit access to the treatment works and monitoring wells to those personnel required to operate, inspect and maintain the treatment works and to collect samples.

(9B) The permittee shall identify each monitoring well by permanently affixing to the steel protective casing of the well a tag with the identification number listed in the permit.

(10) Monitoring. Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity. Monitoring must be conducted according to test procedures approved under 40 CFR Part 136 unless other test procedures are specified in the permit.

(11) Recordkeeping. The permittee shall retain records of all monitoring information, including all calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by the permit, and all records of all data used to complete the application for the permit, for a period of at least three years from the date of the sample, measurement, report or application. This period may be extended by request of the Department at any time. Records of monitoring information shall include:

(a) The date, exact place, and time of sampling or measurements;
(b) The individual(s) who performed the sampling or measurement;
(c) The date(s) analyses were performed;
(d) The individual(s) who performed the analyses;
(e) The analytical techniques or methods used; and
(f) The results of such analyses.

(12) Prohibition of bypassing. Except as provided in 314 CMR 5.16(13), bypassing is prohibited, and the Department may take enforcement action against a permittee for bypassing unless:

(a) The bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;
(b) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if the permittee could have installed adequate backup equipment to prevent a bypass which occurred during normal periods of equipment downtime or preventive maintenance; and
(c) The permittee submitted notice of the bypass to the Department:
    1. In the event of an anticipated bypass, at least ten days in advance, if possible; or
    2. In the event of an unanticipated bypass, as soon as the permittee has knowledge of the bypass and no later than 24 hours after its first occurrence.

(13) Bypass not exceeding limitations. The permittee may allow a bypass to occur which does not cause effluent limitations to be exceeded, but only if necessary for the performance of essential maintenance or to assure efficient operation of treatment facilities.

(14) Permit actions. The permit may be modified, suspended, or revoked for cause. The filing of a request by the permittee for a permit modification, reissuance, or termination, or a notification of planned changes or anticipated non-compliance does not stay any permit condition.

(15) Duty to reapply. If the permittee wishes to continue an activity regulated by the permit after the expiration date of the permit, the permittee must apply for and obtain a new permit. The permittee shall submit a new application at least 180 days before the expiration date of the existing permit, unless permission for a later date has been granted by the Department in writing.

(16) Property rights. The permit does not convey any property rights of any sort or any exclusive privilege.

(17) Other laws. The issuance of a permit does not authorize any injury to persons or property or invasion of other private rights, nor does it relieve the permittee of its obligation to comply with any other applicable Federal, State, and local laws and regulations.

(18) Oil and hazardous substance liability. Nothing in the permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties to which the permittee is or may be subject under § 311 of the Federal Act, 33 U.S.C. § 1321, and M.G.L. c. 21E.

(19) Removed substances. Solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters shall be disposed in a manner consistent with applicable Federal and State laws and regulations including, but not limited to, the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26 through 53 and the Federal Act, , 33 U.S.C. § 1251 *et seq*, the Massachusetts Hazardous Waste Management Act, M.G.L. c. 21C, and the Federal Resource Conservation and Recovery Act, 42 U.S.C. § 6901, *et seq.*, 310 CMR 19.000 and 30.000, and other applicable regulations.

(20) Reporting requirements.

(a) Monitoring reports. Monitoring results shall be reported on a Discharge Monitoring Report (DMR) at the intervals specified elsewhere in the permit. If the permittee monitors any pollutant more frequently than required by the permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the DMR.

(b) Compliance schedules. Reports of compliance or non-compliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of the permit shall be submitted no later than 14 days following each schedule date.

(c) Planned changes. The permittee shall give notice to the Department as soon as possible of any planned physical alterations or additions to the permitted facility or activity which could significantly change the nature or increase the quantity of pollutants discharged. Unless and until the permit is modified, any new or increased discharge in excess of permit limits or not specifically authorized by the permit constitutes a violation.

(d) Anticipated non-compliance. The permittee shall give advance notice to the Department of any planned changes in the permitted facility or activity which may result in non-compliance with permit requirements.

(e) 24 hour reporting. The permittee shall report any non-compliance which may endanger health or the environment. Any information shall be provided orally within 24 hours from the time the permittee becomes aware of the circumstances. A written submission shall also be provided within five days of the time the permittee becomes aware of the circumstances. The written submission shall contain a description of the non-compliance, including exact dates and times, and if the non-compliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the non-compliance. The following shall be included as information which must be reported within 24 hours:

1. Any unanticipated bypass which exceeds any effluent limitation in the permit.
2. Violation of a maximum daily discharge limitation for any of the pollutants listed by the Department in the permit to be reported within 24 hours.

(f) Other non-compliance. The permittee shall report all instances of non-compliance not reported under 314 CMR 5.16(20)(a), (b), or (e) at the time monitoring reports are submitted. The reports shall contain the information listed in 314 CMR 5.16(20)(e).

(g) Toxics. All manufacturing, commercial, mining, or silvicultural dischargers must notify the Department as soon as they know or have reason to believe:

1. That any activity has occurred or will occur which would result in the discharge of any toxic pollutant listed in 314 CMR 3.17 which is not limited in the permit, if that discharge will exceed the highest of the following notification levels:
   a. 100 micrograms per liter (100 ug/l);

b. 200 micrograms per liter (200 ug/l) for acrolein and acrylonitrile; 500 micrograms per liter (500 ug/l) for 2,4-dinitrophenol and for 2-methyl-4,6-dinitrophenol; and one milligram per liter (1 mg/l) for antimony;
c. Five times the maximum concentration value reported for that pollutant in the permit application; or

2. That they have begun or expect to begin to use or manufacture as an intermediate or final product or byproduct any toxic pollutant which was not reported in the permit application.

(h) Indirect dischargers. All Publicly Owned Treatment Works shall provide adequate notice to the Department of the following:
1. Any new introduction of pollutants into the POTW from an indirect discharger which would be subject to § 301 or 306 of the Federal Act, 33 U.S.C. § 1311 or 1316, if it were directly discharging those pollutants; and
2. Any substantial change in the volume or character of pollutants being introduced into the POTW by a source introducing pollutants into the POTW at the time of issuance of the permit.

(i) Information. Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application or in any report to the Department, it shall promptly submit such facts or information.

(21) Signatory requirement. All applications, reports, or information submitted to the Department shall be signed and certified in accordance with 314 CMR 3.15 and 5.14.

(22) Severability. The provisions of the permit are severable, and if any provision of the permit, or the application of any provision of the permit to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of the permit, shall not be affected thereby.

(23) Reopener clause. The Department reserves the right to make appropriate revisions to the permit in order to establish any appropriate effluent limitations, schedules of compliance, or other provisions which may be authorized under the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26 through 53 or the Federal Act, 33 U.S.C. §1251 *et seq* in order to bring all discharges into compliance with said statutes.

(24) Approval of treatment works. All discharges and associated treatment works authorized herein shall be consistent with the terms and conditions of this permit. Any modification to the approved treatment works shall require written approval of the Department prior to the construction of the modification.

(25) Transfer of Permits.
(a) RCRA facilities. Any permit which authorizes the operation of a RCRA facility which is subject to the requirements of 314 CMR 8.07 shall be valid only for the person to whom it is issued and may not be transferred.
(b) Transfers by modification. Except as provided in 314 CMR 5.16(25)(a) and (c), a permit may be transferred by the permittee to a new owner or operator provided that the permit has been modified or revoked and reissued or a minor modification is made to identify the

new permittee in accordance with 314 CMR 5.12(3) and (4).

(c) Automatic transfers. For facilities other than Privately Owned Wastewater Treatment Facilities (PWTFs) that treat at least some sewage from residential uses, hospitals, nursing or personal care facilities, residential care facilities, and/or assisted living facilities, PWTFs that have been required to establish financial assurance mechanism(s) pursuant to 314 CMR 5.15(6), and RCRA facilities subject to the requirements of 314 CMR 8.07, a permit may be automatically transferred in accordance with 314 CMR 5.12(5).

(26) Permit Compliance Fees and Inspection Information. Except as otherwise provided, any permittee required to obtain a surface water or ground water discharge permit pursuant to M.G.L. c. 21, § 43 and 314 CMR 3.00 and 5.00, shall be required to submit the annual compliance assurance fee established in accordance with M.G.L. c. 21A, § 18 and 310 CMR 4.00 as provided in 314 CMR 2.12. The requirement to submit the annual compliance fee does not apply to any local government unit other than an authority. Any permittee required to obtain a surface water or ground water discharge permit pursuant to M.G.L. c. 21, §43 and 314 CMR 3.00 and 5.00 may be required to submit inspection information annually as a condition of the permit as provided in 314 CMR 2.12.

Appendix 4-1

Hyannis WPCF Monthly Operating Data

Appendix 4-1
Hyannis WPCF Monthly Operating Data Summary

	INFLUENT FLOWS (mgd)			5 DAY BOD			TOTAL SUSPENDED SOLIDS (TSS)			MONTHLY PARAMETERS (EFFLUENT)		
	SEWAGE	SEPTAGE	TOTAL	INFLUENT		EFFLUENT	INFLUENT		EFFLUENT	NITRATE (NO_3)	NH3	TOTAL NITROGEN (TN)
				mg/L	lb/d	mg/L	mg/L	lb/d	mg/L	mg/L	mg/L	mg/L
Sep-06	2.06	0.04	2.10	237	4,150	6	78	1,370	7	4	0.2	5
Oct-06	1.78	0.04	1.81	197	2,980	8	78	1,190	7	3	0.2	5
Nov-06	1.55	0.04	1.59	201	2,660	9	81	1,070	14	4	0.1	6
Dec-06	1.30	0.03	1.32	235	2,590	7	84	920	10	2	0.1	4
Average	1.67	0.04	1.70	218	3,090	8	80	1,140	10	3	0.1	5
Max Month	2.06	0.04	2.10	237	4,150	9	84	1,460	14	4	0.2	6
Min Month	1.30	0.03	1.32	197	2,170	6	78	860	7	2	0.1	4
% Removal						97			88			
Jan-07	1.19	0.02	1.21	188	1,910	4	77	780	9	2	0.3	4
Feb-07	1.04	0.02	1.06	216	1,910	5	75	670	7	2	0.5	4
Mar-07	1.22	0.03	1.25	221	2,300	5	77	800	6	2	0.6	5
Apr-07	1.49	0.04	1.53	191	2,430	3	71	910	3	2	0.9	4
May-07	1.72	0.03	1.75	215	3,140	8	70	1,020	8	3	0.6	6
Jun-07	2.04	0.04	2.08	209	3,620	4	69	1,200	7	3	0.2	5
Jul-07	2.47	0.05	2.51	246	5,160	8	82	1,730	11	2	0.6	5
Aug-07	2.29	0.05	2.34	234	4,570	8	74	1,440	5	3	0.5	5
Sep-07	1.69	0.04	1.73	228	3,300	6	72	1,050	4	3	0.2	6
Oct-07	1.45	0.04	1.48	198	2,450	4	75	930	6	3	0.2	5
Nov-07	0.99	0.03	1.02	187	1,600	4	97	820	10	3	0.2	6
Dec-07	0.72	0.02	0.74	206	1,280	6	90	560	13	2	0.1	4
Average	1.53	0.03	1.56	212	2,750	5	77	1,010	7	2	0.4	5
Max Month	2.47	0.05	2.51	246	5,160	8	97	2,030	13	3	0.9	6
Min Month	0.72	0.02	0.74	187	1,160	3	69	430	3	2	0.1	4
% Removal						97			90			
Jan-08	No data											
Feb-08	0.85	0.02	0.87	211	1,530	8	73	530	11	2	0.8	4
Mar-08	0.91	0.03	0.94	235	1,840	5	73	570	5	2	0.6	4
Apr-08	1.17	0.04	1.21	235	2,360	6	69	690	4	2	0.7	5
May-08	1.46	0.04	1.50	231	2,900	8	79	990	11	3	0.9	6
Jun-08	1.41	0.05	1.46	240	2,930	6	77	940	5	6	0.6	9
Jul-08	1.90	0.05	1.95	234	3,800	4	114	1,850	3	5	0.2	6
Aug-08	1.86	0.04	1.89	213	3,360	5	63	1,000	6	5	0.3	7
Sep-08	1.48	0.04	1.52	223	2,830	3	75	960	4	4	0.1	5
Oct-08	1.49	0.04	1.53	204	2,600	5	66	840	3	4	0.5	5
Nov-08	1.45	0.04	1.49	203	2,520	4	72	900	5	4	0.3	6
Dec-08	No data											
Average	1.40	0.04	1.44	223	2,670	6	76	910	6	4	0.5	6
Max Month	1.90	0.05	1.95	240	3,890	8	114	1,850	11	6	0.9	9
Min Month	0.85	0.02	0.87	203	1,470	3	63	460	3	2	0.1	4
% Removal						97			93			
Jan-09	1.31	0.02	1.33	235	2,610	6	80	880	5	4	0.3	5
Feb-09	1.33	0.02	1.35	223	2,520	5	87	980	5	4	0.3	6
Mar-09	1.31	0.02	1.34	238	2,660	8	96	1,080	12	4	1.0	7
Apr-09 [1]	1.38	0.04	1.41	211	2,480	7	102	1,200	9	5	0.2	7
May-09	1.49	0.04	1.54	226	2,890	7	93	1,190	8	3	0.5	5
Jun-09	1.64	0.04	1.68	220	3,090	4	92	1,290	4	3	0.3	4
Jul-09	1.85	0.04	1.89	240	3,780	8	95	1,500	8	2	1	4
Aug-09	1.94	0.04	1.97	227	3,740	7	90	1,480	12	2	0.5	4
Average	1.53	0.03	1.56	228	2,970	7	92	1,200	8	3	0.5	5
Max Month	1.94	0.04	1.97	240	3,940	8	102	1,680	12	5	1	7
Min Month	1.31	0.02	1.33	211	2,340	4	80	880	4	2	0.2	4
% Removal						97			92			
Overall Average	1.51	0.03	1.55	219	2,840	6	81	1,040	7	3	0.4	5
Overall Max Month	2.47	0.05	2.51	246	5,160	9	114	1,850	14	6	1	9
Overall Min Month	0.72	0.02	0.74	187	1,280	3	63	530	3	2	0.1	4
Overall % Removal						97			91			

Note:

1. SCADA malfunction - only 6 days of sewage flow data.
2. All data are monthly averages from the WPCF monthly monitoring reports.

Appendix 4-2

Hyannis WPCF Typical Monthly Report

MONTHLY REPORT

BARNSTABLE WASTEWATER
TREATMENT PLANT

DIVISION OF WATER POLLUTION CONTROL
SOUTHEAST REGIONAL OFFICE
20 RIVERSIDE DRIVE
LAKEVILLE, MA 02347

BARNSTABLE WPCD

_____Chief Operator
_____Supervisor

Date	WEATHER			SEWAGE		SEPTAGE	GRIT	POST CHLORINATION	SETTLEABLE SOLIDS	Date
	Rainfall	Temp.		Flow Max.	Flow Total	Haulers	Removed	Residual Final	Final Effluent	
	Inches	High	Low	MGD	MG	Gallons X 1000	TONS	mg/l	ml/l	
1	T	76	59/63	5.89	1.7615	51.9	16.12	0.57	< 0.1	1
2	1.02	71	62/63	5.54	1.8731	44.7		0.52	< 0.1	2
3	0.76	67	60/67	5.59	1.9335	16.9		0.61	< 0.1	3
4	0	72	60/65	5.31	1.9172	6.0		0.79	< 0.1	4
5	0	78	58/67	5.83	1.7837			0.58	< 0.1	5
6	0	78	59/72	5.34	1.7795	33.4		0.74	< 0.1	6
7	0.00	78	62/68	5.79	1.7821	60.9		0.64	< 0.1	7
8	1.10	72	59/62	5.11	1.8551	35.7		0.59	< 0.1	8
9	T	68	58/59	5.22	1.7799	59.5		0.50	< 0.1	9
10	0.00	68	50/68	5.38	1.7830	73.2		0.37	< 0.1	10
11	0.00	73	50/61	5.36	1.8043	18.3		0.27	< 0.1	11
12	1.12	69	61/65	5.30	1.8631	3.0		0.35	< 0.1	12
13	0.00	73	58/67	4.95	1.7698	66.9		0.57	< 0.1	13
14	0.00	76	57/68	5.31	1.7324	67.1		0.54	< 0.1	14
15	0.00	77	59/61	5.02	1.7217	71.4		0.42	< 0.1	15
16	0.00	78	61/71	5.06	1.4005	74.3	6.08	0.15	< 0.1	16
17	0.00	76	66/69	5.13	1.8392	62.3		0.39	< 0.1	17
18	1.07	83	70/71	5.56	2.0185	28.2		0.23	< 0.1	18
19	0.00	78	65/75	5.55	1.7862	8.1		0.38	< 0.1	19
20	0.00	78	63/78	5.82	1.8667	33.6		0.35	< 0.1	20
21	T	81	65/66	5.89	1.9426	37.5		0.39	< 0.1	21
22	0.67	71	66/70	4.92	1.9014	54.2		0.50	< 0.1	22
23	0.00	78	64/73	5.03	1.9043	54.0		0.43	< 0.1	23
24	1.07	73	63/68	5.46	2.0634	42.6		0.32	< 0.1	24
25	T	69	62/69	5.57	1.9714			0.22	< 0.1	25
26	0.00	78	67/70	4.96	1.8648	7.7		0.20	< 0.1	26
27	T	80	72/77	5.49	1.8886	66.5		0.49	< 0.1	27
28	0.00	80	69/78	5.58	1.8682	61.0		0.39	< 0.1	28
29	0.00	80	71/73	5.17	1.8772	34.5		0.41	< 0.1	29
30	0.04	77	71/74	5.45	1.9285	56.9		0.38	< 0.1	30
31	0.00	81	67/75	5.54	1.9834	38.3		0.29	< 0.1	31
TOTAL	6.85				57.2448	1268.6	22.20			
MEDIAN		77		5.38	1.8648	44.7		0.40	< 0.1	

Date	RECIRCULATION		AERATION TANKS			SOLIDS				COLIFORM	Date
	RAS	TSS	MLSS	MLVSS	SVI_{30}	PRIMARY Suspended	FINAL Suspended	FINAL Dissolved	FINAL Total	FINAL Effluent	
	MGD	mg/l	mg/l	mg/l	ml/l	mg/l	mg/l	mg/l	mg/l	MF/100 ml	
1	1.4815	7460	4420	3495	198	92	4	334	338	< 1	1
2	1.3797										2
3	1.4250										3
4	1.4292										4
5	1.4285										5
6	1.4346	7150	4057		201					< 1	6
7	1.3263					85	6	342	348		7
8	1.3621	7610	3775	3295	193	100	7	312	319	< 1	8
9	1.3746										9
10	1.3760										10
11	1.4425										11
12	1.4310										12
13	1.4466	7720	3977	3150	175	92	5	388	393		13
14	1.3570									3	14
15	1.4470	7320	4008	3330	149	90	6	290	296		15
16	1.3826										16
17	1.4669									1	17
18	1.4661										18
19	1.4278										19
20	1.4730	8000	4330	3635	158					2	20
21	1.3981					125	13	327	340		21
22	1.4201										22
23	1.4638	8000	4183	3495	152	115	11	345	356	4	23
24	1.4172										24
25	1.4515										25
26	1.4347										26
27	1.3304	8410	3620	2990		72	4	532	536	5	27
28	1.3524										28
29	1.4109	7710	3708	3230	152	86	14	354	368	10	29
30	0.9609										30
31	1.0616										31
MEDIAN	1.4250	7710	4008	3313	167	92	6	342	348	4	

BARNSTABLE WATER POLLUTION CONTROL

Date	Dissolved Oxygen	BOD_5		Chloride	Sodium	Nitrogen						Alkalinity		Date
	Final Effluent	Primary	Final Effluent	Final Effluent	Final Effluent	Primary NH_3-N	Primary NO_3-N	Primary TKN	Final NH_3-N	Final NO_3-N	Final Total-N	Primary	Final Effluent	
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
1	5.32	271	5	80	100	31.2	0.63	38.4	0.27	1.9	2.57	180	95	1
2	5.16													2
3	6.51													3
4	6.30													4
5	6.17													5
6	5.14													6
7	5.10	213	7	84	93	33.7	0.55	39.8	1.64	1.3	3.07	195	103	7
8	5.10	245	8	85	89	33.4	0.68	42.3	2.34	1.2	3.68	192	111	8
9	5.34													9
10	5.16													10
11	5.51													11
12	5.16													12
13	5.35	212	7	86	82	30.9	0.44	37.5	0.82	1.7	3.62	190	109	13
14	5.53													14
15	5.22	232	7	83	86	29.2	0.58	38.7	0.82	1.8	4.33	198	116	15
16	5.47													16
17	4.96													17
18	5.66													18
19	6.49													19
20	4.88													20
21	5.28	280	12	79	81	31.4	0.54	42.6	0.98	1.1	5.20	192	112	21
22	5.62													22
23	5.08	258	14	90	94	31.8	0.56	40.9	2.52	1.1	5.70	198	123	23
24	4.75													24
25	4.96													25
26	4.88													26
27	5.48	199	6	92		33.0	2.90	39.2	1.08	2.0	3.66	192	139	27
28	5.00													28
29	5.10	246	8	92		34.9	0.60	38.4	1.48	1.3	4.38	188	116	29
30	4.81													30
31	5.35													31
MEDIAN	5.22	245	7	85	89	31.8	0.6	39.2	1.08	1.3	3.68	192	112	

BARNSTABLE WATER POLLUTION CONTROL

Date	pH		Sludge	Sludge	Grease	Sand Filters		Date
	Primary	Final Effluent	WAS	Primary	Haulers	Bed Number	Total Dosage	
			Gallons x 1000	Gallons x 1000	Gallons x 1000		MGD	
1	7.43	7.12		24.3		12,15,17	1.7615	1
2		7.06	26.97	21.0	1.6		1.8731	2
3		7.10					1.9335	3
4		7.12	74.25				1.9172	4
5		7.11					1.7837	5
6		7.10		23.3			1.7795	6
7	7.31	7.08	79.65		4.8		1.7821	7
8	7.22	7.10	57.42	36.0	1.6	18,21,22	1.8551	8
9		7.07	54.60		3.3		1.7799	9
10		7.06	40.50	34.1	2.2		1.7830	10
11		7.04					1.8043	11
12		7.02					1.8631	12
13	7.06	6.69		36.0	1.1		1.7698	13
14		6.82	50.40		6.9		1.7324	14
15	7.28	6.77		36.0	7.3		1.7217	15
16		6.78	45.00		4.3		1.4005	16
17		6.78		28.5	4.3		1.8392	17
18		6.80					2.0185	18
19		7.04					1.7862	19
20		6.66		31.5	3.0		1.8667	20
21	7.41	6.77	75.60		5.8		1.9426	21
22		6.90	50.40	18.0	6.5		1.9014	22
23	7.39	6.86	43.40	11.3	6.0		1.9043	23
24		6.86	33.60	9.0	5.7		2.0634	24
25		6.82					1.9714	25
26		6.80					1.8648	26
27	7.25	6.85	56.00	18.0	7.6		1.8886	27
28		6.98	50.40		8.3		1.8682	28
29	7.22	6.86			3.1		1.8772	29
30		6.85	52.20	27.0	8.1	18,21,22	1.9285	30
31		6.67	43.50	32.0			1.9834	31
TOTAL			833.89	385.93	91.4		57.2448	
MEDIAN	7.28	6.86	50.40	27.0	4.8		1.8640	

COMPOSITE SAMPLE INFORMATION

1. Composited from: 7:30 to 7:30
2. Number of samples in composite: 24
3. Interval between samples: 1 hour
4. Composite from: Equal volumes

GENERAL COMMENTS

Dry tons removed =

12/17/08: North Train on line for trial
4/13/09: Tanks 1 & 2 all anoxic

PLANT DESIGN DATA

Type: Activated sludge/diffused air
Design Capacity: 4.20 MGD
Present Average Flow: **1.8466** MGD
Population Served: 45,000

MLSS, DO, pH, Cl Residual & F. Coliform are GRAB samples. All others are composite.

Appendix 4-3

Inventory of Existing Process Facilities and Equipment at Hyannis WPCF

INVENTORY OF TREATMENT FACILITIES AND PROCESS EQUIPMENT
Hyannis WPCF
Town of Barnstable, Massachusetts

Manual Bar Screens

Location	Pretreatment Building
Type	Hand cleaned
Number of coarse bar screens	2
Number of fine bar screens	1
Coarse bar separation, inches	2
Fine bar separation, inches	1
Year placed in service	1975

Mechanical Bar Screen

Location	Pretreatment Building
Type	Reciprocating raked
Number of mechanical bar screen	1
Manufacturer and model	Fairfield Services Company, Type "RPFF"
Bar separation, inches	½
Motor horsepower	1-1/2
Year placed in service	2009
Type of level element	Ultrasonic level differential controller
Location	Pretreatment Building
Number of units	1
Manufacturer and model	Siemens, Hydroranger Model 200
Year placed in service	2009

Screenings Conveyor

Location	Pretreatment Building
Type	Shaftless screw, washer and compactor
Number of mechanical bar screen	1
Manufacturer and model	JDV Equipment Corporation, U-trough Model U-260
Motor horsepower	3
Year placed in service	2009

Grit Removal

Type	Aerated chamber
Location	Pretreatment Building
Tank volume, gallons	45,500
Blower type	Positive displacement, on VFDs
Number of blowers	2
Blower manufacturer and model	Gardner Denver; Sutorbuilt; Tuthill Corp.

Grit Removal continued

Blower horsepower	3
Year placed in service (blowers)	1980
Year placed in service (blower motors)	2009
Type of diffusers	Coarse bubble
Location	Pretreatment Building
Manufacturer	ITT Sanitaire
Year placed in service	2009
Type of grit conveyor	Shaftless screw, with hydraulic drive
Location	Pretreatment Building
Manufacturer and model	JDV Equipment Corporation, U-trough Model U-355
Number of grit conveyor	1
Motor horsepower	5
Year placed in service	2009
Type of grit pump	Recessed impeller
Location	Pretreatment Building
Number of grit pump	1
Manufacturer and model	Wemco Pump, 3" Model C
Capacity, gpm	200
Motor horsepower	10
Year placed in service	2009

Grit Handling Unit

Hydrocyclone manufacturer	Krebs Engineers
Location of hydrocyclone	Pretreatment Building
Number of hydrocyclone units	1
Size of vortex finder, inches	3
Year placed in service	2009
Grit washer manufacturer and model	WesTech Engineering, Inc., CleanGrit™ Model SW400C
Grit washer location	Pretreatment Building
Number of grit washer units	1
Grit washer agitator motor horsepower	¾
Grit washer spiral motor horsepower	½
Year placed in service	2009

Flow Measuring

Location	Pretreatment Building
Flow element	Parshall flume
Number of units	2 (1 presently in service)
Throat width, inches	18

Flow Measuring continued

Flow meter type	Ultrasonic
Flow range, mgd	0.6 – 15.6
Flow meter manufacturer	Pulsar
Year ultrasonic sensor placed in service	2008

Building Sump Pump

Location	Pretreatment Building
Number of Units	1
Type	Submersible, explosion proof
Manufacturer and Model	Zoeller, Model NX163
Motor Horsepower	½
Year Placed in Service	2009

Pretreatment Odor Control

Scrubber

Location	Pretreatment Building
Number of scrubber unit	1
Manufacturer	Celicote
Chemical No. 1	Sodium hypochlorite
Chemical No. 2	Sodium hydroxide
Scrubber chemical pump type	Electronic metering pump
Number of scrubber chemical pump units	2 (1 for each chemical)
Scrubber chemical pump manufacturer	LMI
Scrubber chemical pump models	E731-410SI (sodium hydroxide), E731-410HI (sodium hypochlorite)
Number of scrubber fan	1
Scrubber fan motor horsepower	5
Scrubber fan mfgr, model	Celicote, CLMR 14
Number of scrubber pump	1
Scrubber pump motor horsepower	3
Year placed in service	1991 (scrubber pump motor and chemical pumps replaced in 2009)

Hydrogen Peroxide (50%) Addition

Storage Location	Adjacent to Pretreatment Bldg Exterior
Type of hydrogen peroxide storage tank	Crosslinked HDPE, vertical cylindrical
Number of hydrogen peroxide storage tanks	1
Working capacity of storage tank, gallons	3,000
Manufacturer	Poly Processing Company
Hydrogen peroxide storage tank dimensions	
Outer diameter	10'-2"
Overall height	7'-9-1/2"
Type of hydrogen peroxide feed pumps	Peristaltic
Number of hydrogen peroxide feed pumps	3
Hydrogen peroxide pump mfgr and model	Watson Marlow/Bredel Pumps, Model 520DuS/R2

Pretreatment Odor Control (continued)	
Pump Enclosure mfgr, material	Enpac, polypropylene
Year placed in service	2009
Primary Clarification	
Number of tanks	2
Type	Circular, center feed, pier supported
Tank dimensions	
Diameter, feet	60
Sidewater depth, feet	10
Total surface area (both tanks), SF	5,655
Total weir length (both tanks), feet	377
Influent well	
Diameter, feet	10
Depth, feet	4
Equipment manufacturer	Smith & Loveless
Drive horsepower, each unit	1
Year placed in service	1980
Primary Sludge Pumping	
Sludge pump	
Location	Primary Pump Building
Number of units	2
Type	Progressive cavity, on VFDs
Capacity, gpm	50-150
Manufacturer and model	Netzsch Incorporated, Model NM063SY01L07K
Motor horsepower	7-1/2
Year placed in service	2009
Primary sludge grinders	
Location	Primary Pump Building
Number of units	2
Grinder No. 1	
Manufacturer and model	JWC Environmental, Muffin Monster, Model 30001-12-6
Motor horsepower	3
Year placed in service	1993
Grinder No. 2	
Manufacturer and model	JWC Environmental, Muffin Monster, Model 30004T-1206-DI
Motor horsepower	3
Year placed in service	2009

Primary Sludge Pumping (continued)

Building sump pump	
Location	Primary Pump Building
Number of units	1
Type	Vertical centrifugal
Manufacturer	Myers

Biological Reactors

Process	Activated sludge, MLE process
Number of treatment trains	3
Total tank volume, cubic feet	170,000
Treatment tank dimensions	
Length	120
Width	40
Sidewater depth	12
Aeration tank distribution box sump pumps	
Number	2
Location	Compartment for biofilter drain
Type	Submersible effluent pump
Manufacturer and model	ITT Goulds, WE Series Model 3885
Capacity gpm	45 (minimum)
Sump pump motor horsepower	1/3
Year placed in service	2009
Aeration equipment	
Type	Diffused aeration, forced air
Blowers	
Location	Aeration blower building
Type	Multi stage centrifugal
Number of units	5
Manufacturer (Blower Nos. 1-4)	Hoffman
Manufacturer (Blower No. 5)	Houston Service Industries, Inc. (HSI), Model 8606
Capacity, scfm	1,800
Discharge pressure, psig	7.0
Motor horsepower	100
Year placed in service (Blower Nos. 1-4)	1998
Year placed in service (Blower No. 5)	2009
Diffusers	
Type	Fine bubble, membrane
Size	9-inch
Number of grids per tank	5
Manufacturer	ITT Sanitaire

Submersible mixers

Location	Aeration tank anoxic zone and anoxic/aerobic switchzone
Number of mixers per tank	2
Manufacturer (Mixer Nos. 1-4)	US Filter
Manufacturer (Mixer Nos. 5 and 6)	WILO-EMU USA LLC, Model TR60-2.18-6/16REx
Motor horsepower	6
Year placed in service (Mixer Nos. 1-4)	1998
Year placed in service (Mixer Nos. 5 and 6)	2009

Nitrate recycle pumps

Location	Aeration tank
Type	Submersible, on VFDs
Number per tank	1
Manufacturer (Mixer Nos. 1 and 2)	US Filter
Manufacturer (Mixer Nos. 3)	WILO-EMU USA LLC, Model RZP50-3.58-4/16REx
Motor horsepower	10
Year placed in service (Mixer Nos. 1 and 2)	1998
Year placed in service (Mixer No. 3)	2009

Aeration controls

Controls	DO probes
Location	Aeration tanks
Number of units per tank	1
Manufacturer (Nos. 1 and 2)	Hach
Manufacturer and model (No. 3)	Hach, Model LDO-57900-00 (sensor), Model SC100-LXV401.52.0002 (transmitter)
Year placed in service (Nos. 1 and 2)	1998
Year placed in service (No. 3)	2009

Controls	Pressure indicating transmitter
Location	Aeration blower building
Number of units	1
Year placed in service	2009

Aeration odor control

Odor control covers

Type	Flat, aluminum, with hinged hatches
Location	Aeration tank distribution box and Aeration tank anoxic zone and anoxic/aerobic switchzone
Manufacturer	Hallsten Corporation
Year placed in service	2009

Biofilter

Number of biofilter unit	1
Biofilter vessel material	FRP
Biofilter manufacturer and model	Biorem, Model BASYS™
Number of biofilter fan	1
Biofilter fan type	Centrifugal, with enclosure
Biofilter fan capacity, scfm	4,200 – 5,500
Biofilter fan motor horsepower	20
Number of recirculation pump	1
Recirculation pump capacity, gpm	30
Recirculation pump motor horsepower	1-1/2
Year placed in service	2009

Secondary Clarification

Number of tanks	3
Units 1 & 2	
Type	Circular, center feed, pier supported
Tank dimensions	
Diameter, feet	70
Sidewater depth, feet	10
Total surface area (both tanks), SF	7,690
Total weir length (both tanks), feet	440
Influent well	
Diameter, feet	10
Depth, feet	4
Equipment manufacturer	Smith & Loveless
Drive horsepower, each unit	1
Year placed in service	1980
Unit 3	
Type	Circular, center feed, pier supported, spiral scraper
Tank dimensions	
Diameter, feet	85
Sidewater depth, feet	13
Total surface area, SF	5,670
Total weir length, feet	267
Equipment manufacturer	Westech
Year placed in service	1997

Secondary Sludge Pumping

RAS pumps	
Location	Secondary Pump Building
Number of units	3
Type	Horizontal, end suction
Speed control	variable frequency drive (VFD)

Capacity	925 gpm @ 24.5' TDH
Manufacturer	PACO
Impeller size, inch	11.93"
Motor horsepower	10
Year placed in service	
WAS pumps	
Location	Secondary Pump Building
Number of units	2
Type	Progressive cavity
Speed control	Adj. belt drive
Manufacturer	Dresser Monoflo
Motor horsepower	15
Year placed in service	1997
Plant Water pumps	
Location	Secondary Pump Building
Number of units	3
Type	Horizontal centrifugal
Speed control	variable frequency drive (VFD)
Capacity, gpm	275
Manufacturer	Peerless – C820A
Motor horsepower	15
RAS flowmeter	
Location	Secondary Pump Building
Number of units	1
Type	Magmeter
Size, inch	12
Manufacturer	Fischer-Porter
Model	MAGX 10D1435U
Disinfection	
Type	Chemical
Chemical	Liquid 50% sodium hypochlorite
Storage, gallons	8,000
Feed pumps	
Location	Outside control building
Type	electronic diaphragm
Number of Units	2
Manufacturer	LMI
Capacity, gph	9
Year placed in service	1991
Contact Tank	
Number of units	2
Volume of each tank, gallons	73,300
Contact time at 3.8 mgd, min	27.8 per tank

Treated Water Pumping	
Location	Control building basement
Number of units	4
Type	Vertical centrifugal, close coupled
Speed control	Constant speed
Level control	Bubbler system
Capacity of each, gpm	2,300 gpm @ 50' TDH
Manufacturer	Allis-Chalmers
Model	No. 300 NSWV 8x8x14
Motor horsepower	50
Year placed in service	1980
Treated Water Recharge	
Type	Sand Infiltration Beds
Surface Area, SF	
System 1 (Beds 1-2)	50,000
System 2 (Beds 12-22)	267,000
System 3 (Beds 23-33)	270,000
System 4 (Beds 34-49)	264,000
	851,000
Grease Concentrator	
Number of units	1
Location	Septage processing building
Capacity, gpm	40, dilute grease
Skimmer drive, HP	1/2
Grinder, HP	7.5
Manufacturer and model	Saracco Model No. 40-500
Year placed in service	1991
Current use	Currently unused
Concentrated grease pump	
Type	Two-stage progressive cavity
Location	Septage processing building
Capacity, gpm	15
TDH, feet	138
Speed, rpm	150
Drive, HP	5
Manufacturer and model	Robbins & Meyers Model No. 2J6CDQAAA
Year placed in service	1991
Grease feed pumps	
Number	2
Location	Pretreatment building
Type	Plunger
Manufacturer	ITT-Marlow

Septage Processing

Storage Tanks	
Number of units	4
Volume, gallons (each)	50,000
Blowers (mixing and aeration)	
Location	Septage building basement
Number of units	5
Type	Positive displacement
Capacity, cfm (each)	75-210
Manufacturer	Roots
Model	53U-RAI
Year placed in service	1991
Cyclone feed pumps	
Location	Septage building sub-basement
Number of units	2
Type	Recessed impeller
Capacity, gpm (each)	350
Manufacturer	WEMCO
Model	Model 'C'
Motor horsepower	50
Year placed in service	1991
Raw septage grinders	
Location	Septage building sub-basement
Number of units	2
Manufacturer	JWC Environmental
Model	Muffin Monster 30001-12-6
Motor horsepower	3
Year placed in service	1991
Grit cyclone	
Location	Septage building second floor
Number of units	2
Manufacturer	WEMCO
Year placed in service	1991
Grit classifier	
Location	Septage building second floor
Number of units	2
Type	Screw
Manufacturer	WEMCO
Year placed in service	1991
De-gritted septage pumps	

Location	Septage building sub-basement
Number of units	2
Type	Progressive cavity
Manufacturer	Moyno
Year placed in service	1991
De-gritted septage grinders	
Location	Septage building sub-basement
Number of units	2
Manufacturer	JWC Environmental
Model	Muffin Monster
Motor horsepower	3
Year placed in service	1991
Thickened septage/Sludge transfer pumps	
Location	Septage building second floor
Type	9-inch Duplex Plunger
Number of units	2
Manufacturer	Watson-Marlow
Motor Horsepower	5
Year placed in service	1991
Sludge/Septage Thickeners	
Location	Septage building second floor
Type	Gravity belt (GBT)
Number of units	2
Manufacturer	Ashbrook
Feed rate, gpm	170
Belt width, m	2
Year placed in service	1991
Polymer Feed System	
Location	Septage building second floor
Number of units	1
Manufacturer	Acrison
Year placed in service	1991
Capacity	
Dry polymer, lb/hr	8
Liquid polymer, gpm	1
Metering pumps	
Capacity, gph	30
Drive, HP	1
Type	Diaphragm
Transfer pump	
Type	Progressive cavity
Capacity, gph	7

Booster pumps	
Location	Septage building second floor
Type	horizontal centrifugal
Number of units	2
Manufacturer	Peerless
Odor control system	
Capacity, cfm (at 8-inch water column and 100 ppm H_2S influent)	14,000
Fan, HP	25
Recirculation pump	
Capacity, gpm	216
TDH, feet	70
Motor horsepower	15
pH control pump	
Capacity, gph	4
Motor horsepower	1/2
ORP control pump	
Capacity, gph	85
Motor horsepower	1/2

Additional Sludge Facilities (currently not used)

Sludge holding tanks	
Number of tanks	2
Volume, both tanks, cubic feet	20,700
Current use	(Currently unused)
Sludge aeration	
Type	Coarse bubble
Blowers	
Type	Positive displacement
Location	Sludge process blower building
Number of units	3
Capacity, cfm	90-250
Motor horsepower, each blower	25
Year placed in service	1991
Sludge Mixing	
Unit 1	
Manufacturer	Philadelphia
Model	PSA-8QB
HP	15
Output speed, rpm	30

Unit 2	
Manufacturer	Flygt
Model	4660, 410A #9480011
Installed	1995
Sludge thickener	
Diameter, feet	45
Surface area, SF	1,590
Sidewater depth, feet	10
Volume, gallons	135,000
Odor control system	
Location	Sludge Process Blower Building
Capacity, cfm (at 8-inch water column and 100 ppm H_2S influent)	4,000
Fan, HP	7.5
Recirculation pump	
Capacity, gpm	144
TDH, feet	70
Motor horsepower	5
pH control pump	
Capacity, gph	2
Motor horsepower	1/4
ORP control pump	
Capacity, gph	42
Motor horsepower	1/2
Sludge transfer pumps in Sludge Dewatering Building	
Unit 1	
Manufacturer	Voglesang
Model	V136-70
Installed	2000
Type	Rotary Lobe
Capacity	
hp	1.7
gpm	130
head, psi	60
Unit 2	
Type	Plunger
Drive, HP	50 gpm
Manufacturer and Model	Dorr-Oliver
Year laced in service	1968

Appendix 4-4

Marstons Mills WWTF Monthly Operating Data Summary

Appendix 4-4
Marstons Mills Middle School WWTF Monthly Operating Data Summary

	INFLUENT FLOWS (gallons)	5 DAY BOD			TOTAL SUSPENDED SOLIDS (TSS)			MONTHLY PARAMETERS (EFFLUENT)			
		INFLUENT		EFFLUENT	INFLUENT		EFFLUENT	NITRATE (NO_3)	TKN	NH3	TOTAL NITROGEN (TN)
		mg/L	lb/d	mg/L	mg/L	lb/d	mg/L	mg/L	mg/L	mg/L	mg/L
Oct-06	9,480	84	6.6	7	312	24.7	2	3	1	0.9	4
Nov-06	9,550	51	4.0	14	102	8.1	3	9	2	0.4	13
Dec-06	7,900	139	9.2	13	112	7.4	5	6	2	0.2	9
Average	8,980	91	6.8	11	175	13.1	3	6	2	0.5	9
Max Month	9,550	139	11.1	14	312	24.9	5	9	2	0.9	13
Min Month	7,900	51	3.3	7	102	6.7	2	3	1	0.2	4
% Removal				88			98				
Jan-07	9,420	101	7.9	24	113	8.9	4	6	1	0.1	8
Feb-07	11,900	94	9.3	11	132	13.1	5	2	2	0.3	3
Mar-07	13,300	140	15.5	5	140	15.5	5	3	2	0.4	5
Apr-07	11,500	161	15.5	29	644	61.8	4	1	18	15.8	19
May-07	10,500	419	36.7	19	840	73.6	5	4	2	2.1	7
Jun-07	6,810	284	16.1	6	132	7.5	3	1	1	0.3	2
Jul-07	3,920	165	5.4	4	940	30.7	3	3	2	0.6	6
Aug-07	4,780	41	1.6	6	No data		2	3	No data	1.1	7
Sep-07	9,360	35	2.7	3	99	7.7	3	8	2	0.6	10
Oct-07	1,170	69	0.7	6	93	0.9	3	5	2	1.1	6
Nov-07	1,070	81	0.7	5	160	1.4	5	6	2	0.2	9
Dec-07	10,400	109	9.5	5	No data		4	3	No data	0.3	4
Average	7,840	142	9.3	10	329	21.5	4	4	3	1.9	7
Max Month	13,300	419	46.5	29	940	104.3	5	8	18	15.8	19
Min Month	1,070	35	0.3	3	93	0.8	2	1	1	0.1	2
% Removal				93			99				
Jan-08	11,500	17	1.6	8	130	12.5	8	2	2	0.6	5
Feb-08	9,950	36	3.0	10	248	20.6	8	2	5	0.6	8
Mar-08	10,800	53	4.8	7	No data		4	2	No data	3.3	6
Apr-08	9,240	62	4.8	7	No data		5	1	No data	3.3	8
May-08	8,890	46	3.4	10	No data		4	3	No data	7.2	11
Jun-08	7,460	72	4.5	9	No data		6	2	No data	1.3	5
Jul-08	3,870	52	1.7	4	No data		2	1	No data	0.3	2
Aug-08	5,218	10	0.4	4	No data		2	2	No data	0.2	3
Sep-08	10,300	177	15.2	4	No data		2	8	No data	0.3	1
Oct-08	9,860	146	12.0	70	No data		3	11	No data	0.6	3
Nov-08	7,950	141	9.4	12	No data		4	5	No data	0.7	11
Dec-08	8,810	61	4.5	17	No data		3	1	No data	0.2	3
Average	8,640	74	5.3	13	189	13.6	4	3	4	1.7	6
Max Month	11,500	177	16.9	70	248	23.8	8	11	5	7.2	11
Min Month	3,870	10	0.3	4	130	4.2	2	1	2	0.2	1
% Removal				82			98				
Jan-09	11,200	26	2.4	3	No data		2	1	No data	0.2	2
Feb-09	8,070	33	2.2	4	No data		2	1	No data	0.2	2
Mar-09	10,400	45	3.9	6	No data		3	1	No data	1.8	3
Apr-09	10,500	71	6.2	7	No data		3	1	No data	1.7	4
May-09	11,400	33	3.1	5	No data		5	1	No data	0.3	5
Jun-09	9,340	30	2.3	6	No data		10	1	No data	0.3	3
Jul-09	4,070	15	0.5	8	No data		4	3	No data	0.4	5
Aug-09	4,520	19	0.7	3	No data		2	2	No data	0.4	4
Sep-09	9,070	35	2.7	3	No data		2	1	No data	2.6	3
Average	8,730	34	2.5	5			4	1		0.9	3
Max Month	11,400	71	6.7	8			10	3		2.6	5
Min Month	4,070	15	0.5	3			2	1		0.2	2
% Removal				86			n/a				
Cumulative Average	8,430	88	6.7	10	280	19.6	4	3	3	1.4	6
Cumulative Max Mo	13,300	419	36.7	70	940	73.6	10	11	18	15.8	19
Cumulative Min Mor	1,070	10	0.4	3	93	0.9	2	1	1	0.1	1
Cumulative % Removal				88			99				

Note:

1. All data are monthly averages.

Appendix 5-1

Action Plan for the Barnstable Ponds

Action Plan for the Barnstable Ponds

EcoLogic LLC
Stearns & Wheler GHD

December 31, 2009

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1 Introduction and Scope

This report summarizes the current water quality and aquatic habitat conditions of many freshwater ponds located in the Town of Barnstable, Massachusetts, and recommends priority actions to ensure the ponds' protection and restoration. The Town of Barnstable is currently working with Stearns & Wheler GHD of Hyannis, Massachusetts to prepare a comprehensive nutrient management strategy that will guide the community's development in a manner that protects natural resources, including the quality of the coastal embayments, inland freshwater ponds and groundwater. This action strategy for the freshwater ponds is one component of the overall nutrient management planning project.

As summarized in the July 2008 report to the Town of Barnstable Conservation Commission prepared by the Cape Cod Commission and the Coastal Resources Group of the UMASS School of Marine Science and Technology (Eichner et al. 2008), the Town of Barnstable has 182 freshwater ponds, totaling 1,856 acres. About half of the town's freshwater ponds are extremely small, occupying less than one acre. There are 93 ponds one acre or greater in surface area. Of these, only 25 are larger than 10 acres and are consequently classified as "Great Ponds" by the state. The location of the freshwater ponds is illustrated in Figure 1, which was prepared by Town of Barnstable GIS staff.

This report sets forth recommendations to the Town of Barnstable as they integrate management of the inland ponds into an overall nutrient management plan. The recommendations consider effectiveness (both short-term and long-term), cost, permitting issues and recreational impacts. The recommended actions include institutional, technical and public education components. Some recommendations are town-wide, while others are directed to specific ponds. An overall implementation strategy is presented that defines priority actions and sequencing of recommendations.



Hamblin Pond: Recreational use

In accordance with guidance from the Massachusetts Department of Environmental Protection (MA DEP), the analysis and recommendations in this report do not provide a foundation for defining a Total Maximum Daily Load for phosphorus input to the town's freshwater ponds.



Aerial Photo Taken April 19, 2008

Major Roads

Town Boundary

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Freshwater Ponds
Figure 1

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1869

N
W E
S

Miles

0 0.25 0.5 1 1.5 2

CWNMP_Ponds_11x17.mxd J.A.B. 4/13/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD

2 Nutrients and Eutrophication

> *"Lakes seem, on the scale of years or human life spans, permanent features of the landscape, but they are geologically transitory, usually born of catastrophe and mature and die quietly and imperceptibly" (Hutchinson 1957).*

This often-cited quote from a classic limnology text provides excellent context for reviewing the current and future conditions of the ponds of Barnstable. The ponds may be arrayed along a continuum from open, clear, water with little visible algal growth to extremely shallow, productive systems well on their way to becoming wetlands.



Shubael Pond – Deep, with exceptionally clear water, sandy bottom.



Aunt Betty's Pond – Ultra-shallow, very productive with submerged and floating-leaved plants evident.

Eutrophication, the term for both the process and the effects of enrichment of surface water systems (including lakes, ponds, estuaries, and reservoirs), is a significant water quality concern for many aquatic ecosystems. As aquatic systems become increasingly enriched with plant nutrients, organic matter and silt, the result is increased biomass of algae and plants, reduced water clarity, and ultimately, a reduction in volume. Aesthetic quality and habitat conditions are degraded, and affected waters may no longer be suitable for drinking water or recreation.

While eutrophication is a natural process, it can be greatly accelerated by human activities. There are numerous lakes and ponds included in state compendia of impaired waters; most are listed due to excessive nutrient inputs from nonpoint sources such as agricultural or urban runoff, or seepage from on-site wastewater disposal systems. Less frequently, the impairment of surface waters is attributed to excessive discharge of nutrients from point sources; these may be piped discharges of inadequately treated wastewater from industrial or municipal sources.

Water resources managers focus on identifying and controlling the sources of nutrients, organic material, and silt to aquatic ecosystems in an effort to slow the eutrophication process. Phosphorus is most often the limiting nutrient for primary productivity and algal growth in inland lakes and ponds. While phosphorus is the key to managing eutrophication of inland

ponds, nitrogen is usually the limiting nutrient for primary production of coastal ecosystems. Nitrogen enrichment has resulted in degradation of estuarine and marine water quality and habitat conditions, and wastewater is a major source of nitrogen. Scientists and regulators from the EPA, the MA DEP, the academic community and the Cape Cod Commission have supported the coastal municipalities in a systematic process to define the need for and extent of reductions in nitrogen loading (MA DEP 2003 "The Massachusetts Estuaries Project Embayment Restoration and Guidance for Implementation Strategies"). Findings of this analysis are now being incorporated into land use and facilities decisions across Cape Cod.



Mystic Pond (Indian Ponds)



Middle Pond (Indian Ponds)



Hamblin Pond (Indian Ponds)

3 Kettle Pond Ecosystems

Most of the inland freshwater ponds of Cape Cod are kettle ponds, formed as depressions left behind by ice blocks as the glacial ice retreated between 14,000 and 17,000 years ago. According to Portnoy et al (2001), while kettle ponds have a common glacial origin, their subsequent evolution differs based on the depth of the original ice block, landscape position relative to sea level, and the texture (particle size) of the soils in the ponds' watersheds. Cultural effects are also to be added to this list; the ponds of Cape Cod are influenced by the amount and type of development in the watershed, invasions of exotic species, application of lime to raise the naturally low pH of the waters, and fisheries management practices.

Unlike most lakes and ponds, kettle ponds do not have prominent tributary streams (inlets) and outlets (**Figure 2**). Groundwater seepage and direct precipitation, rather than surface water flows, are the source of water to the kettle ponds. The quality of the water in the ponds, therefore, is directly affected by the quality of the groundwater resource.

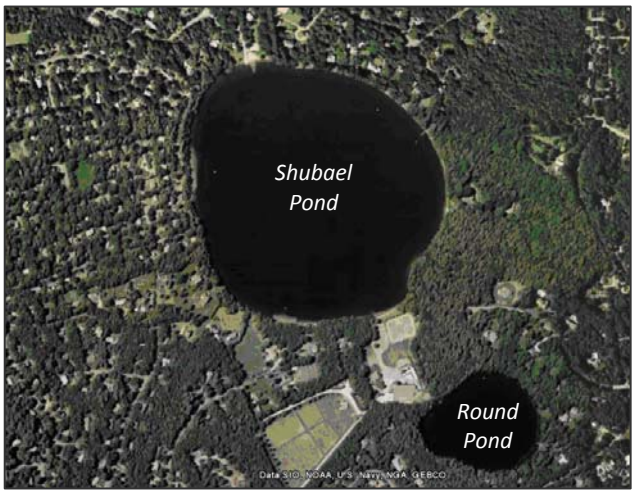

Figure 2. Aerial photograph of Shubael and Round Ponds illustrating hydrologic isolation of kettle ponds.

The lack of defined inlets and outlets for most kettle ponds has some important implications for the cycling of nutrients and organic material. Nitrogen and phosphorus enter the ponds primarily as dissolved nutrients where they are incorporated into biomass. Water leaves the ponds through groundwater seepage and evaporation. Particulate biomass consequently remains in the ponds, and the nutrients continue to cycle through the food web. Through this natural phenomenon, kettle ponds become more productive over time, as there is little opportunity for particulate material to leave the system. The Cape Cod Commission compiled dissolved oxygen (DO) measurements in the lower waters of 41 kettle ponds; data were from 1948 and 2001. Comparison of the data revealed that 76% of the measurements were lower in 2001 than 1948. These data provide strong evidence of an increasing level of productivity in the ponds over the intervening five decades (Cape Cod Commission, May 2003 p. 46).



Round Pond

Another important consideration for the kettle

ponds of Barnstable is that many of the ponds are shallow, with extensive wetland and littoral zones and macrophyte communities. Cooke et al. (1993) point out that the complexity of nutrient flux and food web interactions at the sediment-water interface in highly productive shallow regions of lakes and ponds cannot be ignored. Nutrient cycling and biological interactions in shallow, weedy sections of the ponds may contribute to maintaining elevated nutrient levels and undesirable plant growth long after external loading controls have been implemented.



Elizabeth Pond

4 Sources of Data and Information

A recent report summarizes the water quality status of the ponds of Barnstable (Eichner et al. 2008). After reviewing available data, the authors of this report concluded that:

> *"Available data for most ponds in Barnstable is limited. Other than the PALS Snapshots and sampling following the alum treatment at Hamblin Pond, sampling of most of the ponds has been sporadic. Given the sporadic available data and since the PALS Snapshots are designed to sample ponds during what is likely to be their worst water quality conditions, interpretation of available data must be approached with an understanding of these limitations."*

This Action Plan builds on the information provided in the 2008 report, and incorporates other data sources as summarized in **Table 1**. Of the 59 ponds listed in the table, data sources were available for 64% of the ponds.

Table 1. Data Sources Used to Develop Barnstable Ponds Action Plan

Named Pond[1]	CCC GIS ID[2]	Eichner, 2008[3]	Lake Wequaquet[4]	CCC Atlas: description[5]	Bathing beach bacteria testing[6]	2009 Visual Assessment[7]
1. Aunt Betty's	BA-756	✓				✓
2. Bearse	BA-617	✓		✓		
3. Bog	BA-802	✓				
4. Campground	BA-574					
5. Coleman	BA-819	✓				
6. Crystal	BA-878	✓				
7. Dunn's	BA-723	✓				
8. Eagle	BA-815	✓		✓		✓
9. Elizabeth	BA-795	✓				✓
10. Fawcett's	BA-748	✓				
11. Flax	BA-473					
12. Flint Rock	BA-614					
13. Flowing	BA-733					
14. Fresh	BA-701					
15. Garrett's	BA-510	✓		✓		✓
16. Hamblin	BA-668	✓		✓	✓	✓
17. Hathaway (North)	BA-565	✓		✓	✓	✓
18. Hathaway (South)	BA-594	✓				✓
19. Hinckley	BA-411	✓				
20. Israel	BA-585					
21. Joshua	BA-807	✓		✓	✓	✓
22. Lamson	BA-596					
23. Lewis	BA-881	✓				
24. Lewis (airport)	BA-670					
25. Little Israel	BA-608					
26. Little Parker	BA-841	✓				

Named Pond[1]	CCC GIS ID[2]	Eichner, 2008[3]	Lake Wequaquet[4]	CCC Atlas: description[5]	Bathing beach bacteria testing[6]	2009 Visual Assessment[7]
27. Little / Stony	BA-564	✓				
28. Long (C'ville)	BA-737	✓		✓		✓
29. Long (MM)	BA-675	✓		✓		✓
30. Lovell's	BA-759	✓		✓		✓
31. Lumbert	BA-719	✓				✓
32. Mary Dunn	BA-646	✓				
33. Micah	BA-797	✓		✓		
34. Middle	BA-640	✓				✓
35. Mill (MM)	BA-746	✓				✓
36. Mill (WB)	BA-391	✓				
37. Muddy	BA-694	✓				✓
38. Mystic	BA-584	✓				✓
39. Naomi	BA-812					
40. Neck	BA-874	✓				
41. No Bottom	BA-523	✓				
42. North (C'ville)	BA-752					
43. North (Ost)	BA-816					
44. Parker	BA-875	✓				
45. Patty's	BA-731					
46. Red Lily (North)	BA-782	✓				✓
Red Lily (South)	BA-782	✓				
47. Round (Bar)	BA-587					
48. Round (MM)	BA-691	✓				✓
49. Rushy Marsh	BA-914					
50. Sam	BA-820					
51. Sandy Hill	BA-542					
52. Schoolhouse	BA-806	✓				
53. Shallow	BA-626	✓				✓
54. Shubael	BA-664	✓		✓		✓
55. Simmons	BA-789					
56. Spruce	BA-535					
57. Upper Gate	BA-673					
58. Wequaquet	BA-605	✓	✓	✓	✓	✓
59. West	BA-764					

[1]Named ponds as listed in CCC Atlas 2003.

[2]CCC GIS ID: CCC GIS staff assigned a unique number to each waterbody digitized from a spring 1994 aerial photograph. The numbering system consisted of a two-letter town code and a unique number for each pond. These are presented in the CCC Atlas of 2003.

[3]Eichner, 2008: Eichner, E. 2008. Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities. School of Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA.

[4]Lake Wequaquet: SMAST. 2008. Lake Wequaquet Water Quality Assessment draft FINAL REPORT October, 2008 for the Town of

Named Pond[1]	CCC GIS ID[2]	Eichner, 2008[3]	Lake Wequaquet[4]	CCC Atlas: description[5]	Bathing beach bacteria testing[6]	2009 Visual Assessment[7]

Barnstable and Cape Cod Commission. Prepared by Coastal Systems Group School of Marine Science and Technology University of Massachusetts Dartmouth.

[5]CCC Atlas description: Cape Cod Commission. 2003. Cape Cod Pond and Lake Atlas. Project 2000-02. Prepared by Cape Cod Commission for Massachusetts Executive Office of Environmental Affairs, Community Foundation of Cape Cod, and School of Marine Science and Technology at University of Massachusetts Dartmouth. May 2003.

[7]Visual assessment conducted by EcoLogic staff on July 29, 2009.

4.1 Cape Cod Commission Reports

Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities (Eichner et al. 2008). In 2008, the Cape Cod Commission, in cooperation with the Coastal Systems Group School of Marine Science and Technology University of Massachusetts Dartmouth, issued a report on the current status, available data, and recommendations for future activities for the Barnstable Ponds. Data from 38 ponds were identified, which generally focused on two sources: 1) individual pond studies with intensive year-long data collection; and 2) data collect through the Pond and Lake Stewardship (PALS) Snapshots conducted through the CCC and the SMAST between 2001 and 2007. The report concluded that available datasets for Barnstable's ponds were generally insufficient for drawing conclusions regarding the sources of nutrients and other factors affecting water quality and habitat conditions in individual ponds, but were sufficient for comparing conditions among ponds.

Lake Wequaquet Water Quality Assessment draft FINAL REPORT October, 2008 for the Town of Barnstable and Cape Cod Commission (SMAST, 2008). The Town of Barnstable contracted with the Coastal Systems Program, School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth through the Cape Cod Commission (CCC) to update the analysis of water quality conditions in Lake Wequaquet and connecting waterways. Sampling was conducted in summer 2007. This report documents the sampling results and their interpretation, as well as an evaluation of the relationship of the lake to its watershed through water, nitrogen, and phosphorus budgets.

Cape Cod Pond and Lake Atlas, Final Report (CCC Water Resources Office, 2003). The Cape Cod Commission Water Resources Office published the Cape Cod Pond and Lake Atlas in May 2003; this document presents a summary and analysis of water quality status of twelve of the Barnstable ponds. The summaries provide an overview, indicating location, the nature of the shoreline, and predominant land uses. The fish community and stocking activities are described. Results of an August 2001 sampling program are tabulated for 35 ponds; chlorophyll-*a*, phosphorus and nitrogen concentrations are compared with thresholds for impaired ponds.

4.2 Visual field assessment

In July 2009, EcoLogic LLC conducted a field visit of 20 of the Barnstable ponds to observe water clarity and color, shoreline vegetation and development, public access and recreational uses, and the presence of algae and macrophytes.

4.3 Delineation of contributing areas

The Town of Barnstable GIS Unit developed a draft map delineating the recharge areas and land use in the Town. Information on this map included acreage of the recharge areas, number of parcels, existing residential units, and existing commercial building square footage. A build-out analysis was conducted to estimate the total extent of development possible under existing zoning regulations.

5 Inventory of ponds

The Barnstable ponds exhibit a range of physical characteristics (**Table 2**). Additional details are presented in Appendix A.

Table 2. Physical Characteristics of the Barnstable Ponds

Pond	Area (acres)	Access	Water Clarity	Shoreline	Aquatic Plants
Aunt Betty's	7.1	Very limited	--	Developed	Present
Fawcett's	11.9	--	--	Developed	--
Lumbert	9.7	Private	Tannic	Developed	Present
Mary Dunn	18	--	--	Undeveloped	--
Mill (Marstons Mills)	6.0	--	Clear	Undeveloped	Present
Mill (West Barnstable)	16.7	--	--	--	--
Red Lily	4.5	Very limited	--	Vegetated	Present
Bearse	66.8	Permission	Clear	Developed	--
Eagle	8.5	Conservation	Clear	Undeveloped	Present
Elizabeth	6.3	Very limited	--	--	Present
Garrett's	27.9	Permission	Tannic	Developed	Present
Hinckley	10.3	--	--	Developed	--
Joshua	14.7	Public	Clear	Undeveloped	--
Long (Centerville)	51	Limited	Clear	Developed	Not evident
Long (Marstons Mills)	54.8	Conservation	Clear	Developed	Not evident
Muddy	24.6	None	--	Developed	--
Parker	10.9	--	--	Developed	--
Round (Marstons Mills)	9.8	Private	Clear	Developed	Present
Shallow	78.4	--	Clear	Developed	Not evident
Crystal	10.1	--	--	Developed	--
Hamblin (Indian Ponds)	115.4	Public	V. Clear	Developed	Present
Hathaway (North)	20.9	Public	V. Clear	Undeveloped	--
Lovell's	55.5	Public	--	Developed	Not evident
Micah	16.0	Conservation	--	Undeveloped	--
Middle (Indian Ponds)	104.6	Public	V. Clear	Developed	Minimal
Mystic (Indian Ponds)	148.4	Public	Clear	Developed	Present
Neck	13.6	--	--	Developed	--
Shubael	55.1	Public	V. Clear	Developed	Present
Wequaquet	596.3	Public	--	Developed	--
Lamson	12.3	--	--	Undeveloped	--
West	10.1	--	--	--	--

5.1 Current Water Quality and Habitat Conditions

Ponds deeper than about 5 m typically exhibit some degree of thermal stratification during the summer. Bottom waters isolated from the atmosphere become depleted of oxygen (i.e., develop anoxia) as the microbial community decomposes organic material that settles to the lake bottom. As ponds become more productive, oxygen depletion is evident higher in the water column.

The shallowest ponds do not develop stable thermal stratification, because the winds are able to keep the water column mixed from top to bottom. As a consequence, oxygen added to the pond from the atmosphere and from photosynthesis mixes throughout the water column and the waters remain oxygenated.



Eagle Pond

Ponds deep enough to stratify and productive enough to experience seasonal anoxia have elevated concentrations of phosphorus in the lower waters, due to the chemical changes at the sediment surface that occur during anoxia. As a result of these chemical changes, phosphorus is released from sediments to the overlying waters. In some lakes, wind-induced mixing and internal waves (seiches) may draw the phosphorus-rich water into the upper sunlit layer where the nutrient can support algal growth (the photic zone) during the summer. Several of the shallower ponds are susceptible to the effects of internal phosphorus loading during summer. As waters cool in the fall, the density gradients that prevented wind mixing break down and the phosphorus-rich layer is mixed into the water column of all ponds, regardless of depth.

Limnologists have developed guidelines to delineate the transition between trophic states based on phosphorus, water clarity, chlorophyll-a, and deep water dissolved oxygen concentrations (**Table 3**). However, assigning a lake or pond to one category still requires professional judgment considering the cumulative evidence of water quality conditions and the level of productivity (**Table 4**).



Lovell's Pond, with algal bloom
July 2009

Table 3. Trophic State and Indicator Parameters

Trophic State	TSI Values	Attributes and Recreational Use	*TSI Calculation* *TSI(TP) = 14.42 ln(TP) + 4.15* Total Phosphorus	*TSI(CHL) = 9.81 ln(CHL) + 30.6* Chlorophyll-a	*TSI(SD) = 60 – 14.41 ln(SD)* Secchi disk transparency
Oligotrophic	<30-40	Clear water, oxygen throughout the year in the hypolimnion. At TSI >30, hypolimnia of shallower lakes may become anoxic. Salmonid fisheries.	<6 to 12 µg/l	<0.95 to 2.6 µg/l	>8 to 4 m
Mesotrophic	40-50	Water moderately clear; increasing probability of hypolimnetic anoxia during summer. Hypolimnetic anoxia results in loss of salmonids.	12 to 24 µg/l	2.6 to 7.3 µg/l	4 to 2 m
Eutrophic	50-70	Anoxic hypolimnia, macrophyte problems possible. At TSI >60, blue-green algae dominate, algal scums and macrophyte problems. Warm-water fisheries only. Bass may dominate. At TSI >60, nuisance macrophytes, algal scum, and low transparency may discourage swimming and boating.	24 to 96 µg/l	7.3 to 56 µg/l	2 to 0.5 m
Hypereutrophic	>70	Light limited productivity. Dense algae and macrophytes. Rough fish dominate; summer fish kills possible.	96 to 384 µg/l	56 to >155 µg/l	0.5 to <0.25 m

after Carlson and Simpson (1996); Carlson TSI developed in algal dominated, northern temperate lakes

Table 4. Summary of Trophic State Parameters, Barnstable Ponds

Trophic State	Depth Class		
	Ultra-Shallow	**Shallow**	**Deep**
Oligotrophic	Hathaway (South) Mary Dunn Mill (MM) Red Lily	Garrett's Joshua	Hamblin Hathaway (North) Micah Middle Neck Shubael
Mesotrophic	Aunt Betty's Bog Fawcett Lumbert	Bearse Coleman No Bottom Shallow	Crystal Lovell's Mystic Wequaquet
Eutrophic	Dunn's Little/Stony Mill (WB)	Eagle Elizabeth Hinckley Long (C'ville) Long (MM) Muddy Parker Round (MM)	
Hypereutrophic	Little Parker	Schoolhouse	

based on Eichner, 2008

The visual assessment conducted by EcoLogic in July 2009 confirmed that the Barnstable Ponds are in various stages of eutrophication.

While data are limited, they do provide a basis for making an assessment of trophic state using the standard indicators described in **Table 3**. Note that the concentrations of chlorophyll-a and phosphorus used to delineate trophic state (**Table 3**) are not the same as the concentrations used to define ecoregional reference lake conditions (**Table 5**). The ecoregional criteria are based on water quality conditions measured in eight pristine Cape Cod ponds.

Table 5. Ecoregional Criteria

Parameter	**Subecoregion 84 Reference Condition Threshold**	**Cape Cod Ponds based on 2001 PALS Data**
Secchi depth	2 m	Not calculated
Chlorophyll-a	6 µg/l	1.7 µg/l
Total Nitrogen	0.41 mg/l	0.31 mg/l
Total Phosphorus	9 µg/l	10 µg/l

EPA is encouraging development of ecoregional criteria, designed to reflect site-specific conditions of watershed geology, land use, and hydrologic setting. These values are used to define thresholds for impacted and non-impacted conditions and thus target levels. Ecoregional

criteria for Cape Cod ponds have been described in the Cape Cod Pond and Lake Atlas (Cape Cod Commission, May 2003); the ecoregional values (designated as subregion 84) are derived from a statistical evaluation of existing water quality conditions of "unimpacted" ponds for coastal New England, including Cape Cod. The 2001 PALS data were used to calculate thresholds for reference conditions using eight Cape Cod ponds. The eight ponds included a range of deep and shallow ponds; all were characterized with low nutrient and chlorophyll concentrations. One of these eight reference ponds was Barnstable's Micah Pond.

The status of the Barnstable Ponds with respect to the ecoregional criteria is summarized in **Table 6**, based on the data summaries provided by Eichner (2008).

Table 6. Status of Barnstable Ponds, based on Cape Cod Ponds Thresholds.

Pond	Impacted Criteria (Affected by Human Activities)		
	Chlorophyll-a >1.7 µg/l	Total N > 0.31 mg/l	Total P > 10 µg/l
Ultra-Shallow (0.5 and 1.2 m)			
Aunt Betty's	Impacted	Impacted	At Risk
Bog	Impacted	Impacted	At Risk
Dunn's	Impacted	Impacted	Impacted
Fawcett	Impacted	Impacted	At Risk
Hathaway (South)	Unimpacted	Unimpacted	Unimpacted
Little Parker	Impacted	Impacted	Impacted
Little/Stony	Impacted	Impacted	At Risk
Lumbert	Impacted	Impacted	At Risk
Mary Dunn	Impacted	Impacted	At Risk
Mill (MM)	Impacted	Impacted	Impacted
Mill (WB)	Impacted	Impacted	Impacted
Red Lily (North)	Impacted	Impacted	At Risk
Red Lily (South)	Impacted	Impacted	At Risk
Shallow (2.1 and 8.6 m)			
Bearse	Impacted	Impacted	At Risk
Coleman	Impacted	Impacted	Impacted
Eagle	At Risk	Impacted	At Risk
Elizabeth	Impacted	Impacted	Impacted
Garrett's	Impacted	Unimpacted	At Risk
Hinckley	Impacted	Impacted	Impacted
Joshua	At Risk	At Risk	At Risk
Long (C'Ville)	Impacted	Impacted	At Risk
Long (MM)	Impacted	Impacted	Impacted
Muddy	Impacted	At Risk	Impacted
No Bottom	Impacted	Impacted	Impacted
Parker	Impacted	Impacted	Impacted
Round (MM)	Impacted	Impacted	At Risk
Schoolhouse	Impacted	Impacted	Impacted
Shallow	Impacted	Impacted	At Risk

Table 6. Status of Barnstable Ponds, based on Cape Cod Ponds Thresholds.

Pond	Impacted Criteria (Affected by Human Activities)		
	Chlorophyll-a >1.7 µg/l	Total N > 0.31 mg/l	Total P > 10 µg/l
Deep (9.3 and 17.3 m)			
Crystal	Impacted	Impacted	Impacted
Hamblin	Impacted	At Risk	At Risk
Hathaway (North)	Impacted	Unimpacted	Impacted
Lovell's	Impacted	Impacted	Impacted
Micah	Impacted	At Risk	Impacted
Middle	Impacted	At Risk	At Risk
Mystic	Impacted	At Risk	Impacted
Neck	At Risk	Impacted	Impacted
Shubael	Impacted	Impacted	Impacted
Wequaquet	Impacted	Impacted	Impacted

In addition to grouping the ponds based on the degree to which human activities have altered them from their natural (pristine) condition, each state classifies surface waters for a desired "best use". This concept focuses on human use of the resource, but incorporates the ecological condition of the resource as well. Examples of designated use include public water supply, fishing, swimming (water contact recreation), aesthetic enjoyment and support of shellfish, wildlife and fisheries. The best use of Barnstable's inland kettle ponds is typically recreation in and on the water and fishing. It is important to note that the designation of a pond as showing evidence of impact by humans (i.e., "impacted" or "at risk") does not imply that the pond's designated uses are not being supported. Overall, the town's inland ponds fully support their designated use.

Based on this analysis, the Barnstable Ponds may be grouped into categories describing current water quality and habitat conditions. This grouping is presented in **Table 7.**

Table 7. Summary of Current Water Quality Conditions and Use Attainment.

Depth Categories:	Water Quality and Aquatic Habitat Status		
	Supports Desired Uses	**Currently Supports Desired Uses, with Evidence of Degradation**	**Does Not Support Desired Uses**
Ultra-shallow (less than 1.2 m maximum depth)	Aunt Betty's Hathaway (South) Lumbert Mary Dunn Mill (MM)	Red Lily Bog Dunn's Fawcett Little/Stony Mill (WB)	Little Parker
Shallow (from 2.1 to 8.6 m maximum depths)	Garrett's Joshua Eagle	Bearse Coleman Long(MM) Elizabeth No Bottom Round (MM) Shallow	Hinckley Long (C'ville) Muddy Parker Schoolhouse
Deep (from 9.3 to 17.3 m maximum depths)	Hathaway (North) Micah Middle Neck	Chrystal Hamblin Mystic Shubael Wequaquet	Lovell's

The nitrogen: phosphorus (N: P) ratio is another measure of pond conditions. Algae require many nutrients, and their nutritional requirements are within a relatively consistent range. As a general rule, higher N:P ratios are associated with lower productivity. When the elemental N:P ratio in the water column falls below about 16, nitrogen becomes the limiting nutrient for algal growth. Many species of cyanobacteria are able to fix atmospheric nitrogen (i.e., convert nitrogen gas (N_2) to ammonia and other more readily useable forms of nitrogen). As a consequence, growth of these species is not limited by the availability of nitrogen in the water, and cyanobacterial abundance can reach nuisance levels in eutrophic lakes.

The N:P ratio of the Barnstable ponds (**Table 8)** tends to be high. The N:P ratio, on average, decreases from more than 100 for the less productive ponds to less than 10 for the most nutrient-rich and productive ponds. Lovell's Pond, which was closed for swimming in July 2009 due to a cyanobacterial bloom, exhibited a relatively low N: P ratio of 25:1 in 2001.

Table 8. Nitrogen:Phosphorus Ratios, Barnstable Freshwater Ponds, 2001

Ultra-Shallow		Shallow		Deep	
Oligotrophic (>100)		*Oligotrophic (>100)*		*Oligotrophic (>100)*	
Red Lily (Lower)	179:1	Long (August)	112:1		
Mid-Range (<100 and >10)		*Mid-Range (<100 and >10)*		*Mid-Range (<100 and >10)*	
Aunt Betty's	29:1	Bearse	19:1	Crystal	52:1
Bog	26:1	Coleman	25:1	Hathaway North	65:1
Fawcett's	61:1	Elizabeth	16:1	Lovell's	25:1
Hathaway (South)	29:1	Garrett's	44:1	Micah	53:1
Little	51:1	Long (Sept.)	31:1	Middle	46:1
Mary Dunn	33:1	Muddy	22:1	Mystic	23:1
		Parker	72:1	Shubael	73:1
		Round	45:1	Wequaquet Middle	22:1
		Shallow	32:1		
Eutrophic (<10)		*Eutrophic (<10)*		*Eutrophic (<10)*	
Dunns	9:1	Schoolhouse	8:1		

Based on data from Cape Cod Pond and Lake Atlas, May 2003.

5.2 Data Gaps

The evaluation of the data in Eichner (2008) repeatedly emphasized that only limited data were available to analyze the status and trends of the Barnstable ponds.

> *"When looking at all of this data, there are two significant factors that must also be considered: all of these characterizations are based on very limited data and there are a number of Barnstable ponds that do not have any data. Except for Mystic, Middle, and Hamblin, the rest of the ponds have not had water quality samples collected since 1986 except for PALS Snapshots. The PALS Snapshot data is useful for what it was designed for, a Cape-wide picture of pond water quality, but it is not sufficient for definitively stating the status of individual ponds or designing remedial strategies." (Eichner, 2008)*

5.3 Land Use and Phosphorus Sources

Phosphorus can reach the inland kettle ponds from several sources. Runoff from impervious surfaces, such as roadways, can transport dissolved and particulate material, including phosphorus, to the ponds. Eroding shorelines can contribute particulate material as well. Groundwater seepage transports dissolved nutrients into ponds; the concentrations of dissolved nutrients can be elevated when groundwater is affected by sewage disposal. There are biological sources as well, including waterfowl and humans.

Maps of current land use, depicting the number and location of residences, were reviewed during preparation of this Action Plan for Barnstable. This coverage area of impervious surfaces is important to consider in quantifying phosphorus loading to the ponds from the surrounding watershed due to surface runoff. The density of development is a factor in phosphorus loading from septic systems.



Mill Pond – Conservation Area visitor location map.

Review of the map of government-owned land and protected open space (Town of Barnstable, 2009) indicates that the majority of parcels within the town are in private ownership and not under conservation protection. However, many of the smaller ponds have a substantial portion of the watershed in town-owned or conservation lands.

Most of the town is not served by sanitary sewers. Therefore, septic effluent is likely a contributing factor in phosphorus loading to most of the Barnstable ponds. Once the contributing area of groundwater flow into each pond is delineated, these data can be used to help quantify the potential contribution of septic effluent to each pond.

Parcels in the Town of Barnstable that have sewer accounts have been mapped. According to a map[1] dated October 2007, these parcels are predominantly located on the eastern side of town, east of the Lake Wequaquet region. One would anticipate that parcels with sewer accounts would have fewer active septic systems, and that septic contributions of phosphorus to the ponds adjacent to these parcels would be reduced. Ponds in this region include:

Aunt Betty's	Fawcett's	Lewis
Crooked	Fresh	Mary Dunn
Duck	Fresh Hole	Upper Gate
Dunn's	Hathaway (South)	

5.4 Build-out Analysis

Changes in land use over time will have an impact on the Barnstable ponds. To estimate the amount of development possible in the town, and thereby identify ponds likely to be most affected, a build-out analysis was conducted. The analysis grouped 29 ponds into 17 areas around Barnstable, and tallied the existing and build-out quantities for residential dwelling units and commercial building square footage (**Table 9**).

[1] http://www.town.barnstable.ma.us/InformationSystems/GIS/SEWERED.PDF

Table 9. Build-out Analysis of Residential Dwelling Units and Commercial Building Square Footage, Town of Barnstable.

Pond(s)	Residential Dwelling Units			Commercial Bldg Sq Footage		
	Existing	Build-out	Change	Existing	Build-out	Change
Lovell	245	353	+108	0	0	0
Muddy, Long (MM)	138	143	+5	0	0	0
Eagle	60	61	+1	0	0	0
Mystic, Middle, Hamblin, Shubael, Little	756	823	+67	0	0	0
Mill (WB)	53	71	+18	0	0	0
Bog	82	104	+22	2,202	9,478	+7,276
Micah, Joshua	207	216	+9	316,330	316,330	0
West, Flowing	210	218	+8	0	0	0
Garrett's	132	158	+26	1,477	1,477	0
Wequaquet, Bearse, Shallow, Long (C'ville)	927	1,002	+75	22,737	31,569	+8,832
Hinckley	21	26	+5	0	0	0
Hathaway	0	23	+23	9,820	90,450	+80,630
Simmons, Ben	215	219	+4	6,728	23,073	+16,345
Fawcett's	205	239	+34	7,768	19,089	+11,321
[Number 15 on map]	0	0	0	43,192	180,657	+137,465
Mary Dunn	0	0	0	1,410	1,410	0
Israel, Lamson	0	0	0	119,114	464,441	+345,327

from draft GIS map "Town of Barnstable Freshwater Ponds Recharge Areas", August 2009

Ponds that have potential for extensive future residential development, based on this build-out analysis, are:

Lovell	Mystic-Middle-Hamblin-Shubael-Little
Fawcett	Wequaquet-Bearse-Shallow-Long (C'ville)
Garrett's	Hathaway[2]

Other ponds exhibiting potential for extensive future commercial development, based on this build-out analysis, include:

[2] The lands around Hathaway Pond (both North and South) are predominantly owned by the Town and designated for conservation and recreation; therefore, the projected increase in development is unlikely.

Israel-Lamson	Wequaquet-Bearse-Shallow-Long (C'ville)
"Number 15"	Fawcett's
Simmons-Ben	

Given this assessment of potential for development, ponds which presently do not meet desired uses, and ponds with evidence of degradation are considered most at risk (**Table 10**).

Table 10. Water Quality Conditions of Ponds with Potential for Extensive Future Development.

	Water Quality and Aquatic Habitat Status		
Development	**Meets Desired Uses**	**Meets Desired Uses, with Evidence of Degradation**	**Does Not Meet Desired Uses**
Residential	Garrett's Middle	Bearse Fawcett Hamblin Little Mystic Shallow Shubael Wequaquet	Long (C'ville) Lovell's
Commercial		Bearse Fawcett Shallow Wequaquet	Long (C'ville)

Note: there were no data to categorize the water quality conditions of Israel, Lamson, "Number 15", Simmons or Ben.

5.5 Point and nonpoint sources of nutrients

There are no identified point sources of nutrients to the Barnstable Ponds; most of the nonpoint sources are direct inputs to the ponds: septic effluent, wildlife, swimmers, stormwater runoff, and shoreline erosion.

Septic effluent as a nonpoint source is the subject of investigation and debate. The extent to which phosphorus in septic effluent can reach surface waters is an issue of great importance to many communities. Research and monitoring indicates that subsurface phosphorus transport is influenced by depth to groundwater, soil texture, pH, geology, and groundwater quality, as well as by the nature of the on-site wastewater disposal systems (notably age, loading history, and maintenance).

5.6 Transport and attenuation from source to ponds

In general, phosphorus is considered relatively immobile in the subsurface environment. However, phosphorus transport through groundwater to surface waters has been documented; for example, phosphorus associated with the sewage plume from the Massachusetts Military Reservation on Cape Cod is reaching Ashumet Pond (McCobb et al 2003). Phosphorus from septic systems may reach surface waters when intervening distances and travel times are short, when the groundwater environment is reducing (anoxic), or when sites for sorption of phosphorus onto aluminum and iron oxides are already saturated with phosphorus (Portnoy et al 2001). The Ashumet Pond investigation by USGS documented that phosphorus can desorb from subsurface soils exposed to uncontaminated groundwater with low pH (McCobb et al. 2003). This implies that phosphorus from on-site systems remains a reservoir in the soil that may be slowly mobilized and transported to the ponds along with groundwater.

Controlled experiments by Cogger et al (1988) examined the movement of nutrients and bacteria from septic systems installed in the sandy soils of a coastal barrier island. They reported that phosphorus was most likely to be mobile in wet, sandy soils, and that both loading rate and water table location affected phosphorus concentrations in the groundwater surrounding the leach field. Data from this investigation were also consistent with two processes for adsorption occurring: a fast reaction and a slow reaction.

The ponds of Barnstable are situated in sandy soils, and the surrounding land areas have a variable depth to groundwater. Background pH is low, averaging 5.5 (McCobb et al. 2003). The sandy soils provide abundant iron and aluminum hydroxides for phosphorus adsorption. The reaction of soluble reactive phosphorus with sandy soil is described by two processes: a fast and reversible adsorption reaction on the surface of aluminum and iron oxides and a slow, diffusion-controlled process where the phosphorus either precipitates with aluminum or iron, or diffuses into micropores and becomes adsorbed to surfaces deep in the soil matrix (Shoumans and Breeuwsma 1997).

It appears that the soils of Barnstable have the cation exchange capacity and mineralogy to adsorb soluble phosphorus present in groundwater. However, phosphorus removal is not permanent. Under certain chemical conditions, phosphorus adsorbed to the surface aluminum and iron hydroxides may desorb and move with the groundwater towards the kettle ponds. Groundwater pH on Cape Cod is within the range where this desorption reaction will occur. Phosphorus movement from subsurface soils would be exacerbated by conditions such as high organic loading that contribute to microbial activity and de-oxygenation of the groundwater resource.

6 Summary of Findings

- **Water Quality Conclusions (Eichner, 2008).** The focus of the conclusions was centered on total phosphorus, chlorophyll-a, and dissolved oxygen as key data sets indicating pond health. In all cases, further data collection was recommended to refine the characterization of each pond. *Overall recommendation*: Standard best management practices to minimize stormwater runoff would help maintain/improve existing conditions.

    a. Ultra-shallow Ponds – Total phosphorus and chlorophyll-a concentrations were generally higher than threshold concentrations, while dissolved oxygen was compliant with the regulatory standards. Hathaway South and Mary Dunn Ponds are relatively pristine and undeveloped, and should be a priority for protection.

    b. Shallow Ponds – Total phosphorus and/or chlorophyll-a concentrations were excessively higher than threshold concentrations, while six of the 15 ponds exhibited dissolved oxygen concentrations in the deeper waters that were below the regulatory standards. Joshua was identified as a relatively pristine pond that should be protected.

    c. Deep Ponds - Total phosphorus and/or chlorophyll-a concentrations were higher than threshold concentrations, while eight of the 10 ponds exhibited dissolved oxygen concentrations in the deeper waters that were below the regulatory standard. None of the ponds may be considered relatively pristine, but several have only recently shown signs of water quality impairment: Micah, Middle and Neck. The alum treatment of Hamblin Pond continues to provide residual water quality benefits.

- **Impacted Waters.** The Barnstable Ponds are in various stages of eutrophication; many are considered "impacted waters" based on regional criteria developed from limited measurements of water quality conditions in eight pristine Cape Cod ponds. However, designated uses are generally met. The ponds are used for swimming, boating, recreational fishing and aesthetic enjoyment. While a few ponds exhibit visual degradation of water quality conditions, most are aesthetic assets and provide habitat for a diverse assemblage of aquatic plants and animals.

- **Phosphorus Loading.** Phosphorus is the limiting nutrient for primary production in the Barnstable Ponds, and therefore has an influence on water quality conditions and pond health.

    a. Unlike the nitrogen-limited coastal embayments, production of algae and macrophytes in inland ponds is limited by phosphorus. The ratio of nitrogen to

phosphorus in ponds is likely to influence the species composition of the algal community, particularly the importance of blue-green algae.

b. Phosphorus enters the Barnstable Ponds from several sources; few (if any) of these sources are easily controlled. External sources of phosphorus include: groundwater influx; wastewater disposal (septic sewage plumes in groundwater); surface runoff; atmospheric deposition; shoreline erosion; and users of the ponds (swimmers and wildlife).

c. In deeper ponds subject to seasonal anoxia, phosphorus held in sediments can be released to the overlying waters; this internal loading can be a significant fraction of the annual supply of phosphorus available to support algal growth.

d. Kettle ponds are susceptible to phosphorus accumulation, due in part to the lack of surface outlets.

e. The watershed area of many of the Barnstable ponds includes parcels with on-site wastewater disposal systems. Installation of sewers to collect domestic wastewater before it enters the groundwater would likely reduce phosphorus loading to these ponds.

f. Build-out analysis was used to identify ponds where there is a high potential for future residential and commercial development. Such future development could increase phosphorus loading from surface runoff and groundwater seepage of sewage plumes.

7 Recommendations

Given the nature of the kettle ponds and the sources of phosphorus to the Barnstable Ponds, there are no simple answers to long-term water quality protection and improvement. Strategies fall into several categories: reducing the inputs of nutrients and sediment, altering internal cycling, increasing the output of nutrients and sediment, and/or mitigating the symptoms of eutrophication. Feasible alternatives for protection and restoration of the Barnstable Ponds are summarized in **Appendix B**. The following actions are recommended.

- **Develop town-wide strategies for water quality protection.**

  Some of these strategies would be implemented through Town Codes and regulation, while other strategies could be implemented without regulatory involvement. Storm water runoff controls would be one example of a regulatory action. Public education would be an example where regulatory involvement is not required.

- **Develop pond-specific strategies to protect and/or restore individual Barnstable Ponds.**

  Each pond has its own unique situation, based on its size and depth, the nature of the surrounding watershed, and the extent of groundwater influences. With a more detailed understanding of the individual pond through additional data collection, it will become more apparent whether actions such as alum treatment or weed harvesting are appropriate in a given pond.

- **Obtain more detailed data on priority ponds.**

  As noted above, there are very limited recent data to characterize water quality and habitat conditions of the town's ponds Additional data collection should be prioritized to ponds that are the most impaired, and that provide the greatest opportunity for public uses. Moreover, data collection should be focused on closing data gaps needed to make effective management decisions.

7.1 Priority Ponds

An assessment of the priority status of the Barnstable Ponds **(Table 11) includes** Barnstable inland ponds reviewed as part of this assignment; the list is not inclusive of all town ponds.

Table 11. Summary of existing conditions, recommended actions, and priorities for managing Barnstable Ponds

Pond	Priority (low-moderate-high-protect)	Findings (Trophic States: O, M, E, H)	Recommended Actions
Ultra-Shallow			
Aunt Betty's	Low	M; Limited public access	Education, watershed BMP
Bog	Low	M; Impacted/at risk	Education, watershed BMP
Dunn's	Moderate	E; Impacted	Education, watershed BMP
Fawcett's	Low	M; Impacted/at risk; potential for increased residential development	Education, watershed BMP; guide future development to minimize nutrient export
Hathaway (South)	Protect	O; Unimpacted	Low impact recreational use & education in protected watershed
Little Parker	High	H; Impacted; does not support desired uses	Watershed BMPs; mitigate symptoms to improve aesthetics and recreational use: hand-pulling, benthic barriers
Little/Stony	Moderate	E; Impacted/at risk	Education, watershed BMP
Lumbert	Low	M; Private; Impacted/at risk	Education, watershed BMP
Mary Dunn	Low	O; Impacted/at risk	Education, watershed BMP
Mill(MM)	Protect	O; Impacted; Conservation area	Low impact recreational use & education in protected watershed
Mill (WB)	Moderate	E; Impacted	Education, watershed BMP
Red Lily (North, South)	Low	O; Impacted/at risk; Limited public access	Education, watershed BMP
Shallow			
Bearse	Moderate	M; Impacted/at risk; fanwort; potential for increased residential development	Macrophyte survey, strategies to control exotics; consider reducing density of future development

Pond	Priority (low-moderate-high-protect)	Findings (Trophic States: O, M, E, H)	Recommended Actions
Coleman	Low	M; Impacted	Mitigate symptoms of eutrophication in recreational areas (benthic mats, hand harvesting); watershed BMPs
Eagle	Protect	E; At risk; watershed in land trust	Consider hand pulling emergent vegetation to improve shoreline access; maintain trails and prevent erosion
Elizabeth	Moderate	E; Impacted; Limited public access	BMPs, control stormwater on roadways
Garrett's	Low	O; At risk; limited public access	Education, watershed BMPs
Hinckley	High	E; Impacted	Stormwater management, septic inspections
Joshua	High	O; At risk; Town beach, natural vegetation; reference pond indicative of pristine conditions	Priority for protection, education, BMPs
Long (C'Ville)	High	E; Impacted; Town beach, highly developed; Does not support desired uses	Stormwater management, septic inspections, mitigating measures to improve recreational use: benthic mats, hand-pulling
Long (MM)	Moderate	E; Impacted; Conservation area; moderately protected	Education, watershed BMPs
Muddy	Moderate	E; Impacted/at risk	Education, watershed BMPs
No Bottom	Low	M; Impacted	Education, watershed BMPs
Parker	Moderate	E; Impacted	Education, watershed BMPs
Round (MM)	Moderate	E; Impacted/at risk; Private	Education, watershed BMPs
Schoolhouse	High	H; Impacted; does not support desired uses	

Pond	Priority (low-moderate-high-protect)	Findings (Trophic States: O, M, E, H)	Recommended Actions
Shallow	Moderate	M; Impacted/at risk; vegetated shoreline; potential for increased residential development	Controls on future density and/or BMPs to minimize phosphorus migration to pond from surface runoff and groundwater
Deep			
Crystal	Low	M; Impacted	Education, watershed BMPs
Hamblin	High	O; At risk; Town Beach, conservation land; alum-treated; potential for increased residential development	Monitor for effectiveness of alum treatment; controls on future density and/or BMPs to minimize phosphorus migration to pond from surface runoff and groundwater
Hathaway (North)	High	O; At risk; Town beach, mix of conservation land and development	Continue acquisition of hydrologically important parcels in watershed
Lovell's	High	M; Impacted; Town beach closed; blue-green algal bloom; does not support desired uses	Priority for monitoring deep water phosphorus levels and N/P ratio; consider nutrient inactivation
Micah	Protect	O; At risk; Undeveloped, reference pond	Priority for monitoring deep water phosphorus levels
Middle	Protect	O; At risk; Public access, very clear	Priority for monitoring deep water phosphorus levels; consider acquisition of key parcels to control density
Mystic	High	M; Impacted/at risk; Public access, endangered mussels; permit phase for alum application; potential for increased residential development	Priority for alum treatment program; guide future development to minimize surface runoff and groundwater nutrient input

Pond	Priority (low-moderate-high-protect)	Findings (Trophic States: O, M, E, H)	Recommended Actions
Neck	Moderate	O; Impacted/at risk;	Period monitoring to detect symptoms of degradation; watershed BMPs;
Shubael	High	O; Impacted; Town beach, exceptionally clear water potential for increased residential development	Priority for monitoring deep water phosphorus levels; septic inspections; guide future development to minimize nutrient input from surface runoff and groundwater seepage
Wequaquet	High	M; Impacted; Town beach, potential for future residential and commercial growth	Priority for monitoring deep water phosphorus levels; septic inspection; consider density controls on future development

Trophic states: O – Oligotrophic; M – Mesotrophic; E – Eutrophic; H -Hypereutrophic
Higher priority assigned to ponds with town beach and/or public access
BMP- Best Management Practices

7.2 Protection Measures

The following are measures that may be taken to protect the Barnstable Ponds from further degradation in water quality and habitat conditions. These measures are typically implemented in the watershed surrounding the ponds, rather than within the pond itself. These protection measures may be applied to all the ponds, though more information regarding existing storm water infrastructure could help the town refine priorities.

- Storm water management. Stormwater basins with water quality controls; operations and maintenance are critical. Improved stormwater management on parking lots adjacent to ponds.

- Septic discharge. Regulatory programs for septic systems existing in similar environments to the Cape Cod area show a variety of setback requirements, as summarized in **Appendix C**. In addition to setbacks, there are alternative technologies, some of which show excellent phosphorus removal capabilities. The Massachusetts Alternative Septic Systems Test Center and the Barnstable County Department of Health are an informational resource. For a listing of current MADEP approved alternative systems, refer to the web site http://www.mass.gov/dep/water/wastewater/techsum.htm

- Public Education. Conduct forums to discuss pond ecology, range of conditions in Town ponds, and effective measure for improving water quality conditions. Educate the public regarding the importance of remaining on trails and protecting riparian (shoreline) areas. Also, educate land owners about the impacts of fertilizer and pesticide applications adjacent to ponds.

- Land acquisition. Pursue and acquire open space, while incorporating resource-based priorities into decisions. Place a high priority for acquisition of properties in riparian areas.

- Bioengineering. Revegetate shoreline areas to reduce shoreline erosion. Plan, install and maintain trails through public lands to reduce potential for erosion.

- Other structural measures. Implement wastewater collection to reduce phosphorus loading via septic systems. Install public toilet facilities for beach areas, and keep them cleaned and maintained to encourage use.

- Inspection and Monitoring. Inspection and maintenance of onsite septic systems. Routine participation in volunteer (PALS) water quality monitoring program. Additional monitoring suggestions are summarized in **Appendix D**.

7.3 Restoration Options

The following are measures that may be taken to restore the impacted Barnstable Ponds. These measures would be implemented as needed on a pond-by-pond basis. Additional data from the impacted ponds is required before selecting an appropriate restoration option.

- Alum treatment to seal bottom sediments. Alum application to seal bottom sediments and prevent phosphorus release. This treatment option is applicable to deep ponds that develop stable thermal stratification, and where internal (sediment) phosphorus release is a significant component of the annual TP budget.

- Mixing. Use aerators or mixers to keep the water column oxygenated and accelerate the rate of decomposition of organic material.

- Benthic barriers. To prevent the excessive growth of vegetation, a symptom of eutrophication. This technique may be applicable to limited areas to restore recreational use.

- Mechanical or hand removal of weeds. To eliminate invasive species and reduce the excessive growth of aquatic plants that impairs desired uses of the pond.

- Water level management (drawdown) to control aquatic plants.

8 Priority Actions Recommended for the Town of Barnstable for 2010-2011

Convene a public educational forum to discuss current water quality and habitat conditions of the ponds of Barnstable. Solicit public input on the desired future for the ponds (overall and for individual ponds). Major topics include:

- The eutrophication process
- The unique nature of the kettle ponds in nutrient cycling
- How conditions have changed in recent decades
- Alternatives for protection and restoration
- Why each pond requires a different strategy (no action, protection, active intervention) based on its physical characteristics, current conditions, and desired use
- The costs and benefits associated with alternatives
- How overall wastewater and facilities decisions may affect the ponds

Initiate a focused monitoring program to evaluate use attainment, confirm priorities for intervention, and assess the effectiveness of control measures.

The recommended monitoring plan is included as Appendix D.

Prepare an annual Pond Report Card to enhance public understanding of water quality conditions and contributing factors.

Consider a local law requiring periodic inspection and pump out of individual on-site wastewater treatment systems. The frequency can be linked to distance to ponds, with more stringent requirements within a defined buffer zone.

Review local erosion and sedimentation control laws and determine if they could be improved to prevent sediment loss to the ponds. If warranted, propose revisions for approval.

Convene technical committee (or engage a consultant) to initiate detailed planning and cost estimating, identify funding sources, secure non-local funding as available, and acquire permits for alum application to ponds as identified by the Town based on new data.

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10 Appendices

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Appendix B. Summary of Pond Management Alternatives

Appendix C. Summary of Regulatory Setbacks and Recommendations for Septic Systems in Coastal Areas

Appendix D. Recommended Water Quality Monitoring Program

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Ultra-shallow Ponds - depths between 0.5 and 1.2 m							
Aunt Bettys	7.1	N	VL		Buildings encroach, most of shoreline remains undisturbed	Submerged and yellow lilies	Very limited public access and recreational use
Fawcetts	11.9	Y	na	na	na	na	na
Lumbert	9.7	Y	Pv	Brown-tannin	Fully vegetated (from vantage point of survey)	More surface growth	Roadway pulloff Private
Mary Dunn	18	Y	na	na	na	na	na
Mill (Marston Mills)	6.0	N		Clear	Natural	Emergents	Roadway historical marker; impoundment. Conservation area.
Mill (West Barnstable)	16.7	N	na	na	na	na	na
Red Lily	4.5	N	VL		Vegetation mostly intact; few large homes	Extensive lilies	Connected to Elizabeth (to the south)

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Shallow Ponds: depths between 2.1 and 8.6 m							
Bearse	66.8	Y	Pm (2003)	2.3m Secchi (2003)	Residential development (2003)	Treated to limit growth of fanwort (2003)	Connected to Wequaquet High TP and chlorophyll suggest productive algal population (2003)
Eagle	8.5	Y	CA	Clear	Intact. Undeveloped	Pink water lilies, black benthic mat	Walking trails, full-land trust (Mary Barton Land Trust) "relatively clean, largely unimpacted lake" (2003)
Elizabeth	6.3	N	VL			Extensive lilies	Connected to Red Lily (to the north)
Garretts	27.9	N	Pm	Tannins	Some development, few cleared lawns	Yellow lilies	"relatively clean lake with uncertain deep water quality concerns" (2003)
Hinckley	10.3	N	na	na	na	na	na
Joshua	14.7	Y	TB	Clear water; brown benthic layer	Completely natural vegetation		town beach and bath house "relatively clean, largely unimpacted lake" (2003)

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Shallow Ponds: (continued)							
Long (Centerville)	51.0	Y	WTW; Limited	Clear	Highly developed, lots of clearing	Not evident (Sonar treatment)	Hydrilla, restricted access to reduce spread of this invasive Town Beach (2003) "impacted with water quality problems" (2003)
Long (Marstons Mills)	54.8	Y	CA	Clear	Mostly intact, some developed shoreline. Moderately protected	None evident	LI conservation area "impacted with water quality concerns" (2003)
Muddy	24.6	Y	None	--	--	--	Sand pile along shoreline
Parker	10.9	Y	na	na	na	na	na
Round (Marston Mills)	9.8	N	WTW	Clear	Vegetation present	Benthic algal mat, emergents (cattails)	Private. Good setbacks in riparian zone.
Shallow	78.4	Y	na	Clear	Shoreline mostly vegetated. Developed	Sandy bottom	Benthic detrital/ algal mat

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Deep Ponds: depths between 9.3 and 17.3 m							
Crystal	10.1	N	na	na	na	na	na
Hamblin (Indian Ponds)	115.4	Y	Yes	Very clear	Mostly intact, some cleared lawns. (2009) Beach conservation land (2003)	Emergent (fringe) Cranberry bog (2003)	Bath house, swimming, kayak access. 1995 alum treatment; 10hp motor limit. (2009) "clearly impacted" (2003)
Hathaway (North)	20.9	N	TB	Very clear	Extensive, overhanging vegetation. Development surrounds pond. (2009) Town-owned conservation land (2003)	sandy bottom; some benthic macroalgae	Town beach, bath house, swimming area. Stocked with fish (smallmouth and largemouth bass, perch, pickerel, and sunfish). (2009) "relatively clean, largely unimpacted lake" (2003)
Lovells	55.5	Y	TB	Evidence blue-green algal bloom	Mostly intact; some cleared lawns	Sandy bottom, little vegetation visible	Town beach (closed on 7/30/09 due to algal bloom) and bath house; "impacted with water quality concerns" (2003)

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Deep Ponds: (continued)							
Micah	16.0	Y	CA (2003)	--	Undeveloped public land (2003)	--	Selected as one of 8 reference ponds for Cape Cod during development of Cape Cod thresholds; "relatively clean, largely unimpacted" (2003)
Middle (Indian Ponds)	104.6	Y	Yes	Very clear		Minimal	Boating
Mystic (Indian Ponds)	148.4	Y	Yes	Clear	Mostly intact, more lawns than other ponds in the Indian Ponds group.	Pondweed	Public access, swimming and boating. Permit phase, alum. Endangered mussels.
Neck	13.6	N	na	na	na	na	na
Shubael	55.1	Y	TB	Exceptionally clear	Some Phragmites and cattails.	Sandy bottom, minimal benthic algal	Beaches, small boats. Horse farm (2009) Well-developed, stocked with fish; "impacted with water quality concerns" (2003)

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Deep Ponds: (continued)							
Wequaquet	596.3	Y	TB		Densely developed (2003)		Bath house, beach, sailing, boat launch (2009) "relatively clean but impacted" (2003)
No depth information							
Lamson	12.3	Y	na	na	na	na	na
West	10.1	Y	na	na	na	na	na

[1]Delineated watershed based on information provided in Eichner, 2008.

[2]Physical characteristics are primarily from the 2009 field visual assessment conducted by EcoLogic, unless noted by "(2003)" to indicate the information was obtained from the CCC Lakes and Ponds Atlas published in May, 2003.

[3]CA – Conservation Area; Pm – Permission granted for public access; Pv – Private access; TB – Town Beach; VL – very limited access and/or recreational use; na – no information available; WTW – Way to Water posted.

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 1: Control Inputs from Watershed

	Option 1 – Wastewater Collection	Option 2 – Modifications to on-site wastewater disposal systems	Option 3 – Inspect/Maintain on-site wastewater disposal systems
Method	Reduce phosphorus from on-site wastewater disposal systems by centralized collection and disposal outside of watershed zone of influence	Various engineering alternatives to enhance removal of nitrogen, BOD, solids, and phosphorus (in various combinations) from domestic wastewater	Reduce phosphorus from on-site wastewater disposal systems by requiring frequent inspections and maintenance of systems
How does it work?	Collection system and treatment/disposal	Alternatives to conventional on-site wastewater disposal systems	Modification to local laws
Potential Benefits	Decreased loading of all wastewater contaminants, including pathogens	Decreased loading of nutrients and organic material to subsurface	Decreased loading of all wastewater contaminants, including pathogens
Potential Drawbacks	Could increase development pressure	More complex systems, more maintenance.	Public acceptance needs to be very high
Data gaps to make decision	Integrated with rest of wastewater decisions. Existing data do not define extent of problem	Existing data do not define extent of problem	Existing data do not define extent of problem
Costs (Relative)	High (likely to receive some public funds)	Moderate (may receive approval to install as a pilot system)	Low (borne by homeowners)
Permitting issues	Collection system will have environmental impact. Need to identify acceptable site for disposal to groundwater. Conservation Commission approval needed.	Massachusetts Alternative Septic System test center is in Sandwich, on Otis Air National Guard base. This is a cooperative program of the state, Barnstable County and SMAST	Dept. of Health & Conservation Commission approvals
Longevity	High	Moderate	Moderate
Ponds appropriate for this alternative	Ponds with high number of on-site systems. Insufficient data.	Impaired ponds with >20 residences. Non-impaired ponds, at least 15 residences. Based on water quality.	All ponds

*Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009*

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 1: Control Inputs from Watershed (continued)

	Option 4 – Infiltration Basins	Option 5 – Public Education	Option 6 – Wildlife Control
Method	Water quality inlets to stormwater infiltration basins	Public education and outreach	Discourage high populations of wildlife (especially gulls, geese) from spending long periods of time in ponds.
How does it work?	Stormwater collection and treatment prior to groundwater discharge	Educate public on importance of landscaping, erosion controls, beach sanitation	By using scare techniques to scare away birds, attain reduction of nutrient deposition from birds
Potential Benefits	Reduced loading	Reduced loading. Increase public awareness of ponds and their vulnerability	Reduced loading of nutrients and bacteria
Potential Drawbacks	Most systems designed to capture sediment. Higher maintenance	None	Scare tactics can be disruptive to human community.
Data gaps to make decision	No estimate of the contribution of soluble P from stormwater	None	Estimate maximum number of gulls, use research reported in Portnoy (1990)
Costs (Relative)	Low	Low	Low
Permitting issues	Requires siting, Conservation Commission approval needed.	None	Needs approvals from Fish and Wildlife, MADEP. Conservation Commission approval needed.
Longevity	Moderate	Moderate (prevention of incremental source likely to be a small source)	Likely to be effective only while active measures are taken, although birds may move to other areas
Ponds appropriate for this alternative	All, especially those with developed watersheds and evidence of sediment deposition from runoff. Insufficient data.	All	Insufficient data.

*Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009*

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 2: Alter Internal Cycling of Nutrients in Pond

	Option 1 – Alum Application	Option 2 – Sediment Oxidation	Option 3 - Circulation
Method	Alum application to remove phosphorus from water column	Sediment oxidation	Artificial circulation.
How does it work?	Alum hydrolyzes in water, forming a floc. As the floc settles it removes particulate material as well as any dissolved P. If applied properly, forms a barrier on sediment surface that continues to trap P.	Procedure injects calcium nitrate into top 10" sediment to break down organics and promote denitrification, and injecting ferric chloride to bind available phosphorus released from sediments.	Compressed air is injected into the lower waters. Eliminates thermal stratification. Oxygenates lower waters, more oxygen available to break down organic material.
Potential Benefits	Long history of use. Does not seem to affect other aquatic organisms. May create layer over sediments retarding future sediment P release. Long-term results. Readily available.	If successful will greatly reduce internal P loading from sediments	Reduces surface algal blooms, improved habitat for aquatic biota, may retard sediment P release
Potential Drawbacks	Low pH ponds, need buffering (sodium aluminate). Potential for aluminum toxicity if pH declines. Loss of benthic organisms.	Optimal pH of sediments 7 – 7.5; would require liming. Considered an experimental technique.	Results may be subtle. Requires energy source to power. May increase algal production throughout water column.
Data gaps to make decision	Sediment testing to estimate optimal dose	Sediment testing to calculate dose	DO profiles over growing season, history
Costs (Relative)	Can be high, application rate estimated at $70 per 40-lbs.(40 lbs. treats 1 acre-ft) * High initial cost - $100-$500 per acre.**	Can be high, $8,000 – $12,000 per acre *	Approximately $150/acre**. Variable, depending on power source. Solar-powered mixing devices: $25,000.
Permitting issues	Requires permit, testing for optimal dose. Conservation Commission approval needed.	Requires permit, testing for optimal dose. Conservation Commission approval needed.	Conservation Commission approval needed.
Longevity	Moderate (at least several years)	Moderate (at least several years)	Only effective when mixers working
Ponds appropriate for this alternative	Deeper ponds with elevated TP in lower waters. Insufficient data.	Impaired ponds with DO depletion. Insufficient data.	Insufficient data.

*Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009*

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 2: Alter Internal Cycling of Nutrients in Pond (continued)

	Option 4 - Dredging	Option 5 – Pond Drawdown
Method	Dredging	Drawdown of pond water level to expose sediments
How does it work?	Sediment is physically removed, also removing accumulated nutrients and organic material	Lowering water level will dry sediments and allow sediments to oxidize and compact.
Potential Benefits	Reduced internal nutrient supply, increases water depth, can reduce sediment oxygen demand	May alter nutrient availability for the better. Opportunity for shoreline cleanup. Nuisance plant species may die back.
Potential Drawbacks	Expensive if disposal site not nearby. Temporary turbidity, removes macroinvertebrates, temporarily interferes with recreation. Might reduce ponds' natural capacity for denitrification and thus allow more soluble nitrogen to make its way to coastal embayments.	Possible impacts on contiguous wetlands, may change habitat for amphibians. Desirable species of plants may die. Ponds with water level controls may be managed for herring. Temporary loss of waterfowl habitat. Potential to create highly unappealing aesthetic conditions for neighbors.
Data gaps to make decision	Quality of sediments affects disposal options and costs (e.g. hazardous waste). Detailed bathymetry required to estimate volumes and costs.	Water level control needed, therefore not feasible for most kettle ponds which lack such controls
Costs (Relative)	$15,000 - $50,000/acre*, depending on transportation needs to remove dredge spoils from site.	<$100/acre if structures adequate*
Permitting issues	Requires permit for dredging and disposal Conservation Commission approval needed.	Permit required, complexity depends on impacts on wetland and other ponds. Conservation Commission approval needed.
Longevity	Moderate to long-term	Moderate to long-term
Ponds appropriate for this alternative	Insufficient data.	Insufficient data.

*Sources for cost estimates: *Holdren et al. 2001; ** NYSFOLA, 2009*

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 3: Mitigate Symptoms of Eutrophication - Weeds and Algae

	Option 1 – Mechanical Harvesting of Weeds	Option 2 – Mechanical Weed Removal	Option 3 – Hand-Harvesting Weeds
Method	Mechanical harvesting of weeds	Mechanical removal of weeds, by rotovating (rototilling) or hydroraking.	Removal of plants by hand.
How does it work?	Upper part of plants cut in place, deeper waters; roots are not harvested. Cuttings collected and removed from pond.	Removes rooted aquatic plants from targeted areas by means of large cutters that dislodge roots and plants from sediment.	Removes rooted aquatic plants from targeted areas, using human labor.
Potential Benefits	Immediate results. Improved recreational access. Remaining lower part of plants continues to provide habitat.	More effective than mechanical harvesting, as the roots as well as plants are removed.	Effective rapid-response to invasive species. Selective plant management.
Potential Drawbacks	Non-selective, may alter plant communities, may remove native insects that help control plants.	Creates turbidity, disturbs the sediment, may spread some plants by fragmentation. Not selective; cuts all plants.	Labor intensive, restricted to small areas. May spread some plants by fragmentation.
Data gaps to make decision	Species and habitat affected, water depth. Equipment access, disposal.	Useful for shallower areas where recreational access is limited by weeds	Useful for small areas where recreational access is limited by weeds
Costs (Relative)	Leasing a harvester, $600-$2,400/acre**, depending on size of harvester.	Hydroraking or rotavation services $1,000** to $2,000* per acre	$100/acre* up to $1,000/acre**
Permitting issues	Minor, need to develop plan for harvesting and upland disposal sites. Conservation Commission approval needed.	Turbidity, avoidance of critical habitat areas and spawning/early life stages of fish community Conservation Commission approval needed.	Minimal; Conservation Commission approval needed.
Longevity	Two or more harvests during the recreational season.	Usually needs to be repeated several times year	Usually needs to be repeated once or twice a year
Ponds appropriate for this alternative	Insufficient data.	Insufficient data.	Areas where homeowners' access is diminishing. Insufficient data.

Source for cost estimates: *Holdren et al. 2001 ; ** NYSFOLA, 2009

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 3: Mitigate Symptoms of Eutrophication - Weeds and Algae (continued)

	Option 4 – Benthic Barriers	Option 5 – Chemical Control Algae	Option 6 – Aquatic Herbicides
Method	Benthic barriers, benthic screens	Chemical control of algae (several copper-based and organic compounds approved for this use)	Chemical control of weeds (Diquat, 2,4-D, Endothol, Glyphosate, Fluridone, Trichlopyr, copper-based herbicides)
How does it work?	Mat of variable composition laid on bottom of target areas. Blocks light and restricts space for plant growth.	Algaecides kill algae by direct toxicity or by metabolic interference	Toxins in contact with or taken up by plant; biochemical pathways disrupted. Ultimately results in plant senescence and death.
Potential Benefits	Used effectively in a variety of lake conditions; can be sited by homeowners.	Rapidly eliminates algae from water column	Reduces density of macrophytes in treated areas.
Potential Drawbacks	Cumbersome to place and anchor. Require maintenance.	Toxic to other organisms; decaying algae may release nutrients, increase oxygen demand. May restrict water uses.	Toxic to other organisms; decaying plants may release nutrients, increase oxygen demand. May restrict water uses.
Data gaps to make decision	Useful for areas where recreational access is limited by weeds	Water pH, alkalinity, background concentrations of metals; sediment quality (AVS and TOC)	Detailed species inventories needed to select most appropriate chemicals
Costs (Relative)	Professional installation $20,000/acre**	Depends on compound: Chelated copper $150 – 300/acre per application*. Copper sulfate $5-$25/acre-foot**.	$200 to $1,500 per acre** Some treatments may need to be repeated. Cost vary with chemical, dose rate, etc.
Permitting issues	Minimal, need to avoid critical habitat Conservation Commission approval needed.	Requires permit and approvals from environmental and public health agencies, including Conservation Commission.	Requires permit and approvals from environmental and public health agencies, including. Conservation Commission
Longevity	Need to be replaced every 1 – 2 years	Short-term (weeks to months)	Annual
Ponds appropriate for this alternative	Areas where homeowners' access is diminishing. Insufficient data..	Insufficient data.	Insufficient data.

Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009

Appendix B - Category 3: Mitigate Symptoms of Eutrophication - Weeds and Algae (continued)

	Option 7 – Biomanipulation	Option 8 – Barley straw
Method	Stocking or removing specific organisms to shift ecological conditions to improve lake for desired uses ("top-down" approach)	Dried barley straw
How does it work?	Stocking fish that eat plankton-eating fish to reduce predation on zooplankton. As a result, zooplankton species increase in size and abundance and feed on more algae, thus controlling algae populations and improving water clarity. Removing bottom-feeding fish that cause turbidity and increase nutrient concentrations by disturbing and consuming organic material at the bottom of the lake.	Dried barley straw, loosely netted to allow maximum oxygen exchange within the straw. Anchored floats hold the netted straw in place in the upper three to four feet of water. Not clearly understood how barley straw affects algae.
Potential Benefits	Serves to achieve multiple water quality objectives while increasing the population of desirable fish species.	Reduces algae levels in ponds and lakes, most effective in controlling new algae growth than at removing pre-existing algae. Public perception that it is "natural" method.
Potential Drawbacks	Results are not easily predictable. May cause unexpected side effects. May control palatable algae and leave blue-green algae.	Not practical for ponds greater than 100 acres. Inconsistent track record. Removing water-logged bales (150 lbs) labor-intensive.
Data gaps to make decision	Experimental procedure. Detailed food web analysis to evaluate appropriateness of using this method to achieve water quality objectives.	Experimental procedure. Water temperatures and temporal patterns of algal blooms during the growing season to optimize deployment of the bales..
Costs (Relative)	$100-$200 per hundred fish. Estimate 100 to 1,000 fish/acre**	Ranges from $20 to $400 per acre, depending on the cost and quantity of straw required.
Permitting issues	Class 2 public stocking license. Conservation Commission approval needed.	Uncertain
Longevity	Depends on whether stocked fish survive and reproduce.	30 to 90 days (based on rate of decomposition of bales)
Ponds appropriate for this alternative	Insufficient data.	Insufficient data.

Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009

Appendix C. Summary of Regulatory Setbacks and Recommendations for Septic Systems in Coastal Areas.

Buzzards Bay Watershed Management Plan	• Recommends 250 ft setback from surface waters and wetlands, (viral pollution) • Where this setback cannot be met, changes in system design and application rate are required to ensure removal of viruses.
New Hampshire's Shoreland Protection Act [3.10 Leach Field And Septic Tank Setback (Added 1990, Amended 1992)]	• "Where the naturally occurring receiving soil down-gradient of the leaching portions of a septic system is a porous sand and gravel material with a percolation rate faster than two (2) minutes per inch, the setback shall be at least 125 feet. • For naturally occurring receiving soils with restrictive layers within 18 inches of the surface, the setback shall be at least 100 feet; and • For naturally occurring receiving soils with any other characteristics the setback shall be at least 75 feet.."
CAMA Handbook For Development In Coastal North Carolina: Section 3	• Septic tanks and drainfields must be located at least 100 feet from waters classified as WS IV by the Environmental Management Commission. • No sewers, septic tank fields or other sources of pollution may be built within 500 feet of the edge of the Fresh Pond in the Nags Head/Kill Devil Hills Fresh Pond watershed. Between 500 feet and 1,200 feet from the pond, septic systems are limited to one system serving a single-family home with no more than four bedrooms (or an equivalent volume of sewage) on a tract of land at least 40,000 square feet in size.
Rhode Island towns:	
Burrillville:	200 ft from wetlands
Charlestown:	• 100 feet from a freshwater or coastal wetland. • 200 feet from a ten-foot-wide flowing body of water. • 100 feet from flowing bodies of water less than 10 feet wide. • 100 feet from intermittent streams. • 100 feet from floodplains.
Foster:	200 ft from any pond, stream, spring or brook
Glocester:	150 ft from ponds, streams or springs
Jamestown:	150 ft from any freshwater
Narrangasett:	Special use permits for septic systems within 150 ft. of coastal and freshwater wetlands.

Appendix C. Summary of Regulatory Setbacks and Recommendations for Septic Systems in Coastal Areas. (continued)

Rhode Island towns (continued):

New Shoreham:	• 150 feet of vegetated buffer shall be maintained from any septic system to a freshwater wetland or coastal feature. • 200 feet of vegetated buffer shall be maintained from any septic system to Sands Pond, Peckham Pond and Fresh Pond.
Scituate:	150 ft from surface waters
South Kingstown:	Requires special use permits for all septic systems located: • Within 50 feet of a bog, marsh, swamp or pond. • Within 200 feet of flowing bodies of water 10 feet or more in width. • Within 100 feet of flowing bodies of water less than 10 feet in width. • Within 150 feet of floodplains. • Within 150 feet of other freshwater wetlands
Warren:	150 ft from any body of water, including wetlands
West Greenwich:	200 ft from edge of any pond or stream

Appendix D. Recommended Water Quality Monitoring Program

As described in Eichner et al (2008), there is currently no on-going water quality monitoring program to track the condition of Barnstable's inland kettle ponds. Monitoring can be a costly and time-consuming endeavor; therefore, we recommend a focused monitoring program clearly linked to specific management objectives. This focused monitoring program will provide strategic information regarding the water quality and ecological status of the Barnstable freshwater ponds. Measuring various physical, chemical, and biological attributes of the inland ponds can help municipal leaders and other stakeholders evaluate use attainment, trends and the effectiveness of control measures.

- *Recommended Action: Conduct water quality monitoring using the established PALS protocol on a three-year rotation*

Objective: Develop a program to sample priority ponds on a three-year cycle. This will enable comparisons between ponds and within ponds over time.

- *Recommended Action: Measure water quality conditions in the upper and lower waters of Lovells, Wequaquet and Mystic Ponds from April – October, 2010*

Objective: Evaluate the magnitude and importance of sediment TP flux in deep ponds affected by increased productivity.

Rationale: Internal sediment TP can be remediated for a period of a decade or more with an alum treatment program. For this treatment to be effective, internal TP flux during summer anoxia must be a significant fraction of the TP budget. Moreover, TP released from sediment must reach the upper, sunlit waters where algal production occurs.

Parameter list:

Parameter	Depth	Frequency	Note
TP, TN, total alkalinity	3 m intervals through water column	Monthly (minimum) Biweekly(recommended)	Discrete samples
DO, temperature, pH, specific conductance	1 m intervals through water column	Monthly (minimum) Biweekly(recommended)	Field meter
Secchi disk transparency	From surface	Biweekly	Volunteer monitoring possibility
Chlorophyll-*a*	Composite sample through photic zone	Monthly (minimum) Biweekly(recommended)	

Recommended Action (2): Develop a surveillance program for cyanobacterial blooms

Objective: Adopt a reliable near-real time technique for evaluating whether the public is at risk from harmful algal blooms.

Rationale: Certain species of cyanobacteria (blue-green algae) can exude potentially harmful compounds. Restrictions on swimming during bloom conditions may be warranted to protect public health. Sampling and analysis of the algal community can be costly if in-house expertise is not available, and may extend over several days before results are received and interpreted. A field meter to screen for the presence and concentration of phycocyanin, a pigment associated with cyanobacterial blooms, may provide a screening tool.

Appendix 5-2

Land Use Codes and Description

LAND USE CODE	DESCRIPTION
RESIDENTIAL USE CODES	
1010	RESIDENTIAL
1010	SINGLE FAMILY
1011	RESIDENTIAL
1011	SINGLE FAMILY
1020	CONDOMINIUM
1020	RESIDENTIAL
1021	CONDOMINIUM
1030	RESIDENTIAL LAND
1040	RESIDENTIAL
1040	TWO FAMILY
1041	TWO FAMILY
1050	RESIDENTIAL
1050	THREE FAMILY
1051	THREE FAMILY
1060	ACCESSORY LAND W/IMPROVEMENT
1060	RESIDENTIAL
1061	ACCESSORY LAND W/IMPROVEMENT
1090	MULTIPLE HOUSES ON ONE PARCEL
1090	RESIDENTIAL
1091	MULTIPLE HOUSES ON ONE PARCEL
1110	APARTMENTS - 4-8 UNITS
1110	RESIDENTIAL
1111	APARTMENTS - 4-8 UNITS
1120	APARTMENTS - MORE THAN 8 UNITS
1120	RESIDENTIAL
1121	APARTMENTS - MORE THAN 8 UNITS
1210	RESIDENTIAL
1210	ROOMING & BOARDING HOUSE
1211	ROOMING & BOARDING HOUSE
1230	RESIDENT HALL/DORMITORY
1230	RESIDENTIAL
1231	RESIDENT HALL/DORMITORY
1260	BED & BREAKFAST
1260	RESIDENTIAL
1261	BED & BREAKFAST
1300	DEVELOPABLE LAND
1300	RESIDENTIAL LAND
1300	RESIDENTIAL
1301	DEVELOPABLE LAND
1310	POTENTIALLY DEVELOPABLE LAND
1310	RESIDENTIAL LAND
1310	RESIDENTIAL
1311	POTENTIALLY DEVELOPABLE LAND
1320	RESIDENTIAL LAND
1320	RESIDENTIAL
1320	UNDEVELOPABLE LAND
1321	UNDEVELOPABLE LAND
1400	CHILD CARE FACILITY
1400	RESIDENTIAL
1401	CHILD CARE FACILITY

LAND USE CODE	DESCRIPTION
COMMERCIAL USE CODES	
3000	COMMERCIAL
3000	HOTEL
3001	HOTEL
3010	COMMERCIAL
3010	MOTEL
3011	MOTEL
3020	COMMERCIAL
3020	INN
3021	INN
3030	COMMERCIAL
3030	MOTEL CONDO/TIME SHARE
3031	MOTEL CONDO/TIME SHARE
3040	COMMERCIAL
3040	NURSING HOME
3041	NURSING HOME
3060	TRANSIENT CARE & TREATMENT FAC
3061	TRANSIENT CARE & TREATMENT FAC
3070	COMMERCIAL
3070	MOTEL CONDO/NON-TIME SHARE
3071	MOTEL CONDO/NON-TIME SHARE
3100	COMMERCIAL
3100	RETAIL OIL STATION
3101	RETAIL OIL STATION
3110	COMMERCIAL
3110	RETAIL GAS STATION
3111	RETAIL GAS STATION
3130	COMMERCIAL
3130	LUMBER YARD
3131	LUMBER YARD
3150	COMMERCIAL
3150	PIERS/WHARVES/DOCKS
3151	PIERS/WHARVES/DOCKS
3160	COMMERCIAL
3160	OTHER WAREHOUSE FACILITIES
3161	OTHER WAREHOUSE FACILITIES
3170	FARM BUILDINGS
3180	COMMERCIAL
3180	COMMERCIAL GREENHOUSE
3181	COMMERCIAL GREENHOUSE
3190	COMMERCIAL
3190	WAREHOUSE CONDO
3191	WAREHOUSE CONDO
3210	COMMERCIAL
3210	HARDWARE STORE
3211	HARDWARE STORE
3220	COMMERCIAL
3220	RETAIL STORE/SHOP
3221	COMMERCIAL
3221	RETAIL STORE/SHOP
3222	COMMERCIAL
3230	COMMERCIAL
3230	SHOPPING CENTER/MALL
3231	SHOPPING CENTER/MALL
3240	COMMERCIAL

LAND USE CODE	DESCRIPTION
3240	SUPERMARKET
3241	SUPERMARKET
3250	COMMERCIAL
3250	CONVENIENCE FOOD/RETAIL
3251	CONVENIENCE FOOD/RETAIL
3260	COMMERCIAL
3260	RESTAURANT/CLUB
3261	RESTAURANT/CLUB
3270	COMMERCIAL
3270	RETAIL CONDO
3271	RETAIL CONDO
3300	AUTO VEHICLE SALES/SERVICE
3300	COMMERCIAL
3301	AUTO VEHICLE SALES/SERVICE
3310	AUTO SUPPLIES SALES/SERVICE
3310	COMMERCIAL
3311	AUTO SUPPLIES SALES/SERVICE
3320	AUTO REPAIR FACILITIES
3320	COMMERCIAL
3321	AUTO REPAIR FACILITIES
3330	COMMERCIAL
3330	FUEL SERVICE AREA
3331	FUEL SERVICE AREA
3340	COMMERCIAL
3340	GASOLINE SERVICE STATION
3341	GASOLINE SERVICE STATION
3350	CAR WASH FACILITIES
3350	COMMERCIAL
3351	CAR WASH FACILITIES
3370	COMMERCIAL
3370	PARKING LOT - COMMERCIAL
3371	PARKING LOT - COMMERCIAL
3380	COMMERCIAL
3380	OTHER MOTOR VEHICLE SALES/SVC
3381	OTHER MOTOR VEHICLE SALES/SVC
3400	COMMERCIAL
3400	GENERAL OFFICE BUILDING
3401	COMMERCIAL
3401	GENERAL OFFICE BUILDING
3410	BANK BUILDING
3410	COMMERCIAL
3411	BANK BUILDING
3420	COMMERCIAL
3420	MEDICAL OFFICE BUILDING
3421	MEDICAL OFFICE BUILDING
3430	COMMERCIAL
3430	OFFICE CONDOMINIUM
3431	OFFICE CONDOMINIUM
3500	COMMERCIAL
3500	POST OFFICE
3501	POST OFFICE
3510	COMMERCIAL
3520	COMMERCIAL
3520	DAY CARE CENTERS
3521	DAY CARE CENTERS

LAND USE CODE	DESCRIPTION
3530	COMMERCIAL
3530	FRATERNAL ORGANIZATIONS
3531	FRATERNAL ORGANIZATIONS
3540	COMMERCIAL
3540	TRANSPORTATIONAL FACILITIES
3541	TRANSPORTATIONAL FACILITIES
3550	COMMERCIAL
3550	FUNERAL HOME
3551	FUNERAL HOME
3560	COMMERCIAL
3560	PROFESSIONAL ASSOCIATIONS
3561	PROFESSIONAL ASSOCIATIONS
3600	COMMERCIAL
3600	MUSEUM
3601	MUSEUM
3610	ART GALLERY
3610	COMMERCIAL
3611	ART GALLERY
3620	COMMERCIAL
3620	MOTION PICTURE THEATERS
3621	MOTION PICTURE THEATERS
3690	COMMERCIAL
3690	OTHER CULTURAL/ENTERTAINMENT
3691	OTHER CULTURAL/ENTERTAINMENT
3700	BOWLING
3700	COMMERCIAL
3701	BOWLING
3740	COMMERCIAL
3740	HEALTH SPA
3741	HEALTH SPA
3750	COMMERCIAL
3750	TENNIS/RACQUETBALL CLUB
3751	TENNIS/RACQUETBALL CLUB
3760	GYMNASIUM/ATHLETIC CLUB
3761	GYMNASIUM/ATHLETIC CLUB
3800	COMMERCIAL
3800	GOLF COURSE
3801	GOLF COURSE
3810	COMMERCIAL
3810	TENNIS COURT
3811	TENNIS COURT
3820	RIDING STABLE
3821	RIDING STABLE
3830	BEACH/SWIMMING POOL
3830	COMMERCIAL
3831	BEACH/SWIMMING POOL
3840	COMMERCIAL
3840	MARINA/YACHT CLUB
3841	COMMERCIAL
3841	MARINA/YACHT CLUB
3850	FISH/GAME CLUB
3851	FISH/GAME CLUB
3880	COMMERCIAL
3880	OTH OUTDOOR RECREATIONAL PROP
3881	OTH OUTDOOR RECREATIONAL PROP

LAND USE CODE	DESCRIPTION
3890	STRUCTURES ON 61B LAND
3891	STRUCTURES ON 61B LAND
3900	COMMERCIAL LAND
3900	COMMERCIAL
3900	DEVELOPABLE LAND
3901	DEVELOPABLE LAND
3910	COMMERCIAL LAND
3910	COMMERCIAL
3910	POTENTIALLY DEVELOPABLE LAND
3911	POTENTIALLY DEVELOPABLE LAND
3920	COMMERCIAL LAND
3920	UNDEVELOPABLE LAND
3921	UNDEVELOPABLE LAND
3930	AG/HORT LAND NOT CH 61A
3930	COMMERCIAL LAND
3931	AG/HORT LAND NOT CH 61A

LAND USE CODE	DESCRIPTION
INDUSTRIAL USE CODES	
4000	INDUSTRIAL
4000	MANUFACTURING BUILDING
4001	MANUFACTURING BUILDING
4010	INDUSTRIAL
4010	MANUFACTURED GOODS WAREHOUSE
4011	MANUFACTURED GOODS WAREHOUSE
4020	INDUSTRIAL
4020	MANUFACTURING OFFICE BUILDING
4021	MANUFACTURING OFFICE BUILDING
4030	INDUSTRIAL LAND
4030	LAND USED AS INTEGRAL PART MFG
4031	LAND USED AS INTEGRAL PART MFG
4040	INDUSTRIAL
4040	RESEARCH & DEVELOPMT FACILITY
4041	RESEARCH & DEVELOPMT FACILITY
4100	INDUSTRIAL
4100	SAND AND GRAVEL
4101	SAND AND GRAVEL
4130	INDUSTRIAL
4130	OTHER MINING AND QUARRYING
4131	OTHER MINING AND QUARRYING
4200	INDUSTRIAL
4200	PUBLIC UTILITY TANK
4201	PUBLIC UTILITY TANK
4230	ELECTRIC TRANS RIGHT-OF-WAY
4231	ELECTRIC TRANS RIGHT-OF-WAY
4240	ELECTRICITY REGULATING SUBSTAT
4240	INDUSTRIAL
4241	ELECTRICITY REGULATING SUBSTAT
4300	INDUSTRIAL
4300	TELEPHONE EXCHANGE STATION
4301	TELEPHONE EXCHANGE STATION
4310	INDUSTRIAL
4310	TELEPHONE RELAY TOWER
4311	TELEPHONE RELAY TOWER
4320	CABLE TV TRANSMITTING FACILITY
4320	INDUSTRIAL
4321	CABLE TV TRANSMITTING FACILITY
4330	INDUSTRIAL
4330	RADIO/TV TRANSMISSION FACILITY
4331	RADIO/TV TRANSMISSION FACILITY
4400	DEVELOPABLE INDUSTRIAL LAND
4400	INDUSTRIAL LAND
4400	INDUSTRIAL
4401	DEVELOPABLE INDUSTRIAL LAND
4410	INDUSTRIAL LAND
4410	INDUSTRIAL
4410	POT DEVELOPABLE INDUSTRIAL LND
4411	POT DEVELOPABLE INDUSTRIAL LND
4420	INDUSTRIAL LAND
4420	UNDEVELOPABLE INDUSTRIAL LAND
4421	UNDEVELOPABLE INDUSTRIAL LAND

LAND USE CODE	DESCRIPTION
FOREST PROPERTY USE CODES	
6010	61 LAND
6010	ALL CHAPTER 61 LAND
6011	ALL CHAPTER 61 LAND
AGRICULTURAL/HORTICULTURAL LND USE CODES	
7100	61A LAND
7100	CRANBERRY BOG
7101	CRANBERRY BOG
7120	61A
7120	VEGETABLES
7121	VEGETABLES
7130	61A
7130	FIELD CROPS - HAY/WHEAT
7131	FIELD CROPS - HAY/WHEAT
7140	61A
7140	ORCHARDS - PEARS/APPLES
7141	ORCHARDS - PEARS/APPLES
7150	GRAPE VINEYARDS
7151	GRAPE VINEYARDS
7160	TILLABLE FORAGE CROPLAND
7161	TILLABLE FORAGE CROPLAND
7170	61A LAND
7170	WOODLAND/PRODUCTIVE-XMAS TREES
7171	WOODLAND/PRODUCTIVE-XMAS TREES
7180	61A LAND
7180	PASTURE
7181	PASTURE
7190	61A LAND
7190	NURSERIES
7191	NURSERIES
7200	61A LAND
7200	NON-PROD NECESSARY RELATED LND
7201	NON-PROD NECESSARY RELATED LND
7220	WETLAND/SCRUB/ROCKLAND
7221	WETLAND/SCRUB/ROCKLAND
RECREATIONAL LAND USE CODES	
8000	RECREATION
8030	RECREATION
8050	GOLF COURSE
8050	RECREATION
8051	GOLF COURSE
8060	RECREATION
8070	RECREATION

LAND USE CODE	DESCRIPTION
EXEMPT PROPERTY USE CODES	
9000	EXEMPT
9000	UNITED STATES GOVERNMENT
9001	UNITED STATES GOVERNMENT
9010	COMMONWEALTH OF MASSACHUSETTS
9010	EXEMPT LAND
9011	COMMONWEALTH OF MASSACHUSETTS
9020	COUNTY
9020	EXEMPT
9021	COUNTY
9030	EXEMPT LAND
9030	MUNICIPALITY
9031	MUNICIPALITY
9032	EXEMPT
9033	EXEMPT
9035	EXEMPT
9035	EXEMPT LAND
9040	EXEMPT LAND
9040	PRIVATE SCHOOL/COLLEGE
9041	PRIVATE SCHOOL/COLLEGE
9050	EXEMPT LAND
9050	HOSPITAL/CHARITABLE ORGANIZATI
9051	HOSPITAL/CHARITABLE ORGANIZATI
9060	CHURCH/SYNAGOGUE/TEMPLE
9060	EXEMPT
9061	CHURCH/SYNAGOGUE/TEMPLE
9070	121A CORPORATION/URBAN RENEWAL
9070	EXEMPT
9071	121A CORPORATION/URBAN RENEWAL
9080	EXEMPT LAND
9080	HOUSING AUTHORITY
9081	HOUSING AUTHORITY
9090	EXEMPT LAND
9090	FIRE DISTRICTS
9091	FIRE DISTRICTS
9100	EXEMPT
9200	EXEMPT

LAND USE CODE	DESCRIPTION
MIXED USE CODES	
0101	RESIDENTIAL
0101	SINGLE FAMILY
0102	CONDOMINIUM
0103	MOBILE HOME
0104	RESIDENTIAL
0104	TWO FAMILY
0105	RESIDENTIAL
0105	THREE FAMILY
0106	RESIDENTIAL
0109	RESIDENTIAL
0111	APT 4-8 UNIT
0111	RESIDENTIAL
0112	APT OVER 8
0112	RESIDENTIAL
0130	PRIMARILY RESIDENTIAL
0130	RESIDENTIAL
0131	RESIDENTIAL
0132	RESIDENTIAL
0140	CHILD CARE FACILITY
0140	RESIDENTIAL
0300	HOTEL
0301	MOTEL
0302	INN
0304	NURSING HOME
0305	COMMERCIAL
0305	PRIVATE HOSPITAL
0306	CARE & TREATMENT FACILITY
0310	COMMERCIAL
0310	FUEL DISTRIBUTION FACILITY
0311	BOTTLED GAS/PROPANE TANKS
0313	LUMBER YARD
0315	DOCKYARDS
0316	COMMERCIAL
0316	WAREHOUSE & OTHER STORAGE
0317	FARM BUILDINGS
0318	COMMERCIAL GREENHOUSES
0321	COMMERCIAL
0321	HARDWARE STORE
0322	COMMERCIAL
0322	DISCOUNT STORE
0323	SHOPPING CENTER/MALL
0324	SUPERMARKET
0325	COMMERCIAL
0325	SMALL RETAIL & SERVICE STORE
0326	COMMERCIAL
0326	RESTAURANT/CLUB
0330	AUTOMOTIVE DEALERSHIP/SERVICE
0330	COMMERCIAL
0331	AUTOMOTIVE SUPPLIES/SERVICE
0332	AUTO REPAIR FACILITY
0332	COMMERCIAL
0333	FUEL SERVICE AREA/FUEL ONLY
0334	COMMERCIAL
0334	GAS STATION/SERVICE

LAND USE CODE	DESCRIPTION
0335	CAR WASH FACILITY
0337	COMMERCIAL
0337	PARKING LOT
0338	OTHER MV SALES/SERVICE
0340	COMMERCIAL
0340	OFFICE BUILDING
0341	BANK BUILDING
0342	COMMERCIAL
0342	MEDICAL OFFICE BUILDING
0343	OFFICE CONDOMINIUM
0350	COMMERCIAL
0350	POST OFFICE
0351	EDUCATIONAL PROPERTY
0352	DAY CARE CENTER
0355	COMMERCIAL
0355	FUNERAL HOME
0361	COMMERCIAL
0374	HEALTH SPA
0384	COMMERCIAL
0384	MARINA
0393	AH-NOT 61A
0432	INDUSTRIAL
0710	61A
0712	61A
0713	61A
0714	61A
0717	61A
0718	61A
0718	61A
0719	61A
0720	61A
0722	61A
0803	RECREATION
0806	RECREATION
0904	EXEMPT
0905	EXEMPT

Appendix 5-3

Summary of Proceedures Uses to Develop Buildout Estimates

SUMMARY OF BUILDOUT CALCULATION METHODOLOGY[1]

In 2008 / 2009 a buildout analysis was completed for the purpose of wastewater planning in the Town of Barnstable. On a parcel by parcel basis, projections were made to estimate potential development that may occur at a future time of buildout. For each individual parcel in the Town of Barnstable, the number of residential dwelling units and the non-residential building square footage were estimated for future buildout conditions.

Certain parcels that were considered unlikely to be further developed were tagged for exclusion from the buildout projections. These parcels were assumed to remain at their current level of development, or to remain undeveloped. Excluded parcels included: protected open space, schools, churches, fire / water district parcels, cemeteries, Town beaches, Town facilities such as Town offices, the land fill, the Water Pollution Control Facility and the airport, utility parcels such as electric substations and radio and telephone towers, and parcels located entirely within the VE Velocity Flood Zone.

All calculations that were based on the acreage or square footage of parcels include only the upland portion of the parcel in the area figure. Upland acreage for each parcel was calculated by overlaying parcels with the MassGIS DEP Wetlands layer and subtracting any wetland portion of each parcel from its total area.

Parcels in Residential Zones

- Existing dwelling units (DUs) were calculated according to the Assessor's landuse code for each parcel (i.e. single family = 1 DU, two family = 2 DUs, etc.)
    - For condominiums and apartment buildings the existing DUs were set to equal the number of existing units / apartments on the parcel.
- Dwelling units (DUs) at buildout for residentially zoned, undeveloped parcels that met the minimum lot size requirement for their zoning district were calculated based on the upland area of the parcel: *Total DUs at Buildout = upland area ÷ minimum lot size requirement*
    - Parcels that resulted in more than 4 DUs were recalculated by first subtracting 15% from the upland area to allow for utilities, access, etc.
- Undeveloped residential parcels that had upland area greater than or equal to 5,000 sq.ft. , but less than the minimum lot size requirement were considered grandfathered and were assigned one dwelling unit at buildout.
- Dwelling units (DUs) at buildout for residentially zoned, developed parcels with residential landuse were calculated based on the remaining upland area of the parcel after subtracting area for the existing dwelling units: *Total DUs at Buildout = Existing DUs +((upland area – (minimum lot size requirement * number of existing DUs)) ÷ minimum lot size requirement)*
    - Parcels that resulted in more than 4 DUs were recalculated by first subtracting 15% from the remaining upland area to allow for utilities, access, etc.

[1] Developed by CWMP Land Use and Projected Buildout Working Group, July 2010

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    - Existing residential condominiums and apartment buildings were assumed to have no further growth at buildout beyond the existing DUs.
- Dwelling units at buildout for undeveloped, permitted Chapter 40B developments were set to the number of permitted units.
- Parcels with commercial landuses in residential zones were assumed to remain in commercial use at buildout. The commercial building square footage (sq.ft.) at buildout was calculated by multiplying the upland parcel square footage by a Floor Area Ratio (FAR) of 0.15: *Commercial Building sq.ft. at Buildout = 0.15 * upland parcel sq.ft*
- Parcels with mixed landuses (commercial & residential) in residential zones were assumed to be redeveloped as 100% residential at buildout. Dwelling units (DUs) at buildout were calculated by multiplying the upland parcel square footage by a Floor Area Ratio (FAR) of 0.15 and then converting the resulting building square footage into equivalent dwelling units based on 850 sq.ft. per dwelling unit: *Total DUs at Buildout = (upland parcel sq.ft. * 0.15) ÷ 850*
- Agricultural and golf course parcels were assumed to be redeveloped for residential use at buildout. Dwelling Units (DUs) at buildout were calculated based on the upland area of the parcel: *Total DUs at Buildout = upland area ÷ minimum lot size requirement*
    - Parcels that resulted in more than 4 DUs were recalculated by first subtracting 15% from the upland area to allow for utilities, access, etc.
- Some exceptions to the above procedures were made for individual parcels in order to better reflect the most likely growth scenario for those parcels. The most notable exception was:
    - Cape Cod Community College: assumed 250 additional DUs at buildout for future dormitories and doubling of existing commercial square footage for future classroom expansion.

Parcels in Commercial Zones

- Existing commercial building square footage (sq.ft.) was calculated by summing the building "living area" from the Assessment data for each parcel.
    - In cases where a parcel contained multiple buildings, the living area for all buildings on the parcel were summed.
    - The "living area" represents the finished, heated/cooled portion of a building.
- Commercial building square footage (sq.ft.) at buildout for commercially zoned parcels with commercial landuses was calculated by applying a Floor Area Ratio (FAR) to the upland parcel area: *Commercial Building sq.ft. at Buildout = FAR * upland parcel sq.ft*
    - Floor Area Ratios (FARs) for commercial zoning districts were developed for the purpose of projecting commercial buildout. The FARs used for the buildout projections are listed below.

Zoning District	FAR Used for Buildout
HVB, HD	2.0
HG	0.8

DRAFT

BA Osterville Center, OM, MS, SCROD	0.75
S&D, HB, B, SF, VB-A Marstons Mills Center, BA Centerville, BA Osterville Main Street, TD	0.5
MSOD	0.4
IND, IND LTD	0.35
SD-1, HO	0.3
MB-A1, MB-A2, MB-B	0.25
VB-B West Barnstable	0.2
VB-A Barnstable Village, VB-A on Route 28 in Marstons Mills	Assumed no further growth

In some cases, these FARs are different than what is allowable under the zoning regulations. Because it is unrealistic to expect every parcel to be developed to the maximum allowable FAR., judgment was applied to represent a somewhat more realistic development pattern that might occur. Even so, applying these FARs to every commercial parcel may project a level of buildout that is unlikely to occur in the foreseeable future.

- Commercially zoned parcels with residential landuses were assumed to remain in residential use at buildout. Dwelling units (DUs) at buildout were calculated by multiplying the upland parcel square footage by the Floor Area Ratio (FAR) for the zoning district (see table above) and then converting the resulting building square footage into equivalent dwelling units based on either 1,000 sq.ft. per dwelling unit or 850 sq.ft. per dwelling unit depending on the zoning district as follows:
    - HB, HO, SD, SD-1, VB-B West Barnstable, VB-A Barnstable Village, BA Osterville Center: 1DU = 1,000 sq.ft. building area:
      *Total DUs at Buildout = (upland parcel sq.ft. * FAR) ÷ 1000*
    - B, SF, MS, HD, HVB, OM, TD, HG, MB-A1, MB-A2, MB-B, IND, IND LTD, VB-A Marstons Mills Center, BA Centerville: 1 DU = 850 sq.ft. building area:
      *Total DUs at Buildout = (upland parcel sq.ft. * FAR) ÷ 850*
- Parcels with mixed landuses (commercial & residential) in commercial zones were assumed to be redeveloped as 100% residential at buildout. Dwelling units (DUs) at buildout were calculated by multiplying the upland parcel square footage by the Floor Area Ratio (FAR) for the zoning district (see table above) and then converting the resulting building square footage into equivalent dwelling units based on either 1,000 sq.ft. per dwelling unit or 850 sq.ft. per dwelling unit depending on the zoning district as follows:
    - HB, HO, SD, SD-1, VB-B West Barnstable, VB-A Barnstable Village, BA Osterville Center: 1DU = 1,000 sq.ft. building area:
      *Total DUs at Buildout = (upland parcel sq.ft. * FAR) ÷ 1000*
    - B, SF, MS, HD, HVB, OM, TD, HG, MB-A1, MB-A2, MB-B, IND, IND LTD, VB-A Marstons Mills Center, BA Centerville: 1 DU = 850 sq.ft. building area:
      *Total DUs at Buildout = (upland parcel sq.ft. * FAR) ÷ 850*

DRAFT

Data Sources

- Fiscal Year 2007 Town of Barnstable GIS parcel data and Assessment data.
- Town of Barnstable GIS Zoning map as amended through February 28, 2008.
- MassGIS DEP Wetlands GIS data (April 2007).
- MassGIS FEMA Q3 Flood Zone data (July 1997).
- Locations of existing (as of 2008) accessory affordable apartments, in-law / family apartments, and permitted Chapter 40B units.

DRAFT

Appendix 5-4

Nitrogen Removal Information Suggested by the Massachusetts Estuaries Project (MEP) on a Subwatershed Basis

SANDWICH

WEST BARNSTABLE

BARNSTABLE

YARMOUTH

Cummaquid

6

Note 1

0%

Hyannis Water Pollution Control Facility

MARSTONS MILLS

CENTERVILLE

80%

3.4%

25%

0%

0%

0%

+12%

+14%

74%

86%

100%

80%

HYANNIS

82%

80%

35%

0%

40%

Craigville

OSTERVILLE

+57%

80%

80%

COTUIT

MASHPEE

100%

0%

Hyannisport

Centerville Harbor

20%

20%

0%

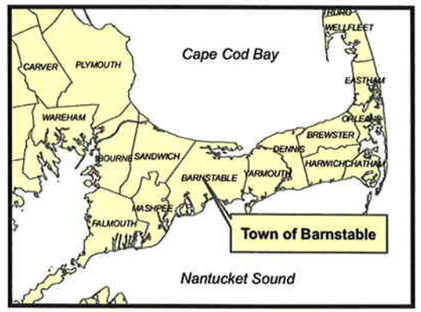
100%

100%

0%

100%

Nantucket Sound



N

Legend

- Town Boundary
- Village Boundary
- Watershed Boundary
- Parcel Boundary
- -50% — Percent Wastewater Nitrogen Removal Suggested by MEP
- +12% — Percent Additional Wastewater Nitrogen Removal That Could Be Added (Suggested by MEP)

Data Source: Mass GIS, Mass Estuaries Project, ESRI

File Location: I:\Jobs\80000\861247400 Barnstable\Figures\Figure 5.1 revisions\Figure N-1.mxd

Notes:
1.) Nitrogen Limits have not been developed as of May 2010
2.) Based on Massachusetts Estuaries Project and MassDEP evaluations and reports.

STEARNS & WHELER LLC
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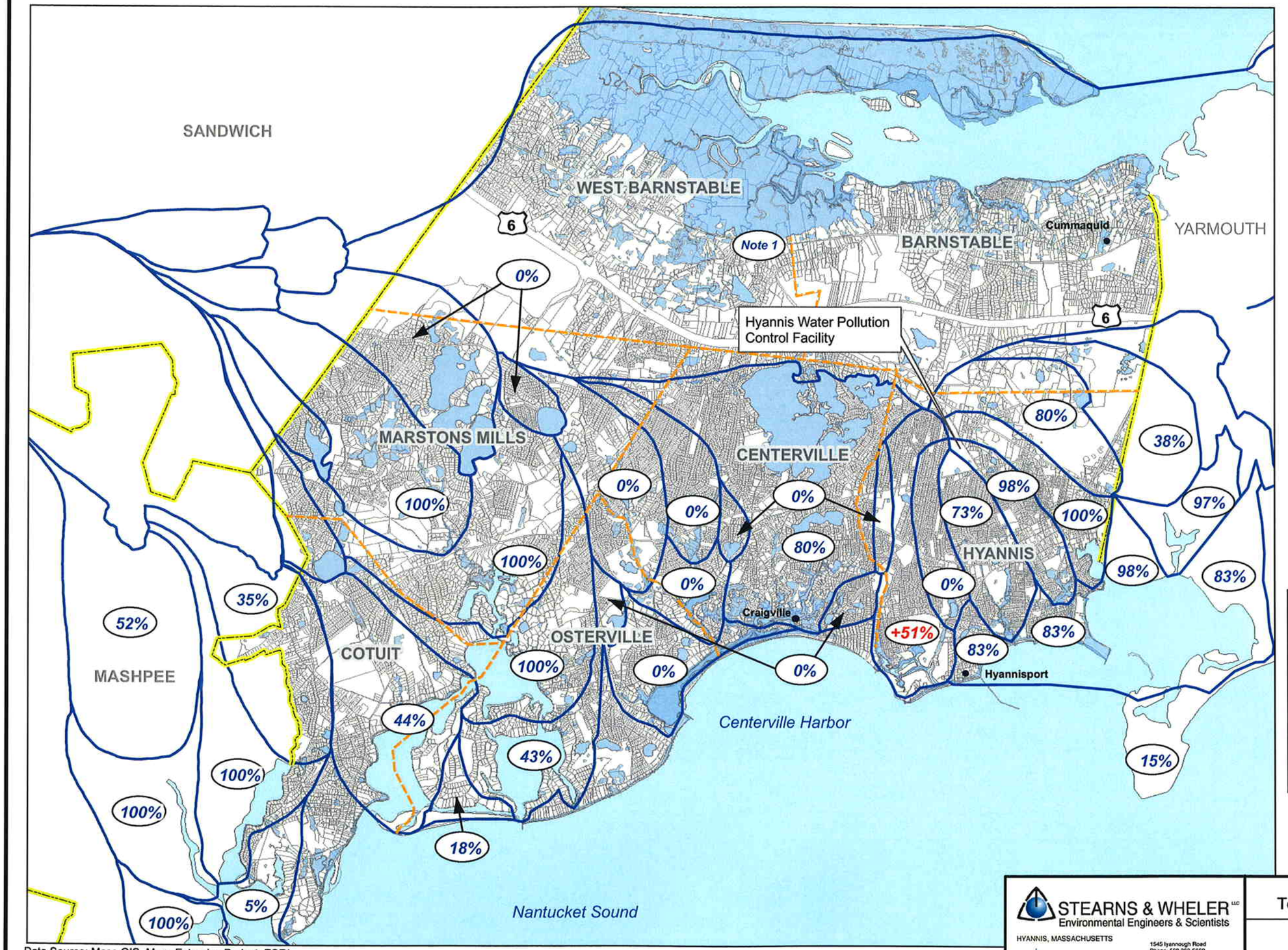
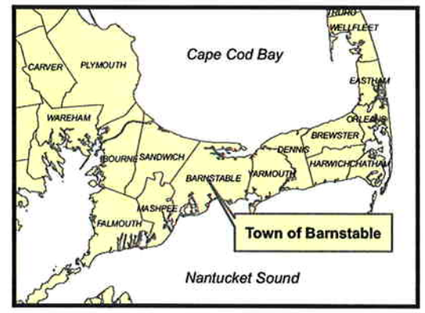
Date: 4/29/2010

Town of Barnstable, Massachusetts

Existing Septic System Nitrogen Removals to Meet TMDLs (2)

FIGURE N-1





N

Legend

- Town Boundary
- Village Boundary
- Watershed Boundary
- Parcel Boundary
- -50% — Percent Wastewater Nitrogen Removal Suggested by MEP
- +12% — Percent Additional Wastewater Nitrogen Removal That Could Be Added (Suggested by MEP)

Data Source: Mass GIS, Mass Estuaries Project, ESRI

File Location: I:\Jobs\80000\861247400
Barnstable SRF\Figures\Nutrient Management March 2010\Figure N-2 .mxd

Notes:
1.) Nitrogen Limits have not been developed as of May 2010
2.) Based on Massachusetts Estuaries Project and MassDEP evaluations and Reports.

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Date: 5/20/2010

Town of Barnstable, Massachusetts

Future Septic System Nitrogen Removals to Meet TMDLs (2)

FIGURE N-2

Map #	Sub-Embayment Name
1	Snake Pond GT10
2	Snake Pond LT10
3	Pimlico Pond GT10
4	Pimlico Pond LT10
5	Peters Pond GT10
6	Peters Pond LT10
7	Mashpee-Wakeby Pond GT10 W
8	Mashpee-Wakeby Pond GT10 E
9	Mashpee-Wakeby Pond LT10
10	Santuit Pond GT10
11	Santuit Pond LT10
12	Upper Mashpee River GT10 W
13	Upper Mashpee River GT10 E
14	Upper Mashpee River LT10
15	Lower Mashpee River GT10
16	Lower Mashpee River LT10
17	Quaker Run
18	Santuit River GT10
19	Santuit River LT10
20	Shoestring Bay GT10
21	Shoestring Bay LT10
22	Pinquickset Cove
23	Ockway Bay GT10
24	Ockway Bay LT10
25	Popponesset Creek
26	Popponesset Bay
27	Quaker Run Well
28	Cotuit Well #5
29	Rock Landing Wells

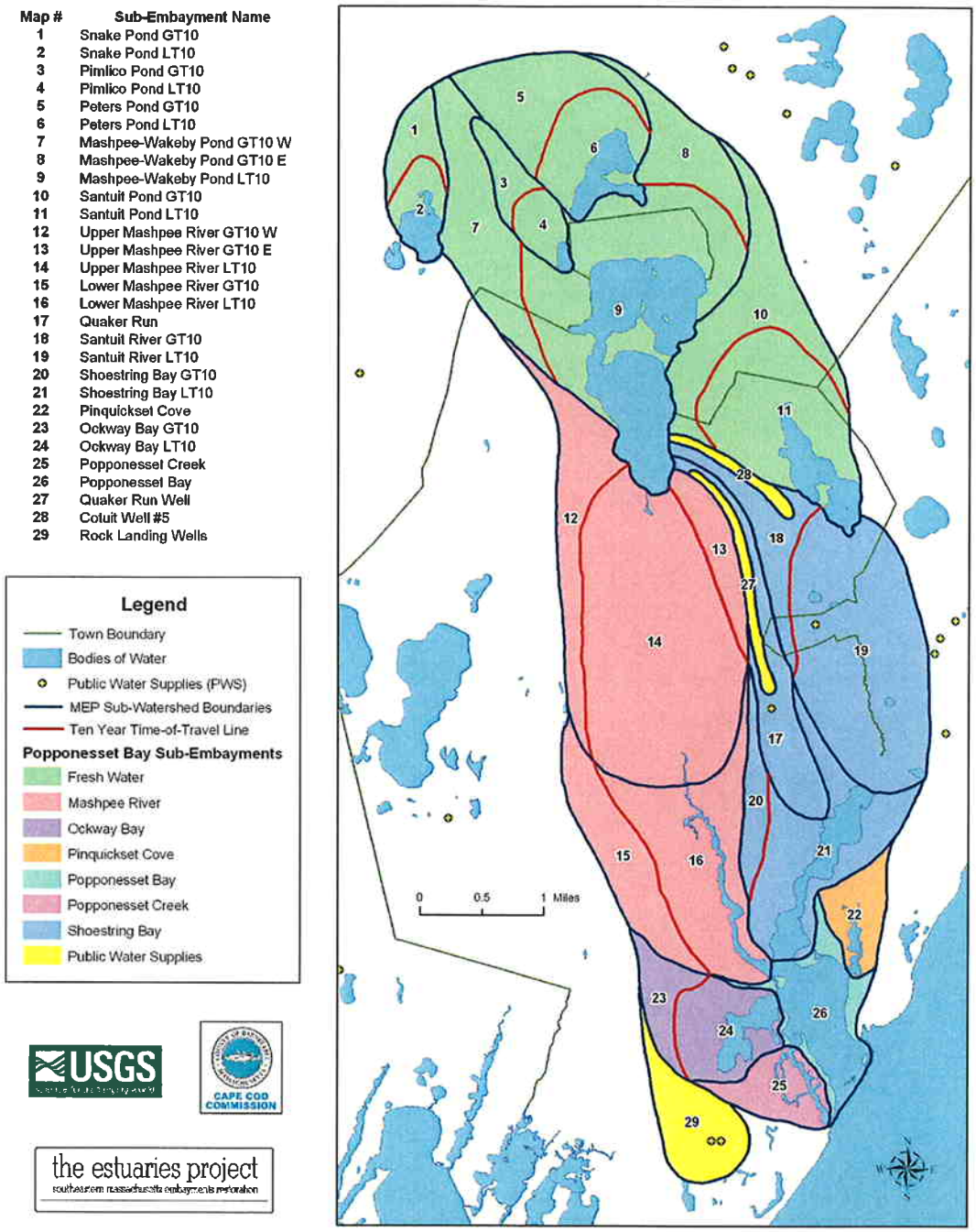


Figure III-1. Watershed and sub-watershed delineations for Popponesset Bay. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a "10" in the figure legend (above at left). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

lower freshwater and salt water reaches of the Mashpee and Santuit Rivers provide opportunities for enhancing natural attenuation of their nitrogen loads. Restoration or enhancement of wetlands and ponds associated with the lower ends of rivers and streams discharging to estuaries is seen as providing a dual service of lowering infrastructure costs associated with wastewater management and increasing aquatic resources associated within the watershed and upper estuarine reaches.

Although the above modeling results provide one manner of achieving the selected threshold levels for the sentinel site within this estuarine system, the specific examples do not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment. As the restoration process continues, the MEP will work with the Towns of Mashpee and Barnstable to develop additional specific water quality modeling scenarios, to be run to evaluate other nitrogen removal strategies. One such proposed scenario, removing the discharges from the existing wastewater facilities from the watershed (pipeline), was partially evaluated by the MEP Team. At present only a tiny fraction (<0.5%) of the watershed nitrogen loading is discharged by the existing treatment facilities. Removing this load would have a very small impact. However, with increased sewering and treatment of wastewater, discharge within the groundwatershed directly discharging to Nantucket Sound has merit. The existing MEP analysis and model provides for the determination of potential discharge sites and the concomitant improvement of the nutrient related habitat quality within the Popponesset Bay System.

Table VIII-1. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Popponesset Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Popponesset Bay	1.58	1.58	0.0%
Popponesset Creek	4.00	0.00	-100.0%
Pinquickset Cove	0.58	0.58	0.0%
Ockway Bay	2.39	0.00	-100.0%
Mashpee River	9.61	0.00	-100.0%
Shoestring Bay	6.94	0.00	-100.0%
Surface Water Sources			
Mashpee River	9.96	5.85	-41.3%
Santuit River (Shoestring Bay)	11.69	7.58	-35.2%
Quaker Run River (Shoestring Bay)	4.69	4.69	0.0%
TOTAL	51.12	19.96	-61.0%

RM-1

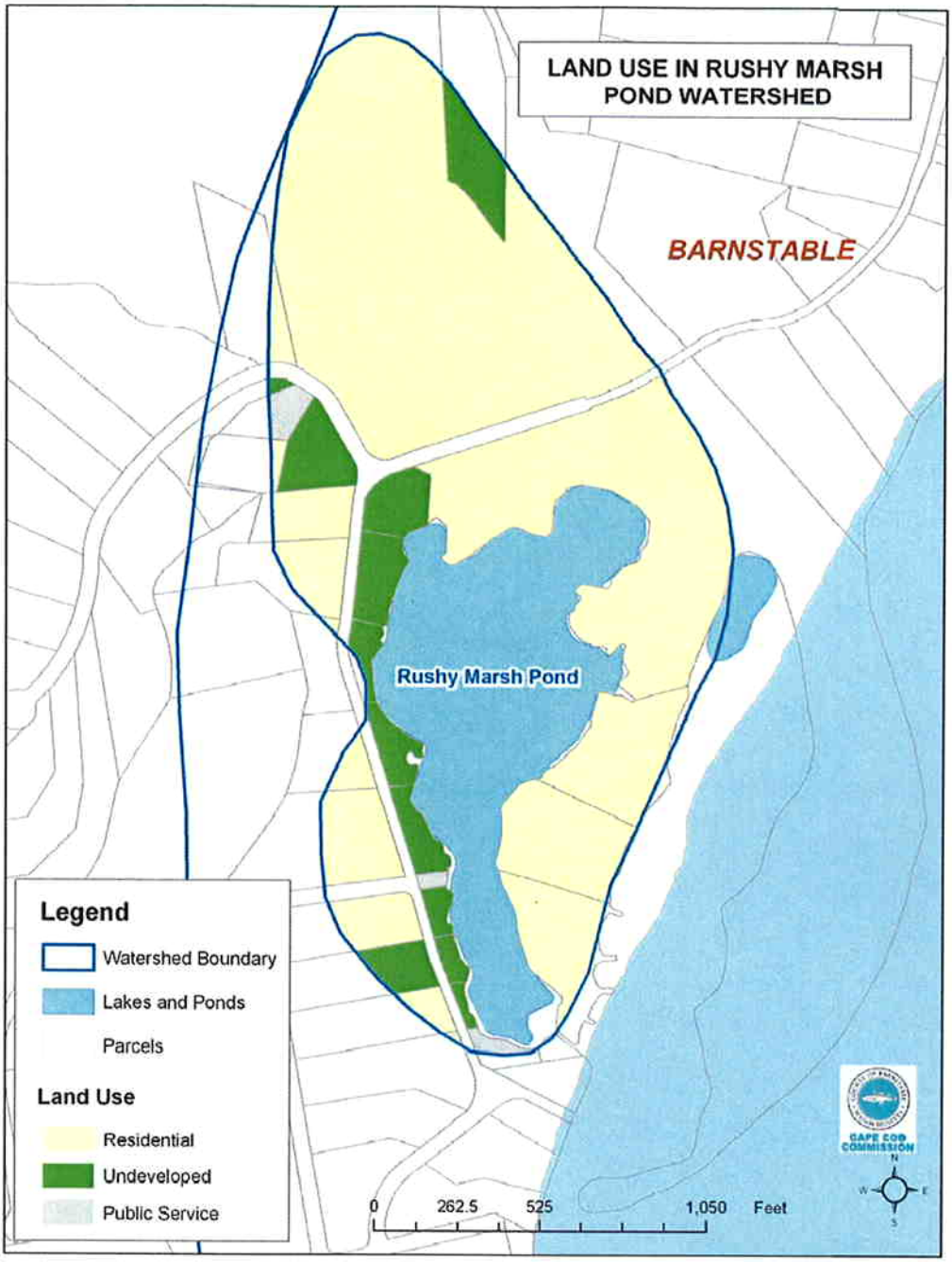


Figure IV-1. Land-use coverage in the Rushy Marsh watershed. Land use classifications are based on assessors' records provided by the Town of Barnstable. Note the shoreline overlaying the water of Nantucket Sound represents the shoreline of 19XX, while the present barrier beach shoreline is shown to the west (white/blue interface). The small pond in the barrier beach is all that remains today of the larger cove created by the spit.

RM-2

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Rushy Marsh system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Rushy Marsh	0.353	0.000	-100.0%

Tables VIII-3 and VIII-4 provide additional loading information associated with the thresholds analysis. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. Removal of 100% of the septic load from the watershed of Rushy Marsh results in an 79% reduction in total nitrogen load. Table VIII-4 shows the breakdown of threshold sub-embayment loads used for total nitrogen modeling. In Table VIII-4, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound.

Table VIII-3. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Rushy Marsh system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Rushy Marsh	0.447	0.093	-79.1%

Table VIII-4. Threshold sub-embayment loads and attenuated surface water loads used for total nitrogen modeling of the Rushy Marsh system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Rushy Marsh	0.093	0.203	-0.113

Comparison of model results between existing loading conditions and the selected loading scenario attempting to achieve the target TN concentrations at the sentinel station is shown in

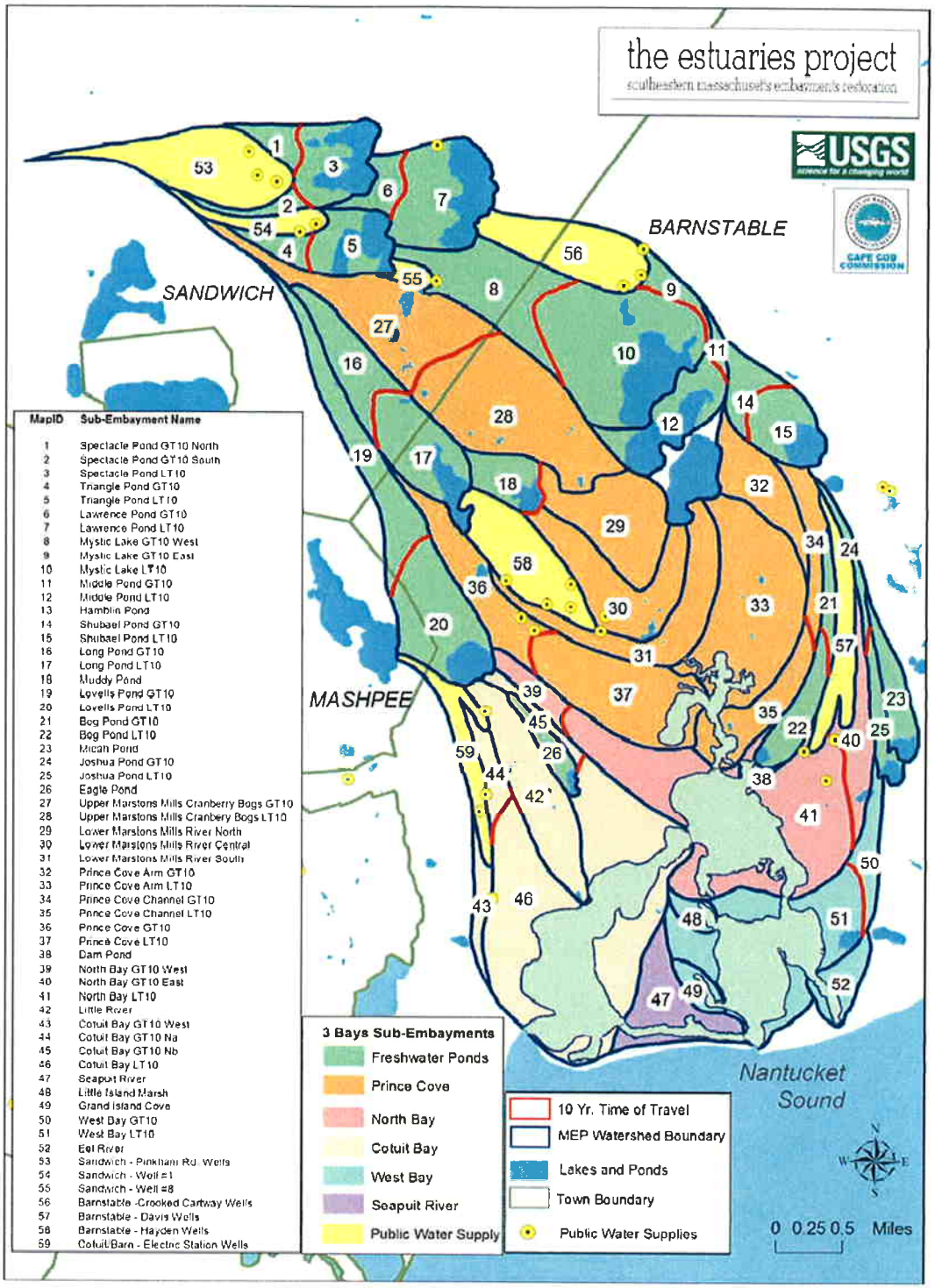


Figure III-1. Watershed and sub-watersheds delineations for the Three Bays estuary system. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a "10" in the watershed names (above). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

TB-2

The basis for the watershed nitrogen removal strategy utilized to achieve the embayment thresholds may have merit, since this example nitrogen remediation effort is focused on watersheds where groundwater is flowing directly into the estuary. For nutrient loads entering the systems through surface flow, natural attenuation in freshwater bodies (i.e., streams and ponds) can help by significantly reduce the load that finally reaches the estuary. Presently, this attenuation is occurring due to natural ecosystem processes and the extent of attenuation being determined by the mass of nitrogen which discharges to these systems. The nitrogen reaching these systems is currently "unplanned", resulting primarily from the widely distributed non-point nitrogen sources (e.g. septic systems, lawns, etc.). Future nitrogen management should take advantage of natural nitrogen attenuation, where possible, to ensure the most cost-effective nitrogen reduction strategies. However, "planned" use of natural systems has to be done carefully and with the full analysis to ensure that degradation of these systems will not occur. One clear finding of the MEP has been the need for analysis of the potential associated with restored wetlands or ecologically engineered ponds/wetlands to enhance nitrogen attenuation. Attenuation by ponds in agricultural systems has also been found to work in some cranberry bog systems, as well. Cranberry bogs, other freshwater wetland resources, and freshwater ponds provide opportunities for enhancing natural attenuation of their nitrogen loads. Restoration or enhancement of wetlands and ponds associated with the lower ends of rivers and/or streams discharging to estuaries are seen as providing a dual service of lowering infrastructure costs associated with wastewater management and increasing aquatic resources associated within the watershed and upper estuarine reaches.

Although the above modeling results provide one manner of achieving the selected threshold level for the sentinel site within the estuarine system, the specific example does not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading in one possible load reduction scenario for the Three Bays system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Cotuit Bay	17.022	13.618	-20.0%
West Bay	15.490	12.392	-20.0%
Seaptuit River	2.921	2.921	0.0%
North Bay	24.978	0.000	-100.0%
Prince's Cove	11.192	0.000	-100.0%
Warren's Cove	6.975	0.000	-100.0%
Prince's Cove Channel	4.767	0.000	-100.0%
Marstons Mills Crescent	3.573	0.000	-100.0%
Surface Water Sources			
Marstons Mills River	10.071	7.553	-25.0%
Little River	3.203	3.203	0.0%

100.2 39.7 → 60.4%

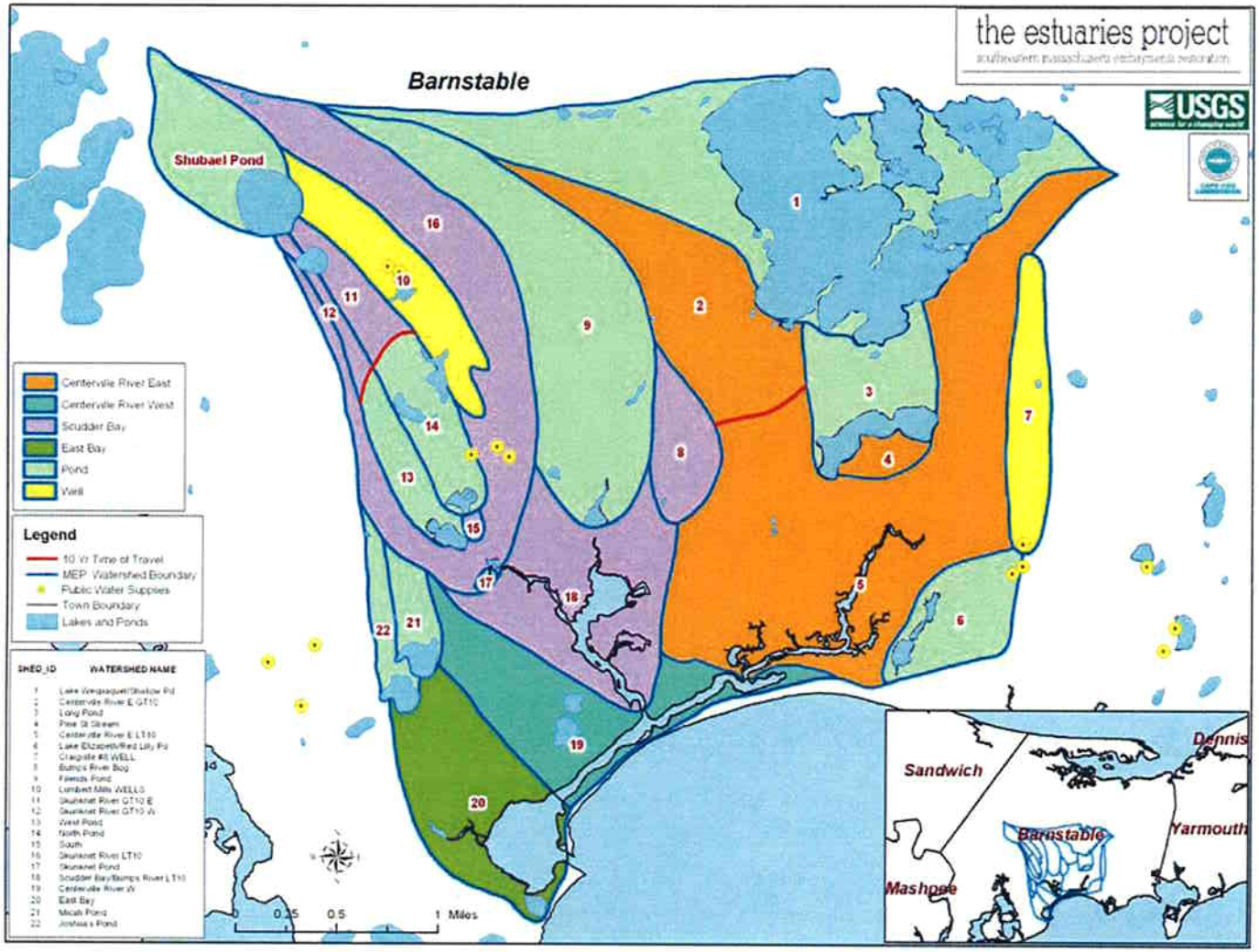


Figure III-1. Watershed and sub-watershed delineations for the Centerville River/East Bay estuary system. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a "10" in the watershed names (above). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

CVR-1

CVR-2

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Centerville River estuary system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Centerville River East	45.929	9.184	-80.0%
Scudder Bay	11.619	11.619	+0.0%
Centerville River West	7.704	7.704	+0.0%
East Bay	6.301	6.301	+0.0%
Surface Water Sources			
Pine Street Stream	2.512	2.512	+0.0%
Lake Elizabeth Stream	1.836	1.836	+0.0%
Bumps River	14.321	14.321	+0.0%
Skunknett River	17.337	17.337	+0.0%

107.6 70.8 34.2%

Tables VIII-3 and VIII-4 provide additional loading information associated with the thresholds analysis. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. Removal of 80% of the septic load from the Centerville River East watershed results in a 66% reduction in total nitrogen load. Table VIII-4 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-4, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound.

Table VIII-3. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Centerville River estuary system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Centerville River East	55.737	18.992	-65.9%
Scudder Bay	14.452	14.452	+0.0%
Centerville River West	9.463	9.463	+0.0%
East Bay	8.627	8.627	+0.0%
Surface Water Sources			
Pine Street Stream	3.452	3.452	+0.0%
Lake Elizabeth Stream	2.274	2.274	+0.0%
Bumps River	16.912	16.912	+0.0%
Skunknett River	21.260	21.260	+0.0%

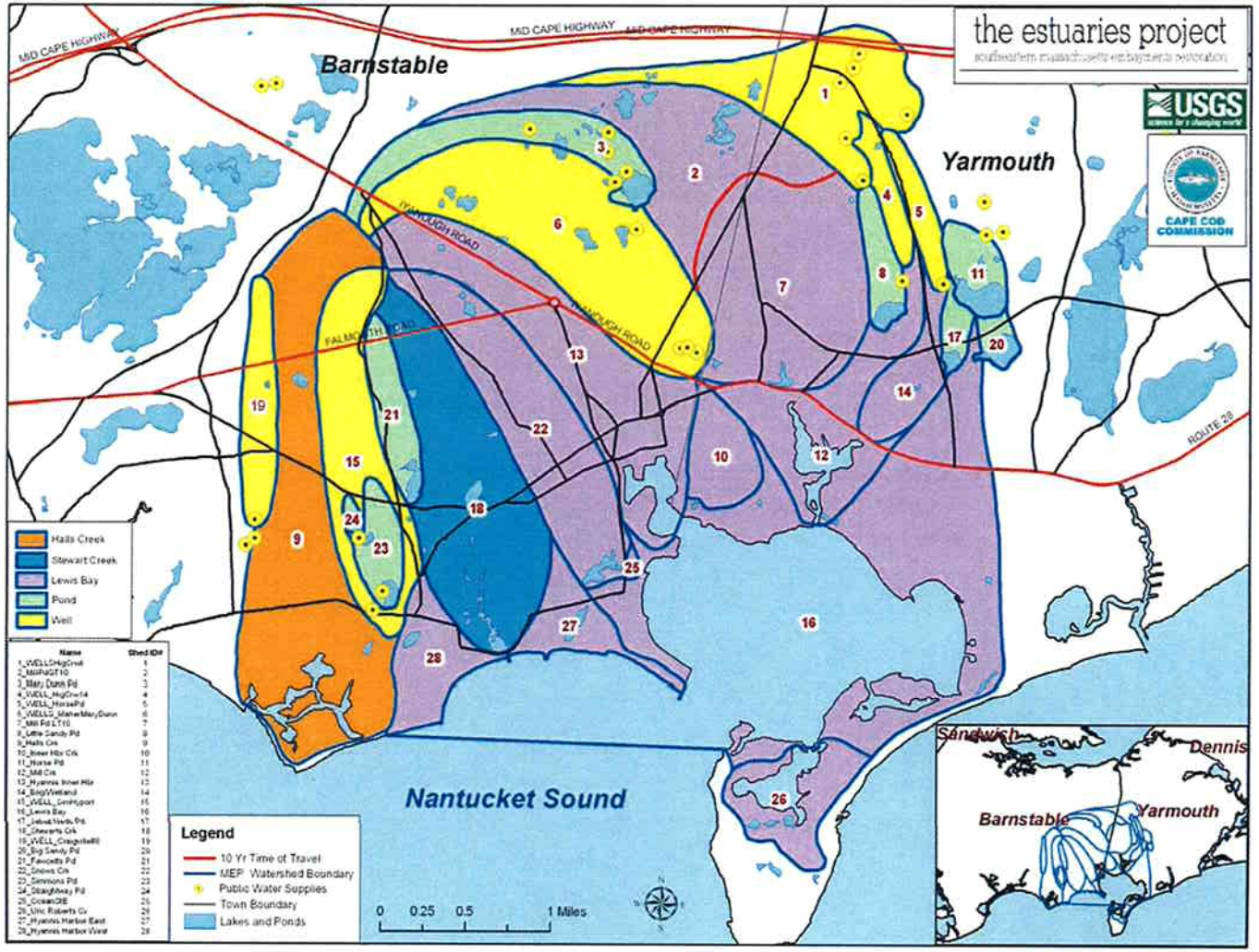


Figure III-1. Watershed and sub-watershed delineations for the Lewis Bay estuary system. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a "10" in the watershed names (above). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

LB 3 HC 1

reduction in loading from this source to the main basin of Lewis Bay (Watershed 16) and an 80% reduction from this source to Hyannis Inner Harbor (Watershed 13). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Lewis Bay Estuary: Watershed nitrogen loads to Lewis Bay were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel station chosen for the Lewis Bay Embayment System (BHY-3 located in the eastern basin of Lewis Bay), and at the secondary stations in Uncle Roberts Cove, Hyannis Inner Harbor and Mill Creek. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

As shown in Table VIII-2, the nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations required using: 1) Existing Removal Scenario B (as requested by the Towns of Yarmouth and Barnstable) with 2) additional removal of septic N loading to produce an 80% total reduction in loading from this source to the main basin of Lewis Bay (Watershed 16) and 3) an 80% reduction from septic N Loading to Hyannis Inner Harbor (Watershed 13). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Lewis Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	5.299	-80.0%
Uncle Roberts Cove	0.214	0.214	0.0%
Mill Creek	13.570	1.926	-85.8%
Hyannis Inner Harbor	6.847	1.808	-73.6%[1]
Snows Creek	7.970	9.088	+14.0%
Stewarts Creek	21.564	24.178	+12.1%
Surface Water Sources			
Chase Brook	2.488	2.479	-0.3%
Mill Pond	10.425	10.068	-3.4%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

[1] Hyannis Inner Harbor is a combination of Hyannis Inner Harbor watershed (13), and Wells Mary Dunn watershed (6) thus the 80% reduction in septic loading for the threshold does not result in a direct 80% reduction in septic loading.

91.5 55.4 40%

Tables VIII-3 and VIII-4 provide additional loading information associated with the thresholds analysis. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. Removal of septic loads from Existing

LB & HC-3

Table VIII-6. Comparison of sub-embayment ***total watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Halls Creek system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Halls Creek	21.534	32.918	+52.9%
Halls Creek Stream (freshwater)	1.597	3.345	+109.4%
System Total	23.132	36.263	+56.8%

Table VIII-7. Threshold sub-embayment loads used for total nitrogen modeling of the Halls Creek system, with total watershed N loads, atmospheric N loads, and benthic flux

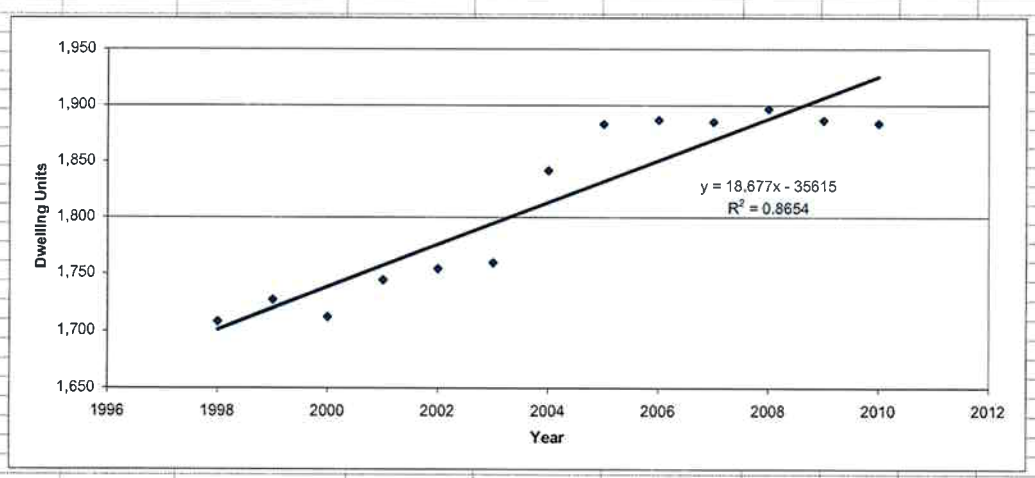
sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Halls marsh	32.918	0.630	6.649
Halls Creek (freshwater)	3.345	-	-
System Total	36.263	0.630	6.649

Table VIII-8. Comparison of model average total N concentrations from present loading and the threshold scenario, with percent change, for the Halls Creek system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Halls Creek - stream	BC-13	1.189	2.037	+71.4%
Halls Creek - mid	**BC-14**	**0.469**	**0.557**	**+18.9%**
Halls Creek - inlet	BC-15	0.385	0.432	+12.1%

Appendix 5-5

Regression Analysis of Land Use Data from 1998 through 2010 to Estimate Residential and Non-Residential Growth Rates in Barnstable

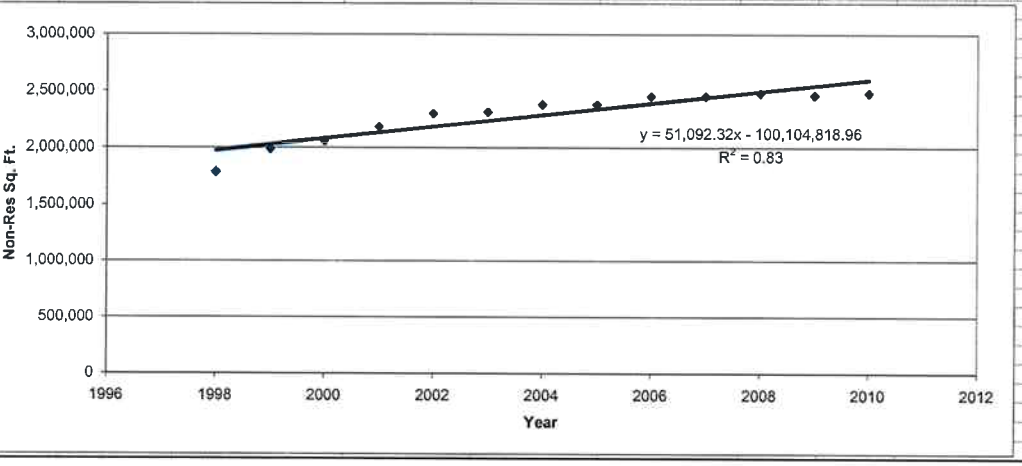


Year	Dwelling Units	Percentage of Buildout/D	Non-Res Sq. Ft	Percentage of Buildout/Date
2010	1,884	51%	2,474,863	28%
2015	2,019	55%	2,846,214	33%
2035	2,393	65%	3,868,061	45%
Buildout	3,703	2105	8,688,829	2129

Year	DU	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	1,708	1,702	42	11,033
1999	1,727	1,720	49	7,375
2000	1,712	1,739	706	10,154
2001	1,745	1,758	170	4,699
2002	1,754	1,776	483	3,461
2003	1,760	1,795	1,247	2,859
2004	1,842	1,814	795	824
2005	1,883	1,832	2,601	4,927
2006	1,887	1,851	1,288	5,440
2007	1,885	1,870	245	5,213
2008	1,897	1,888	71	6,997
2009	1,887	1,907	423	5,378
2010	1,884	1,926	1,755	4,997
		1,813	9,875	73,357

m	b
18.68	-35,615

DU = m*year + b R^2 0.865385774



Year	Sq. Ft	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	1,786,187	1,977,645	36,656,069,510	248,015,645,675
1999	1,992,606	2,028,737	1,305,454,387	85,026,298,207
2000	2,059,157	2,079,829	427,347,957	50,643,763,277
2001	2,181,998	2,130,922	2,608,786,407	10,444,981,508
2002	2,297,145	2,182,014	13,255,137,163	167,606,883
2003	2,313,785	2,233,106	6,509,041,804	875,349,603
2004	2,378,743	2,284,199	8,938,626,399	8,938,626,117
2005	2,376,635	2,335,291	1,709,325,136	8,544,470,980
2006	2,449,049	2,386,383	3,926,985,167	27,175,623,946
2007	2,450,447	2,437,476	168,255,612	27,638,499,811
2008	2,475,440	2,488,568	172,344,006	36,573,237,768
2009	2,458,528	2,539,660	6,582,451,613	30,390,707,520
2010	2,474,863	2,590,753	13,430,407,038	36,352,878,228
	2,284,199		95,690,232,200	570,787,689,523

m	b
51092	-100,104,818

Sq. Ft. = m*year + b R^2 0.832354071

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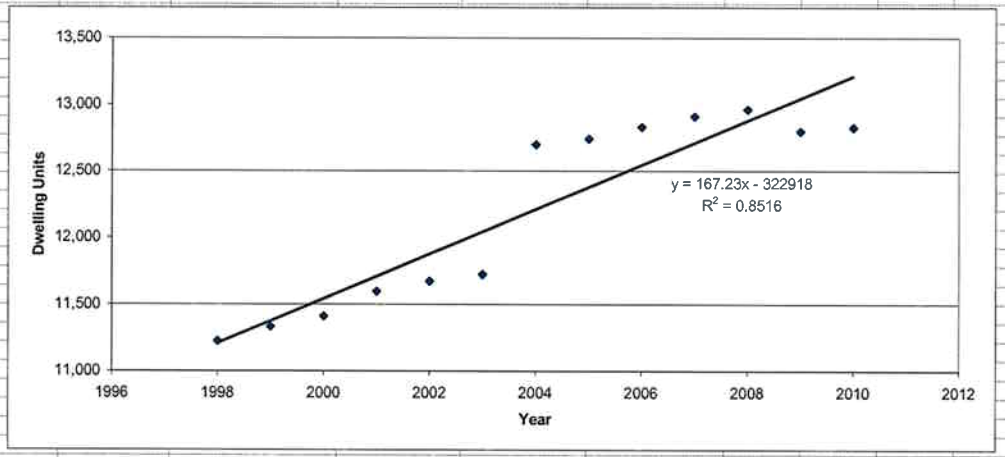
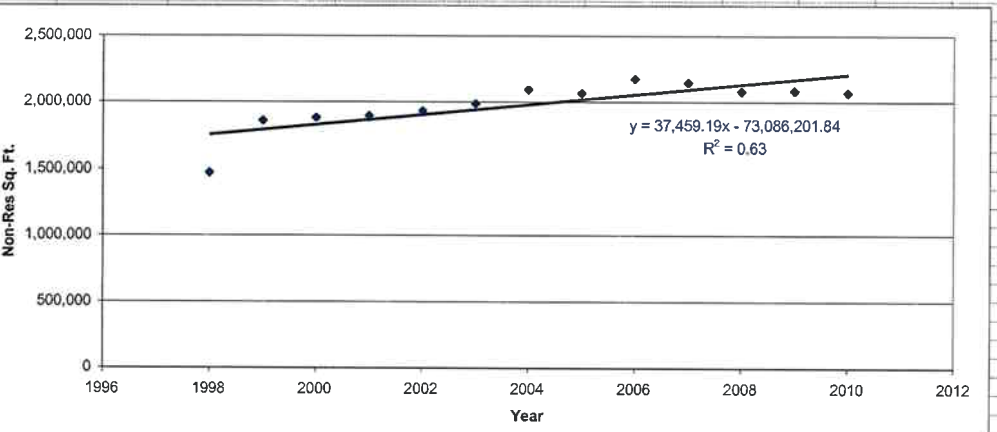


Year	Dwelling Units	Percentage of Buildout/D	Non-Res Sq. Ft	Percentage of Buildout/Date
2010	12,827	90%	2,071,000	49%
2015	14,049	99%	2,394,059	56%
2035	17,394	122%	3,143,243	74%
Buildout	14,256	2016	4,267,728	2065

Year	DU	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	11,223	11,206	284	973,246
1999	11,330	11,374	1,888	773,684
2000	11,412	11,541	16,584	636,318
2001	11,596	11,708	12,526	376,518
2002	11,673	11,875	40,919	288,092
2003	11,724	12,043	101,767	236,428
2004	12,699	12,210	239,450	239,449
2005	12,742	12,377	133,080	283,057
2006	12,830	12,544	81,748	384,866
2007	12,911	12,712	39,744	491,467
2008	12,964	12,879	7,214	568,297
2009	12,797	13,046	62,235	344,191
2010	12,827	13,213	149,218	380,800
	12,210		886,655	5,976,412

m	b
167.23	-322,918

DU = m*year + b R^2 = 0.851640874



Year	Sq. Ft	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	1,474,340	1,757,253	80,040,031,281	257,727,344,944
1999	1,861,409	1,794,713	4,448,403,492	14,544,248,677
2000	1,882,246	1,832,172	2,507,423,045	9,952,564,080
2001	1,898,073	1,869,631	808,947,247	7,045,174,617
2002	1,933,902	1,907,090	718,873,716	2,314,239,043
2003	1,988,318	1,944,549	1,915,694,107	39,809,305
2004	2,096,286	1,982,009	13,059,339,117	13,059,338,216
2005	2,068,044	2,019,468	2,359,655,755	7,402,100,642
2006	2,176,058	2,056,927	14,192,221,491	37,655,193,523
2007	2,148,111	2,094,386	2,886,368,428	27,590,027,729
2008	2,082,131	2,131,845	2,471,506,103	10,024,507,305
2009	2,086,193	2,169,304	6,907,508,459	10,854,402,026
2010	2,071,000	2,206,764	18,431,754,932	7,919,480,227
	1,982,009		150,747,727,173	406,128,430,333

m	b
37459.18	-73,086,183

Sq. Ft. = m*year + b R^2 = 0.628817596

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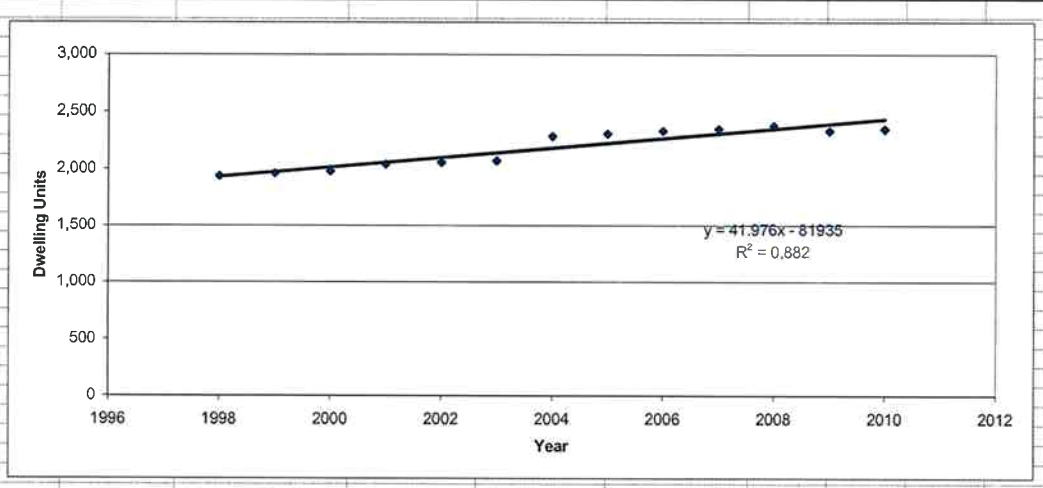
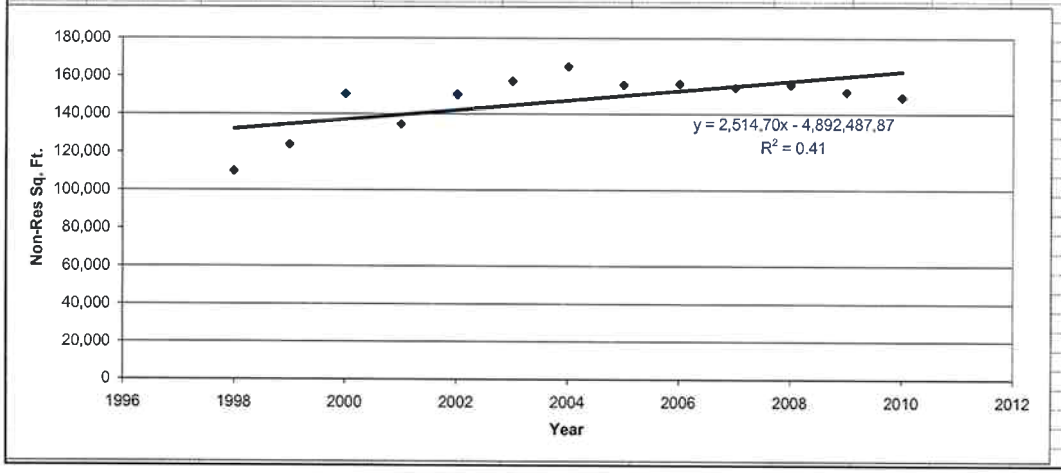


Year	DU	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	1,937	1,932	23	61,046
1999	1,962	1,974	144	49,224
2000	1,981	2,016	1,279	41,479
2001	2,041	2,058	289	20,425
2002	2,059	2,100	1,675	15,595
2003	2,073	2,142	4,786	12,355
2004	2,285	2,184	10,168	10,168
2005	2,309	2,226	6,782	15,457
2006	2,334	2,268	4,329	22,423
2007	2,352	2,310	1,713	27,996
2008	2,378	2,352	661	37,487
2009	2,335	2,394	3,471	22,789
2010	2,349	2,436	7,588	27,141
	2,184		42,907	363,585

m	b
41.98	-81,935

DU = m*year + b R^2 0.881988044

Year	Dwelling Units	Percentage of Buildout/D	Non-Res Sq. Ft	Percentage of Buildout/Date
2010	2,349	89%	148,661	50%
2015	2,646	100%	174,639	59%
2035	3,486	132%	224,933	76%
Buildout	2,634	2015	296,493	2063



Year	Sq. Ft	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	109,754	131,889	489,972,314	1,385,591,816
1999	123,858	134,404	111,218,572	534,513,059
2000	150,527	136,919	185,185,149	12,598,677
2001	134,384	139,433	25,496,727	158,597,211
2002	150,215	141,948	68,341,111	10,481,157
2003	157,126	144,463	160,355,746	102,991,272
2004	164,846	146,978	319,281,919	319,281,918
2005	155,204	149,492	32,624,182	67,674,669
2006	155,651	152,007	13,279,136	75,228,935
2007	153,632	154,522	791,474	44,281,858
2008	155,312	157,036	2,973,389	69,463,249
2009	151,538	159,551	64,209,054	20,797,809
2010	148,661	162,066	179,687,553	2,834,043
	146,978		1,653,416,327	2,804,335,673

m	b
2514.70	-4,892,488

Sq. Ft. = m*year + b R^2 0.410407127

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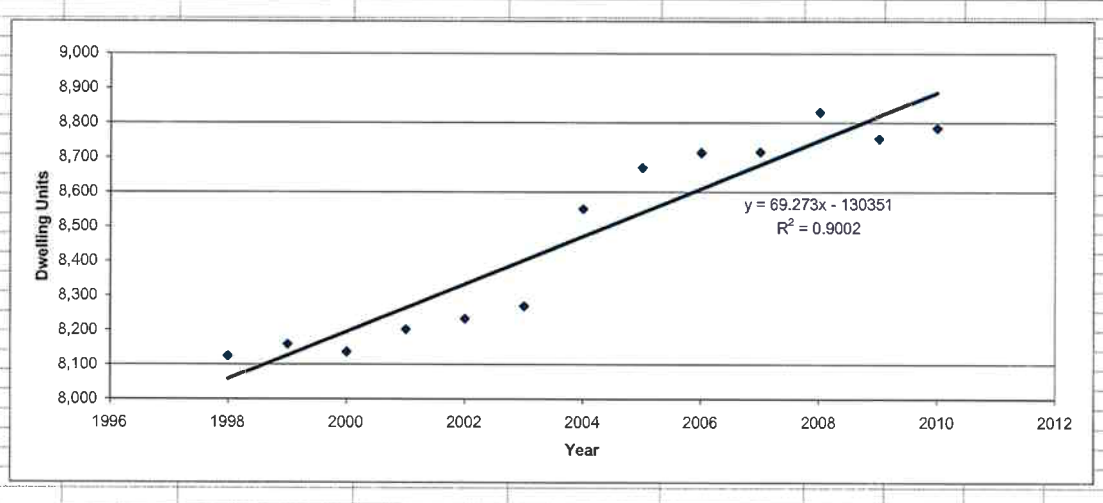
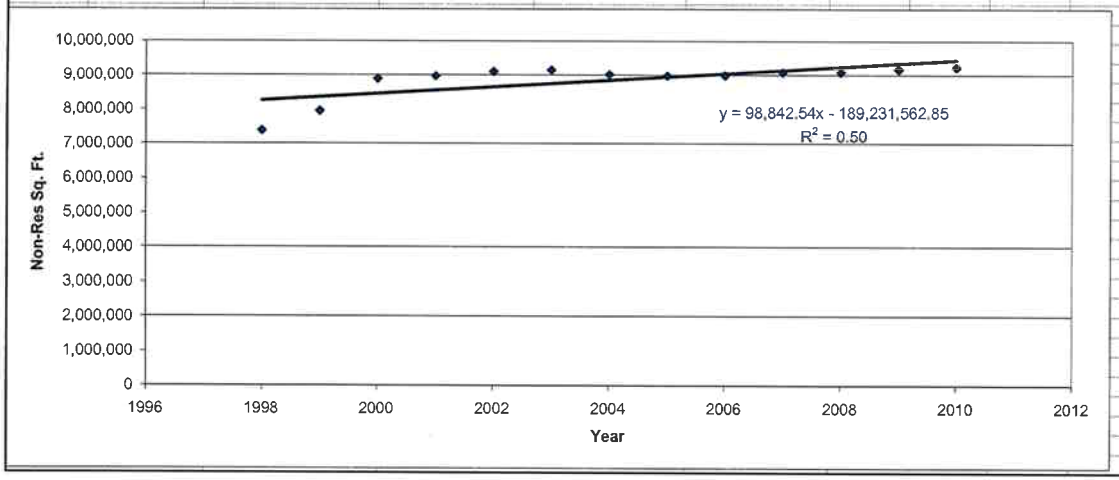


Year	DU	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	8,124	8,056	4,607	120,939
1999	8,157	8,125	1,022	98,848
2000	8,136	8,195	3,453	112,800
2001	8,201	8,264	3,954	73,278
2002	8,232	8,333	10,210	57,404
2003	8,269	8,402	17,762	41,025
2004	8,552	8,472	6,375	6,375
2005	8,668	8,541	16,134	38,531
2006	8,714	8,610	10,687	58,527
2007	8,716	8,680	1,345	59,777
2008	8,828	8,749	6,240	126,796
2009	8,751	8,818	4,475	78,103
2010	8,784	8,887	10,586	97,812
		8,472	96,849	970,214

m	b
69.27	-130,351

DU = m*year + b R^2 0.900177534

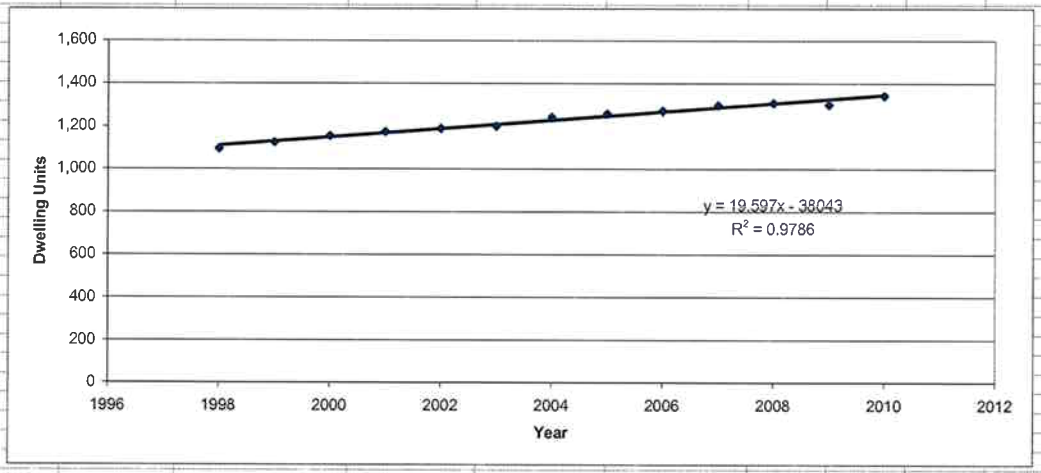
Year	Dwelling Units	Percentage of Buildout/D	Non-Res Sq. Ft	Percentage of Buildout/Date
2010	8,784	74%	9,232,741	32%
2015	9,234	78%	9,936,152	34%
2035	10,619	89%	11,913,003	41%
Buildout	11,897	2053	28,836,804	2206



Year	Sq. Ft	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	7,380,968	8,255,829	765,381,765,644	2,154,778,060,556
1999	7,949,698	8,354,672	164,003,565,213	808,535,877,605
2000	8,895,962	8,453,514	195,760,166,361	2,216,316,356
2001	8,974,520	8,552,357	178,221,924,892	15,784,346,510
2002	9,100,239	8,651,199	201,636,785,049	63,179,220,015
2003	9,148,125	8,750,042	158,470,321,235	89,545,037,970
2004	9,018,890	8,848,884	28,901,962,132	28,901,961,572
2005	8,981,731	8,947,727	1,156,287,817	17,648,264,095
2006	8,996,668	9,046,569	2,490,140,360	21,840,042,448
2007	9,091,278	9,145,412	2,930,473,146	58,754,739,362
2008	9,089,071	9,244,254	24,081,882,444	57,689,684,114
2009	9,175,604	9,343,097	28,053,878,856	106,745,807,606
2010	9,232,741	9,441,939	43,763,995,811	147,346,019,284
		8,848,884	1,794,853,148,960	3,572,965,377,492

m	b
98842.54	-189,231,563

Sq. Ft. = m*year + b R^2 0.497657279

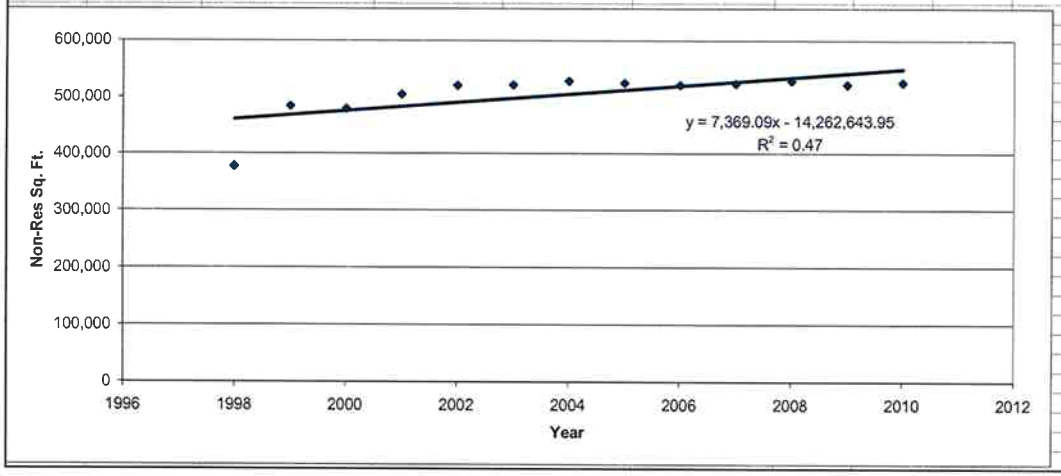


Year	DU	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	1,096	1,112	233	17,644
1999	1,126	1,131	25	10,609
2000	1,157	1,151	40	5,188
2001	1,176	1,170	31	2,830
2002	1,191	1,190	2	1,435
2003	1,201	1,209	67	772
2004	1,244	1,229	214	214
2005	1,259	1,249	115	919
2006	1,272	1,268	14	1,841
2007	1,299	1,288	135	4,956
2008	1,310	1,307	7	6,559
2009	1,302	1,327	638	5,287
2010	1,344	1,347	8	13,170
	1,229		1,530	71,424

m	b
19.60	-38,040

DU = m*year + b R^2 0.978584756

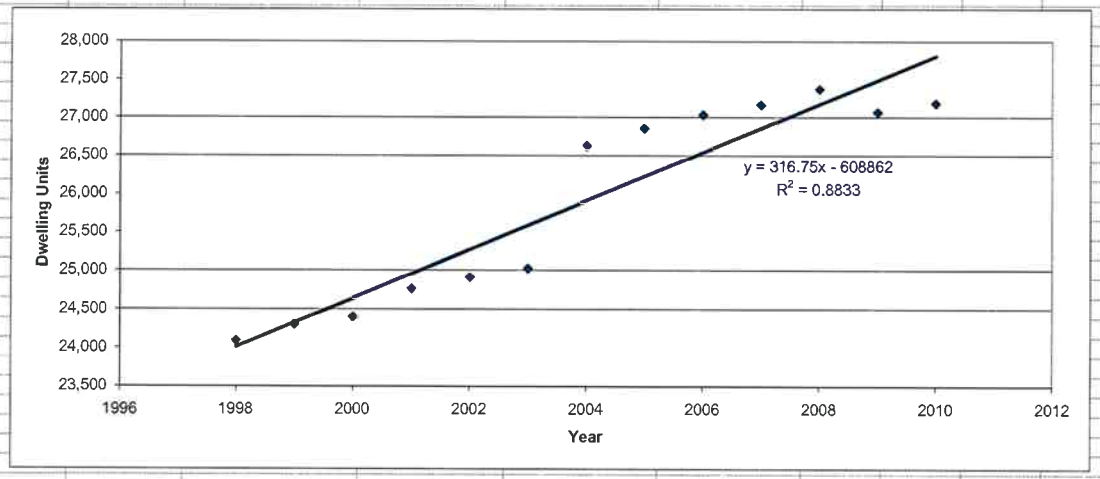
Year	Dwelling Units	Percentage of Buildout/I	Non-Res Sq. Ft	Percentage of Buildout/Date
2010	1,344	66%	525,731	45%
2015	1,445	70%	586,068	50%
2035	1,837	90%	733,450	62%
Buildout	2,051	2046	1,176,707	2095



Year	Sq. Ft	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	377,245	460,794	6,980,385,793	16,323,443,137
1999	484,290	468,163	260,086,868	429,245,086
2000	479,474	475,532	15,540,318	651,996,941
2001	504,952	482,901	486,248,059	3,162
2002	520,866	490,270	936,111,858	251,468,845
2003	521,861	497,639	586,698,365	284,015,831
2004	528,592	505,008	556,194,172	556,194,171
2005	525,083	512,377	161,434,337	402,996,360
2006	521,632	519,746	3,555,462	276,349,703
2007	524,025	527,115	9,551,157	361,637,512
2008	529,149	534,485	28,468,441	582,776,739
2009	522,207	541,854	385,991,660	295,797,663
2010	525,731	549,223	551,862,713	429,433,165
	505,008		10,962,129,203	20,845,358,314

m	b
7369.09	-14,262,644

Sq. Ft. = m*year + b R^2 0.474121335

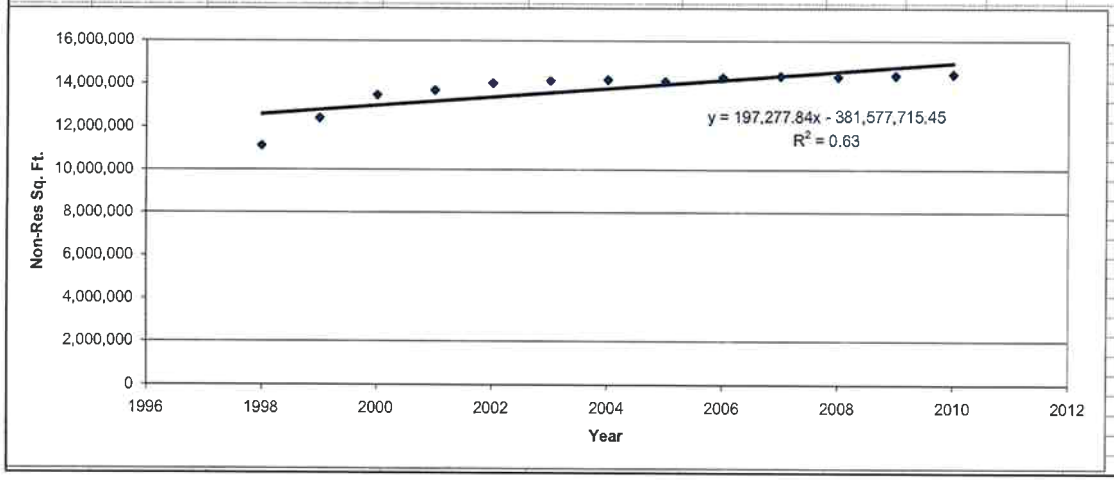


Year	DU	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	24,089	24,008	6,605	3,309,634
1999	24,303	24,324	440	2,575,175
2000	24,398	24,641	59,051	2,280,130
2001	24,759	24,958	39,486	1,320,123
2002	24,910	25,275	132,800	995,844
2003	25,027	25,591	318,595	776,503
2004	26,622	25,908	508,887	508,887
2005	26,861	26,225	405,010	908,506
2006	27,037	26,542	245,227	1,273,979
2007	27,164	26,858	93,151	1,576,182
2008	27,376	27,175	40,476	2,155,590
2009	27,071	27,492	176,910	1,352,920
2010	27,188	27,809	384,989	1,638,489
	25,908		2,411,626	20,671,964

m	b
316.75	-608,862

DU = m*year + b R^2 0.883338301

Year	Dwelling Units	Percentage of Buildout/D	Non-Res Sq. Ft	Percentage of Buildout/Date
2010	27,188	79%	14,452,996	33%
2015	29,392	85%	15,937,133	37%
2035	35,728	103%	19,882,690	46%
Buildout	34,541	2031	43,266,560	2154



Year	Sq. Ft	Fi	(Yi - Fi)^2	(Yi-Ybar)^2
1998	11,128,494	12,583,410	2,116,781,114,592	6,962,121,465,697
1999	12,411,861	12,780,688	136,033,377,027	1,836,611,032,140
2000	13,467,366	12,977,966	239,512,488,187	89,826,821,849
2001	13,693,927	13,175,244	269,032,355,874	5,350,956,262
2002	14,002,367	13,372,522	396,705,291,006	55,361,275,505
2003	14,129,215	13,569,799	312,945,824,332	131,143,763,903
2004	14,187,357	13,767,077	176,635,084,421	176,635,084,425
2005	14,106,697	13,964,355	20,261,224,692	115,341,587,652
2006	14,299,058	14,161,633	18,885,654,910	283,003,538,831
2007	14,367,493	14,358,911	73,654,979	360,499,095,941
2008	14,331,103	14,556,189	50,663,523,956	318,125,068,356
2009	14,394,070	14,753,466	129,165,796,014	393,119,932,668
2010	14,452,996	14,950,744	247,753,343,652	470,484,557,983
	13,767,077		4,114,448,733,644	11,197,624,181,212

m	b
197277.84	-381,577,715

Sq. Ft. = m*year + b R^2 0.632560562

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Appendix S

2017 PALS STUDY

Pond Water Quality Assessment of 23 Ponds in the Town of Barnstable using Pond and Lake Stewardship (PALS) Protocols

Dr. David R. Schlezinger,
Dr. Brian L. Howes
Ms. Sara Sampieri Horvet

Coastal Systems Program
School of Marine Science and Technology - UMD

February 17, 2017

Overview:
The Coastal Systems Program (CSP) within the University of Massachusetts-Dartmouth (UMD) School for Marine Science and Technology (SMAST) has developed and implemented water quality monitoring programs throughout all of southeastern Massachusetts and the Islands including estuarine specific programs in the majority of the estuaries as well as monitoring in the lakes/ponds of Cape Cod, Martha's Vineyard and Nantucket Islands. The long term water quality monitoring undertaken across the region was designed to collect necessary baseline nutrient related water quality data in freshwater systems and for determining estuarine specific nitrogen thresholds as well as tracking restoration and management "success" in each estuary relative to the established MassDEP/USEPA TMDL1. In addition, CSP scientists developed and implemented the Pond and Lake Stewardship (PALS) Program across Cape Cod whereby PALS Snapshots of water quality take place in 150 to 180 Cape Cod ponds each year. Over the past 15 years (2001-2016), these data have been collected through a network of town-based volunteers with laboratory services provided by the SMAST Coastal Systems Program Analytical Facility. More than 500 pond samples per year are analyzed following a consistent pond sampling protocol developed by CSP scientists. These data have been used to support larger more detailed assessments and modeling efforts to determine site-specific management plans for numerous

[1] TMDL or Total Maximum Daily Load is the regulatory requirement for restoration of an aquatic system under the Clean Water Act as proscribed by MassDEP and USEPA.

lakes and ponds, as well as to establish a long-term baseline of Cape Cod Ponds. This effort has recently expanded to include more than 30 lakes and ponds off-Cape (e.g. Plymouth, Carver, Wareham), that have eutrophication concerns related to phosphorus enrichment.

The sampling was undertaken by the CSP scientific staff and trained volunteers, where appropriate. All sampling and analysis was consistent with the protocols established for the Cape Cod Pond and Lakes Stewardship Program (PALS) and results from effort are directly cross comparable to previous PALS water quality snapshots completed in previous years.

Pond Sampling and Analysis:
This work included a total of 23 ponds listed below.

Mill Pond	West Barnstable,	13.83 ac.
Lamson Pond	Barnstable,	13.27 ac.
Fawcett's Pond	Hyannis,	12.77 ac.
Coleman Pond	Osterville,	9.74 ac.
Flowing Pond	Centerville,	8.61 ac.
Israel Pond	Barnstable,	8.45 ac.
Patty's Pond	Marstons Mills,	8.39 ac.
Simmon's Pond	Hyannis,	8.04 ac.
Flintrock Pond	Barnstable,	6.72 ac.
Upper Gate Pond	Hyannis,	6.22 ac.
Mill Pond	Centerville,	5.55 ac.
Sam's Pond	Osterville,	5.46 ac.
108 Pond, BA-372	West Barnstable,	5.27 ac.
Weathervane Pond	Marstons Mills,	4.98 ac.
Ben's Pond	Hyannis,	4.97 ac.
North Pond	Osterville,	4.85 ac.
Lewis Pond	Hyannis,	4.09 ac.
Fresh Hole Pond	Hyannis,	4.67 ac.
286 Pond, BA-799	Hyannis,	3.78 ac.
Campground Pond	Barnstable,	3.69 ac.
106 Pond, BA-382	West Barnstable,	3.31 ac.
Three Pond	Centerville,	3.17 ac.
Flax Pond	Barnstable,	3.16 ac.

Each pond received one sampling event during which field dissolved oxygen and temperature profiles and Secchi clarity readings were collected at the deepest point in each selected pond or lake in either August or September. All sampling was completed between August 15 – September 30. Samples were collected between 9 AM and 3 PM to maximize phytoplankton activity. The sampling period was selected in order to sample what is likely to be the worst nutrient related water quality conditions in the ponds. Individual sampling dates within the sampling period were based primarily on weather conditions (avoiding major storm events).

Additionally water color, weather and plant presence (emerged macrophyte coverage on percentage of pond surface area basis) was recorded in the field data sheets. For ponds for which there was no bathymetric map, the CSP science team conducted a moderately detailed bathymetric survey to locate the deepest point in the pond and use the field data to produce a bathymetric map.

Water quality samples were collected at a minimum of two depths in each pond (a 0.5 /surface sample and a sample 1 m off the bottom) and each pond had an additional QA sample. If the pond was less than 1.5 meters deep, two samples at the 0.5 meters depth were collected. In ponds deeper than 10 meters, a third sample at a 3 meter depth was added, and in ponds deeper than 11 meters, a fourth sample was added at a 9 meter depth. GPS coordinates were recorded for each pond sampling location. A maximum of 5 samples (4 depths+1 QA dup) were be collected at any pond.

The sampling protocol required locating the deepest location on the pond, collection of dissolved oxygen and temperature profiles (at 1 m depth intervals) at that location, measuring Secchi transparency, and collecting water quality samples at standardized depths. Dissolved oxygen and temperature profile readings were recorded using a YSI-55 meter (or similar) calibrated prior to each sampling event. Membranes or cartridges on the meter probe were changed according to recommendations in the meter operations manual. Sampling location GPS coordinates were determined for those ponds without prior sampling and past coordinates were followed for those stations where coordinates have been determined previously.

All water column samples for water quality analysis were collected with Niskin samplers and sub-samples were transferred to dark HDPE acid-washed 1 liter bottles and transported in coolers with ice packs (4°C) to the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST), University of Massachusetts Dartmouth in New Bedford which has a state-approved Quality Assurance Plan, and completes all water quality laboratory analyses for the Massachusetts Estuaries Project and the Cape Cod Pond and Lake Snapshots (approximately 150 ponds sampled per year). Chain of Custody, sample handling and transport followed procedures developed during SMAST/CSP's 15 years of Cape Cod Pond and Lake Snapshots. Samples were analyzed for: pH (stnd units), Total Phosphorus (µM or mg/L), Total Nitrogen (µM or mg/L), Alkalinity (mg $CaCO_3$/L), Chlorophyll a (µg/L), Phaeophytin (µg/L), Salinity (ppt).

Field Pondwater Sampling and Bathymetry:

A field team comprised of a water quality technical associate and an instrument specialist (bathymetry) deployed to each pond using guidance on access provided by the Town. For ponds that have a bathymetric map, the deepest part of the pond (the targeted sampling site) was located using the map and an acoustic depth finder. However, most of the ponds did not have available bathymetric information. Given the state-of-the-art bathymetric survey tools available within CSP-SMAST, CSP conducted low-moderate level bathymetric surveys of these ponds. Bathymetry located the deepest part of the pond as well as providing information needed for management, including key aspects such as the volume of the pond and how contaminants and water move within and through the pond. In addition, recent regulatory agency deliberations

have identified plant and freshwater mussel surveys as important considerations in review of pond management plans.

For each pond 3-4 cross pond transects were conducted, so as to cover as much of the pond bottom as possible. Surveys were referenced to a common datum (State Plane Mainland (m); NAVD88). The bathymetry surveys were performed using a shallow draft boat, capable of traversing the shallowest regions of each pond. Both parallel and crossing transects were assayed using a field portable bathymetric data acquisition system. A fathometer with depth resolution to 0.10 ft. was used in conjunction with a differential geographic positioning system (DGPS) or Real Time Kinetic system (RTK). This system records depth as a function of survey location. An integrated survey software package was used to record depth and position data simultaneously to a laptop computer.

Positions were recorded in Massachusetts State Plane 1983 coordinate system (X-Y) at an approximate rate of one value every two seconds. Depending upon boat speed during the survey (estimated at 3-5 knots), position measurements were made approximately every 10-15 feet along each survey line. Depth values were recorded continuously (approximately every 0.5 seconds, or every 3 feet along the survey line). While this data was used to locate the deepest portion of each pond for sampling, CSP-SMAST also used this data to construct bathymetric maps for each pond where bathymetry did not currently exist.

Determination of Pond Health or Trophic Status:
Previous work on Cape Cod ponds (Eichner, 2003) has used the trophic classification developed by Carlson (1977). The Carlson trophic state index (TSI) is used here for the sake of consistency and comparability. Using easily measured proxies of total biomass, Total Phosphorus, Chlorophyll a and Secchi depth, ecosystems are placed on a scale from 1-100 (Carlson and Simpson, 1996). The equations used and the associated pond characteristics can be found in Table 1. Individual TSI values are provided for each pond as well as means and standard deviations. Further explanation and limitations to using trophic indices can be found in the Cape Cod Pond Atlas (Eichner, 2003).

Table 3. – Carlson Trophic State Index (TSI)					
TSI Calculations					
TSI(SD) = 60 - 14.41 ln(SD)				SD = Secchi disk depth (meters)	
TSI(CHL) = 9.81 ln(CHL) + 30.6				CHL = Chlorophyll a concentration (µg/L)	
TSI(TP) = 14.42 ln(TP) + 4.15				TP = Total phosphorus concentration (µg/L)	
TSI values and likely pond attributes					
TSI Values	Chl a (µg/L)	SD (m)	TP (µg/L)	Attributes	Fisheries & Recreation
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic	Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Hypolimnetic anoxia results in loss of salmonids.
50-60	7.3-20	2-1	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes	
>80	>155	<0.25	192-384	Algal scums, few macrophytes	Rough fish dominate; summer fish kills possible
after Carlson and Simpson (1996); Carlson TSI developed in algal dominated, northern temperate lakes					

Caveats to the 2016 Sampling:

The Summer of 2016 represented a severe drought for most of eastern Massachusetts. Water levels in lakes, ponds and reservoirs throughout the state were far below normal. On Cape Cod high water level marks were typically more than a meter above observed water lines. Low water levels made some ponds inaccessible, impossible to navigate, or in some cases the ponds had entirely dried up. Every attempt was made to collect data when possible. In the case of Lewis Pond, Uppergate Pond and 108 Pond there simply was not enough water to sample. In the cases of 286 Pond, Lamsons Pond, and Flowing Pond there was sufficient water for sample collection,

but insufficient water to support water craft required for a proper bathymetric survey. Upon discussion with the program administrators and steering committee members, we hope to form a plan to sample and survey the remaining ponds when conditions are favorable to produce good data that most benefits the aims and objectives of the project as a whole.

Carlson, R.E. 1977. A trophic state index for lakes. *Limnology and Oceanography.* 22: 361-369.
Carlson, R.E. and J. Simpson. 1996. *A Coordinator's Guide to Volunteer Lake Monitoring Methods*. North American Lake Management Society. 96 pp. (summarized at http://dipin.kent.edu/tsi.htm#A).
Eichner, E.M. et al. 2003. Cape Cod Pond and Lake Atlas Project 2000-02. Cape Cod Commission. Barnstable, MA. 50pp.

Mill Pond

Barnstable GIS ID: 105
CCC GIS ID: BA-391

Area (acres): 13.83
Bathymetry: CSP, 2016
Maximum Depth (m): 0.9
Lake Association:

PALS Sampling	9/22/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.9 m		
Total Depth	0.9 m		
Surface pH	6.88	6.5 – 8.3	MassDEP
Deepest DO	10.76 mg/L	5.0 mg/L	MassDEP
Shallow temp	24.9°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.68 µg/L	1.7 µg/L	CCC
Surface TP	27.96 µg/L	10 µg/L	CCC
Surface TN	0.46 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

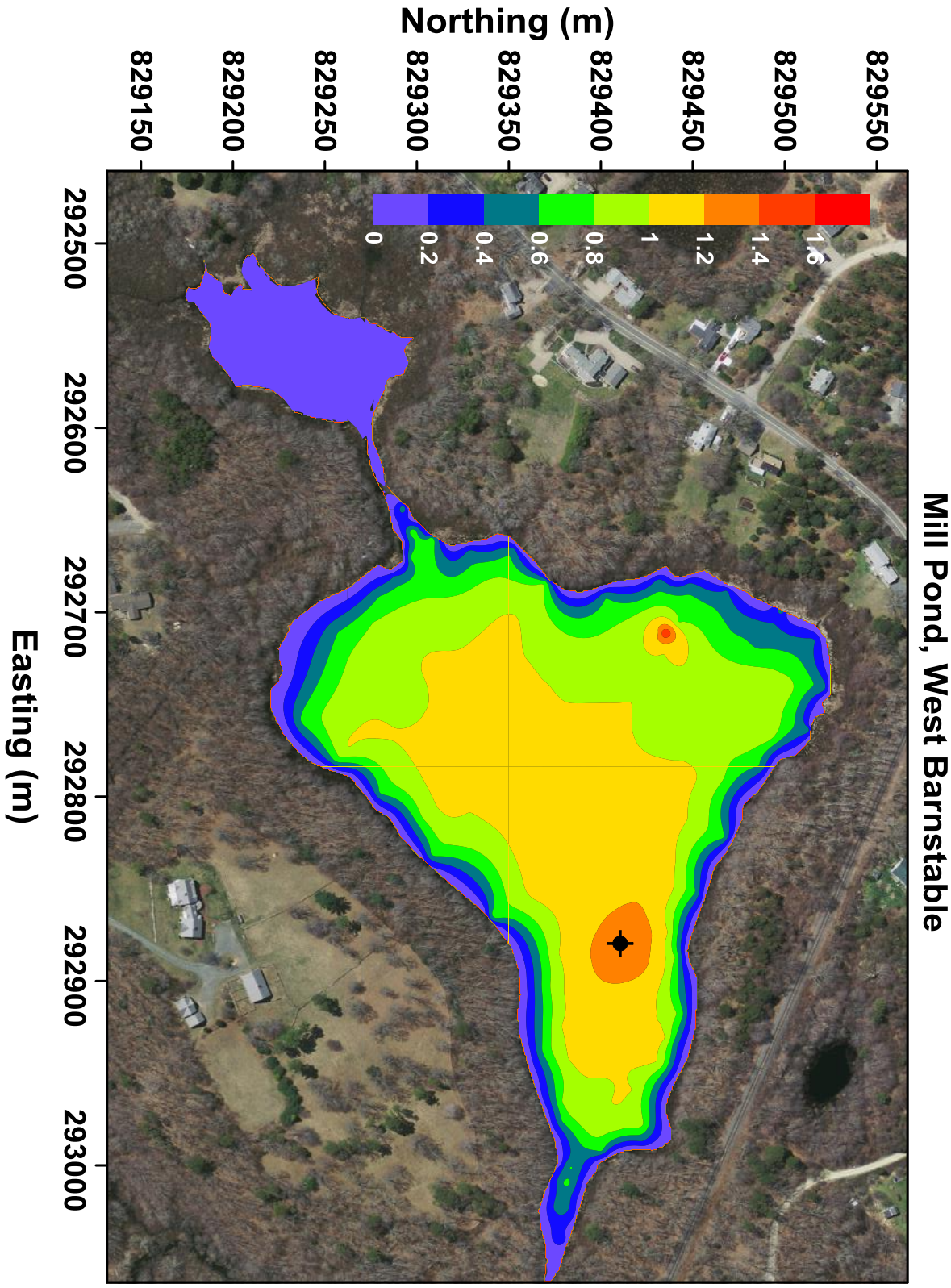
OVERVIEW

Mill Pond is located in West Barnstable, south of rail lines and east of Maple Street. Shoreline development is fairly sparse with five houses around its shoreline with most of these located along the western shore. There is no formal public access, though a winding trail at the end of Gemini Drive is used by neighbors as a landing for small fishing craft.

WATER QUALITY

Mill Pond is shallow with sunlight reaching the bottom at the time of the 2016 sampling. Temperatures and dissolved oxygen readings showed a stratified water column with increasing DO near the sediments; surface saturation level was 89%, while 0.9 m depth level was 130%. A thick layer, >50cm in places, of macrophytes on the bottom provided an explanation of the inverted DO profile. Calm, cloudless conditions during sampling and the previous 48 hours likely contributed to the observed stratification. Total phosphorus concentration was well above the ecoregion threshold, while the chlorophyll-a concentration was just below its threshold. Shallow total nitrogen concentration was above its threshold.

Based on the available information, Mill Pond is mesotrophic according to the average TSI of 46±8.9 (P=52; Chl=40; Secchi=NA), however, the extensive coverage of macrophytes within this pond suggests eutrophic may be a better classification. Additional monitoring would be required to determine the extent of impairment.



Sampling Location (WGS84): N 41.709, W 70.384
(NAD83): E 29881, N 829411

Lamson Pond

Barnstable GIS ID: 084
CCC GIS ID: BA-596

Area (acres): 13.27
Bathymetry:
Maximum Depth (m): 0.65
Lake Association:

PALS Sampling	9/8/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.65 m		
Total Depth	0.65 m		
Surface pH	4.78	6.5 – 8.3	MassDEP
Deepest DO	7.86	5.0 mg/L	MassDEP
Shallow temp	22.4	28.3°C	MassDEP
Surface Chlorophyll-a	41.24 µg/L	1.7 µg/L	CCC
Surface TP	25.42 µg/L	10 µg/L	CCC
Surface TN	1.89 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

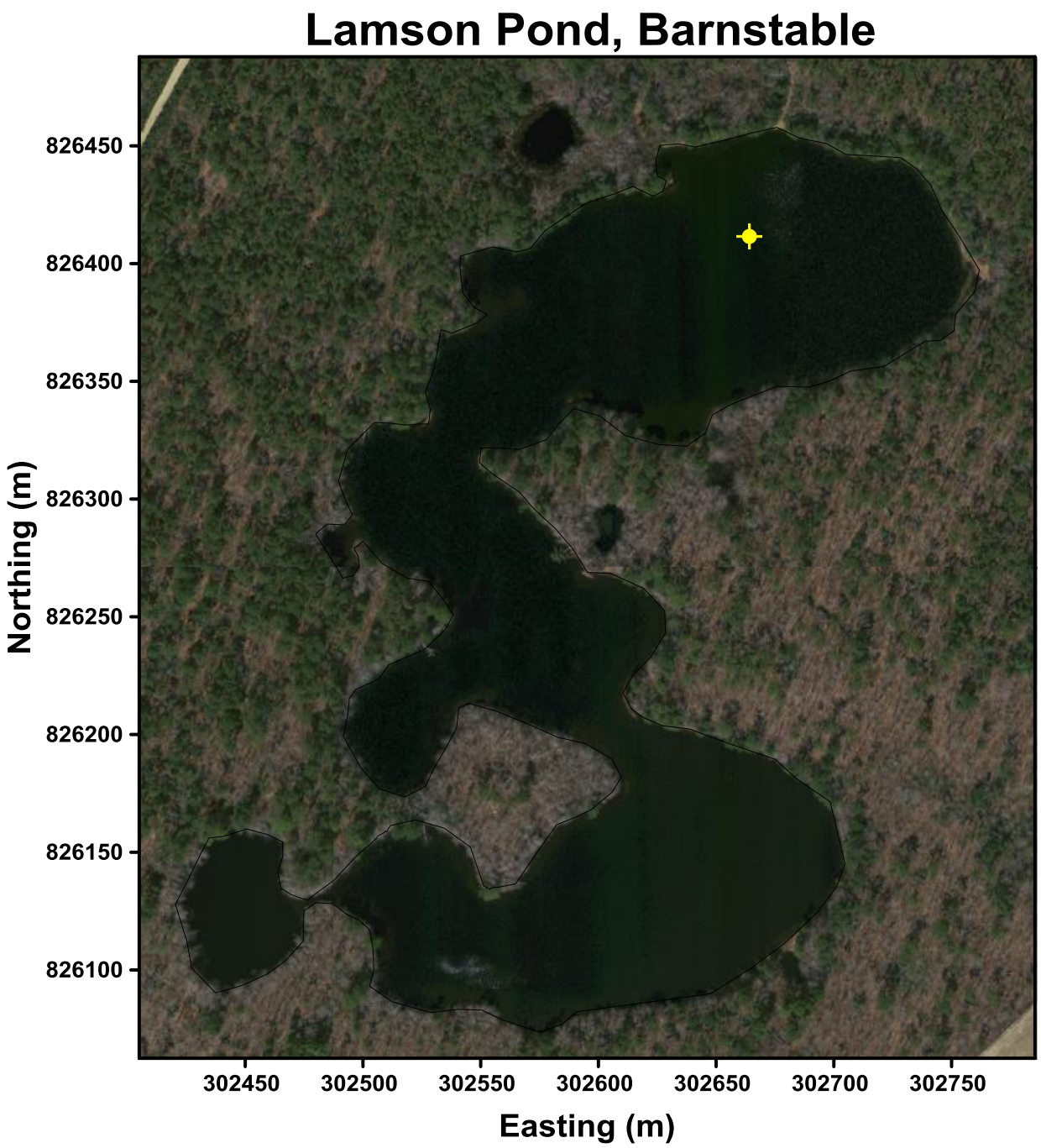
OVERVIEW

Lamson Pond is located in Barnstable, west of Campground Pond There is no shoreline development within the Fish and Game Wildlife conservation area. There is public access from Mary Dunn Road near Israel Pond..

WATER QUALITY

Lamson Pond was very shallow, less than 20cm. throughout most of the pond at the time of sampling in 2016. Reliable temperature and dissolved oxygen readings were impossible due to the shallow water and will need to be performed at a later date when water levels are higher. All nutrient neasures of water quality were well in excess of the ecoregion threshold. Though every care was taken, it is possible that the results reflect some resuspension of sediments which occurred while reaching open water. Sampling in the Spring or during normal PALS sampling in late summer will be required.

Based on the available information, Lamson Pond is eutrophic according to the average TSI of 60±13.3 (P=51; Chl=70; Secchi=NA).



Sampling Location (WGS84): N 41.6813, W 70.2672
(NAD83): E 302645, N 826411

Fawcett's Pond

Barnstable GIS ID: 057
CCC GIS ID: BA-748

Area (acres): 12.77
Bathymetry: CSP, 2016
Maximum Depth (m): 1.2
Lake Association:

PALS Sampling	8/30/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.20 m		
Total Depth	1.20 m		
Surface pH	7.38	6.5 – 8.3	MassDEP
Deepest DO	8.06 mg/L	5.0 mg/L	MassDEP
Shallow temp	27.1°C	28.3°C	MassDEP
Surface Chlorophyll-a	3.35 µg/L	1.7 µg/L	CCC
Surface TP	30.51 µg/L	10 µg/L	CCC
Surface TN	0.96 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

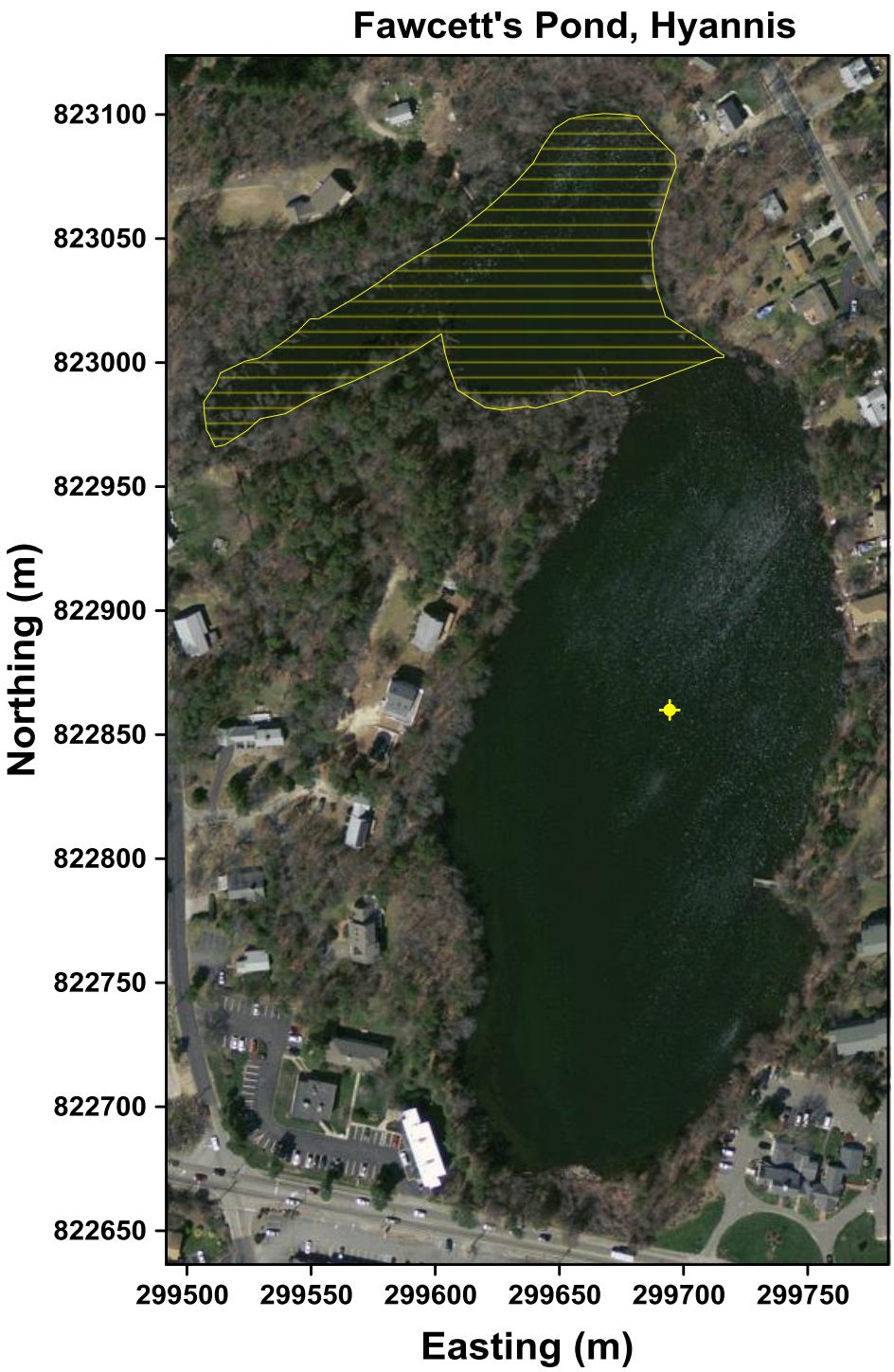
OVERVIEW

Fawcett's Pond is located in Hyannis just north of West Main Street and west of Aunt Bettys Pond. Shoreline development is extensive with commercial properties to the south along the road frontage and homes along the eastern and western shoreline. At the time of sampling the northern part of the pond was inaccessible as a result of emergent grasses and woody plants. Best access is through private property. Access from West Main Street is not recommended due to traffic hazards and the presence of a homeless encampment along the shoreline.

WATER QUALITY

Fawcett's Pond is shallow with light penetration reaching the bottom. Temperatures and dissolved oxygen readings showed a well-mixed water column near saturation throughout. Total phosphorus d total nitrogen concentrations were two to three times the ecoregion threshold. Periodic inputs of nutrients from road runoff and other impermeable surfaces are likely to have a large impact on the pond.

Based on the available information, Fawcett's Pond is mesotrophic according to the average TSI of 49±6.6 (P=53; Chl=44; Secchi=NA). Most of the measures indicate that additional monitoring is warranted. Additional monitoring would be required to determine extent of impairment as well as the impact of extensive macrophytes. Bathymetry data collected during 2016 were suspect as apparent position was seen to change abruptly.



Sampling Location (WGS84): N 41.6497, W 70.3032
(NAD83): E 299695, N 822860

Coleman Pond

Barnstable GIS ID: 008
CCC GIS ID: BA-819

Area (acres): 9.74
Bathymetry: CSP, 2016
Maximum Depth (m): 3.85
Lake Association:

PALS Sampling	9/13/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.50 m		
Total Depth	3.85 m		
Surface pH	6.20	6.5 – 8.3	MassDEP
Deepest DO	7.23 mg/L	5.0 mg/L	MassDEP
Shallow temp	25.0°C	28.3°C	MassDEP
Surface Chlorophyll-a	2.08 µg/L	1.7 µg/L	CCC
Surface TP	16.95 µg/L	10 µg/L	CCC
Surface TN	0.48 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.1		

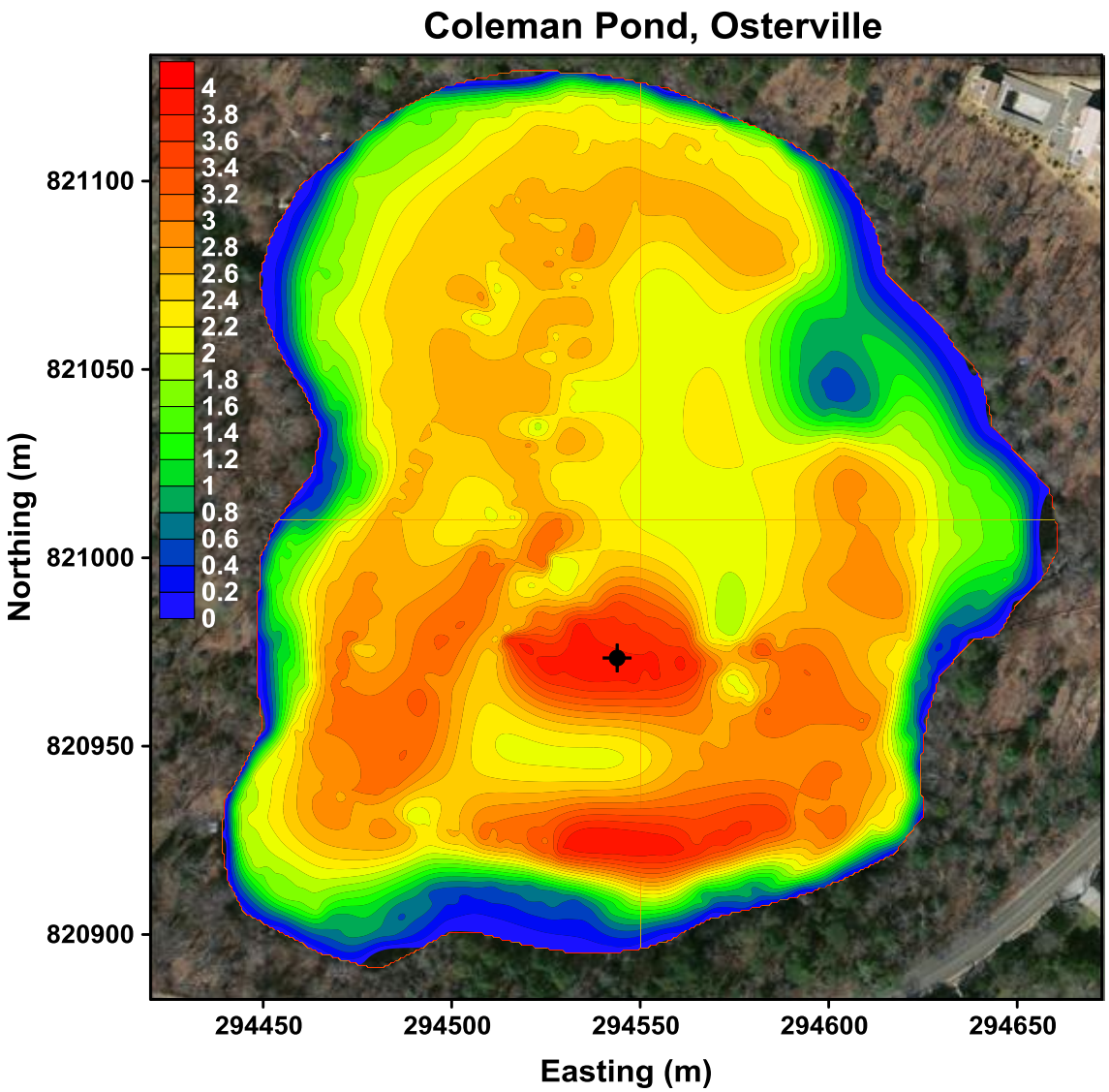
OVERVIEW

Coleman Pond is located in Osterville, north of Centerville River and east of Bumpus River. Shoreline development is fairly sparse with ten houses around its shoreline with most of these located along the western shore. There is no formal public access.

WATER QUALITY

Coleman Pond is relatively shallow with only a little loss in clarity at the time of the 2016 sampling. Temperatures and dissolved oxygen readings showed a mixed water column with a slight increase in DO near the sediments due to rooted macrophytes; DO saturation levels were close to 85% throughout the water column. Shallow total phosphorus, total nitrogen and chlorophyll concentrations were just above the ecoregion threshold.

Based on the available information, Coleman Pond is mesotrophic according to the average TSI of 45±2.9 (P=45; Chl=41; Secchi=47).



Sampling Location (WGS84): N 41.633, W 70.365
(NAD83): E 294543, N 820972

Flowing Pond

Barnstable GIS ID: 029
CCC GIS ID: BA-733

Area (acres): 8.61
Bathymetry:
Maximum Depth (m): 0.4
Lake Association:

PALS Sampling	9/15/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.40 m		
Total Depth	0.40 m		
Surface pH	-	6.5 – 8.3	MassDEP
Deepest DO	4.25 mg/L	5.0 mg/L	MassDEP
Shallow temp	19.4°C	28.3°C	MassDEP
Surface Chlorophyll-a	- µg/L	1.7 µg/L	CCC
Surface TP	12.75 µg/L	10 µg/L	CCC
Surface TN	0.91 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

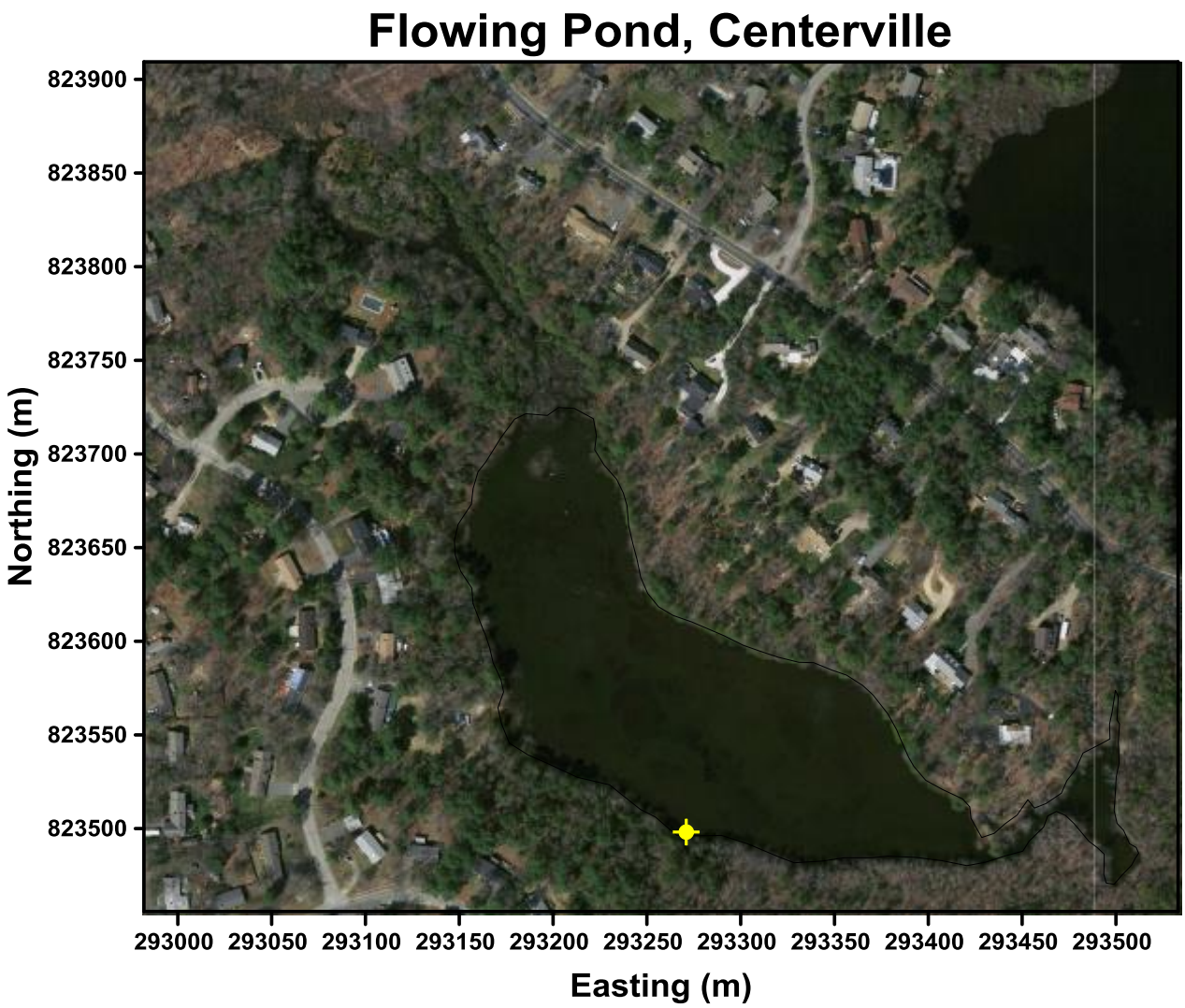
OVERVIEW

Flowing Pond is located in Centerville south of Lumbert Pond. Input from the pond comes from a small stream connecting it to Lumbert Pond. Water flow leaves the pond through a control structure where the sample was taken leaving most of the pond stagnant. Flowing Pond appears to be a holding pond for a long abandoned cranberry farm. There is formal public access from Lumbert Hill Road.

WATER QUALITY

Flowing Pond is very shallow with deepest point at the control structure. Temperatures and dissolved oxygen readings taken in flowing water at the control structure was at less than 50% saturation indicating extensive DO uptake within the pond system. Total phosphorus and total nitrogen concentrations were well above the ecoregion threshold. Additional sampling will be undertaken or during the next round of PALS sampling or in the spring in order to obtain a full suite of analyses for the pond. If water levels have risen bathymetry will also be attempted; at the time of the 2016 sampling shallow water depths, emergent grasses and snags made maneuverability in even the smallest craft impossible. Additionally, tree coverage made GPS positioning unreliable.

Based on the available information, Flowing Pond is mesotrophic according to the average TSI of 41±NA (P=41; Chl=NA; Secchi=NA). Additional measures will be required to make a more robust assessment.



Sampling Location (WGS84): N 41.6562, W 70.308
(NAD83): E 293271, N 823498

Israels Pond

Barnstable GIS ID: 094
CCC GIS ID: BA-585

Area (acres): 8.45
Bathymetry: IEP, 1990
Maximum Depth (m): 0.45
Lake Association:

PALS Sampling	9/8/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.45 m		
Total Depth	0.45 m		
Surface pH	4.78	6.5 – 8.3	MassDEP
Deepest DO	-	5.0 mg/L	MassDEP
Shallow temp	-	28.3°C	MassDEP
Surface Chlorophyll-a	18.96 µg/L	1.7 µg/L	CCC
Surface TP	21.19 µg/L	10 µg/L	CCC
Surface TN	1.01 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

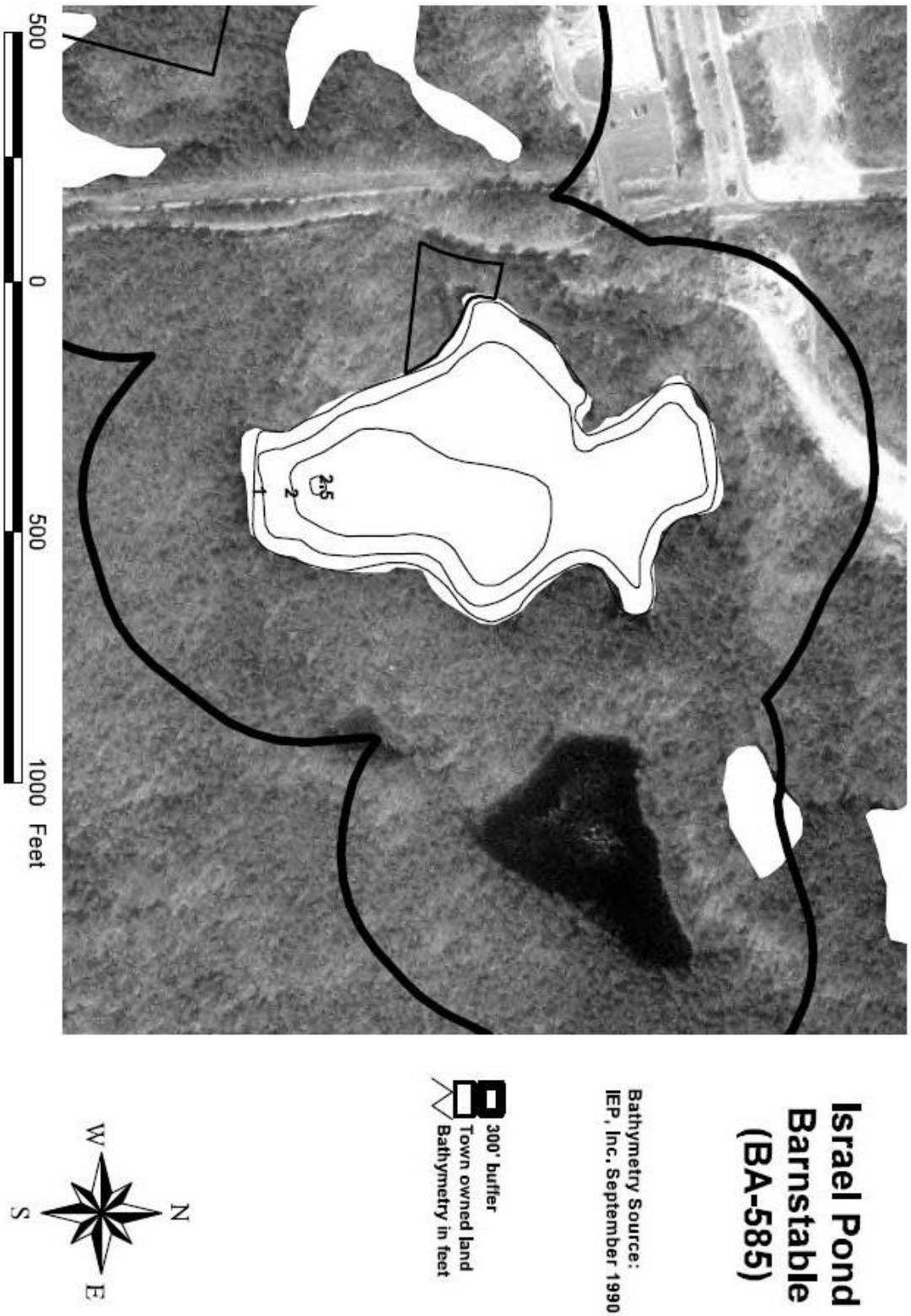
OVERVIEW

Israel Pond is located in Barnstable, west of Mary Dunn Way. There is no shoreline development since the pond is located on conservation land. Access by foot from Mary Dunn Way.

WATER QUALITY

Israel Pond was very shallow. Extensive muddy shoreline was covered with water lilies and other rooted SAV's. DO measurements could not be obtained, though given the shallow water concentrations values were likely within 10% of saturation. Nutrient and chlorophyll measures ranged from 2-3 times (nitrogen and phosphorus) to more than ten times (chlorophyll a) the ecoregion threshold. Shallow water and abundance of macrophytes complicated both sampling and interpretation of results.

Based on the available information, Israel Pond is mildly eutrophic according to the average TSI of 55±9.8 (P=48; Chl=62; Secchi=NA). Additional monitoring at higher water levels seems warranted. Additional monitoring would be required to make an enduring assessment.



Sampling Location (WGS84): N 41.6809, W 70.2789
(NAD83): E 301670, N 826355

Patty's Pond

Barnstable GIS ID: 030
CCC GIS ID: BA-731

Area (acres): 8.39
Bathymetry: CSP, 2016
Maximum Depth (m): 5.5
Lake Association:

PALS Sampling	9/20/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.1 m		
Total Depth	5.5 m		
Surface pH	6.93	6.5 – 8.3	MassDEP
Deepest DO	0.19 mg/L	5.0 mg/L	MassDEP
Shallow temp	24.1°C	28.3°C	MassDEP
Surface Chlorophyll-a	4.01 µg/L	1.7 µg/L	CCC
Surface TP	20.34 µg/L	10 µg/L	CCC
Surface TN	0.58 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.39		

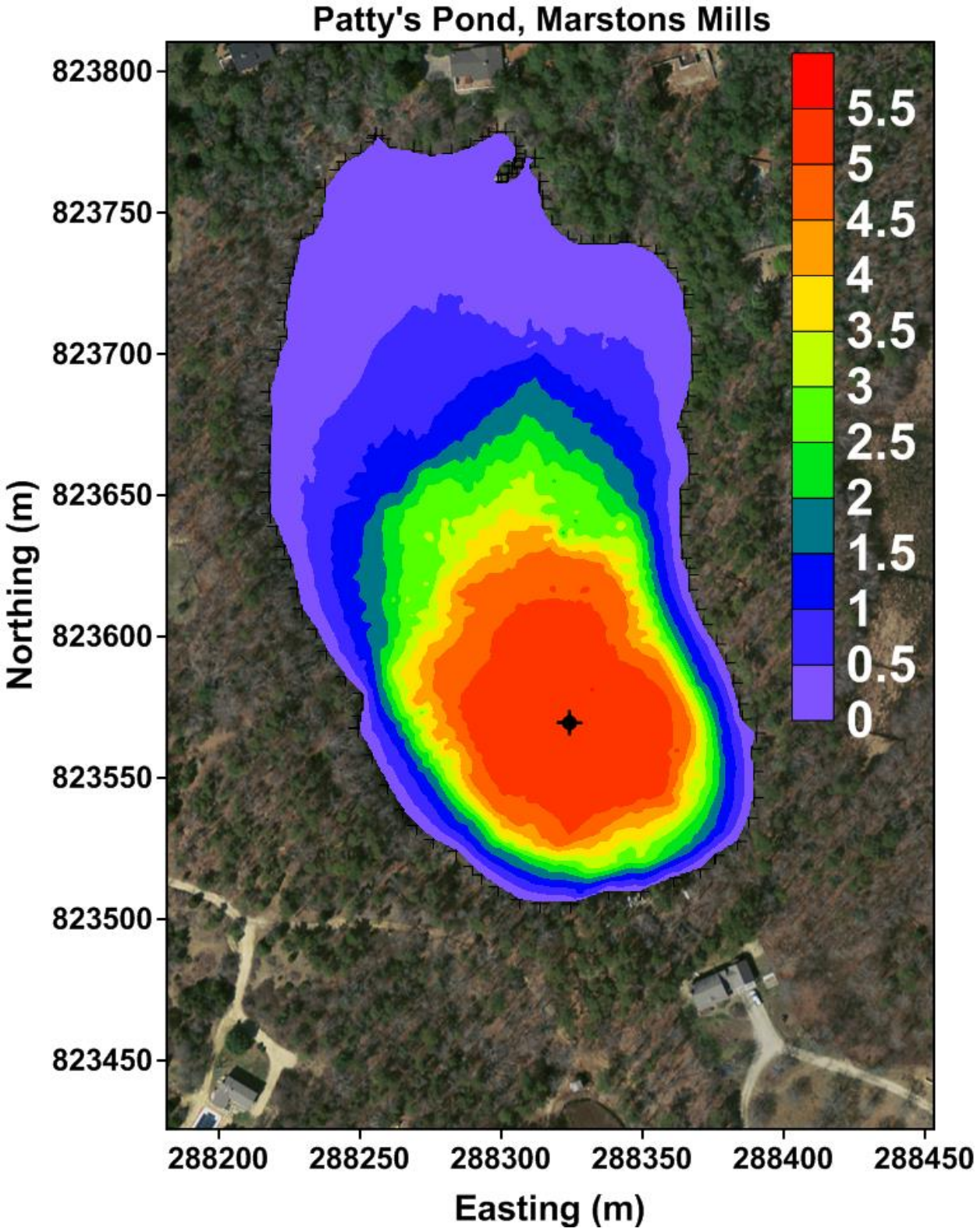
OVERVIEW

Patty's Pond is located in Marstons Mills north of Lovells Pond. Shoreline development is fairly sparse with eight houses around its western and northern shoreline. There is no formal public access.

WATER QUALITY

Patty's Pond is relatively shallow. At the time of the 2016 sampling light penetrated nearly to the bottom. Temperatures and dissolved oxygen readings showed a stratified water column with anoxia occurring just above the bottom at 5 meters. Surface water DO was at saturation. Shallow total phosphorus concentration was two times above the ecoregion threshold, as was the shallow chlorophyll-a concentration. Shallow total nitrogen concentration was above its threshold by a factor of two as well. The deep total phosphorus concentration was slightly lower than the shallow concentration, while the deep total nitrogen was the same. These values would not be expected if the anoxic conditions were persistent suggesting that the anoxia had developed recently.

Based on the available information, Patty's Pond is mesotrophic according to the average TSI of 46±2.6 (P=44; Chl=46; Secchi=49). Additional monitoring would be required to confirm the extent of impairment.



Sampling Location (WGS84): N 41.6574, W 70.4396
(NAD83): E 288324, N 823569

Simmons Pond

Barnstable GIS ID: 052
CCC GIS ID: BA-7891

Area (acres): 8.04
Bathymetry: CSP, 2016
Maximum Depth (m): 3.4
Lake Association:

PALS Sampling	9/14/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.0 m		
Total Depth	3.40 m		
Surface pH	7.08	6.5 – 8.3	MassDEP
Deepest DO	0.08 mg/L	5.0 mg/L	MassDEP
Shallow temp	24.2°C	28.3°C	MassDEP
Surface Chlorophyll-a	3.1 µg/L	1.7 µg/L	CCC
Surface TP	29.6 µg/L	10 µg/L	CCC
Surface TN	0.74 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.63		

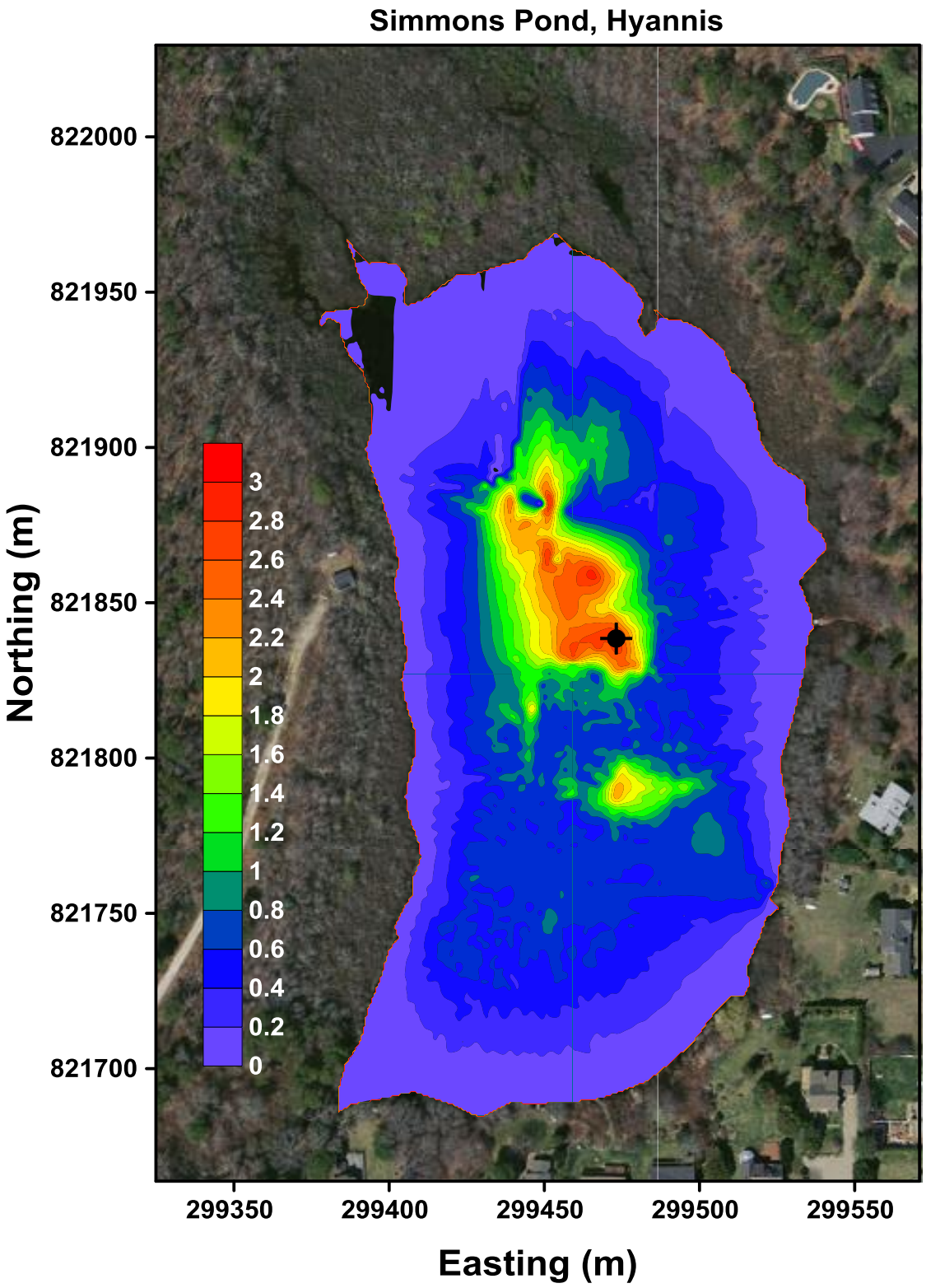
OVERVIEW

Simmons Pond is located in Hyannis, just south of Ben's Pond on a water department parcel. Shoreline development is moderate with fifteen houses around its southern and eastern shoreline. There is no formal public access.

WATER QUALITY

Simmons Pond is relatively shallow with a moderate loss in clarity at the time of the 2016 sampling. Temperatures and dissolved oxygen readings showed a stratified water column with anoxic conditions extending from the sediment up to 2.5 m depth. Total phosphorus, total nitrogen and Chlorophyll-a were all above the ecoregion threshold. Review of nitrogen to phosphorus ratios particularly in the bottom water sample suggests that the anoxic conditions were persistent.

Based on the available information, Simmons Pond is mildly eutrophic according to the average TSI of 50±2.1 (P=51; Chl=47; Secchi=50).



Sampling Location (WGS84): N 41.6405, W 70.3060
(NAD83): E 299473, N 821828

PALS Sampling	9/7/2016		

Flintrock Pond

Barnstable GIS ID: 108505
CCC GIS ID: BA-614

Area (acres): 6.72
Bathymetry: CSP, 2016
Maximum Depth (m): 3.1
Lake Association:

Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.70 m		
Total Depth	3.10 m		
Surface pH	5.94	6.5 – 8.3	MassDEP
Deepest DO	1.61 mg/L	5.0 mg/L	MassDEP
Shallow temp	25.5°C	28.3°C	MassDEP
Surface Chlorophyll-a	31.7 µg/L	1.7 µg/L	CCC
Surface TP	50.84 µg/L	10 µg/L	CCC
Surface TN	1.57 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.17		

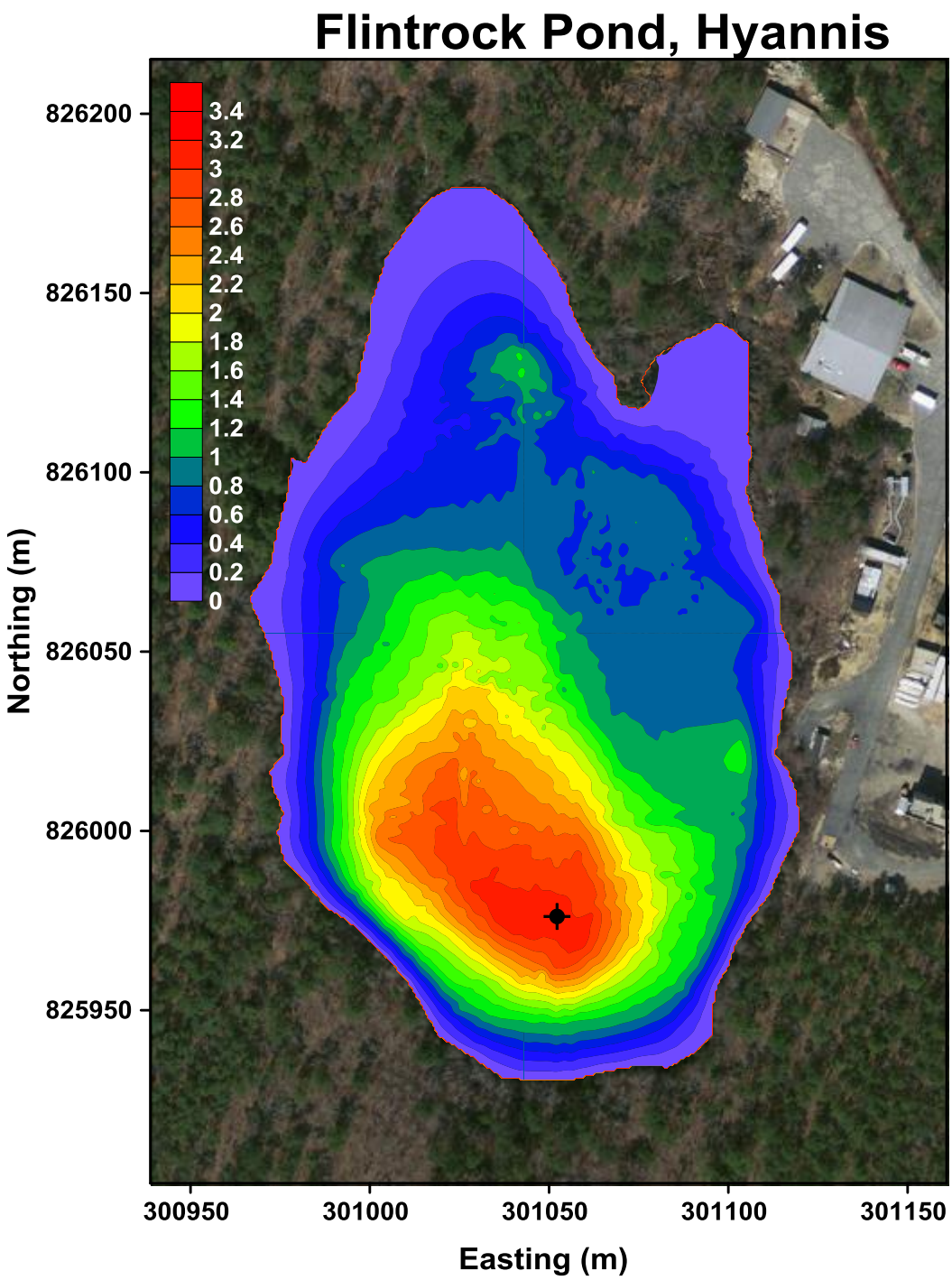
OVERVIEW

Flintrock Pond is located in Hyannis, adjacent to the county fire fighting academy. There are no houses along the shoreline and only four structures which are used in training exercises. Access to the pond is through county land used by the academy.

WATER QUALITY

Flintrock Pond is relatively shallow with poor water clarity at the time of the 2016 sampling. Temperatures and dissolved oxygen readings showed a temperature stratified system with DO concentrations dropping quickly below the depth of light penentration to anoxia at the bottom. Shallow total phosphorus and nitrogen concentrations were five times the ecoregion threshold, while the shallow chlorophyll-a concentration was fifteen times higher than the ecoregion threshold. The deep total phosphorus and total nitrogen concentrations were similar to the shallow totals.

Based on the available information, Flintrock Pond is eutrophic according to the average TSI of 65±3.1 (P=62; Chl=68; Secchi=65).



Sampling Location (WGS84): N 41.6776, W 70.2864
(NAD83): E 301052, N 825976

Mill (Filenes) Pond

Barnstable GIS ID: 019
CCC GIS ID: BA-750

Area (acres): 5.55
Bathymetry: CSP, 2016
Maximum Depth (m): 1.7
Lake Association:

PALS Sampling	9/8/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.7 m		
Total Depth	1.7 m		
Surface pH	6.68	6.5 – 8.3	MassDEP
Deepest DO	9.86 mg/L	5.0 mg/L	MassDEP
Shallow temp	23.3°C	28.3°C	MassDEP
Surface Chlorophyll-a	0.7 µg/L	1.7 µg/L	CCC
Surface TP	30.51 µg/L	10 µg/L	CCC
Surface TN	2.53 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.22		

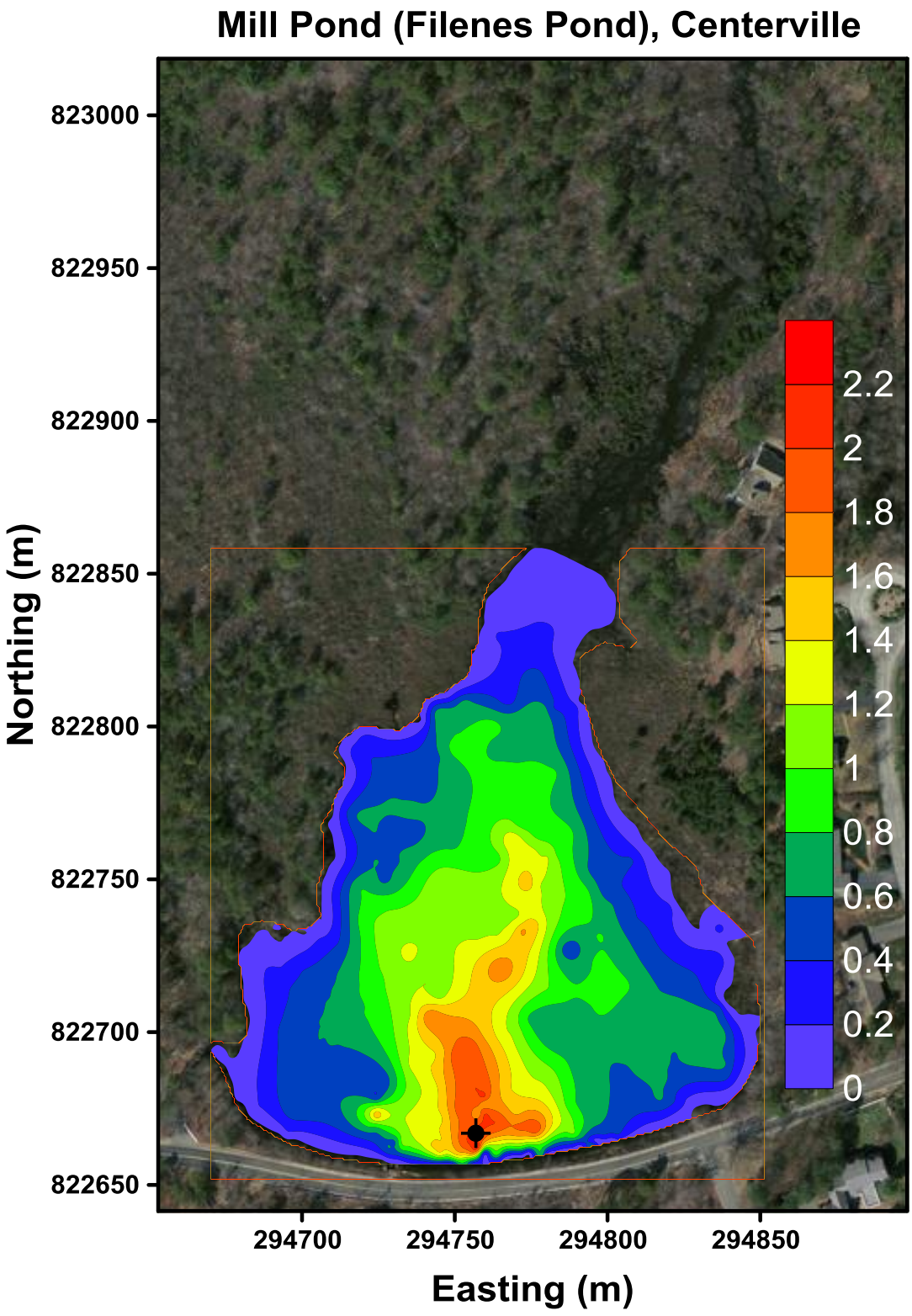
OVERVIEW

Mill Pond is located in Centerville, north of Scudder Bay into which it flows. Shoreline development is fairly sparse with six houses around its shoreline located along the eastern and western shore. To the north the Bumps River provides a water source that passes through open land occupied by untended cranberry bogs. There is no formal public access.

WATER QUALITY

Mill Pond is very shallow and had good water clarity at the time of the 2016 sampling. Temperatures and dissolved oxygen readings showed a mixed water column with surface warming and rooted macrophytes contributing to an inverted water column oxygen gradient. Elevated DO near the sediments was 106% of saturation while the near surface water was under-saturated by 6%; mid-depth DO was at saturation. Both total phosphorus and total nitrogen concentrations were above the ecoregion threshold, while the chlorophyll-a concentration was just below its threshold.

Based on the available information, Mill Pond is mesotrophic according to the average TSI of 47±11.5 (P=55; Chl=39; Secchi=NA).



Sampling Location (WGS84): N 41.639, W 70.376
(NAD83): E 294760, N 822667

Sam's Pond

Barnstable GIS ID: 007
CCC GIS ID: BA-820

Area (acres): 5.46
Bathymetry: CSP, 2016
Maximum Depth (m): 3.5
Lake Association:

PALS Sampling	9/20/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.3 m		
Total Depth	3.5 m		
Surface pH	5.58	6.5 – 8.3	MassDEP
Deepest DO	0.22 mg/L	5.0 mg/L	MassDEP
Shallow temp	23.6°C	28.3°C	MassDEP
Surface Chlorophyll-a	11.01 µg/L	1.7 µg/L	CCC
Surface TP	27.96 µg/L	10 µg/L	CCC
Surface TN	0.74 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.15		

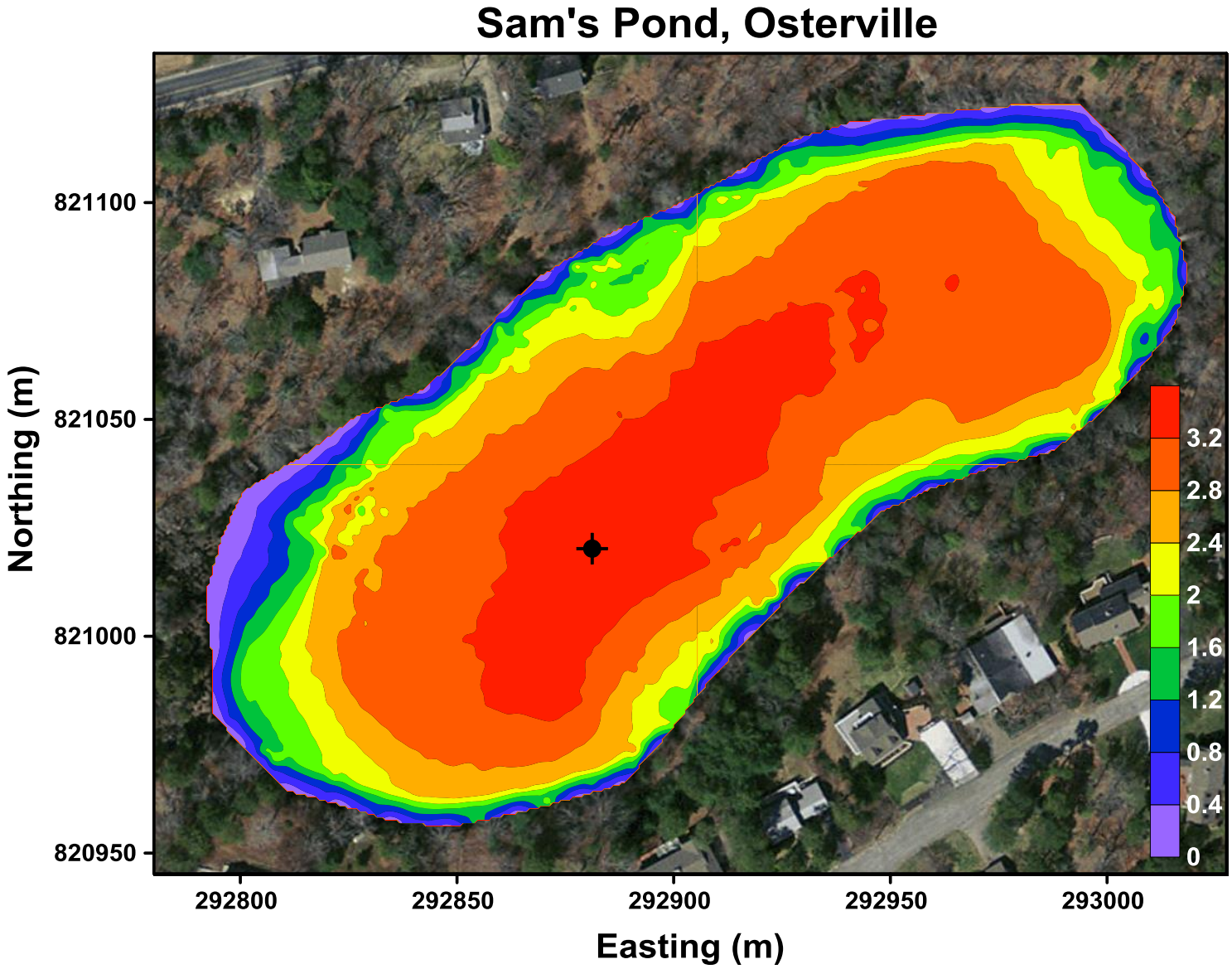
OVERVIEW

Sam's Pond is located in Osterville, south of Joshua Pond. Shoreline development is extensive with twenty-one houses around the shoreline. The southwest corner of the pond merges with a swamp. There is no formal public access.

WATER QUALITY

Sam's Pond is relatively shallow with light penetration nearly to the bottom. Temperatures and dissolved oxygen readings showed a stratified water column with anoxia beginning at a depth of 2.5 m; surface water was fully saturated. Shallow total phosphorus and total nitrogen concentrations were a little over two times higher than the ecoregion threshold. Shallow chlorophyll-a concentration was more than six times its threshold. The deep total phosphorus and deep total nitrogen concentrations were similar to those observed near the pond surface. Bottom water sampling, it should be noted, occurred immediately above the DO minimum, a deeper sample may have shown elevated TN and TP depending on how long the pond had been stratified.

Based on the available information, Sam's Pond is mildly eutrophic according to the average TSI of 56±3.0 (P=53; Chl=59; Secchi=56). Duration of pond stratification would be critical to determine if additional monitoring is warranted. Additional monitoring would be recommended.


Sam's Pond, Osterville
Northing (m)
821100
821050
821000
820950
292800
292850
292900
292950
293000
Easting (m)
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0

Sampling Location (WGS84): N 41.6340, W 70.3853
(NAD83): E 292881, N 821020

Weathervane Pond

Barnstable GIS ID: 033
CCC GIS ID: BA-699

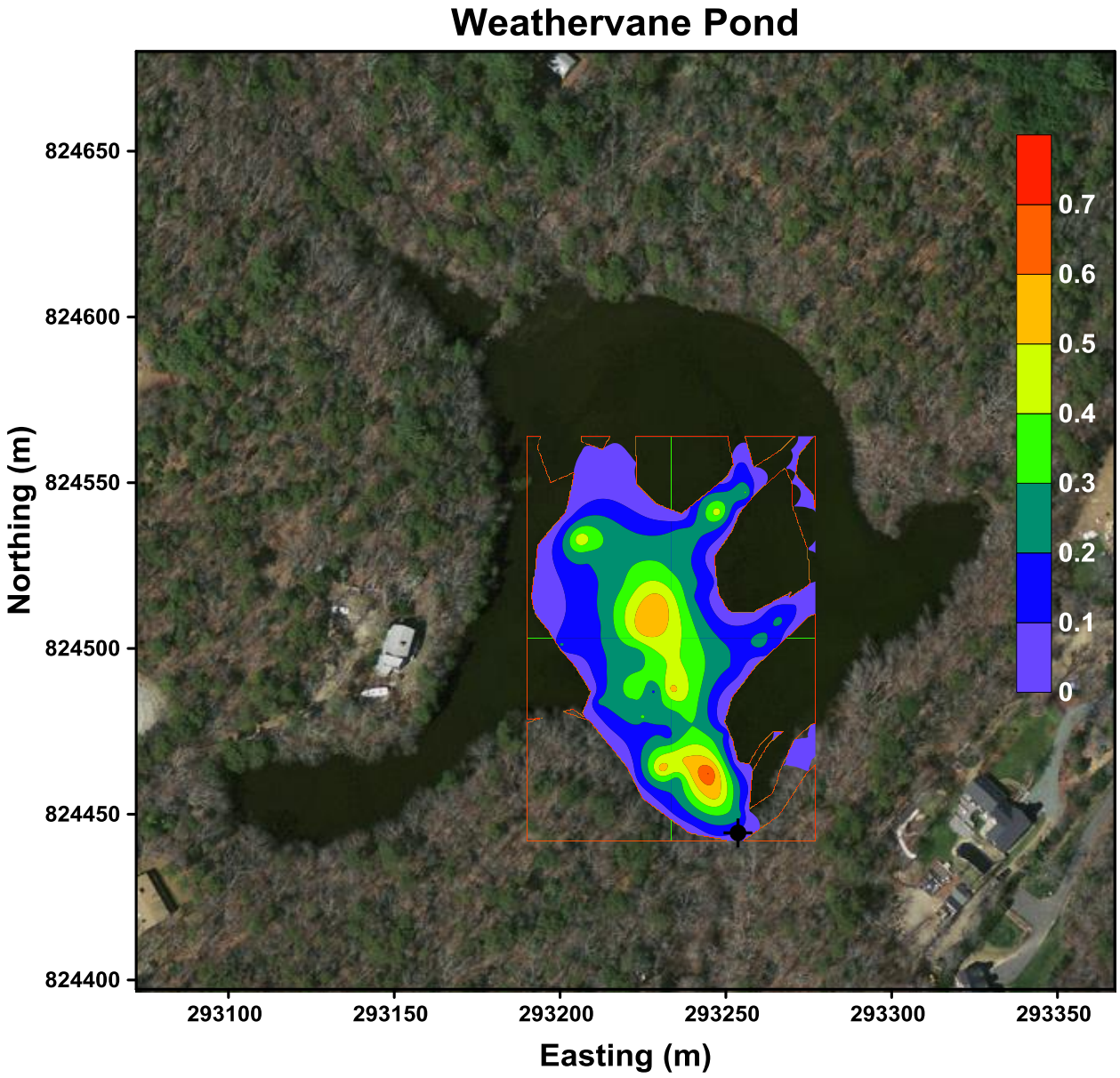
Area (acres): 4.98
Bathymetry: CSP, 2016
Maximum Depth (m): 0.9
Lake Association:
:

PALS Sampling	Sept 2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.65		
Total Depth	0.65		
Surface pH	6.21	6.5 – 8.3	MassDEP
Deepest DO	8.86	5.0 mg/L	MassDEP
Shallow temp	19.6	28.3°C	MassDEP
Surface Chlorophyll-a	1.99 µg/L	1.7 µg/L	CCC
Surface TP	31.35 µg/L	10 µg/L	CCC
Surface TN	0.98 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

OVERVIEW
Weathervane Pond is located in Marstons Mills, north of Lumbert Pond. Shoreline development includes only four houses located along the southern and western shore. Water enters the Pond from a stream in the north and exits through a control structure where the samples were taken. The pond is an abandoned cranberry bog. At the time of sampling more than half the pond was dry. Access was through trail system located off Weathervane Way.

WATER QUALITY
Weathervane Pond was very shallow with clear water during the 2016 sampling. Temperatures and dissolved oxygen readings showed a well-mixed water column with DO near saturation. Shallow total phosphorus concentration was three times the ecoregion threshold, while the shallow chlorophyll-a concentration was just above its threshold. Shallow total nitrogen concentration was also three times its threshold.

Based on the available information, Weathervane Pond is mesotrophic according to the average TSI of 46±6.7 (P=50; Chl=41; Secchi=NA). Additional monitoring at higher water levels would be required to confirm this assessment.



Sampling Location (WGS84): N 41.6647, W 70.5802
(NAD83): E 293256, N 824443

Ben's Pond

Barnstable GIS ID: 105
CCC GIS ID: BA-391

Area (acres): 13.83
Bathymetry: CSP, 2016
Maximum Depth (m): 0.9
Lake Association:

PALS Sampling	9/14/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.65 m		
Total Depth	0.65 m		
Surface pH	6.72	6.5 – 8.3	MassDEP
Deepest DO	6.87 mg/L	5.0 mg/L	MassDEP
Shallow temp	23.2°C	28.3°C	MassDEP
Surface Chlorophyll-a	2.97 µg/L	1.7 µg/L	CCC
Surface TP	30.51 µg/L	10 µg/L	CCC
Surface TN	1.15 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

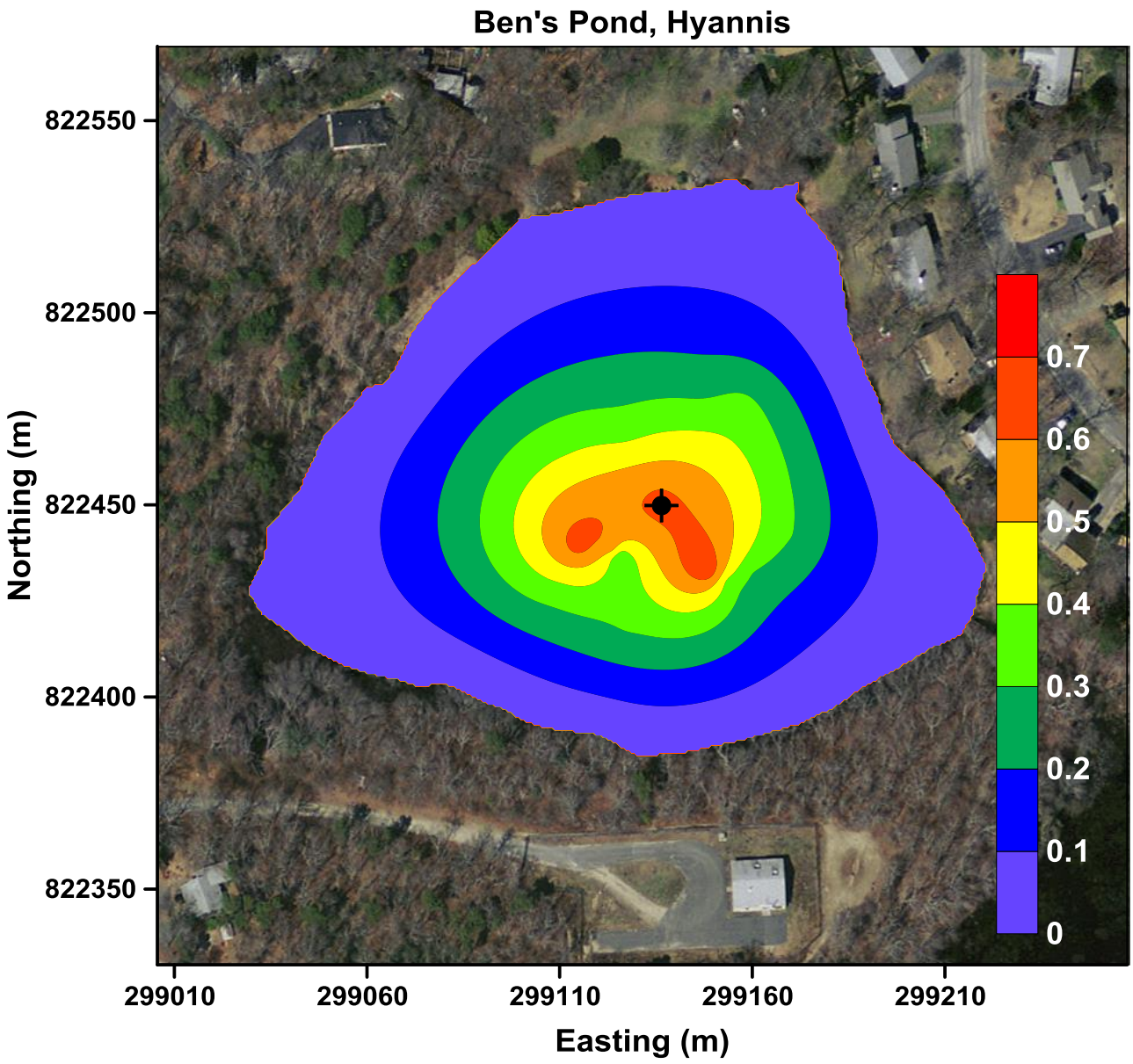
OVERVIEW

Ben's Pond is located in Hyannis, north of water department parcel which includes Simmons Pond. Shoreline development is sparse with seven houses on the eastern shoreline. Abutters claim that Ben's Pond was once connected to a small bog to the south. There is no formal public access.

WATER QUALITY

Ben's Pond is very shallow, generally less than 30cm deep at the time of the 2016 sampling. Temperatures and dissolved oxygen readings were within the standard limits, however, the values for DO were surprisingly depressed considering the extremely shallow depth (78% of saturation). Total phosphorus and total nitrogen concentrations were three times the ecoregion threshold, while the chlorophyll-a concentration was twice the threshold. The water surface was almost entirely covered with water lilies, milfoil, and emergent grasses.

Based on the available information, Ben's Pond is mesotrophic according to the average TSI of 50±4.5 (P=53; Chl=47; Secchi=NA). Additional monitoring would be required to confirm this assessment as water levels were extremely low and the extent of macrophytes was difficult to assess. .



Sampling Location (WGS84): N 41.646, W 70.310
(NAD83): E 299136, N 822451

North Pond

Barnstable GIS ID: 009
CCC GIS ID: BA-816

Area (acres): 4.85
Bathymetry: CSP, 2016
Maximum Depth (m): 3.4
Lake Association

PALS Sampling	9/13/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.45 m		
Total Depth	3.40 m		
Surface pH	6.10	6.5 – 8.3	MassDEP
Deepest DO	0.18 mg/L	5.0 mg/L	MassDEP
Shallow temp	24.0°C	28.3°C	MassDEP
Surface Chlorophyll-a	7.07 µg/L	1.7 µg/L	CCC
Surface TP	33.9 µg/L	10 µg/L	CCC
Surface TN	0.73 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	2.35		

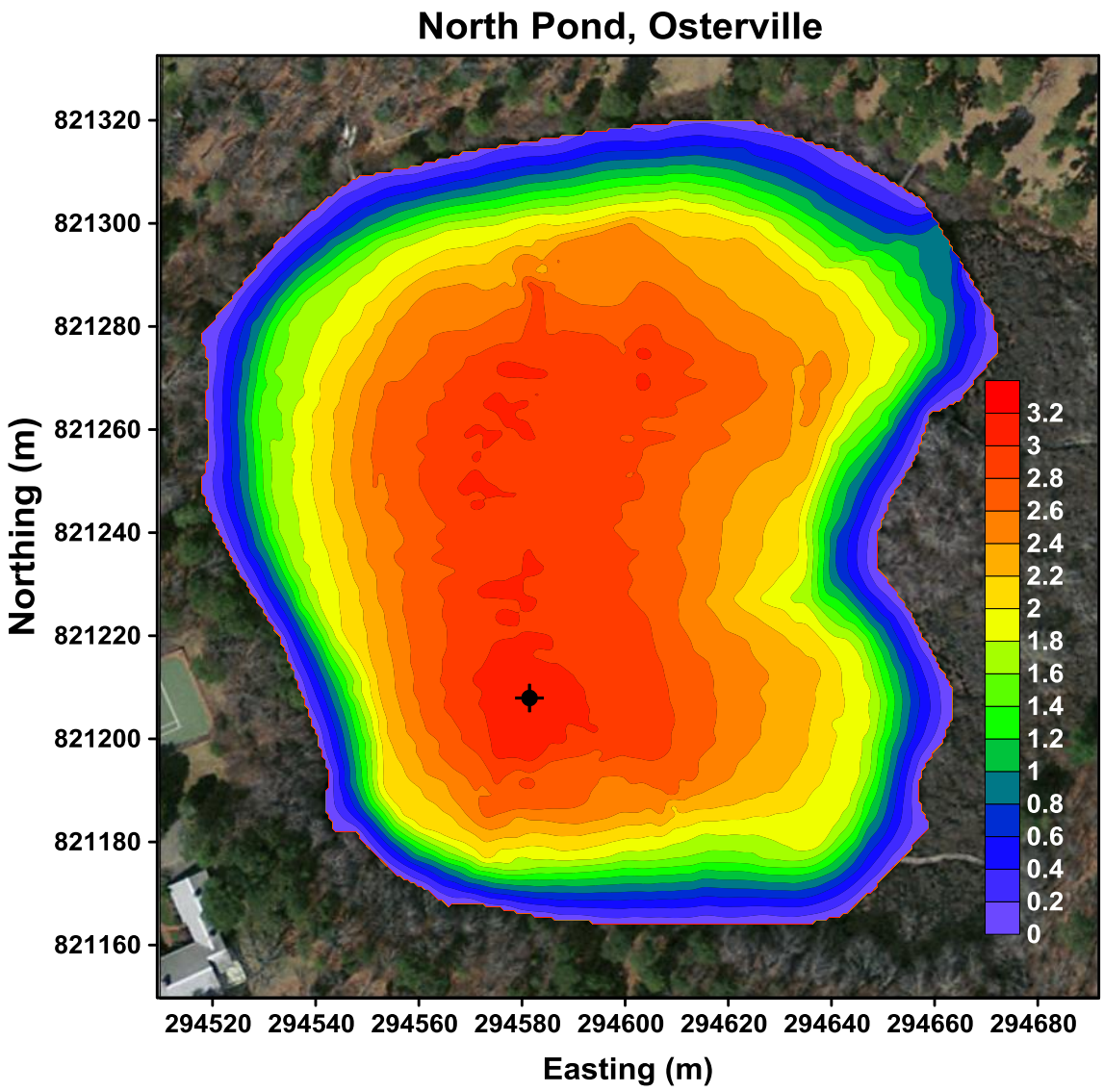
OVERVIEW

North Pond is located in Osterville just north of Coleman Pond. Shoreline development is fairly sparse with eight houses around its shoreline with most of these located along the southern, western and northern shore. A large bog covers most of the eastern shoreline. There is no formal public access.

WATER QUALITY

North Pond is relatively shallow with light nearly penetrating to the bottom at the time of the 2016 sampling. Temperatures and dissolved oxygen readings showed a stratified water column. DO at the surface was near saturation, however the mid water column was supersaturated (107%). The water column became anoxic at a depth of 2.5 m. Shallow total phosphorus concentration was three times above the ecoregion threshold, while the shallow chlorophyll-a concentration was nearly four times its threshold. Shallow total nitrogen concentration was above its threshold by a factor of two and a half. The deep total phosphorus and total nitrogen concentrations were highly elevated above the shallow concentration, which indicated some sediment regeneration of nutrients due to prolonged anoxia. Deep chlorophyll concentrations more than twenty times the ecoregion threshold suggests that an algal bloom developed in response to phosphorus release from the anoxic sediments.

Based on the available information, North Pond eutrophic according to the average TSI of 62±6.3 (P=64; Chl=67; Secchi=55).



Sampling Location (WGS84): N 41.6354, W 70.3648
(NAD83): E 294582, N 821208

Fresh Hole Pond

Barnstable GIS ID: 076
CCC GIS ID: BA-662

Area (acres): 4.67
Bathymetry: CSP, 2016
Maximum Depth (m): 1.3
Lake Association:

PALS Sampling	9/7/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.30 m		
Total Depth	1.50 m		
Surface pH	6.16	6.5 – 8.3	MassDEP
Deepest DO	7.69 mg/L	5.0 mg/L	MassDEP
Shallow temp	23.4°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.1 µg/L	1.7 µg/L	CCC
Surface TP	27.12 µg/L	10 µg/L	CCC
Surface TN	0.81 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

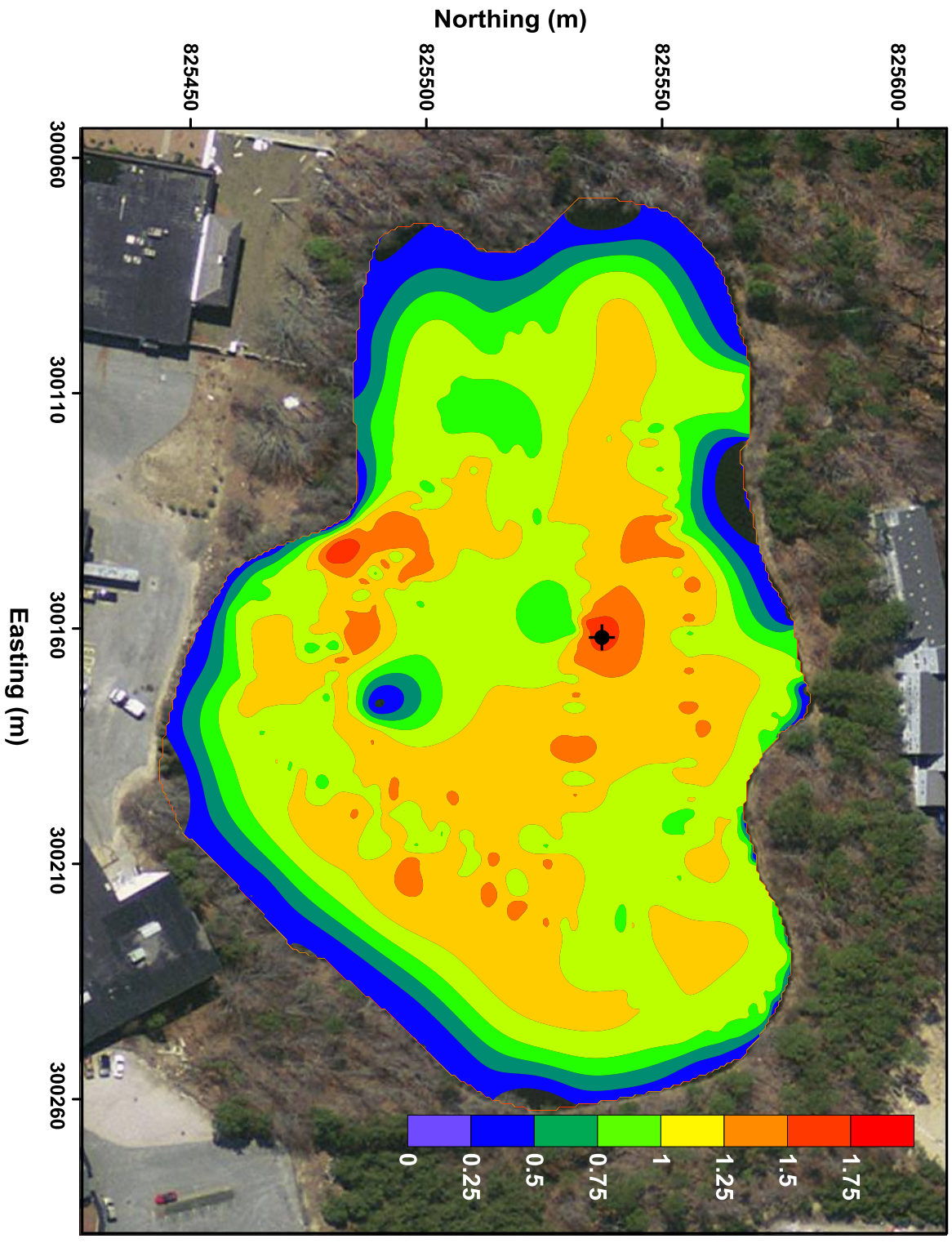
OVERVIEW

Fresh Hole Pond is located in Hyannis between Attucks, Independence, and Airport Roads. Shoreline development is primarily commercial with large swaths of parking lots contributing to significant storm runoff and the presence of trash and floatables along the shore.. There is no formal public access, though the commercial parking lots and loading areas provide an easy place to potage small craft.

WATER QUALITY

Fresh Hole Pond is very shallow with light penetration to the bottom.. Temperatures and dissolved oxygen readings showed a well-mixed water column with 89% saturation throughout. Total phosphorus and total nitrogen concentrations were two and a half times the ecoregion threshold, while the chlorophyll-a concentration was just below its threshold. This apparent anomaly may be due to the particularly high concentration of floating algae near the sampling station.

Based on the available information, Fresh Hole Pond is mildly eutrophic according to the average TSI of 51±5.4 (P=52; Chl=46; Secchi=56). Quantification of storm runoff from impermeable surfaces would be an important addition to identify nutrient loading into the pond.



Sampling Location (WGS84): N 41.6737, W 70.2971
(NAD83): E 300162, N 825537

Campground Pond

Barnstable GIS ID: 096
CCC GIS ID: BA-574

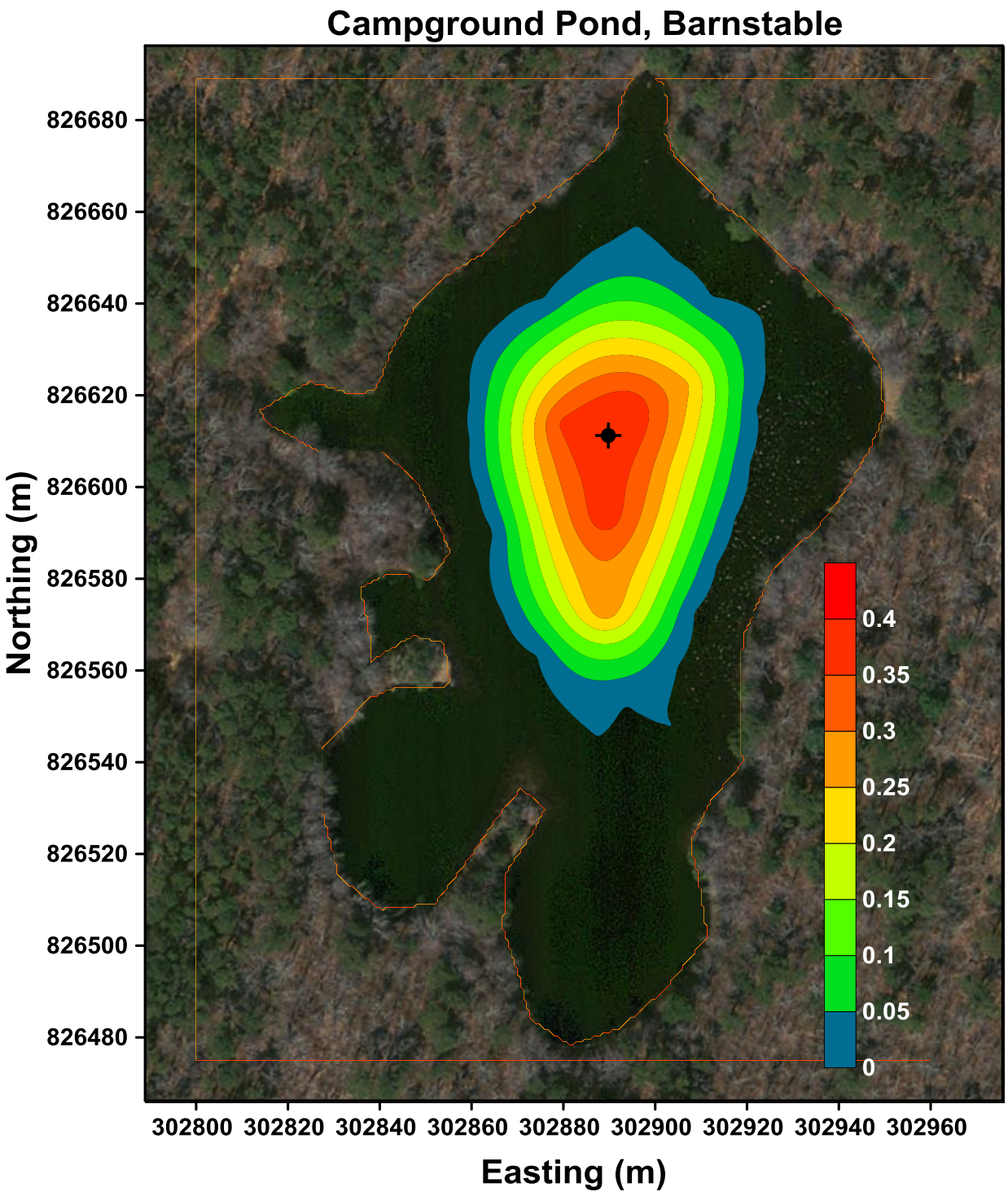
Area (acres): 3.69
Bathymetry: CSP, 2016
Maximum Depth (m): 0.4
Lake Association:
:

PALS Sampling	9/7/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.40 m		
Total Depth	0.40 m		
Surface pH	4.42	6.5 – 8.3	MassDEP
Deepest DO	-	5.0 mg/L	MassDEP
Shallow temp	-	28.3°C	MassDEP
Surface Chlorophyll-a	1.40 µg/L	1.7 µg/L	CCC
Surface TP	0.85 µg/L	10 µg/L	CCC
Surface TN	84 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

OVERVIEW
Campground Pond is located in Barnstable north of Lamsons Pond. Shoreline development is limited to 10 houses along the northeast. Access is off Oak Avenue with permission of home owners association.

WATER QUALITY
Campground Pond is very shallow; at the time of sampling the pond occupied less than half of its high water area. Temperatures and dissolved oxygen readings were not able to be taken, but were unlikely to have varied more than 10% from saturation. Shallow total phosphorus concentration was well below the ecoregion threshold, while the shallow chlorophyll-a concentration was just below its threshold. Shallow total nitrogen concentration was well above its threshold. The nutrient concentrations seem anomalous. Since the pond was too shallow for any boat it is possible that samples were contaminated by detritus resuspended by footsteps.

Based on the available information, Campground Pond health cannot be determined. Additional monitoring is suggested.



Sampling Location (WGS84): N 41.6830, W 70.2642
(NAD83): E 302889, N 826611

Flax Pond

Barnstable GIS ID: 102
CCC GIS ID: BA-473

Area (acres): 3.16
Bathymetry: CSP, 2016
Maximum Depth (m): 0.75
Lake Association:

PALS Sampling	9/9/2016		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	0.75 m		
Total Depth	0.75 m		
Surface pH	5.71	6.5 – 8.3	MassDEP
Deepest DO	5.01 mg/L	5.0 mg/L	MassDEP
Shallow temp	23.1°C	28.3°C	MassDEP
Surface Chlorophyll-a	21.48 µg/L	1.7 µg/L	CCC
Surface TP	47.45 µg/L	10 µg/L	CCC
Surface TN	1.13 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

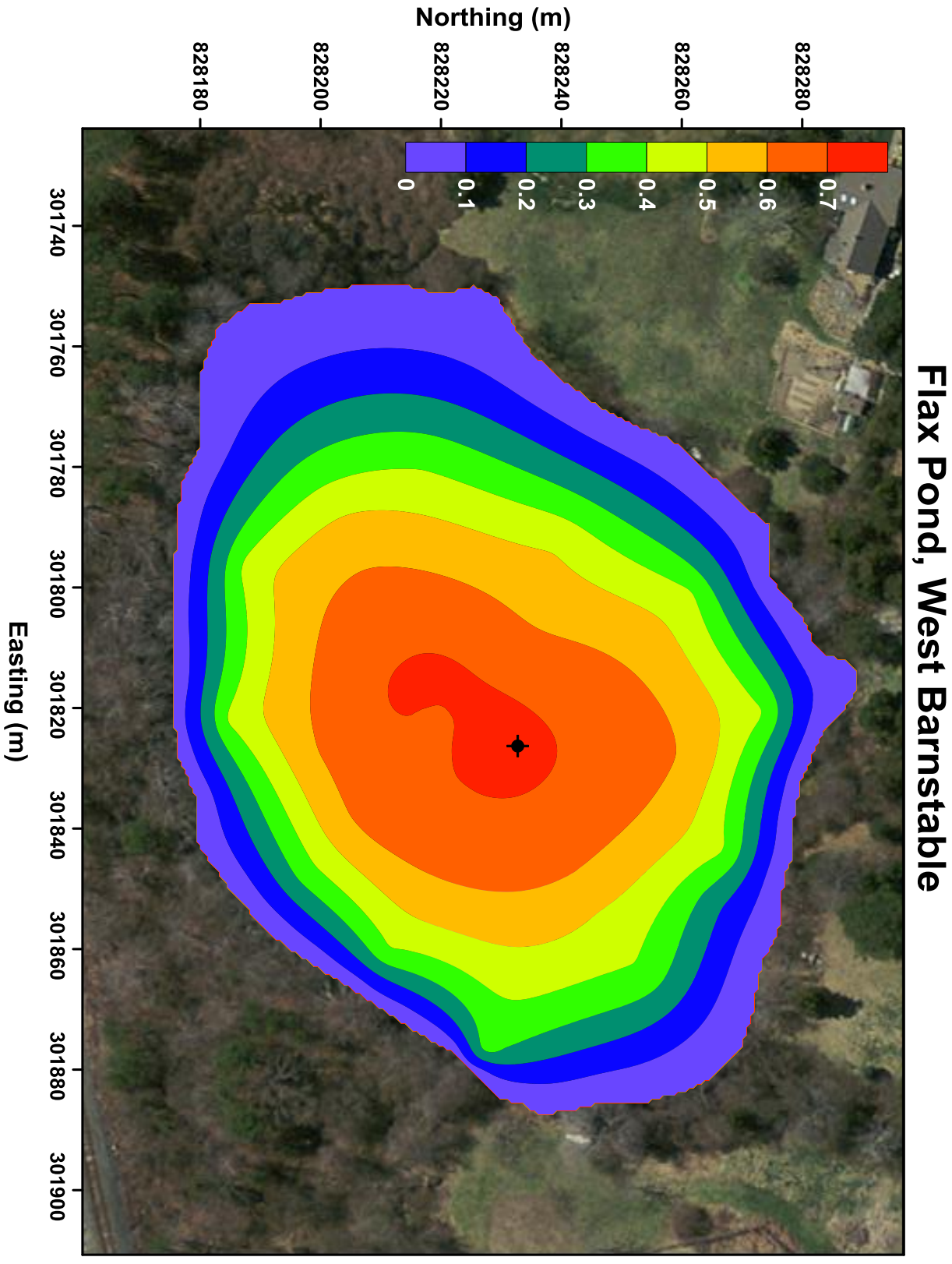
OVERVIEW

Flax Pond is located in West Barnstable, south of Rt 6A and west of Mary Dunn Rd. Shoreline development is fairly sparse with seven houses around its shoreline, with some lots undeveloped. Most of these houses are located to the north and west of the pond. There is no formal public access, rehabilitation center fronting Rt. 6A provided permission for easy access.

WATER QUALITY

Flax Pond is very shallow with nearly 100% coverage by macrophytes at the time of sampling. Temperatures suggest that mixing occurs but, dissolved oxygen readings showed depressed DO values throughout the water column with bottom levels 70% of saturation. All nutrient values were well in excess of the standards. .

Based on the available information, Flax Pond is eutrophic according to the average TSI of 62±3.0 (P=60; Chl=64; Secchi=NA). All measures indicate that additional monitoring is warranted.



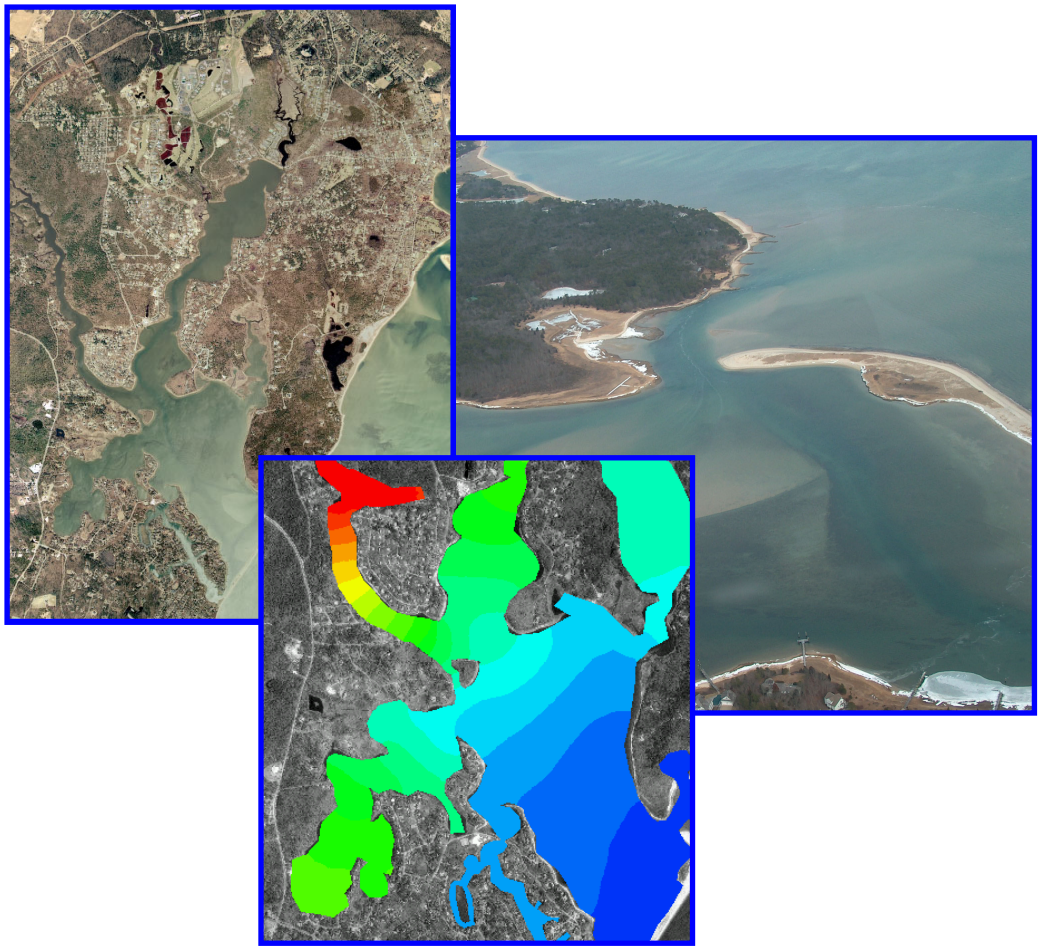
Sampling Location (WGS84): N 41.704, W 70.274
(NAD83): E 301826, N 828233

Appendix T

MEP Technical Report for Popponesset Bay; MEP, September 2004.

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts



University of Massachusetts Dartmouth
School of Marine Science and Technology

Massachusetts Department of
Environmental Protection

FINAL REPORT – SEPTEMBER 2004

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts

FINAL REPORT – SEPTEMBER 2004

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I. INTRODUCTION

The Popponesset Bay System is located within the Towns of Mashpee (north & west) and Barnstable (east), on Cape Cod Massachusetts with a southern shore bounded by water from Nantucket Sound (Figure I-1). The Bay's watershed is distributed among the Towns of Mashpee, Barnstable and Sandwich. It should be noted that Town of Sandwich does have jurisdiction over land and associated land uses in the uppermost portions of the overall watershed to Popponesset Bay. Specifically, portions of the Popponesset Bay watershed that exist within the Town of Sandwich are generally situated above the Mashpee-Wakeby Pond system with the exception of a small area immediately above Wakeby Pond that lies within the Town of Mashpee. As such, in order to achieve effective restoration of Popponesset Bay, it is critical that all three towns (Barnstable, Mashpee, and Sandwich) constituting the total Popponesset Bay watershed be involved in nutrient management discussions. Land uses closest to the embayment are likely to have greater impact than those in the upper portions of the watershed which are subject to nitrogen attenuation during transport through natural aquatic systems (e.g. ponds, rivers, wetlands etc.) prior to discharge to the embayment.

The present Bay results from tidal flooding of drowned river valleys formed primarily by the Mashpee and Santuit Rivers as a result of rising sea level. The Bay is separated from Nantucket Sound by a barrier spit, which grew from the southwestern shore. The spit, Popponesset Beach, as a barrier spit, is a very dynamic geomorphic feature. The Bay exchanges tidal water with Nantucket Sound through a single maintained inlet. The shore to the north of the inlet has been stabilized with riprap, as is the heavily residential southern portion of Popponesset Beach. The current spit is significantly shorter than seen in 1880 Barnstable County or 1938 USGS topographic maps, where the tip of the spit extended north to Rushy Marsh.

The estuarine region of the Popponesset Bay System is composed of a large lower basin, Popponesset Bay, and multiple tributary sub-embayments (Ockway Bay, Pinquickset Cove, Shoestring Bay, Mashpee River, Popponesset Creek). These sub-embayments constitute important components of the Town's natural and cultural resources. In addition, the large number of sub-embayments greatly increases the System's shoreline and decreases the travel time of groundwater from the watershed recharge areas to bay regions of discharge. The nature of enclosed embayments in populous regions brings two opposing elements to bear: as protected marine shoreline they are popular regions for boating, recreation, and land development; as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the Popponesset Bay system and its sub-embayments along the Mashpee and Barnstable shores are at risk of eutrophication (over enrichment) from high nitrogen loads in the groundwater and runoff from their watersheds.

The primary ecological threat to Popponesset Bay embayment system as a coastal resource is degradation resulting from nutrient enrichment. Although the watershed and the Bay have some organic contamination and bacterial contamination issues, these do not appear to be having large System-wide impacts. Organic contamination has been identified associated with an abandoned junkyard in Forestdale (J. Braden Thompson site) where a groundwater plume containing trichloroethylene and tetrachloroethylene is discharging to the surface waters of Mashpee-Wakeby Pond in the upper watershed to the Bay. In addition, a small volatile organic compound plume associated with the former Augat site (on Rt. 28) is discharging

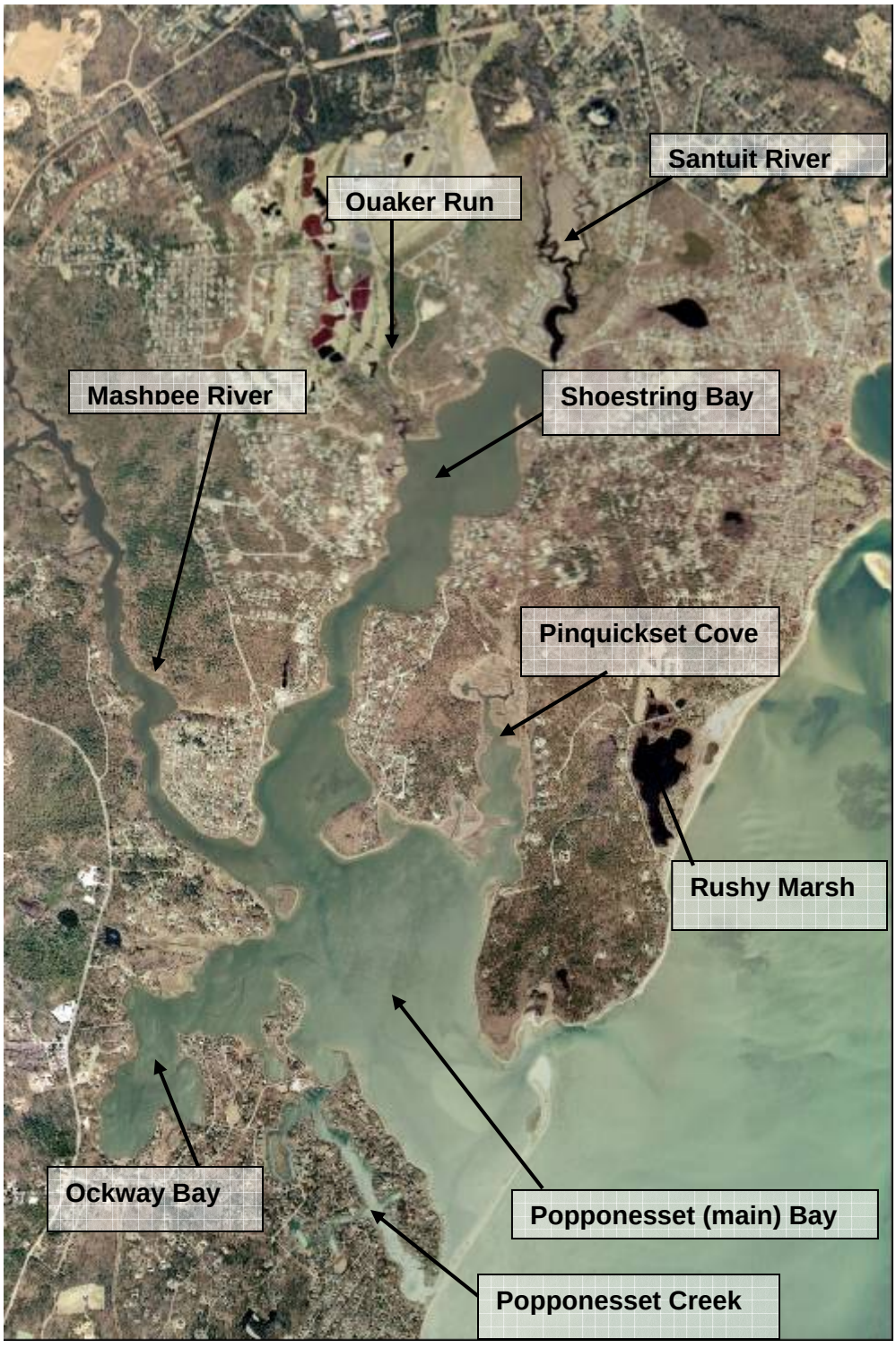


Figure I-1. Study region for the Massachusetts Estuaries Project analysis of the Popponesset Bay System. Tidal waters enter the Bay through the single inlet from Nantucket Sound. Freshwaters enter from the watershed primarily through 3 surface water discharges (Mashpee River, Santuit River, Quaker Run) and direct groundwater discharge. Rushy Marsh is a separate embayment with a direct tidal connection to Nantucket Sound.

directly to Shoestring Bay. Bacterial contamination causes closures of shellfish harvest areas periodically within the Bay System. In contrast, loading of the critical eutrophying nutrient, nitrogen, to the Bay waters has been greatly increased over the past few decades with further increases certain unless nitrogen management is implemented. The nitrogen loading to the Bay, like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater. The Town of Mashpee has been among the fastest growing towns in the Commonwealth over the past two decades and does not have centralized wastewater treatment; although several small privately operated facilities operate within the Popponesset Bay watershed. As existing and probable increasing levels of nutrients impact Mashpee's coastal embayments, water quality degradation will accelerate, with further harm to invaluable environmental resources.

As the primary stakeholder to the Popponesset Bay System, the Town of Mashpee was the first community to become concerned over perceived degradation of Bay waters. The concern over declining habitat quality followed significant on-going efforts to preserve open space within the Mashpee River sub-watershed, most recently related to the Mashpee National Wildlife Refuge (1995). This concern led to one of the first ecological studies of contamination within the estuary, by KV Associates completed in 1991. This effort attempted to develop a plan for managing contamination in the Mashpee and Shoestring Bay estuaries. By the mid-1990's phytoplankton and macroalgal blooms had raised the declining quality of the Bay into the realm of general discussion. The Town of Mashpee through its Board of Selectman, Watershed Management Committee, Waterways Commission and Shellfish Department began the Popponesset Bay Water Quality Monitoring Program in July 1997, in concert with the Cotuit Waders of the Town of Barnstable and SMAST (then the Center for Marine Science and Technology). Initial results from 1997 and 1998, indicated nutrient, chlorophyll a and dissolved oxygen conditions were consistent with significant eutrophication within the Mashpee River, Ockway Bay and Shoestring Bay (Howes and Schlezinger 1998).

The Monitoring Program was then expanded (in recent years with formal Town of Barnstable participation) and has continued through summer 2003 to provide baseline water quality data for the MEP. Preliminary land-use analysis of the watershed to the Popponesset Bay embayment system supported the view that the habitat decline within this large estuarine system was being caused by increased nitrogen inputs from the surrounding watershed due to expanding commercial and residential development (Cape Cod Commission 1998). In 1998 and 1999 the Town of Mashpee allocated funds for a project to quantitatively assess nutrient sources and model nitrogen levels within the System with SMAST scientists. Since it was becoming clear that nitrogen restoration of the Bay would likely require some traditional wastewater treatment approaches, the on-going ecological assessment and modeling project was wrapped into the Town's Wastewater Facilities Planning effort by the Mashpee Sewer Commission. Under the direction of the Mashpee Sewer Commission and the Town of Barnstable DPW, the Popponesset Bay System was included in the first round prioritization of the Massachusetts Estuaries Project to provide state-of-the-art analysis and modeling. However, given that the MEP was able to fully integrate the Towns' on-going data collection and modeling effort, no additional municipal funds were required for MEP tasks.

The common focus of the Mashpee and Barnstable effort has been to gather site-specific data on the current nitrogen related water quality throughout the Popponesset Bay System and determine its relationship to watershed nitrogen loads. This seven-year effort has provided the baseline information required for determining the link between upland loading, tidal flushing, and estuarine water quality. The MEP effort builds upon the Water Quality Monitoring Program, and

previous hydrodynamic and water quality analyses, and includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for each major sub-embayment. These critical nitrogen targets and the link to specific ecological criteria form the basis for the nitrogen threshold limits necessary to complete wastewater master planning and nitrogen management alternatives development needed by the Towns of Mashpee and Barnstable. While the completion of this complex multi-step process of rigorous scientific investigation to support watershed based nitrogen management has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, the results stem directly from the efforts of large number of Town staff and volunteers over many years. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns of Mashpee and Barnstable to develop and evaluate the most cost effective nitrogen management alternatives to restore this valuable coastal resource which is currently being degraded by nitrogen overloading.

I.1 THE MASSACHUSETTS ESTUARIES PROJECT APPROACH

Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The nutrients are primarily related to changes in watershed land-use associated with increasing population within the coastal zone over the past half century. Many of Massachusetts' embayments have nutrient levels that are approaching or are currently over this assimilative capacity, which begins to cause declines in their ecological health. The result is the loss of fisheries habitat, eelgrass beds, and a general disruption of benthic communities. At its higher levels, enhanced loading from surrounding watersheds causes aesthetic degradation and inhibits even recreational uses of coastal waters. In addition to nutrient related ecological declines, an increasing number of embayments are being closed to swimming, shellfishing and other activities as a result of bacterial contamination. While bacterial contamination does not generally degrade the habitat, it restricts human uses. However like nutrients, bacterial contamination is related to changes in land-use as watershed become more developed. The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities.

The primary nutrient causing the increasing impairment of the Commonwealth's coastal embayments is nitrogen and the primary sources of this nitrogen are wastewater disposal, fertilizers, and changes in the freshwater hydrology associated with development. At present there is a critical need for state-of-the-art approaches for evaluating and restoring nitrogen sensitive and impaired embayments. Within Southeastern Massachusetts alone, almost all of the municipalities (as is the case with the Towns of Mashpee and Barnstable) are grappling with Comprehensive Wastewater Planning and/or environmental management issues related to the declining health of their estuaries.

Municipalities are seeking guidance on the assessment of nitrogen sensitive embayments, as well as available options for meeting nitrogen goals and approaches for restoring impaired systems. Many of the communities have encountered problems with "first generation" watershed based approaches, which do not incorporate estuarine processes. The appropriate method must be quantitative and directly link watershed and embayment nitrogen conditions. This "Linked" Modeling approach must also be readily calibrated, validated, and implemented to support planning. Although it may be technically complex to implement, results must be understandable to the regulatory community, town officials, and the general public.

The Massachusetts Estuaries Project represents the next generation of watershed based nitrogen management approaches. The Massachusetts Department of Environmental Protection (MA DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool for watershed-embayment management for communities throughout Southeastern Massachusetts.

The Massachusetts Estuary Project is founded upon science-based management. The Project is using a consistent, state-of-the-art approach throughout the region's coastal waters and providing technical expertise and guidance to the municipalities and regulatory agencies tasked with their management, protection, and restoration. The overall goal of the Massachusetts Estuaries Project is to provide the DEP and municipalities with technical guidance to support policies on nitrogen loading to embayments. In addition, the technical reports prepared for each embayment system will serve as the basis for the development of Total Maximum Daily Loads (TMDLs). Development of TMDLs is required pursuant to Section 303(d) of the Federal Clean Water Act. TMDLs must identify sources of the pollutant of concern (in this case nitrogen) from both point and non-point sources, the allowable load to meet the state water quality standards and then allocate that load to all sources taking into consideration a margin of safety, seasonal variations, and several other factors. In addition, each TMDL must contain an outline of an implementation plan. For this project, the DEP recognizes that there are likely to be multiple ways to achieve the desired goals, some of which are more cost effective than others and therefore, it is extremely important for each Town to further evaluate potential options suitable to their community. As such, DEP will likely be recommending that specific activities and timelines be further evaluated and developed by the Towns (sometimes jointly) through the Comprehensive Wastewater Management Planning process.

In appropriate estuaries, TMDL's for bacterial contamination will also be conducted in concert with the nutrient effort (particularly if there is a 303d listing). However, the goal of the bacterial program is to provide information to guide targeted sampling for specific source identification and remediation. As part of the overall effort, the evaluation and modeling approach will be used to assess available options for meeting selected nitrogen goals, protective of embayment health.

The major Project goals are to:

- provide technical analysis and supporting documentation to Towns as a basis for sound nutrient management decision making towards embayment restoration
- develop a coastal TMDL working group for coordination and rapid transfer of results,
- determine the nutrient sensitivity of each of the 89 embayments in Southeastern MA
- provide necessary data collection and analysis required for quantitative modeling,
- conduct quantitative TMDL analysis, outreach, and planning,
- keep each embayment's model "alive" to address future municipal needs.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. This approach represents the "next generation" of nitrogen management strategies. It fully links watershed inputs with embayment circulation and nitrogen characteristics. The Linked Model builds on and refines well accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied for watershed nitrogen management in approximately 15 embayments throughout Southeastern Massachusetts. In these applications it has become clear that the Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options.

The Linked Watershed-Embayment Model when properly parameterized, calibrated and validated for a given embayment becomes a nitrogen management planning tool, which fully supports TMDL analysis. The Model facilitates the evaluation of nitrogen management alternatives relative to meeting water quality targets within a specific embayment. The Linked Watershed-Embayment Model also enables Towns to evaluate improvements in water quality relative to the associated cost. In addition, once a model is fully functional it can be "kept alive" and updated for continuing changes in land-use or embayment characteristics (at minimal cost). In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

Linked Watershed-Embayment Model Overview: The Model provides a quantitative approach for determining an embayment's: (1) nitrogen sensitivity, (2) nitrogen threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2). This methodology integrates a variety of field data and models, specifically:

- Monitoring - multi-year embayment nutrient sampling
- Hydrodynamics -
  - embayment bathymetry
  - site specific tidal record
  - current records (in complex systems only)
  - hydrodynamic model
- Watershed Nitrogen Loading
  - watershed delineation
  - stream flow (Q) and nitrogen load
  - land-use analysis (GIS)
  - watershed N model
- Embayment TMDL - Synthesis
  - linked Watershed-Embayment N Model
  - salinity surveys (for linked model validation)

- rate of N recycling within embayment
- D.O record
- Macrophyte survey
- Infaunal survey

I.2 SITE DESCRIPTION

The Popponesset Bay embayment system exchanges tidal water with Nantucket Sound through a single maintained inlet at the tip of Popponesset Beach. For the MEP analysis, the Popponesset Bay estuarine system has been partitioned into five general sub-embayment groups: the 1) Popponesset (main) Bay, 2) Pinquickset Cove, 3) Ockway Bay, 4) Mashpee River (lower or tidal region) and 5) Shoestring Bay (see Figure I-1). Popponesset Creek was considered as part of the Popponesset (main) Bay in the modeling and thresholds analysis.

Within the Popponesset Bay System, the tidal portion of the Mashpee River shows the clearest estuarine characteristics, with extensive salt marsh area, tidal flats and large salinity fluctuations. In contrast, Popponesset Bay, Shoestring Bay and Ockway Bay show more typical embayment characteristics dominated by open water areas, having only fringing salt marshes, relatively stable salinity gradients and relatively large basin volumes relative to tidal prism. Although the four sub-embayment systems bounding the main open water portion of Popponesset Bay (Pinquickset Cove, Ockway Bay, Mashpee River lower, and Shoestring Bay) exhibit different hydrologic characteristics (river dominated versus tidally dominated), the tidal forcing for these systems is generated from Nantucket Sound. Nantucket Sound, adjacent Popponesset Beach, exhibits a moderate to low tide range, with a mean range of about 2.5 ft. Since the water elevation difference between Nantucket Sound and Popponesset Bay is the primary driving force for tidal exchange, the local tide range naturally limits the volume of water flushed during a tidal cycle (note the tide range off Stage Harbor Chatham is ~4.5 ft, Wellfleet Harbor is ~10 ft).

Tidal damping (reduction in tidal amplitude) through an embayment can range from negligible indicating “well-flushed” conditions or show tidal attenuation caused by constricted channels and marsh plains indicating a “restrictive” system, where tidal flow and the associated flushing are inhibited. Tidal data indicate only minimal tidal damping through Popponesset Bay inlet. It appears that the tidal inlet is operating efficiently, possibly due to the active inlet maintenance program. Similarly, within the Popponesset Bay System, the tide propagates to the sub-embayments with negligible attenuation, consistent with generally well-flushed conditions throughout.

Given the present hydrodynamic characteristics of the Popponesset Bay System, it appears that estuarine habitat quality is more dependent on nutrient loading to bay waters than tidal characteristics within the component sub-embayments.

Nitrogen loading to the Popponesset Bay System was determined relative to five (5) sub-embayments: Pinquickset Cove, Ockway Bay, Mashpee River (lower or tidal region), Shoestring Bay, and Popponesset Bay. The watershed for this estuarine system contains approximately 13,000 acres, dominated by single-family residences. Commercial and residential land-uses primarily in the southern portion of Mashpee and in the Barnstable region create a large nutrient load to the Popponesset Bay System. The nitrogen loading from the more heavily populated areas of the Town of Mashpee is focused on the northern reaches of the estuarine system.

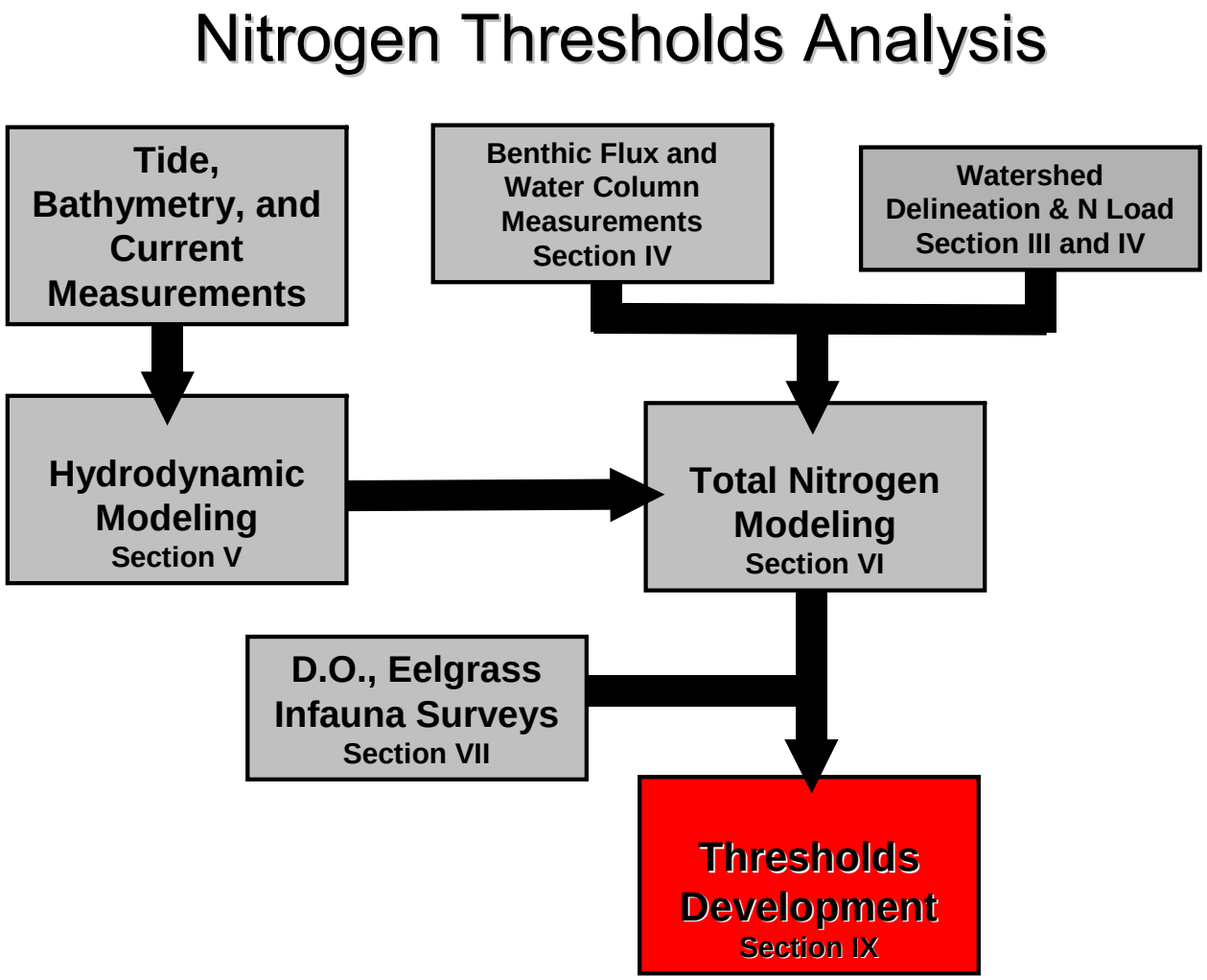


Figure I-2. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

System wide, approximately three quarters of the nitrogen load from single-family dwellings enters the Shoestring Bay sub-embayment as well as the tidally influenced lower reach of the Mashpee River.

As management alternatives are being developed and evaluated, it is important to note that Popponesset Bay is a relatively dynamic system. The spit forming Popponesset Beach is continually expanding and eroding, once nearly reaching the inlet channel to the Three Bays System to the north. The spit frequently experiences periodic over wash (Aubrey and Gaines 1982). The present inlet position is relatively new, resulting from a breach of the spit in the hurricanes of 1954. Similarly, within the main Bay, several islands apparent 50 -100 years ago have been incorporated into other landforms with unquantified effects on the circulation of Bay waters. Thatch Island and Little Thatch Island within the lower main Bay have "joined" with the spit, most likely due to a combination of the natural processes of overwash of the barrier beach and shoreline retreat. Daniels Island, at the entrance to Ockway Bay, has been joined to the mainland by filled causeways, apparently filling salt marshes and changing the local circulation pattern.

Hydrodynamics have also been altered within Popponesset Creek due to dredging and channelization of wetlands. Within the watershed there have been changes to the freshwater systems which attenuate nitrogen during transport to bay waters. Most notable have been the modification to riparian zones either through channelization, restriction, or filling of freshwater wetlands and, in some cases, transformation to cranberry agriculture. Most of the alterations have reduced the nutrient buffering capacity of these systems, magnifying the nitrogen loading to the bay. However, the predominant watershed alteration has been the shifting of fields and pine-oak forest to residential and commercial development, with its resultant increasing nitrogen input to the watershed, aquifer and ultimately bay waters. This recent shift in land-use has likely resulted in this estuary receiving its highest rates of nitrogen loading than at any period over the past 400 years. Previous large shifts in land-use, primarily from forest to agriculture did not have the same resultant enhancement in nitrogen loading as agriculture generally recycled nitrogen (as opposed to commercial fertilizers) and the population was <10% of today. The present year-round population per square mile is greater than the entire town population of 50 years ago (total population based on 2000 census for Towns of Mashpee, Sandwich, and Barnstable are 12,946, 20,136 and 47,821 respectively). It appears that the nitrogen attenuation capacity of the freshwater systems may have been reduced, as the need to intercept the nitrogen loading to the watershed has increased. While this may be a partial cause of the present estuarine decline, it may also represent a potential opportunity for restoration of bay systems.

I.3 NUTRIENT LOADING

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the Popponesset Bay System, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even Cape Cod "rivers" are primarily groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1998, Weiskel and Howes 1992, Smith *et al.* 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal

estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within Popponesset Bay follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. Because nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 and in press, Ramsey et al., 1995, Howes and Taylor, 1990, and the Falmouth Coastal Overlay Bylaw). While each approach may be different, they all focus on changes in nitrogen loading from watershed to embayment, and aim at projecting the level of increase in nitrogen concentration within the receiving waters. Each approach depends upon estimates of circulation within the embayment; however, few directly link the watershed and hydrodynamic models, and virtually none include internal recycling of nitrogen (as was done in the present effort). However, determination of the “allowable N concentration increase” or “threshold nitrogen concentration” used in previous studies had a significant uncertainty due to the need for direct linkage of watershed and embayment models and site-specific data. In the present effort we have integrated site-specific data on nitrogen levels and the gradient in N concentration throughout the Popponesset Bay System monitored by the Popponesset Bay Water Quality Monitoring Program with site-specific habitat quality data (D.O., eelgrass, phytoplankton blooms, benthic animals) to “tune” general nitrogen thresholds typically used by the Cape Cod Commission, Buzzards Bay Project, and Massachusetts State Regulatory Agencies.

Unfortunately, almost all of the estuarine reaches within the Popponesset Bay System (including Popponesset Bay) are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout the System and eelgrass has not been observed for over a decade. The result is that nitrogen management of the primary sub-embayments is aimed at restoration, not protection or maintenance of existing conditions. In general, nutrient over-fertilization is termed “eutrophication” and when the nutrient loading is primarily from human activities, “cultural eutrophication”. Although the influence of human-induced changes has increased nitrogen loading to the systems and contributed to the degradation in ecological health, it is sometimes possible that eutrophication within Popponesset Bay’s sub-embayments could potentially occur without man’s influence and must be considered in the nutrient threshold analysis. While this finding would not change the need for restoration, it would change the approach and potential targets for management. As

part of future restoration efforts, it is important to understand that it may not be possible to turn each embayment into a “pristine” system.

I.4 WATER QUALITY MODELING

Evaluation of upland nitrogen loading provides important “boundary conditions” (e.g. watershed derived and offshore nutrient inputs) for water quality modeling of the Popponesset Bay Systems; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within each system. Therefore, water quality modeling of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. The spread of pollutants may be analyzed from tidal current information developed by the numerical models.

The MEP water quality evaluation examined the potential impacts of nitrogen loading into the Popponesset Bay System, including the tributary sub-embayments of Mashpee River, Ockway Bay, Shoestring Bay, Pinquickset Cove and the Popponesset Bay central basin. A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for each of the systems. Once the hydrodynamic properties of each estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates.

Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic models were then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis, based upon watershed delineations by USGS using a modification of the West Cape model for sub-watershed areas designated by MEP. Almost all nitrogen entering Popponesset Bay is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Nantucket Sound source waters and throughout the Popponesset Bay System were taken from the Popponesset Bay Water Quality Monitoring Program (supported by the Towns of Mashpee and Barnstable, associated with the Coastal Systems Program at SMAST). Measurements of current salinity and nitrogen and salinity distributions throughout estuarine waters of the System were used to calibrate and validate the water quality model (under existing loading conditions).

I.5 REPORT DESCRIPTION

This report presents the results generated from the implementation of the Massachusetts Estuaries Project linked watershed-embayment approach to the Popponesset Bay System for the Towns of Mashpee (lead) and Barnstable. A review of existing water quality studies is provided (Section II). The development of the watershed delineations and associated detailed land use analysis for watershed based nitrogen loading to the coastal system is described in Sections III and IV. In addition, nitrogen input parameters to the water quality model are described. Since benthic flux of nitrogen from bottom sediments is a critical (but often overlooked) component of nitrogen loading to shallow estuarine systems, determination of the site-specific magnitude of this component also was performed (Section IV). Nitrogen loads

from the watershed and sub-watershed surrounding the estuary were derived from Cape Cod Commission data and offshore water column nitrogen values were derived from an analysis of monitoring stations in Nantucket Sound (Section IV). Intrinsic to the calibration and validation of the linked-watershed embayment modeling approach is the collection of background water quality monitoring data (conducted by municipalities) as discussed in Section IV. Results of hydrodynamic modeling of embayment circulation are discussed in Section V and nitrogen (water quality) modeling, as well as an analysis of how the measured nitrogen levels correlate to observed estuarine water quality are described in Section VI. This analysis includes modeling of current conditions, conditions at watershed build-out, and with removal of anthropogenic nitrogen sources. In addition, an ecological assessment of the component sub-embayments was performed that included a review of existing water quality information and the results of a benthic analysis (Section VII). The modeling and assessment information is synthesized and nitrogen threshold levels developed for restoration of the Bay in Section VIII. Additional modeling is conducted to produce an example of the type of watershed nitrogen reduction required to meet the determined Bay threshold for restoration. This latter assessment represents only one of many solutions and is produced to assist the Town in developing a variety of alternative nitrogen management options for this system. Finally, analyses of the Popponesset Bay System was relative to potential alterations of circulation and flushing, including an analysis to identify hydrodynamic restrictions and an examination of dredging options to improve nitrogen related water quality. The results of the nitrogen modeling for each scenario have been presented (Section IX).

II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

In most marine and estuarine systems, such as the Popponesset Bay embayment system, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if nitrogen addition is controlled, then eutrophication is controlled. This approach has been formalized through the development of tools for predicting nitrogen loads from watersheds and the concentrations of water column nitrogen that may result. Additional development of the eutrophication management approach via the reduction of nitrogen loads generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2002).

Until recently, these tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specifics for any given water body. The present Massachusetts Estuaries Project (MEP) study focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species. The linked watershed-embayment model is built using embayment specific measurements, thus enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including the Popponesset Bay System.

A major component of the MEP nutrient analysis is the evaluation of hydrodynamics within the estuarine system. A two-dimensional hydrodynamic and water quality model was previously developed by Aubrey Consulting, Inc. (ACI, 1994). The purpose of this modeling effort was to assess potential impacts of nitrogen loading resulting from the proposed expansion of a sewage treatment plant. Field measurements of water elevations and bathymetry were taken to parameterize the hydrodynamic modeling effort; however, dispersion coefficients for the water quality modeling portion of the study were based upon previous studies of similar estuaries. The water quality modeling portion of the analysis utilized simplified assumptions regarding the incremental effects of increasing nitrogen loads to the estuarine system. It did not include a rigorous evaluation of all nitrogen sources to the estuary and did not include nitrogen sinks. The MEP analysis presented in this report provides a comprehensive analysis of nutrients within the Popponesset Bay estuary; therefore, results from the less rigorous 1994 analysis have been superceded.

Results from the 1994 hydrodynamic modeling study of flushing rates within the Popponesset Bay estuary indicate that central Popponesset Bay is relatively well flushed, since Popponesset Bay is generally shallow and the tide range is significant relative to embayment depth. At the time of this pilot hydrodynamic study greater than 50 percent of the water within the estuary was exchanged during a typical tidal cycle. The sub-embayments (located within the upper portions of the estuary system) to Popponesset Bay, however, show long residence times and receive a high percentage of the nutrient load to the Popponesset Bay system.

Following the initial hydrodynamic modeling effort, the Town of Mashpee, through the Mashpee Waterways Commission, funded a hydrodynamic study focusing on the effects of dredging on tidal flushing within the tidal portion of the Mashpee River (Hamilton, 1996 and 1998). Additional data was utilized to parameterize this model, including updated tide data from 1997 and updated bathymetry data from 1996. Initial modeling efforts (Hamilton, 1996) indicated a measurable reduction in the Mashpee River residence time as a result of dredging, indicating a potential water quality improvement. In later communications (Hamilton, 1998), this

conclusion was changed to indicate that feasible dredging scenarios do not significantly benefit Mashpee River flushing. Although the 1998 study indicated minor improvements to the hydrodynamic model, it is unclear how these modifications were responsible for the substantial change in model results.

For the MEP modeling analysis, the data from the previous studies were evaluated relative to the needs of the Linked Watershed-Embayment Model. Bathymetric data associated with the 1994 study was cursory and was not collected relative to a known tidal datum (e.g. NGVD29) as required for MEP. In addition, the tidal information also was not related to a known tidal datum, rather the tide data was related to a computed mean tide level, which is the average water elevation from the 30-day record. These data shortcomings and recent alterations to the system bathymetry (specifically in the vicinity of Popponesset Bay inlet) necessitated the collection of both bathymetry and tide data to support the MEP analysis.

Based on the above findings, a revised hydrodynamic analysis of the Popponesset Bay system, biological and chemical measurements, and a water quality model were developed that used the tidal flushing inputs and simulated the calculated and measured nitrogen loads to the embayments. This model was then calibrated in a process that rationalizes the resulting calculated water column concentrations with measured values from monitoring programs over the past four years. The water quality model then becomes a predictive tool for evaluating the effects of various nitrogen loading scenarios on nitrogen concentrations in the embayments.

The concern about excessive nitrogen loading to the water bodies in the Mashpee study area is evidenced by the number of studies and analyses conducted over the past 10 years. As early as 1984 attention was being given to possible water quality problems within Popponesset Bay whereby James Begley of the D.E.Q.E. Shellfish Sanitation Section identified excessive levels of coliform bacterial contamination in the Mashpee River. This finding promptly led to closure of the Mashpee River to shellfishing. Contamination problems in Popponesset Bay were further investigated by K-V Associates, Inc. on behalf of the Mashpee Planning Department and Planning Board. Initial concerns over contamination problems in Popponesset Bay resulted in the development of a Interim Report (October 1987) entitled “Sources of Bacterial and Nutrient Contamination into the Mashpee River, Santuit River and Shoestring Bay.” This initial report was followed by a second report also completed by K-V Associates, Inc. in 1988 that examined storm discharges (under winter conditions) to Popponesset Bay as well as undertook recharge zone delineations for the Mashpee River, Quaker Run and the Santuit River. In addition, data on Mashpee River flow and water quality was developed and compiled by Goldberg-Zoino and Associates in a July 1988 report prepared in conjunction with the Mashpee Sewer Commission’s work on a sub-regional wastewater treatment facility proposed to be located adjacent to the former Mashpee landfill. It was clear from the initial studies that the Popponesset Bay System is nutrient overloaded. Based upon water quality indicators (chlorophyll a, total nitrogen, bottom water dissolved oxygen) much of the System would be classified as eutrophic (KV Associates 1984, Howes and Schlezinger 1997, 1998). This section summarizes these studies in chronological order to help put the present study in historical perspective.

One of the first identified studies that address nutrient contamination problems in Popponesset Bay is a Cumulative Impact Assessment performed by K-V Associates, Inc. (1991). The analysis presented in the K-V assessment (1991) supported a plan to reduce and control sources of contamination in the Mashpee River and Santuit River/Shoestring Bay estuaries to Popponesset Bay. However, the overall nutrient data was somewhat limited and suffered from inadequate method detection limits. In addition, the significant development that

has occurred in the intervening years suggests that these data do not reflect current conditions. In addition, this study focused primarily upon the upper bay sub-embayments and the rivers. It did not include a comprehensive land-use analysis and did not account for nitrogen dynamics within the aquatic systems. However, it did point out many of the nutrient issues that continue to be relevant and are to be examined through the MEP analysis.

The Cape Cod Commission (CCC) undertook the Cape Cod Coastal Embayment Project that indicated that nutrient loading to the Popponesset Bay system, which includes the Mashpee River, Shoestring Bay, and Ockway Bay, is a significant problem. The data was based upon the 1996 watershed delineations. Due to the difference in watershed areas, updating of the land-use analysis and refinement of the watershed nitrogen loading model component of the MEP approach, the results from the MEP are different and supersede those of this earlier study.

The most recent survey of nutrient related water quality in the Popponesset Bay embayment system was performed by the University of Massachusetts – Dartmouth, School for Marine Science and Technology (SMAST) (Howes and Schlezinger, 1997) The goal of the 1997 water quality survey was to evaluate the relative nutrient related ecological health of the major component embayments to the Popponesset Bay system and determine if there was nutrient related degradation of the sub-systems to Popponesset Bay. Sampling for the survey was conducted during the summer when eutrophication impacts are generally the greatest in Cape Cod embayments as a joint effort by the Town of Mashpee, SMAST, and private citizen volunteers. The survey was conducted during the summer of 1997 and involved 5 periodic field sampling events through the period of July 31 to September 12, 1997. Major findings of the 1997 water quality survey indicate: 1) nitrogen levels within the Popponesset Bay system are significantly higher than the incoming water from Nantucket Sound with resultant enhancement of phytoplankton biomass, 2) both biomass and total nitrogen (TN) are more than 10 and 2 fold higher, respectively, than the high quality water from Nantucket Sound, 3) there is a distinct nutrient and phytoplankton biomass (chlorophyll-a) gradient within the Popponesset Bay system with highest levels for each being Mashpee River>Shoestring Bay>Ockway Bay>Central Bay>Nantucket Sound, 4) oxygen depletions of bottom waters of the sub-embayments to Popponesset Bay is relatively wide spread and frequent within the Mashpee River, Ockway Bay, and Shoestring Bay. At the time of the 1997 survey the central portion of Popponesset Bay still exhibited relatively high water quality.

The water quality data from this preliminary water quality study have been incorporated with data collected in subsequent years by the same group, the Popponesset Bay Water Quality Monitoring Program, which includes private citizens, the Mashpee Shellfish Department, Mashpee Harbor Master, Mashpee Waterways Commission, Mashpee Watershed Management Committee, Cotuit Waders, and Barnstable DPW (Nutrient Management Committee). The MEP has incorporated all appropriate data from all previous studies to enhance the determination of nitrogen thresholds for the Popponesset Bay System and to reduce costs to the Towns of Barnstable and Mashpee.

III. DELINEATION OF WATERSHEDS

III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). These USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. The USGS has a long history of developing regional models for the six groundwater flow cells on Cape Cod. Through the years, advances in computing, lithologic information from well installations, water level monitoring, stream flow measurements, and reconstruction of glacial history have allowed the USGS to update and refine the groundwater models. The MODFLOW and MODPATH models utilized by to the USGS to organize and analyze the available data utilize up-to-date mathematical codes and create better tools to answer the wide variety of questions related to watershed delineation, surface water/groundwater interaction, groundwater travel time, and drinking water well impacts that have arisen during the MEP analysis of southeastern Massachusetts estuaries, including the Popponesset Bay System.

In the present investigation, the USGS was responsible for the application of its groundwater modeling approach to define the watershed or contributing area to the Popponesset Bay System under evaluation by the Project Team. The Popponesset Bay estuarine system is composed of: the main body of Popponesset Bay, Pinquickset Cove, Ockway Bay, Mashpee River (tidal region), and Shoestring Bay. Further watershed modeling was undertaken to sub-divide the overall watershed to the Popponesset Bay System into functional sub-units based upon: (a) defining inputs from contributing areas to each major sub-embayment within the embayment system (for example Shoestring Bay tributary to the Popponesset Bay System), (b) defining contributing areas to major freshwater aquatic systems which generally attenuate nitrogen passing through them on the way to the estuary (lakes, streams, wetlands), and (c) defining 10 year time-of-travel distributions within each sub-watershed as a procedural check to gauge the potential mass of nitrogen from “new” development, which has not yet reached the receiving estuarine waters. The three-dimensional numerical model employed is also being used to define the contributing areas to public water supply wells on the Sagamore flow cell on Cape Cod as part of a separate Massachusetts DEP effort. Model assumptions for calibration were matched to surface water inputs and flows from current (2002 to 2003) stream gage information.

The relatively transmissive sand and gravel deposits that comprise most of Cape Cod create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by the land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994 a, b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the sources of nitrogen that they carry requires determination of the portion of the watershed that contributes directly to the stream and the portion of the groundwater system that discharges directly into the estuary as groundwater seepage.

Biological attenuation of nitrogen (natural attenuation) occurs primarily within surface aquatic ecosystems (streams, wetlands, ponds) with little occurring within the main aquifer. Biological attenuation of nitrogen is predominantly through denitrification, sometimes directly from nitrate and sometimes indirectly after uptake by plants and remineralization and oxidation back to nitrate in the surface sediments. Burial of decayed plant matter containing nitrogen is

almost always much less important than denitrification in reducing nitrogen transport. The freshwater ponds on Cape Cod provide important environments for the biological attenuation of nitrogen entering them and therefore also require that their contributing areas be delineated. Fresh ponds are hydrologic features directly connected to the groundwater system, which receive groundwater inflow through upgradient shores and discharge water into the aquifer in downgradient areas. Residence time of water within the ponds is a function of pond volume and inflow/outflow rates. Natural nitrogen attenuation is directly related, in part, to residence time.

III.2 MODEL DESCRIPTION

Contributing areas to the Popponesset Bay System and local freshwater bodies were delineated using a regional model of the Sagamore flow cell. The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh, *et al*., 2000) was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program MODPATH4 (Pollock, 2000), which uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. This approach was used to determine the contributing areas to the Popponesset Bay System and also to determine portions of recharged water that may flow through ponds and streams prior to discharging into coastal water bodies.

The Sagamore Flow Model grid consists of 246 rows, 365 columns and 20 layers. The horizontal model discretization, or grid spacing, is 400 by 400 feet. The top 17 layers of the model extend to a depth of 100 feet below sea level and have a uniform thickness of 10 ft. The top of layer 8 resides at sea level with layers 1-7 stacked above sea level to a maximum elevation of +70 feet. In regions like the Sagamore Lens in which the Popponesset Bay System resides, water elevations are greater than 60 ft at the top of the lens and therefore these uppermost layers are required for model operation. At depth within the aquifer, layer 18 has a thickness of 40 feet and layer 19 extends to 240 feet below sea level. The bottom layer, layer 20, extends to the bedrock surface and has a variable thickness depending upon site characteristics.

The glacial sediments that comprise the aquifer of the Sagamore flow cell consist of gravel, sand, silt, and clay that were deposited in a variety of depositional environments. The sediments generally show a fining downward sequence with sand and gravel deposits deposited in glaciofluvial (river) and near-shore glaciolacustrine (lake) environments underlain by fine sand, silt and clay deposited in deeper, lower-energy glaciolacustrine environments. While there are glacial morainal deposits comprising some regions of the aquifer of the Sagamore flow cell, these are generally located adjacent to Buzzards Bay and are not found within the watershed to the Popponesset Bay System. Most groundwater flow in the aquifer occurs in shallower portions of the aquifer dominated by coarser-grained sand and gravel deposits. Lithologic data used to determine hydraulic conductivities used in the model were obtained from a variety of sources including well logs from USGS, local Town records and data from previous investigations. Final aquifer parameters were determined through calibration to observed water levels and stream flows. Hydrologic data used for model calibration included historic water-level data obtained from USGS records and local Towns and water-level and streamflow data collected in May 2002.

The model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Large withdrawals of groundwater

from pumping wells may have a significant influence on water tables and watershed boundaries and therefore the flow and distribution of nitrogen within the aquifer. Since almost all of the Popponesset Bay System watershed is unsewered, 85% of the water pumped from wells was modeled as being returned to the ground via on-site septic systems.

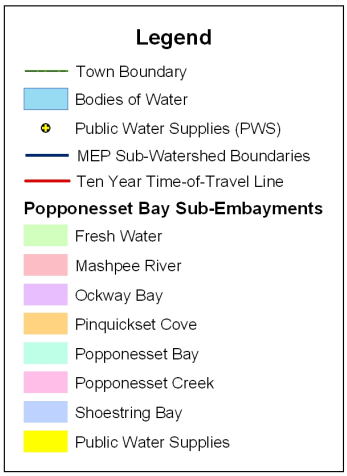
III.3 MASHPEE CONTRIBUTORY AREAS

Revised watershed and sub-watershed boundaries were determined by the United States Geological Survey (USGS) for each of the Popponesset Bay System's five major component sub-embayments (the main body of Popponesset Bay, Pinquickset Cove, Ockway Bay, Mashpee River (estuarine portion), and Shoestring Bay) (Figure III-1). Model outputs of MEP watershed boundaries are "smoothed" (a) to correct for the grid spacing, (b) to enhance the accuracy of the characterization of the shoreline, and (c) to more closely match the sub-embayment segmentation of the tidal hydrodynamic model. The smoothing refinement was a collaborative effort between the USGS and the rest of the MEP Technical Team. Overall, 28 sub-watershed areas were delineated within the watershed to the Popponesset Bay system. Table III-1 provides the daily discharge volumes for various watersheds as calculated by the groundwater model; these volumes were used to assist in the salinity calibration of the tidal hydrodynamic and water quality models. The MEP delineation includes subwatershed delineations to five ponds and public drinking water supply wells and 10 yr time of travel boundaries. Contributing areas for fresh ponds were delineated if the pond covered most of three groundwater model grid cells (400 ft X 400 ft each) generally about 10 acres. The decision to use 3 model grid cells (1 cell is 400 x 400 feet) as a minimum size criteria for ponds to which contributing areas would be developed was based partly on nitrogen attenuation considerations as well as computational complexity. Ponds with a surface area greater than or equal to 10 acres are likely to have the potential for nitrogen attenuation and as such warrant developing a sub-watershed delineation and performing a land use analysis in order to quantify the level of nitrogen attenuation. From a modeling point of view, including ponds less than 10 acres in size adds several degrees of computational complexity thereby making the groundwater models unwieldy with little if any measurable improvement in the watershed nitrogen loading analysis.

The delineations completed for the MEP project are the third delineation in less than 10 years; each delineation has been based on more and better data and has included more subwatersheds. Figure III-2 compares the MEP delineation with the delineations completed for the Cape Cod Commission in 1996 (Eichner, *et al*., 1998) and 2002 (Eichner, *et al*., 2002). The delineation completed in 1996 was based on a water table map developed by the Cape Cod Commission from long-term measurements of groundwater elevations, while the 2002 delineation was completed by the USGS using a previous iteration of the Sagamore Lens groundwater model.

Table III-2 summarizes the differences in watershed areas determined for the Popponesset Bay System from the 3 available delineations. As might be expected, the current MEP delineation agrees quite well with the previous USGS modeling effort in 2002. Overall, the MEP delineation for the System is 7% smaller (900 acres) than the 2002 USGS delineation. The changes in the delineation result from a slight movement of the regional groundwater divide toward the south and a slightly more eastern location for the divide between the Popponesset and Waquoit Bay systems. This latter change in the watershed boundary to the southwest near Nantucket Sound is significant as it relates both to nitrogen loading (area is significantly developed) and to potential groundwater sites which discharge directly to Nantucket Sound. In contrast, the boundary between Popponesset and Three Bays is in the same location.

Map #	Sub-Embayment Name
1	Snake Pond GT10
2	Snake Pond LT10
3	Pimlico Pond GT10
4	Pimlico Pond LT10
5	Peters Pond GT10
6	Peters Pond LT10
7	Mashpee-Wakeby Pond GT10 W
8	Mashpee-Wakeby Pond GT10 E
9	Mashpee-Wakeby Pond LT10
10	Santuit Pond GT10
11	Santuit Pond LT10
12	Upper Mashpee River GT10 W
13	Upper Mashpee River GT10 E
14	Upper Mashpee River LT10
15	Lower Mashpee River GT10
16	Lower Mashpee River LT10
17	Quaker Run
18	Santuit River GT10
19	Santuit River LT10
20	Shoestring Bay GT10
21	Shoestring Bay LT10
22	Pinquickset Cove
23	Ockway Bay GT10
24	Ockway Bay LT10
25	Popponesset Creek
26	Popponesset Bay
27	Quaker Run Well
28	Cotuit Well #5
29	Rock Landing Wells



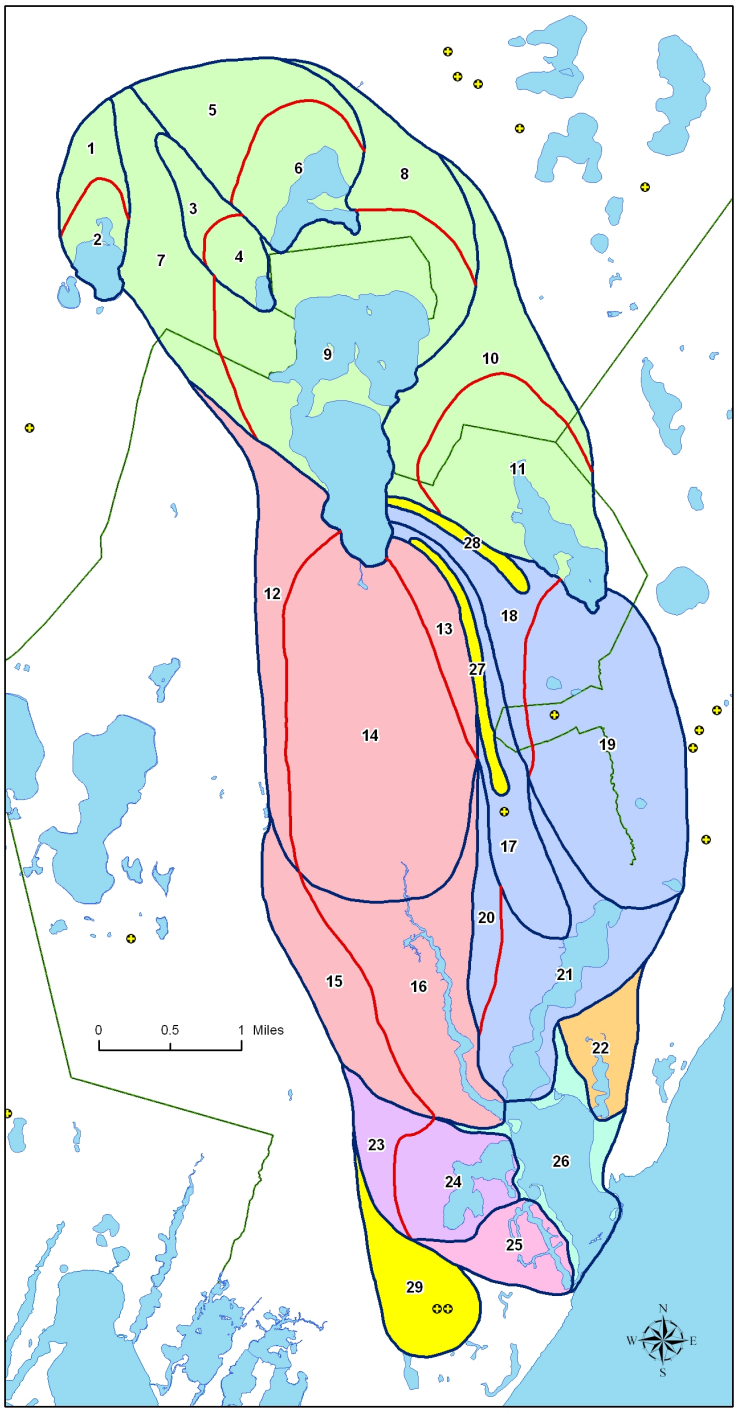


Figure III-1. Watershed and sub-watershed delineations for Popponesset Bay. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a "10" in the figure legend (above at left). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

Table III-1. Long-term average daily groundwater discharge to each of the sub-embayments in the Popponesset Bay system, as determined from the USGS groundwater model.

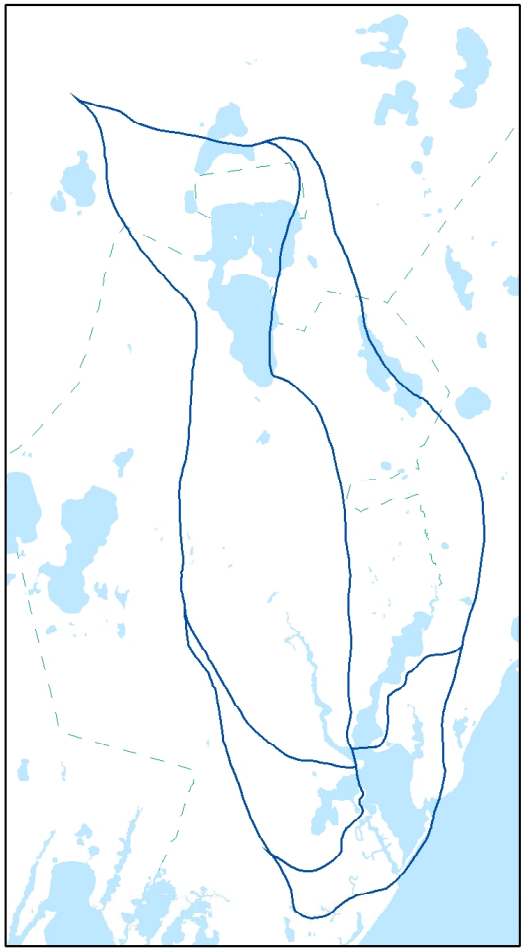
Watershed	Discharge		Watershed	Discharge	
	ft^3/day	m^3/day		ft^3/day	m^3/day
Upper Mashpee River	1,597,053	45,220	Santuit River	709,625	20,093
Lower Mashpee River	204,105	5,780	Quaker Run	131,724	3,730
Ockway Bay	75,887	2,149	Shoestring Bay	146,455	4,148
Pinquickset Cove	54,914	1,555	Popponesset Bay	41,496	1,175
Popponesset Creek	60,596	1,716			

While the MEP and the 2002 USGS delineation generally agree, they are significantly different from the 1996 delineation, both in coverage and acreage. The 2002 delineation expanded the overall area of the system watershed by approximately 2,400 acres as compared to the 1996 delineation. This expansion is mostly due to a more northern location for the regional groundwater divide, which expanded the watersheds to the major ponds (Mashpee-Wakeby, Santuit, and Snake).

Internal subwatershed delineations generally changed ±10-15%, although some of the smaller watersheds had much higher percent changes. For example, the Quaker Run subwatershed was reduced by 53% (253 acres); most of this area was lost to the Mashpee River subwatershed. Ockway Bay subwatershed was reduced by 34% (183 acres); most area was lost to the subwatershed of the Rock Landing public water supply wells. While these shifts do not change the specific sources of nitrogen within the watershed to the Popponesset Bay System, the shifting does potentially affect the amount of natural attenuation of nitrogen during transport. This further enhances the success of future nitrogen management options.

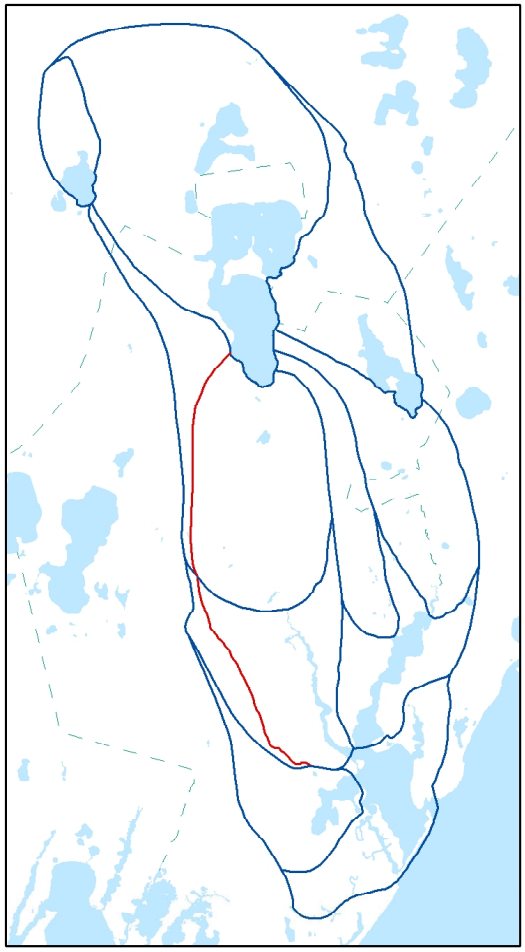
The evolution of the watershed delineations for the Popponesset Bay System have built one on another to increase the underlying hydrologic data underpinning the modeling, thereby increasing the accuracy. This is important as it decreases the level of uncertainty in the final calibrated and validated linked watershed-embayment model used for the evaluation of nitrogen management alternatives. Errors in watershed delineations do not necessarily result in significant errors in nitrogen loading. For example, small errors in watershed area can result in large errors in loading if a large source is counted in or out. Conversely, large errors in watershed area that involve only natural woodlands have little effect on nitrogen inputs to the downgradient estuary. In the case of the Popponesset Bay System, the present level of development and the areas of refinement in the watershed delineations indicate that the current and build-out nitrogen loading estimates were made more accurate through the use of the new delineations.

CCC, 1996.



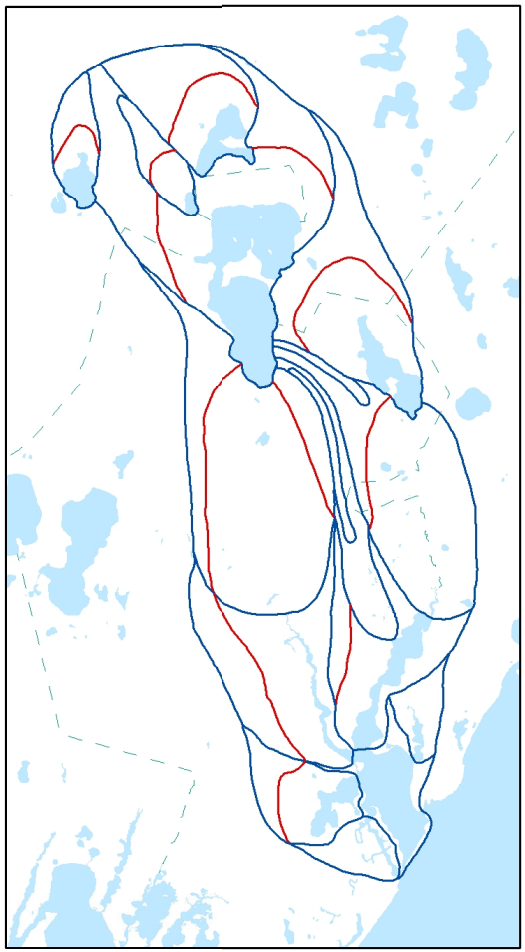
- Used in the 1996 & 2001 Regional Policy Plans. (Eichner, et al., 1998)

USGS, 2002.



- Delineated by USGS (Eichner, et al., 2002.)

MEP, 2004.



- Delineated by USGS for MEP analysis.

** Red lines indicate ten year time-of-travel lines*

Figure III-2. Comparison of previous and current Popponesset Bay watershed and subwatershed delineations.

Table III-2. Percent difference in delineated embayment watershed areas between old and newly revised delineations. Note only 14% of the Snake Pond recharge enters the Popponesset Bay watershed, equivalent to ~20 acres.

Popponesset Bay System	MEP Watershed	2002 Watershed	% difference MEP vs. 2002	1996 Watershed	% difference MEP vs. 1996
WATERSHED	acres	acres		acres	
Mashpee Wakeby Pond	3,474	4,018	-16%	6,042	15%
Upper Mashpee River	2,374	2,616	-10%		
Lower Mashpee River	1,231	1,409	-14%		
Quaker Run	486	742	-53%	3,586	18%
Santuit Pond	1,408	1,396	1%		
Santuit River	1,618	1,422	12%		
Shoestring Bay	879	742	16%		
Ockway Bay	543	726	-34%	1,773	-20%
Lower Popponesset Bay (including Pinquickset Cove and Popponesset Creek)	929	772	17%		
Entire System (excluding Snake Pond)	12,942	13,843	-7%	11,401	12%

IV. WATERSHED NITROGEN LOADING TO EMBAYMENT: LAND USE, STREAM INPUTS, SEDIMENT NITROGEN FLUX AND RECYCLING

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS

Management of nutrient related water quality and habitat health in coastal waters requires determination of the amount of nitrogen transported by freshwaters (surface water flow, groundwater flow) from the surrounding watershed to the receiving embayment of interest. In southeastern Massachusetts, the nutrient of management concern for estuarine systems is nitrogen and this is true for the Popponesset Bay System. Determination of watershed nitrogen inputs to the Popponesset Bay embayment system requires the (a) identification and quantification of the nutrient sources and their loading rates to the land or aquifer, (b) confirmation that a groundwater transported load has reached the embayment at the time of analysis by examining groundwater travel times, and (c) quantification of nitrogen attenuation that can occur during travel through lakes, ponds, streams and wetlands. This latter natural attenuation process is conducted by biological systems that naturally occur within ecosystems. Failure to account for attenuation of nitrogen during transport results in an over-estimate of nitrogen inputs to an estuary and an underestimate of the sensitivity of a system to new inputs (or removals). In addition to the nitrogen transport from land to sea, the amount of direct atmospheric deposition on each embayment surface must be determined as well as the amount of nitrogen recycling within the embayment, specifically nitrogen regeneration from sediments. Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms which may be released to the overlying waters or lost to denitrification within the sediments. Burial of nitrogen is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters and leads to errors in predicting water quality if it is not included in determination of summertime nitrogen load.

The MEP project team includes technical staff from the Cape Cod Commission (CCC). In coordination with other MEP technical team staff, CCC staff developed nitrogen loading rates (Section IV.1) within each of the 28 subwatersheds to the Popponesset Bay embayment system (Section III). After reviewing the percentage of nitrogen loading in the less than 10 year time of travel and greater than 10 year time of travel watersheds (Table IV-1), reviewing Mashpee land use development in 1994 (CCC, 1998) and 2001 in the time of travel watersheds, and reviewing water quality modeling, the 10 year time of travel subwatersheds were eliminated and the number of subwatersheds was reduced to 16. Although the percentage of nitrogen loads in the less than 10-year subwatersheds ranges between 47 and 100%, more than three quarters (76%) of the overall system load is within 10 years flow to Popponesset Bay. The nitrogen loading effort also involved further refinement of watershed delineations to accurately reflect shoreline areas to ponds and embayments.

In order to determine nitrogen loads from large watersheds, detailed individual lot-by-lot data is used for some portion of the loads, while information developed from other detailed studies is applied to other portions. The Linked Watershed-Embayment Management Model (Howes & Ramsey 2001) uses a land-use Nitrogen Loading Sub-Model based upon subwatershed-specific land-uses and pre-determined nitrogen loading rates. For Popponesset Bay, the model used Mashpee, Barnstable, and Sandwich-specific land-use data transformed to nitrogen loads using both regional nitrogen load factors and local site-specific data (such as water use). Determination of the nitrogen loads required obtaining watershed-specific

information regarding wastewater, fertilizers, runoff from impervious surfaces and atmospheric deposition. The primary regional factors were derived for southeastern Massachusetts from direct measurements. The resulting nitrogen loads represent the "potential" nitrogen load to each receiving embayment, since attenuation during transport has not yet been included.

Table IV-1. Percentage of nitrogen loads in less than 10 time of travel subwatersheds to Popponesset Bay

	LT10	GT10	TOTAL	%LT10
WATERSHED	kg/yr	kg/yr	kg/yr	
Mashpee-Wakeby Pond total	4066	2589	6655	61%
Upper Mashpee River	11275	3308	14583	77%
Lower Mashpee River	2728	3071	5799	47%
Santuit Pond	2770	977	3747	74%
Santuit River	8001	2168	10169	79%
Quaker Run	2708		2708	100%
Shoestring Bay	4120	879	4998	82%
Pinquickset Cove	454		454	100%
Popponesset Creek	2285		2285	100%
Popponesset Bay	2316		2316	100%
Ockway Bay	1641	190	1831	90%
TOTAL SYSTEM	42365	13181	55547	76%

Natural attenuation of nitrogen during transport from land-to-sea (Section IV.2) was determined based upon site-specific studies within the freshwater portions of the Mashpee River and the Santuit River. Attenuation during transport through each of the major fresh ponds was determined through (a) comparison with other Cape Cod lake studies and (b) data collected on each pond. Internal nitrogen recycling was also determined within the Popponesset Bay embayment system; measurements were made to capture the spatial distribution of sediment nitrogen regeneration from the sediments to the overlying watercolumn. Nitrogen regeneration focused on summer months, the critical nitrogen management interval and the focal season of the MEP approach and application of the Linked Watershed-Embayment Management Model (Section IV.3).

IV.1.1 Land Use and Database Preparation

Project staff obtained digital parcel and tax assessors data from the Towns of Mashpee, Barnstable, and Sandwich. Mashpee's land use data is from 2001, while Sandwich and Barnstable's data is from 2000. The parcel and assessors databases from the three towns were combined by using the Cape Cod Commission Geographic Information System (GIS) for the MEP analysis.

Figure IV-1 shows the land uses within the study area; assessors land uses classifications (MADOR, 2002) are aggregated into seven land use categories: 1) residential, 2) commercial, 3) industrial, 4) undeveloped, 5) mixed use, 6) golf course, and 7) public service, including road rights-of-way. "Public service" is the land classification assigned by the Massachusetts

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Map #	Sub-Embayment Name
1	Snake Pond
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5	Santuit Pond
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7	Lower Mashpee River
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9	Santuit River
10	Shoestring Bay
11	Pinquickset Cove
12	Ockway Bay
13	Popponesset Creek
14	Popponesset Bay
15	Quaker Run Well
16	Cotuit Well #5

0 0.5 1 Miles

Legend

- MEP Watersheds
- Major Roads
- Numbered Routes
- Other Roads
- Bodies of Water

Land Use *

- Mixed Use
- Residential
- Commercial
- Industrial
- Undeveloped
- Agricultural
- Golf Course
- Public Service

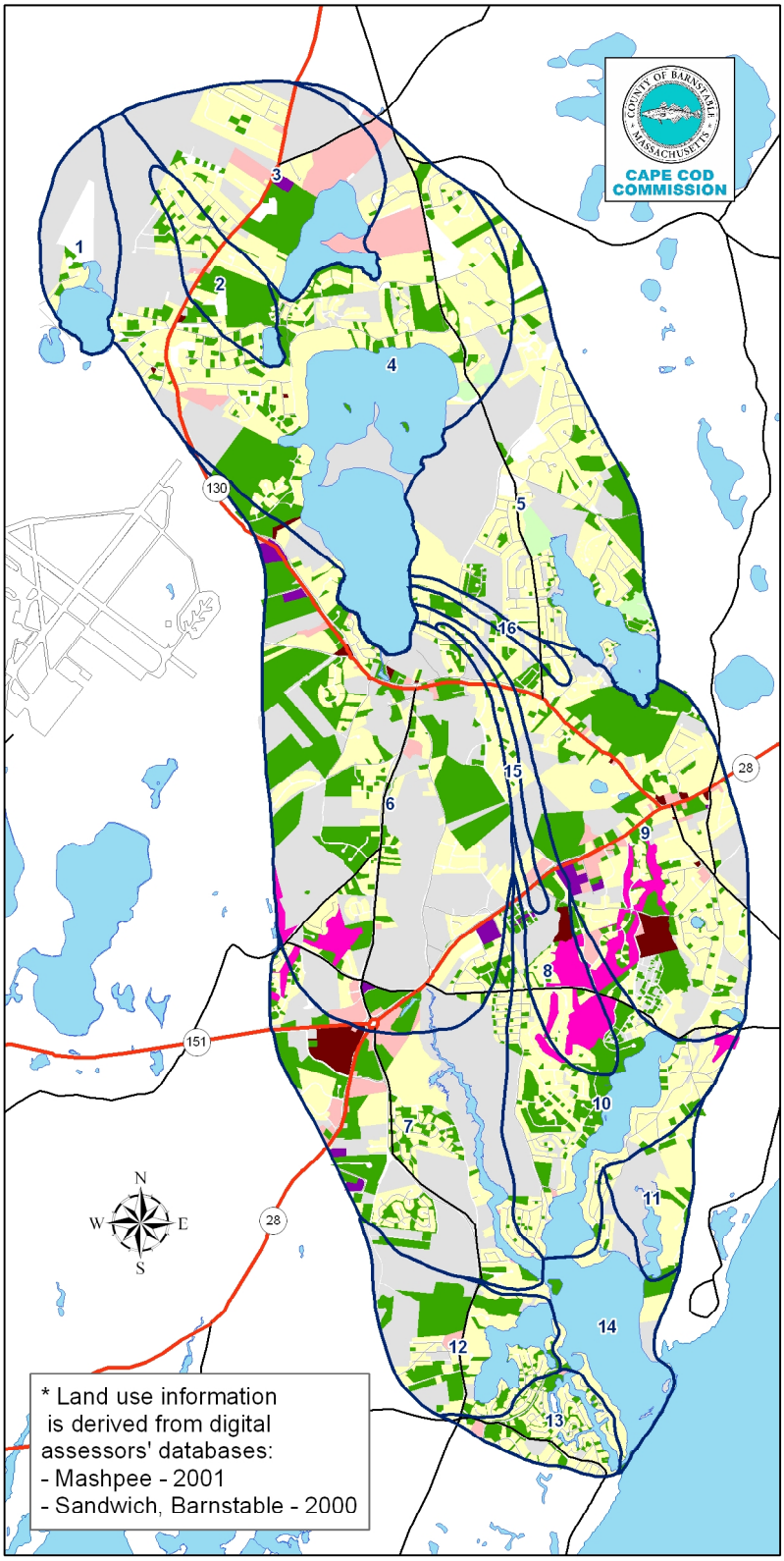

Figure IV-1. Land-use coverage in the Popponesset Bay watershed. Watershed data encompasses portions of the Towns of Mashpee, Barnstable, and Sandwich, MA.

Department of Revenue to tax exempt properties, including lands owned by government (e.g., wellfields, schools, open space, roads) and private groups like churches and colleges. Within the Popponesset Bay subwatersheds, the predominant land use is residential, most of which are single family residences. Single-family residences occupy approximately 13% of the total watershed area to Popponesset Bay and are 67% of the total parcels (Figure IV-2). Commercial properties are located throughout the watershed, with most parcels along Routes 28 and 130. Note that land-use determinations were made within the contributing sub-watersheds to major ponds, river and estuarine basins and to major water supply wells (Quaker Run Well, Cotuit Well #5). In these latter cases, nitrogen withdrawn from the aquifer for potable water distribution was applied as a loss in the nitrogen loading analysis. This nitrogen mass was very small and was redistributed through the water supply.

In order to estimate wastewater flows within the study area, MEP staff also obtained 1997 through 1999 Mashpee Water District water use information from the Mashpee Sewer Commission**,** 1998 through 2000 water use information from the Town of Barnstable, and 1998 through 2000 water use information from the Sandwich Water Department. Water use information was linked to the parcel and assessors data using GIS techniques. In addition to water use information, flow, effluent quality, and the service area information was obtained from the Town of Mashpee and the state Department of Environmental Protection for the four wastewater treatment facilities (WWTFs) operating in the watershed in 1999 to 2000: Mashpee Commons, Willowbend, Stratford Ponds, and Forestdale School (Table IV-2). This information was used instead of water use information to calculate nitrogen loads for parcels within the service areas to these facilities. The WWTFs at Windchime Point and Southcape were constructed after 2000 and, as such, are not included in the nitrogen loads for existing conditions, but are included in the buildout loads.

Table IV-2. Private Wastewater Treatment Facilities in the Popponesset Bay Watershed

System Name	Average Effluent Characteristics		
Facility Name	Flow (gallons per day)	Total Nitrogen Concentration (mg/liter)	Annual Nitrogen Load (kg N/yr)
Mashpee Commons	16,392[a]	2.37[b]	54
Willowbend	14,408[a]	3.15[b]	63
Stratford Ponds	8,902[a]	8.96[b]	110
Forestdale School	951[c]	35[d]	46
Windchime Point[e]	12,700[f]	10[g]	175

Notes: [a] average flow (2000-2002); [b] flow-weighted average concentration (2001-2002); [c] average flow (2000-2003); [d] No apparent TN limit (personal communication, B. Dudley, DEP); [e] Prior to 8/01 all flows treated through on-site septic systems, WWTF information used in buildout analysis; [f] estimated average flow at buildout (153 units) based on flows during 2003 and 2004; [g] state permit concentration. Review of performance data indicates effluent concentrations at estimated buildout flow will be 9.3 mg/l, but given the uncertainty of ramping up the flow, it was determined that the regulatory permit concentration was appropriate for a buildout projection.

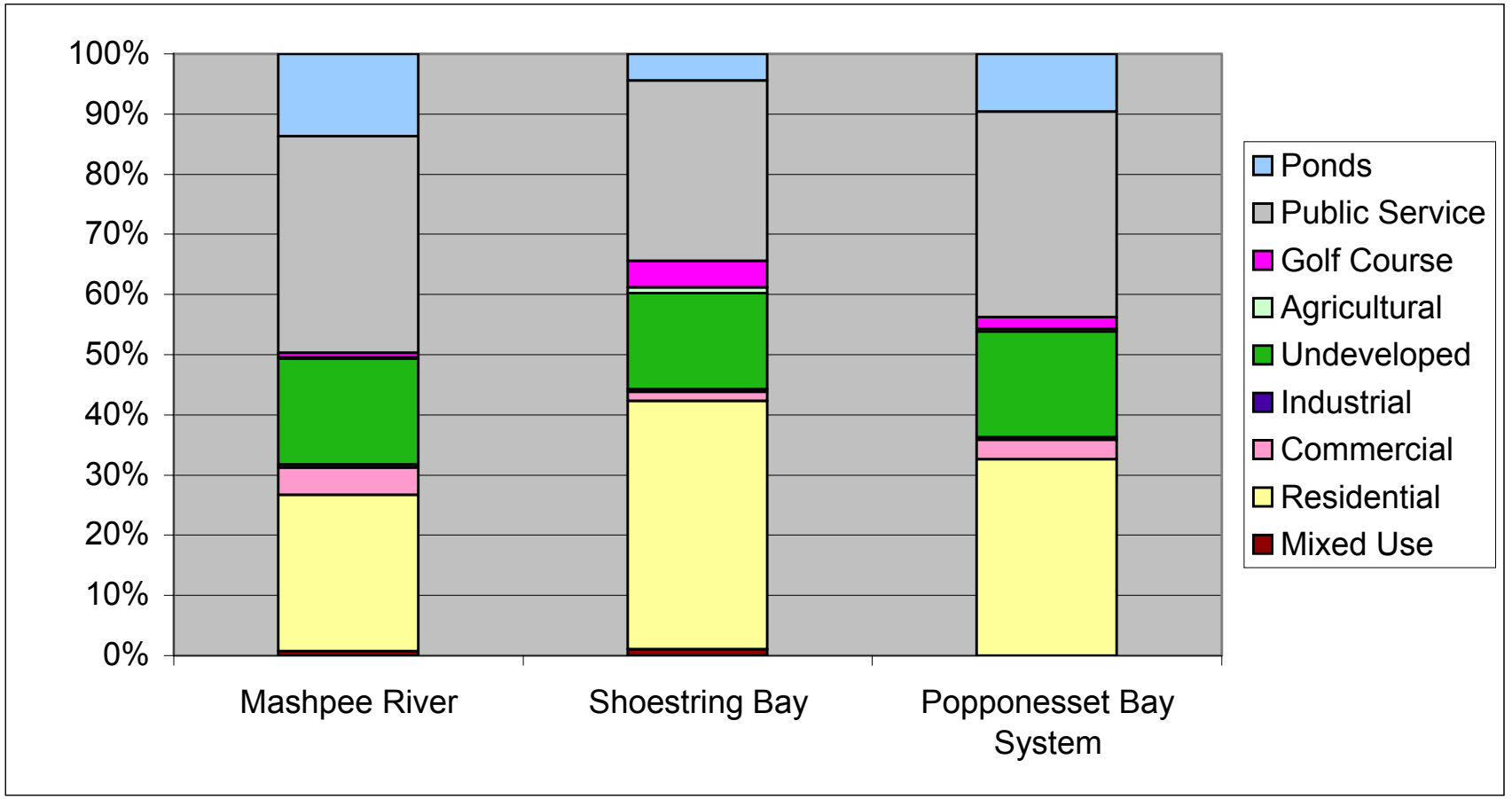

Figure IV-2. Distribution of land-uses within the Mashpee River and Shoestring Bay subwatersheds and the entire Popponesset Bay watershed.

IV.1.2 Nitrogen Loading Input Factors

Wastewater/Water Use

All wastewater is returned to the aquifer within the Popponesset Bay watershed either through individual on-site septic systems or the four WWTFs. Wastewater within the watershed is predominantly treated through on-site septic systems; 97% of the parcels use on-site septic systems. Measured water use is used as a proxy for wastewater, which is assumed to have a nitrogen concentration of 35 mg N/L with 25% nitrogen loss within the septic tank and soil adsorption system. Loss in passage through the septic system is consistent with other regional studies (Howes and Ramsey 2000, Weiskel and Howes 1991, Costa et al. 2001, Brawley et al. 2000). The best local quantitative information on Title 5 septic system nitrogen removals has been conducted at DEP's Alternative Septic System Test Center at the Massachusetts Military Reservation and has found that nitrogen removal in the septic tank is small (1-3%) with most of the removal (20-22%) within the soil adsorption system (Costa et al. 2001).

Only 3% of the parcels within the watershed are connected one of the four wastewater treatment facilities. The Mashpee Commons WWTF is located in the Mashpee River subwatershed, while the Stratford Ponds and Willowbend WWTFs are located within the Shoestring Bay subwatershed. The Forestdale School WWTF is located with the Mashpee-Wakeby Pond subwatershed and the Windchime Point WWTF, which is only included in the buildout scenario, is located in the Mashpee River subwatershed (Figure IV-3). It should be noted that the among these WWTF effluent nitrogen concentrations vary across a wide range.

In order to check the reliability of parcel water use as a proxy for wastewater flow, average influent flow at the Mashpee Commons and Willowbend WWTF was compared to average parcel water use within the respective service areas. Wastewater engineering studies conventionally assume 90% of water used in a town is converted to wastewater (*e.g.*, Stearns and Wheler, 1999). Within the Popponesset Bay watershed, the extensive mix of land uses connected to a municipal treatment facility is not available, but average flows from the two private WWTF are available to gauge whether the 90% return flow is an appropriate assumption. Based on average flows, 79% of the Mashpee Commons water use is returned to the WWTF, while 87% of the Willowbend water use is returned to its WWTF. This analysis supports the use of 90% return flow as an appropriate general adjustment for converting water use to wastewater flows in the nitrogen loading assessment within the Popponesset Bay watershed.

Although this adjustment is an appropriate proxy for wastewater flows on parcels with measured water use, 2,318 (28%) of the parcels in the Popponesset Bay watershed do not have water use in the available database. These parcels are assumed to utilize private wells. A water use estimate for these parcels was developed based on available measured water use from similar land uses. Of the 2,318 parcels without water use data, 2,272 (98%) are classified as residential parcels or condominium parcels (land use codes 101 to 112), 29 are commercial (land use codes 300 to 389) and 9 are industrial (land use codes 400 to 439). In order to address the nitrogen load from these parcels, MEP staff reviewed existing water use for residential, commercial, and industrial properties with measured water use (Table IV-3). Within each of these land use categories are numerous different types of uses. For example, within the commercial category are low water users, like small offices or retail with one or two employees, and large water users, like small motels with a dozen or more rooms. The ranges in Table IV-3 are very similar to those observed in the MEP analysis of water use in Chatham.

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Map #	Sub-Embayment Name
1	Snake Pond
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12	Ockway Bay
13	Popponesset Creek
14	Popponesset Bay
15	Quaker Run Well
16	Cotuit Well #5

CAPE COD COMMISSION

N W E S

0 0.5 1 Miles

Legend

- Town Boundary
- MEP Parcelized Watersheds
- Major Roads
- Numbered Routes
- Other Roads
- Bodies of Water
- Public / Private WWTF

Enhanced Wastewater Treatment

- I/A On-Site System in 2000
- I/A On-Site System @ Buildout
- Served by WWTF in 2000
- Served by WWTF @ Buildout

* *Buildout conditions (Mashpee only) provided by Town of Mashpee Planning Dept., November 11, 2001.*

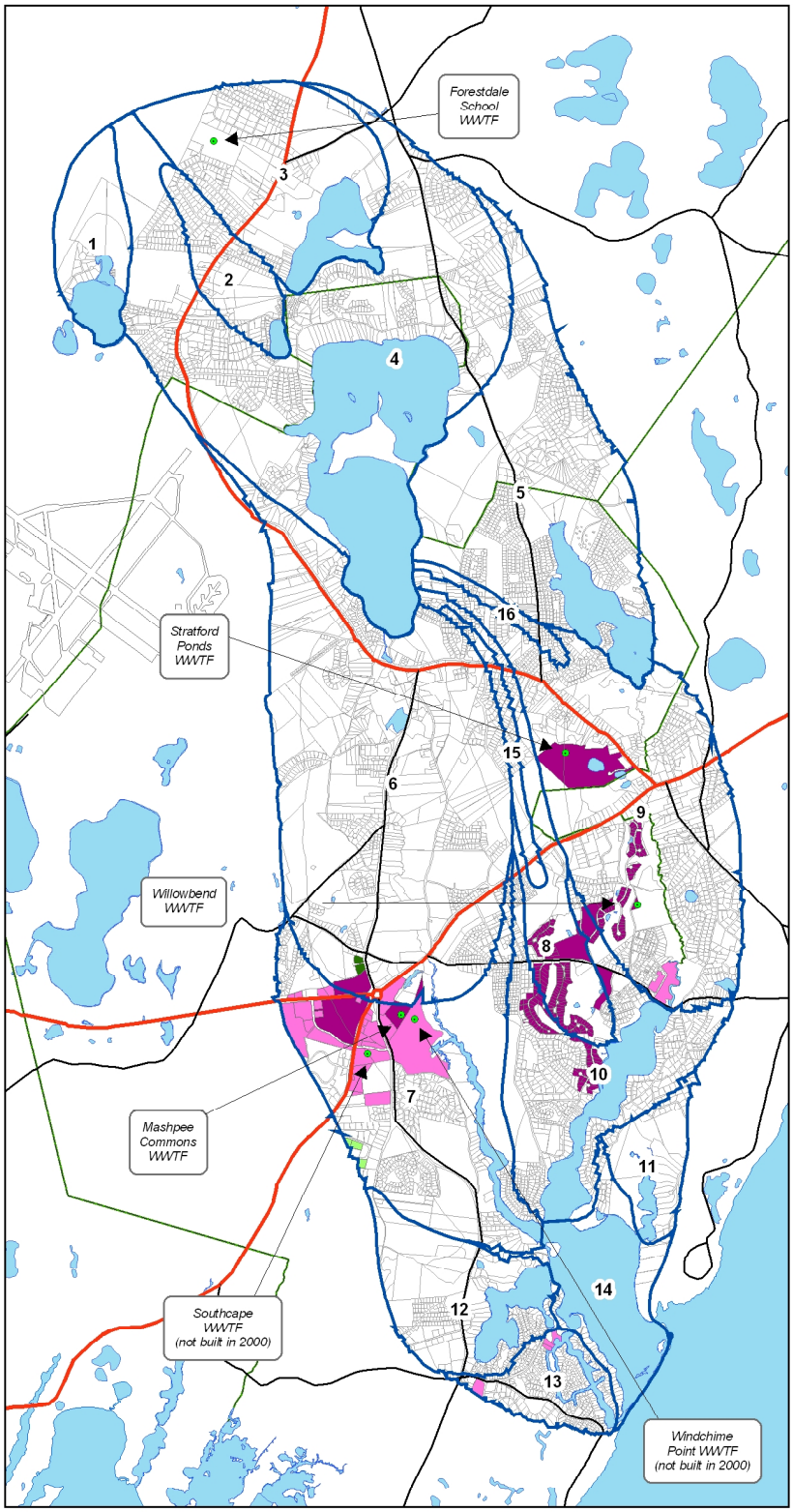


Figure IV-3. Parcels, Parcelized Watersheds, and Private Wastewater Treatment Facilities in the Popponesset Bay watershed.

Table IV-3. Water Use in Popponesset Bay Watershed					
Land Use	State Class Codes	# of Parcels	Water Use (gallons per day)		
			Average	Median	Range
Residential	101	3,462	154	127	0.9 to 3,177
Commercial	300 to 389	47	502	92	12 to 7,343
Industrial	400 to 439	5	286	68	11 to 1,079

Because water use information also forms the basis for evaluation of buildout nitrogen loads and the relatively high percentage of residential properties utilizing wells, MEP staff reviewed other factors to assess whether mean or median water use estimates is most appropriate for residential land uses. The state on-site wastewater regulations (*i.e.*, 310 CMR 15, Title 5) assume that two people occupy each bedroom and each bedroom has a wastewater flow of 110 gallons per day (gpd). Therefore, based on these regulations each person would generate 55 gpd. Average occupancy within the Town of Mashpee during the 2000 US Census was 2.46 people per household, while Barnstable was 2.44 and Sandwich was 2.75. If these occupancies are weighted based on the portion of the Popponesset Bay watershed that each town occupies, the Bay watershed average occupancy is 2.54. If the median water use of 127 gpd is multiplied by 0.9 to correct it to wastewater flows and then divided by 55 gpd, the resulting calculated occupancy is 2.14. In contrast, if the same procedure is applied to the average water use, the resulting occupancy is 2.51, which is approximately the same as the Bay watershed average occupancy. In order to provide a further check whether the average residential water use was appropriate for buildout and parcels with private wells, project staff also reviewed annual water use for the Mashpee Water District between 1988 and 1998 (Earth Tech, 1999). Although the number of service connections more than doubled between 1988 and 1998 (from 1,956 to 5,695), the average annual water use per service connection generally fluctuated over a fairly narrow range (146.9 to 194.8 gpd). The overall average over this period is 161 gpd, while the average for 1998, which is the middle year of those reviewed for this analysis, was 153.7 gpd. The overall average is within 5% of the average water use determined the MEP analysis. Based on these analyses, project staff felt that the average residential water use was most appropriate for use in the nitrogen loading calculations for developed residential parcels without water use information and for new residential parcels determined from the buildout assessment.

Similar comparisons were not available for the commercial or industrial water uses, which have a much wider range of land uses, but only represent less than 0.5% of the parcels. However, commercial and industrial building footprints were made available to project staff as part of an impervious surface GIS coverage provided by the Mashpee Planning Department. Project staff used this data to review water use for these properties based on square footage of building and to determine the percentage of each commercial or industrial lot that is occupied by a building. Based on this analysis, project staff determined that the average commercial and industrial water use is 81.5 gpd/1,000 ft^2 of building. This value was used to determine water use for all existing commercial and industrial buildings without water use in Mashpee and for all buildout additions. Buildout building areas were determined by the Mashpee Planning Department. Based on a review of zoning, no commercial or industrial buildout additions were included for either the Barnstable or Sandwich portions of the Popponesset Bay watershed.

Nitrogen Loading Input Factors: Residential Lawns

In most southeastern Massachusetts watersheds, nitrogen applied to the land to fertilize residential lawns is the second major source of nitrogen to receiving coastal waters after wastewater associated nitrogen discharges. However, residential lawn fertilizer use has rarely been directly measured in previous watershed-based nitrogen loading investigations. Instead, lawn fertilizer nitrogen loads have been estimated based upon a number of assumptions: a) each household applies fertilizer, b) cumulative annual applications are 3 pounds per 1,000 sq. ft., c) each lawn is 5000 sq. ft., and d) only 25% of the nitrogen applied reaches the groundwater (leaching rate). Because many of these assumptions had not been rigorously reviewed in over a decade, the MEP undertook an assessment of lawn fertilizer application rates and a review of leaching rates for inclusion in the land-use Nitrogen Loading Sub-Model.

The initial effort was to determine nitrogen fertilization rates for residential lawns in the Towns of Falmouth, Mashpee and Bourne, and related to inland, fresh ponds and embayments sub-watershed regions. Based upon ~300 interviews and over 2,000 surveys, a number of findings emerged: 1) average residential lawn area is ~5000 sq. ft., 2) half of the residences did not fertilize at all, and 3) the weighted average rate was 1.44 applications per year, rather than the 4 applications per year recommended on the fertilizer bags. Integrating the average residential fertilizer application rate with a leaching rate of 20% results in a fertilizer contribution of N to groundwater of 1.08 lb N per residential lawn for use in the nitrogen loading calculations. It is likely that this still represents a conservative estimate of nitrogen load from residential lawns. It should be noted that professionally maintained lawns were found in the survey to have the higher rate of fertilization (loss to groundwater of 3 lb/lawn/yr).

Nitrogen Loading Input Factors: Other

The nitrogen loading factors for impervious surfaces and natural areas are from the MEP Embayment Modeling Evaluation and Sensitivity Report (Howes and Ramsey 2001). The factors are similar to those utilized by the Cape Cod Commission's Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and Massachusetts DEP's Nitrogen Loading Computer Model Guidance (1999). The recharge rate for natural areas and lawn areas is the same as utilized in the MEP-USGS groundwater modeling effort (Section III). Factors used in the nitrogen loading analysis for Popponesset Bay are listed in Table IV-4. Impervious surfaces in Mashpee (e.g. road, parking, and building areas) were determined from impervious surface coverages provided by the Mashpee Planning Department.

In an early study of the Mashpee River, leaf fall was proposed as an important nitrogen source to the freshwater reach (K-V Associates 1991). We assessed the importance of this potential nitrogen source by evaluating the nitrogen mass delivered to vegetation from rainwater (as the sole source of nitrogen for leaf production). If 100% of the rainfall nitrogen is taken up by plants and converted to leaves in the 10 m (30 ft) swath on both banks to the Mashpee River and if 100% of these leaves fall into the River, then the amount of nitrogen added is less than 0.4% of the watershed loading to the freshwater reach of the River. Since these assumptions are gross over estimates of likely leaf fall, leaf nitrogen inputs to the river were not included in the analysis below. Note that observations of higher N and P in river waters in fall versus spring/summer are easily accounted for by fall plant senescence (particularly in river bank and channel vegetation) and from the observed increases associated with rainfall.

Table IV-4. Primary Nitrogen Loading Factors used in Popponesset Bay MEP analysis. General factors are from the MEP modeling evaluation (Howes & Ramsey 2001). Site-specific factors are derived from Mashpee, Sandwich, and Barnstable data. *Data from MEP lawn study in Falmouth, Mashpee & Barnstable 2001.

Nitrogen Concentrations:	mg/l	Recharge Rates:	in/yr
Wastewater	35	Impervious Surfaces	40
Road Run-off	1.5	Natural and Lawn Areas	27.25
Roof Run-off	0.75	Water Use/Wastewater:	
Direct Precipitation on Embayments and Ponds	1.09	For Parcels wo/water accounts:	gpd
Natural Area Recharge	0.072	Single Family Residence	154
Fertilizer:		Commercial & Industrial Properties	81.5 per 1,000 ft^2 of building
Average Residential Lawn Size (ft^2)*	5,000		
Residential Watershed Nitrogen Rate (lbs/lawn)*	1.08	For Parcels w/water accounts:	Measured annual water use
Nitrogen Fertilizer Rate for golf courses, cemeteries, and public parks determined by site-specific information			
WWTF flow and effluent nitrogen: see Table IV-2		Wastewater determined by multiplying water use by 0.9	

IV.1.3 Calculating Nitrogen Loads

Once all the land and water use information was linked to the parcel coverages, parcels were assigned to various watersheds based initially on whether at least 50% or more of the land area of each parcel was located within a respective watershed. Following the assigning of boundary parcels, all large parcels were examined separately and were split (as appropriate) in order to obtain less than a 2% difference between the total land area of each watershed and the sum of the area of the parcels within each watershed. The resulting "parcelized" watersheds are shown in Figure IV-3. This review of individual parcels straddling watershed boundaries included corresponding reviews and individualized assignment of nitrogen loads associated with lawn areas, septic systems, and impervious surfaces. Individualized information for parcels with atypical nitrogen loading (small public water supplies, golf courses, etc.) were also assigned at this stage. DEP and Town records were reviewed to determine water use for small public water supplies (*e.g.*, non-community public water supplies) and golf course superintendents for two golf courses in the study area were contacted to determine fertilizer application rates.

Following the assignment of all parcels to individual watersheds, tables were generated for each of 28 sub-watersheds to summarize water use, parcel area, frequency, sewer connections, private wells, and road area. As mentioned above, these tables were then condensed to 16 subwatersheds following the elimination of the 10-year time of travel subwatersheds.

The 16 individual sub-watershed assessments were then integrated to generate nitrogen loading tables relating to the Mashpee River and Shoestring Bay subembayments, as well as the overall Popponesset Bay system. The sub-embayments represent the functional embayment units for the Linked Watershed-Embayment Model's water quality component.

For management purposes, the aggregated sub-embayment watershed nitrogen loads are separated into various nitrogen sources to support potential nitrogen mitigation alternative development: wastewater (septic systems and the WWTF), fertilizer, impervious surfaces, direct atmospheric deposition to water surfaces, and recharge from natural areas (Table IV-5). The output of the watershed nitrogen loading effort is the kg N per year loaded into each sub-embayment's contributing area, by land use category (Figures IV-4 a-c), which is then adjusted for natural nitrogen attenuation during transport before use in the Linked Model.

Freshwater Pond Nitrogen Loads

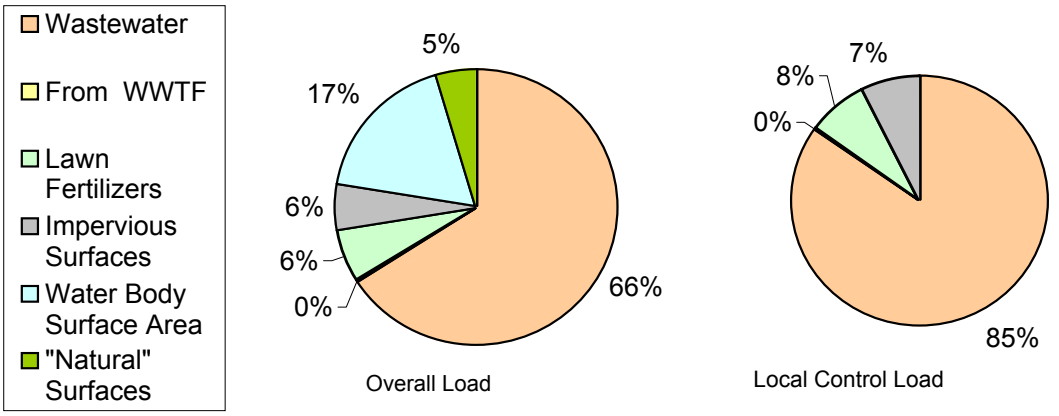
Freshwater ponds on Cape Cod are generally kettle hole depressions that intercept the surrounding groundwater table revealing what some call "windows on the aquifer." Since the ponds are connected to the aquifer, the ecosystems in these ponds have the opportunity to alter the nitrogen loads flowing into them via groundwater flow. This reduction in the nitrogen load takes place as a result of biological interaction within the pond. Following this reduction, the loads flow back into the groundwater system along the downgradient side of the pond or through a stream outlet and eventual discharge into the downgradient embayment. Table IV-5 N Load summary includes both the unattenuated (nitrogen load to each subwatershed) and attenuated nitrogen loads. Nitrogen attenuation in the ponds was assumed to be 50%.

This attenuation assumption was checked through the use of pond water quality information collected from a couple of sources. One source is data collected during late August in both 2001 and 2002 under the Cape Cod Pond and Lake Stewardship (PALS) program, which is a collaborative Cape Cod Commission/SMAST Program. Citizen volunteers in Mashpee and Sandwich collected dissolved oxygen and temperature profiles, Secchi disk depth readings and water samples at various depths within the following ponds: Snake, Pimlico, Peters, Mashpee-Wakeby, Santuit, Ashumet, Johns, and Moody (Figure IV-1). Water samples were analyzed at the SMAST laboratory for total nitrogen, total phosphorus, chlorophyll a, alkalinity, and pH. This data was supplemented with data collected on Ashumet, Johns, Peters, Mashpee-Wakeby, and Snake ponds through various Massachusetts Military Reservation (MMR) monitoring programs (*e.g.*, AFCEE, 1998).

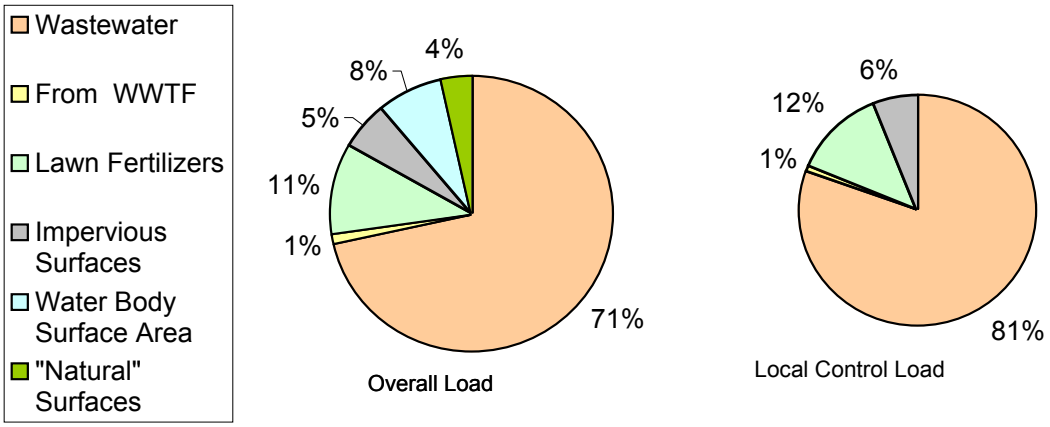
In order to estimate nitrogen attenuation in the ponds physical and chemical data for each pond was assessed. Available bathymetric information was reviewed relative to measured pond temperature profiles to determine the epilimnion (*i.e.*, well mixed, homothermic, upper portion of the water column) in each pond. Following this determination, the volume of this portion was determined and compared to the annual volume of recharge from each pond's watershed in order to determine how long it takes the aquifer to completely exchange the water in this portion of the pond (*i.e.*, turnover time). Using the total nitrogen concentrations collected only within the epilimnion, the total mass of nitrogen within this portion of the pond was determined. This mass was then adjusted using the pond turnover time to determine how much nitrogen is returned to the aquifer through the downgradient shoreline on an annual basis. In ponds with homothermic water columns, the nitrogen mass within the pond was based on the entire water volume.

Table IV-5. Popponesset Bay System Nitrogen Loads.

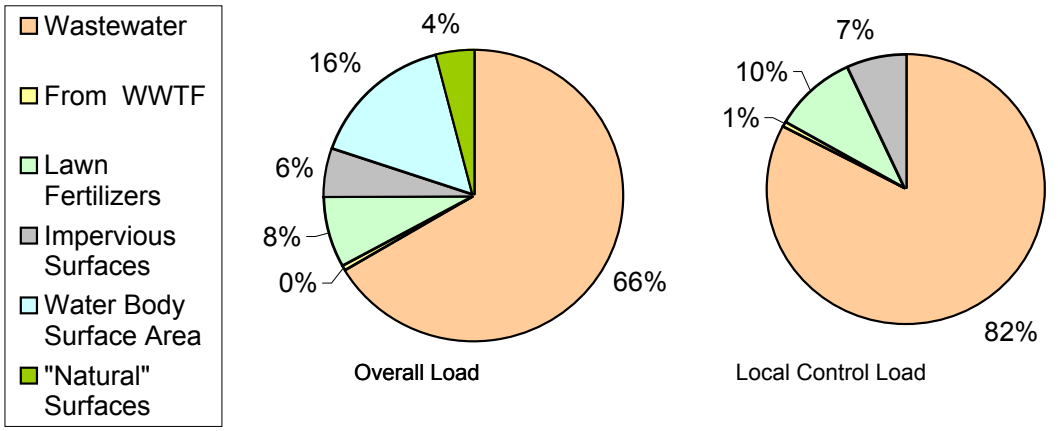
*All values in kilograms/year		*Popponesset Bay Subwatershed N Loads by Input:*							% of Pond Outflow	*Present N Loads*			*Buildout N Loads*		
Name	Watershed ID#	Wastewater	From WWTF	Lawn Fertilizers	Impervious Surfaces	Water Body Surface Area	"Natural" Surfaces	Buildout		UnAtten N Load	Atten %	Atten N Load	UnAtten N Load	Atten %	Atten N Load
Popponesset Bay System	**11, 12, 13, 14 + Shoestring Bay + Mashpee River**	**32300**	**227**	**3765**	**2668**	**7584**	**1971**	**9394**		**48513**		**31885**	**57804**		**39644**
Mashpee River	6, 7 + MWP	16199	54	1458	1411	4238	1153	6643		24512		13010	31051		18796
Upper Mashpee River	6 + MWP	12692	0	1206	1016	3996	941	4566		19851	30%	8349	24314	30%	12058
Mashpee-Wakeby Pond (MWP)	1, 2, 3, 4	7828	0	676	513	3989	503	771	100%	13509	50%	5585	14176	50%	5781
Direct to MWP	4	4572	0	421	321	3212	307	117		8833			8950		
Snake Pond (SNP)	1	5	0	3	2	121	17	10	34%	148	50%	74	54	50%	27
Pimlico Pond (PIP)	2	1139	0	90	63	74	42	563	100%	1407	50%	704	1971	50%	985
Peters Pond (PEP)	3	2112	0	163	126	582	138	80	100%	3121	50%	1560	3201	50%	1601
Lower Mashpee River	7	3507	54	251	395	242	212	2077		4661		4661	6737		6737
Shoestring Bay	8, 9, 10, 15, 16 + SAP	12986	173	1978	986	1379	636	2058		18139		13012	20196		14293
Santuit River	9, 16	8853	173	1075	675	564	440	1623		11780	30%	6653	13403	30%	7500
Cotuit Well No. 5	16	329	0	33	16	0	11	66		388		388	454		454
Quaker Run	8, 15	1598	0	405	99	0	82	232		2183		2183	2415		2415
Quaker Run Wells	15	659	0	37	23	0	18	51		736		736	787		787
Santuit Pond (SAP)	5	4386	0	429	326	758	216	1112	100%	6114	50%	3057	7226	50%	3613
Ockway Bay	12	874	0	103	90	399	83	402		1549		1549	1951		1951
GW Flow to Popponesset Ba	11, 13, 14	2241	0	226	180	1568	98	290		4314		4314	4604		4604
Pinquickset Cove	11	210	0	19	10	106	40	80		385		385	465		465
Popponesset Creek	13	1455	0	171	146	0	31	151		1803		1803	1954		1954
Popponesset Bay	14	576	0	36	24	1462	28	59		2126		2126	2185		2185



a. Mashpee River



b. Shoestring Bay



c. Popponesset Bay System

Figure IV-4. Land use specific unattenuated watershed based nitrogen load (by percent) to Mashpee River, Shoestring Bay, and entire Popponesset Bay system.

Table IV-6 summarizes the pond attenuation estimates calculated from land-use modeled nitrogen inflow loads and nitrogen loads recharged to the downgradient aquifer or to outflow streams from each pond based on pond characteristics and measured nitrogen levels. Nitrogen attenuation within these ponds varies between 51 and 89%. However, a caveat to these attenuation estimates is that they are based upon nitrogen outflow loads from summer water column samples, and are not necessarily representative of the annual nitrogen loads that are transferred downgradient. More detailed studies of other southeastern Massachusetts freshwater systems including Ashumet Pond (AFCEE, 2000) and Agawam/Wankinco River Nitrogen Discharges (CDM, 2001) have supported a 50% attenuation factor. This factor is also consistent with the freshwater pond attenuation factors used for the nitrogen balance for Great, Green and Bournes Ponds (embayments) in the Town of Falmouth (Howes and Ramsey, 2001).

Table IV-6. Nitrogen attenuation by Freshwater Ponds in the Popponesset Bay watershed based upon late summer 2001 and 2002 Cape Cod Pond and Lakes Stewardship (PALS) program sampling and Massachusetts Military Reservation (MMR)-associated monitoring. These data were collected to provide a site specific check on nitrogen attenuation by these systems. The Popponesset Bay analysis using the MEP Linked N Model uses a value of 50% for the non-stream discharge systems.

Pond	PALS ID	Area acres	Maximum Depth m	Overall turnover time yrs	N Load Attenuation %
Mashpee-Wakeby	MA-634	725.8	29.0	4.5	86%
Peters	SA-526	130.6	17.4	1.8	80%
Pimlico	SA-615	16.4	7.6	0.3	89%
Santuit	MA-718	170.5	2.5	0.3	75%
Snake	SA-568	83.5	10.1	2.0	51%
				Mean	73%
				s.d.	16%

Since groundwater outflow from a pond can enter more than one downgradient sub-watershed, the length of shoreline on the downgradient side of the pond was used to apportion the attenuated nitrogen load to respective downgradient watersheds. The apportionment was based on the percentage of pond discharging shoreline bordering each downgradient sub-watershed. The percentages of shoreline from larger ponds are shown in Table IV-5. For the present analysis, all of the outflow from Santuit Pond was discharged to the Santuit River. A small amount of Santuit Pond water is directed though cranberry bog operations to Lovells Pond, outside of the Popponesset Bay watershed. However, water withdrawals for bog operations are only periodic and are generally small compared to the total annual Santuit River flows. Major withdrawals for bog operations generally occur in fall for harvest and in winter for frost protection. Additional data could be collected to yield a precise estimate of this watershed nitrogen export.

Buildout

In order to gauge potential future nitrogen loads resulting from continuing development, the potential number of future residential, commercial, and industrial lots within each subwatershed was determined from the GIS database (Figure IV-5). Buildout of parcels within the Town of Mashpee portion of the Popponesset Bay watershed were determined by the Mashpee Planning Department, including commercial and industrial parcel estimates. Buildout

of parcels within the portions of the watershed within the Towns of Sandwich and Barnstable were based on subdivisions using minimum lot size included in current zoning. All municipal overlay districts (*e.g.*, water resource protection districts) were considered in the determination of minimum lot sizes. A nitrogen load for each parcel was determined for the existing development using the factors presented in Table IV-4 and discussed above. A summary of potential additional nitrogen loading from buildout is presented as unattenuated and attenuated loads in Table IV-5. Only attenuated loads were used in the water quality modeling. Buildout loads, or any alternative future load scenarios, can be used to evaluate water quality impacts of current or alternative zoning and/or other land use regulations.

During the course of discussion of the nitrogen loading analysis with town representatives, MEP staff agreed to provide a limited evaluation of the land use changes that have occurred since the acceptance of the land use databases used in the nitrogen loading. The nitrogen loading analysis discussed above uses Town of Barnstable assessor and land use information from the year 2000. Figure IV-6 shows the changes that occurred in the Barnstable portion of the Popponesset Bay watershed between 2000 and 2004; undeveloped lands in 2000 are outlined in green with 2004 land uses shown. Of the 261 acres in this portion of the watershed classified as undeveloped in 2000, 13 acres (5% of 261) were converted to residential land use by 2004. These 13 acres were turned into 29 lots or an increase of 4% from the number of lots in 2000. These differences are slight, would result in even smaller percentage increases in the overall nitrogen loads, and are within the margin of error in the overall linked model results.

IV.2 ATTENUATION OF NITROGEN IN SURFACE WATER TRANSPORT

IV.2.1 Background and Purpose

Modeling and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land or watershed. This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out or sewering analysis) to changes in water quality and habitat health. Therefore, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems. Rates of nitrogen loading to the sub-watersheds of each sub-embayment of the overall Popponesset Bay embayment system under study was based upon the delineated watersheds (Section III) and their land-use coverages (Section IV.1). If all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters. This condition exists in watersheds where nitrogen transport is through groundwater in sandy outwash aquifers. The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. However, in most watersheds in southeastern Massachusetts, nitrogen passes through a surface water ecosystem on its path to the adjacent embayment. Surface water systems, unlike sandy aquifers, do support the needed conditions for nitrogen retention and denitrification. The result is that the mass of nitrogen passing through lakes, ponds, streams and marshes (fresh and salt) is diminished by natural biological processes which represent removal (not just temporary storage). However, this natural attenuation of nitrogen load is not uniformly distributed within the watershed, but is associated with ponds, streams and marshes. Within the Popponesset Bay System Watershed most of freshwater flow and transported nitrogen passes through a surface water system and frequently multiple systems, producing the opportunity for significant nitrogen attenuation.

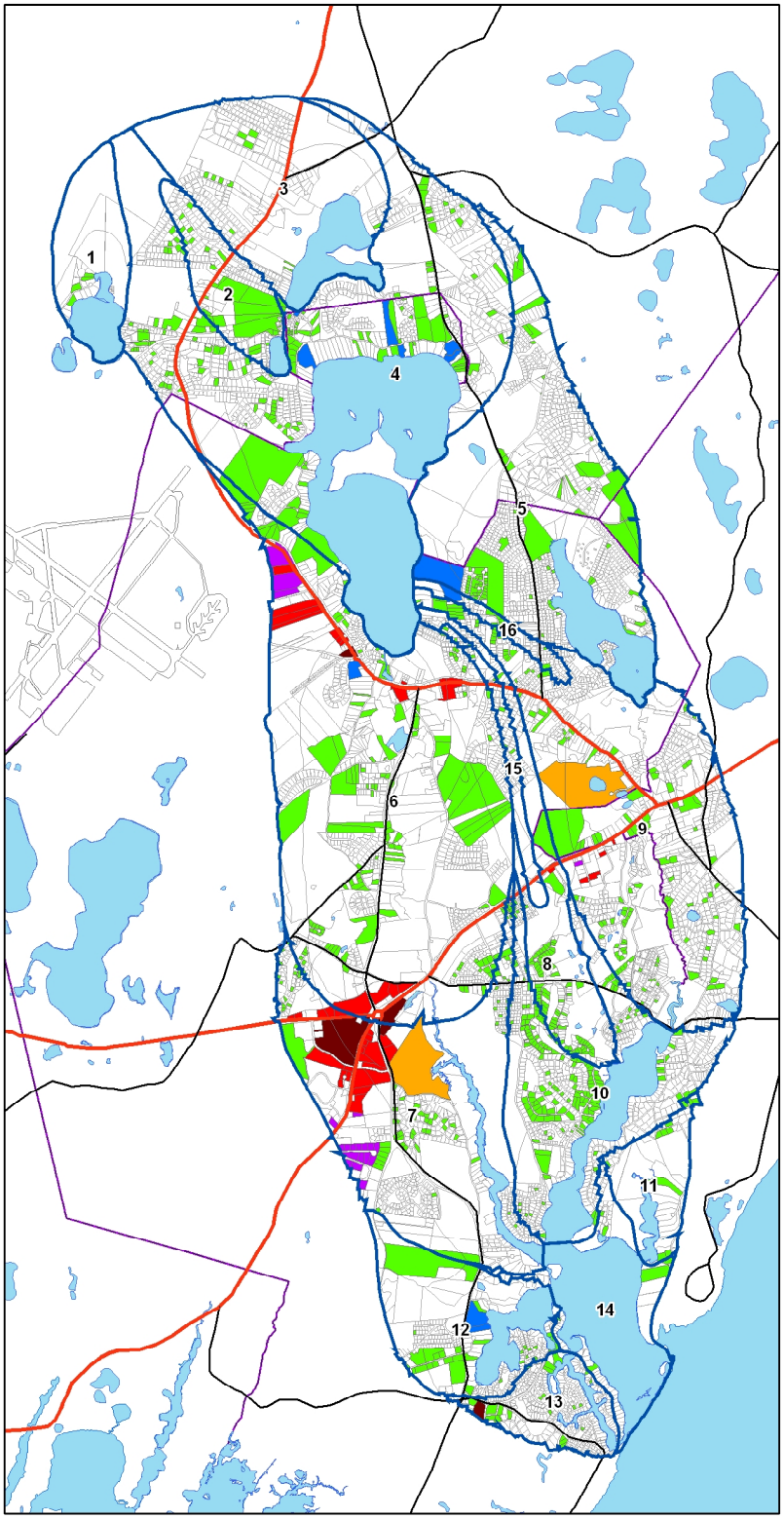


Figure IV-5. Distribution of present parcels that are potentially developable within the Popponesset Bay watershed.

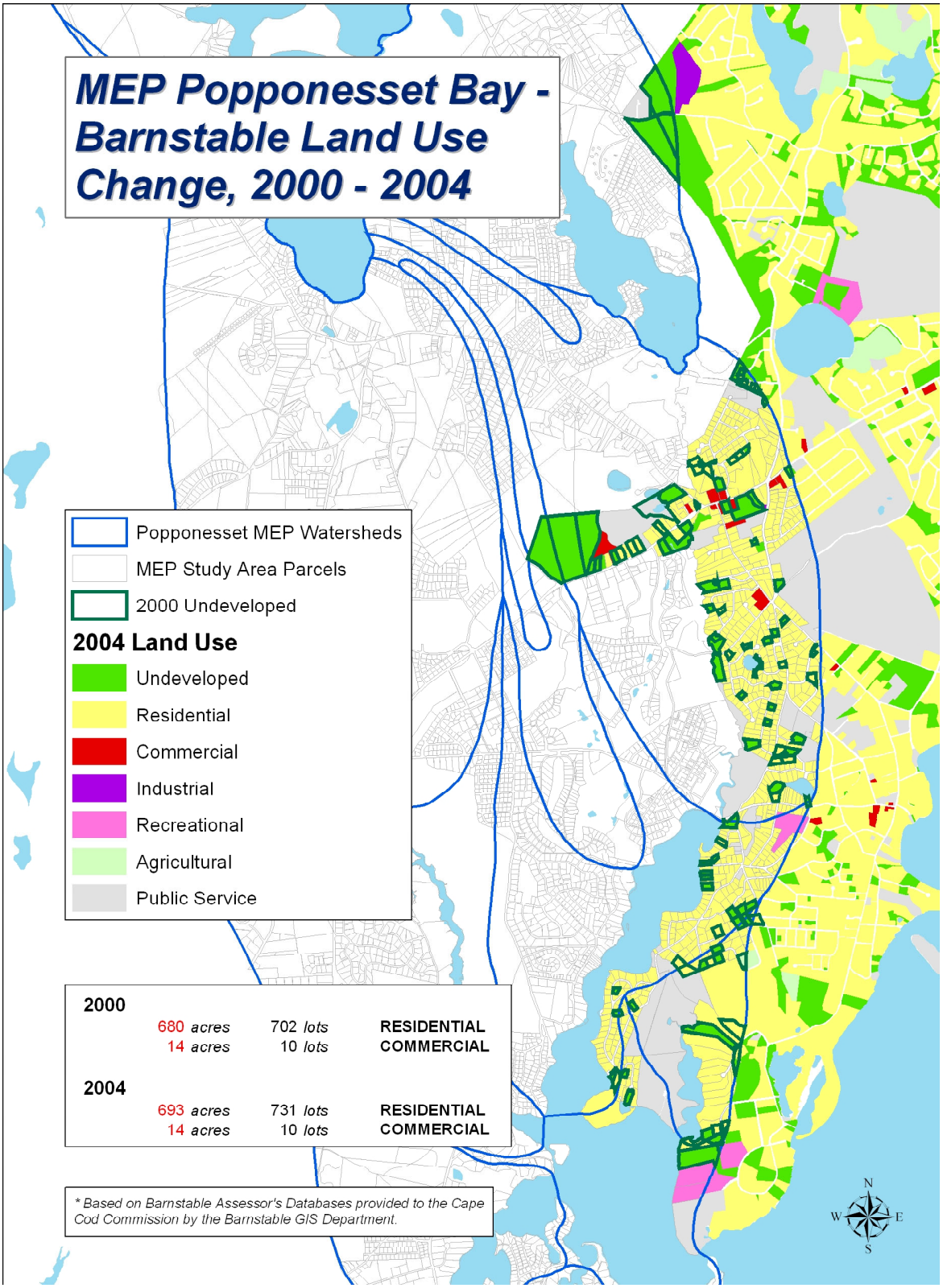


Figure IV-6. Change in Town of Barnstable parcel and land use in the Popponesset Bay watershed between year 2000 and 2004. 2004 land use is shown with 2000 undeveloped parcels outlined in green.

Failure to determine the attenuation of watershed derived nitrogen overestimates the nitrogen load to receiving waters. If nitrogen attenuation is significant in one portion of a watershed and insignificant in another the result is that nitrogen management would likely be more effective in achieving water quality improvements if focused on the watershed region having unattenuated nitrogen transport (other factors being equal). In addition to attenuation by freshwater ponds (see Section IV.1.3, above), attenuation in surface water flows is also important. An example of the significance of surface water nitrogen attenuation relating to embayment nitrogen management was seen in the Agawam River, where >50% of nitrogen originating within the upper watershed was attenuated prior to discharge to the Wareham River Estuary (CDM 2001). Similarly, in a preliminary study of Great, Green and Bournes Ponds in Falmouth, measurements indicated a 30% attenuation of nitrogen during stream transport (Howes and Ramsey 2001). An example where natural attenuation played a significant role in nitrogen management can be seen relative to West Falmouth Harbor (Falmouth, MA), where ~40% of the nitrogen discharge to the Harbor originating from the groundwater discharge from the WWTF was attenuated by a small salt marsh prior to reaching Harbor waters. Similarly, the small tidal basin of Frost Fish Creek in the Town of Chatham showed ~20% nitrogen attenuation or watershed nitrogen load prior to discharge to Ryders Cove. Clearly, proper development and evaluation of nitrogen management options requires determination of the nitrogen loads reaching an embayment, not just loaded to the watershed.

Given the importance of determining accurate nitrogen loads to embayments for developing effective management alternatives and the potentially large errors associated with ignoring natural attenuation, direct integrated measurements were undertaken as part of the MEP Approach. MEP conducted multiple studies on natural attenuation relating to sub-embayments of the Popponesset Bay System in addition to the natural attenuation measures by fresh kettle ponds, addressed above. These additional site-specific studies were conducted in each of the 2 major surface water flow systems, i.e. the Mashpee River discharging to the tidal portion of the Mashpee River sub-embayment and the Santuit River discharging to Shoestring Bay).

Quantification of watershed based nitrogen attenuation is contingent upon being able to compare nitrogen load to the embayment system directly measured in freshwater stream flow (or in tidal marshes, net tidal outflow) to nitrogen load as derived from the detailed land use analysis (Section IV.1). Measurement of the Mashpee River (at Route 28) and Santuit River (at the tidal reach) provide a direct integrated measure of all of the processes presently attenuating nitrogen in the sub-watersheds upgradient from the gauging sites. These upper watershed regions account for more than half of the entire watershed area to the Popponesset Bay System. Flow and nitrogen load were measured at each site for 16 months of record (Figure IV-7). During the study period, velocity profiles were completed on each river every month to two months. Periodic measurement of flows over the entire stream gauge deployment period allowed for the development of a stage-discharge relationship (rating curve) that could be used to obtain flow volumes from the detailed record of stage measured by the continuously recording stream gauges. A complete annual record of stream flow (365 days) was generated for both the Mashpee River and the Santuit River. The annual flow records for both rivers were merged with the nutrient data sets generated through the weekly water quality sampling to determine nitrogen loading rates to the tidally influenced portion of the Mashpee River and to the headwaters of Shoestring Bay. Comparing these measured nitrogen loads based on stream flow and water quality sampling to predicted loads based on the land use analysis allowed for the determination of the degree to which natural biological processes within the watershed currently reduce (percent attenuation) nitrogen loading to the Popponesset Bay embayment system.

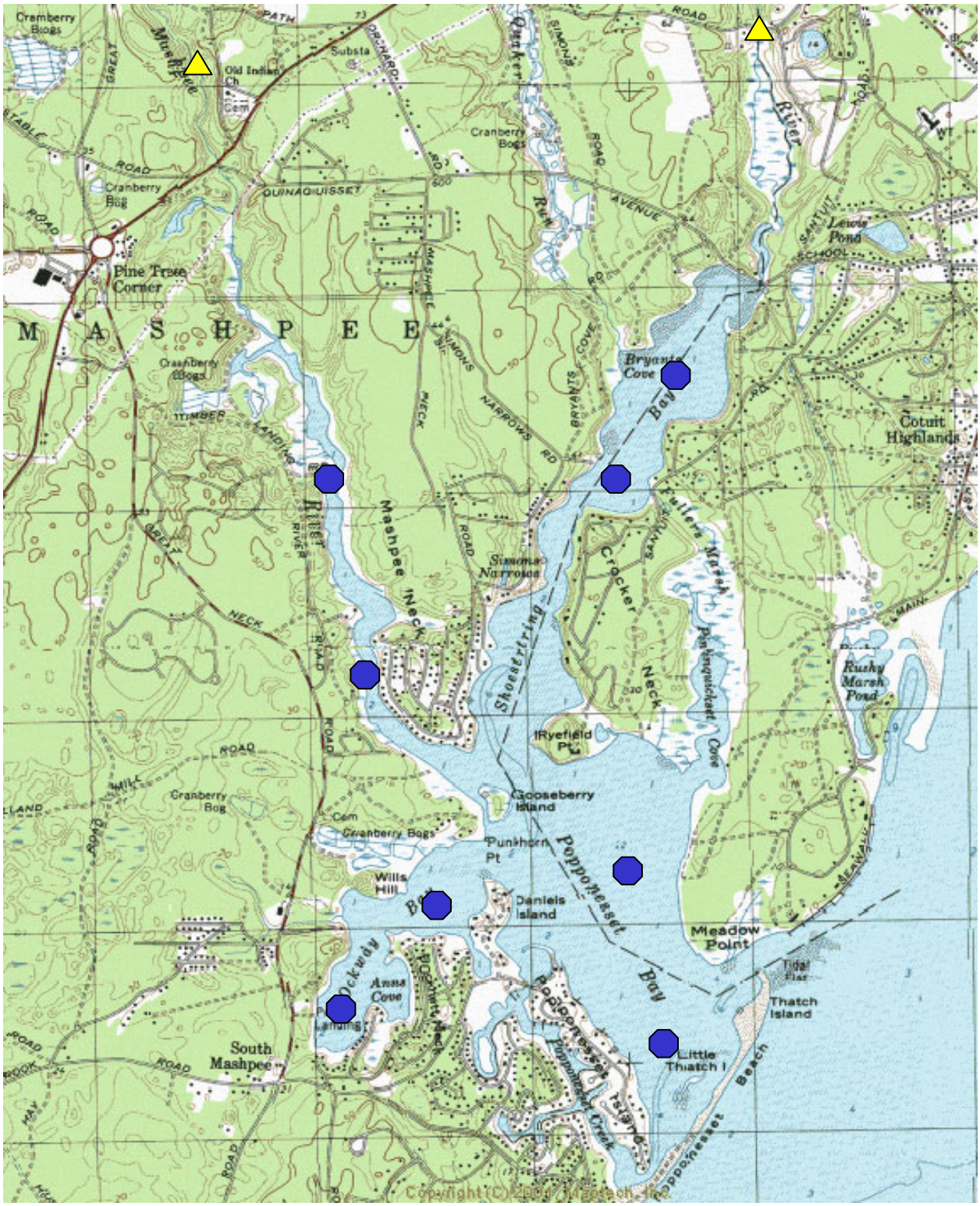


Figure IV-7. Location of Stream gauges (yellow triangles) and benthic coring locations (blue dots) in the Popponesset Bay System.

An additional analysis of flow was undertaken relative to the USGS long term record (1989 – 2002) of flow in the Quashnet River, adjacent to the Popponesset Bay watershed, in order to gage the degree to which the 2003 water year (2002 baseflow period to 2003 baseflow period) in this geographic region was representative of average hydrologic conditions. Using the USGS daily flow record for the Quashnet River for 1989 to 2002, average flow during the 6-month period (April to September) was calculated for the 15-year period 1989 to 2002. The mean flow for the 6-month period, based on the 15-year record of daily flow, was 41,248 m3/day. Considering the USGS flow data for 2003, the mean flow in the Quashnet River for the 6-month period was 49,983 m3/day which is 21 percent higher than the 15 year mean flows for these months. It is therefore likely that the MEP determined flows in the Mashpee River and the Santuit River are also about 20% higher than the long-term average for the same period, since these river systems are proximal to the Quashnet River watershed. Therefore, the percent attenuation determined by the MEP for both the Mashpee River and the Santuit River is likely to be slightly conservative (lower) as residence times in each river system may be a bit shorter and the nitrate concentrations lower than under the average conditions of lower flow.

A similar analysis of USGS historical long term daily flows in the Quashnet River was completed for the 6-month period (October 2002 to March 2003) to ascertain the degree to which flows in the Mashpee and Santuit Rivers may be below mean flow for that period. It was determined that flow in the Quashnet River was approximately 2 percent below mean flow during the period October 2002 to March 2003 and 30 percent below mean flow conditions for the previous period April 2002 to September 2002. Given these low flow conditions in the Quashnet River during the hydrologic year prior to the acquisition of the MEP flow record (September 2002 to September 2003), it is likely that the MEP determined flows in the Mashpee River and the Santuit River are also lower than the long-term average for the same period, since these river systems are proximal to the Quashnet River watershed. As such, percent attenuation during the lower flow periods may be slightly higher than during average flow conditions when stream flow is relatively higher and residence times are shorter. From the perspective of overall nutrient loading to the Popponesset Bay system on an annualized basis, the potentially higher attenuation during the period when stream flow is below average flow conditions is likely to be offset by the lower attenuation rates when the stream flow record appears to be above average flow conditions. As such, the annual attenuated nitrogen load to the Popponesset Bay embayment system during the 2002- 2003 study period is considered representative of average loading conditions.

IV.2.2 Surface Water Discharge and Attenuation of Watershed Nitrogen: Mashpee River to Mashpee River (lower)

Mashpee – Wakeby Pond is one of the largest ponds on Cape Cod and unlike many of the freshwater ponds, this pond has stream outflow rather than discharging solely to the aquifer along its down-gradient shore. This stream outflow, the Mashpee River, may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetlands and stream bed associated with the Mashpee River. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the Mashpee River above the gauge site and the measured annual discharge of nitrogen to the tidal portion of the Mashpee River, Figure IV-7.

At the Mashpee River gauge site, a continuously recording vented calibrated water level gauge was installed to yield the level of water in the freshwater portion of the Mashpee River that carries the flows and associated nitrogen load to the Bay. Calibration of the gauge was

checked monthly. The gauge on the Mashpee River was installed on December 3, 2001 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Due to an instrument upgrade in July of 2002, instrument failure, and vandalism, stage data collection was extended until October 3, 2003. The 12 month uninterrupted record used in this analysis encompasses the summer 2003 field season.

River flow (volumetric discharge) was measured monthly using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Mashpee River site based upon these measurements and measured water levels at the gauge site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. These measurements allowed for the determination of both total volumetric discharge and nitrogen mass discharge to the estuarine portion of the Mashpee River (Table IV-7 and Figure IV-8). In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gauge site.

The annual freshwater flow record for the Mashpee River and Santuit River (see below), determined from measured stage and the stage – discharge relation developed by the MEP, was compared to the flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from the Mashpee River and Santuit River were both ~1/3 lower than the long-term average modeled flows. The lower values are consistent with the extremely low groundwater levels during the initial months of the study period. Given that the streamflows are significantly groundwater fed, and the fact that the ratio of the Mashpee River/Santuit River flows were consistent between the measured (2.00) and modeled (2.25) discharges, the watershed and river datasets appear to be in balance.

Total nitrogen concentrations within the Mashpee River outflow were relatively high, 0.593 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 15,562 g/day (15.6 kg/d) and a measured total annual TN load of 5,680 kg/yr. In the Mashpee River, nitrate was the predominant form of nitrogen (54%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the outflowing stream waters also suggests that plant production within the upgradient freshwater ecosystems is not nitrogen limited.

From the measured nitrogen load discharged by the Mashpee River to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is significant nitrogen attenuation of upper watershed derived nitrogen during transport to the Bay. Based upon lower nitrogen load (15.6 kg N d^{-1}, 5680 kg yr^{-1}) discharged from the freshwater Mashpee River and the nitrogen mass entering from the associated watershed (57.4 kg N d^{-1}, 20,941 kg yr^{-1}) the integrated measure of nitrogen attenuation by the pond/river ecosystem is 71%. This is consistent with the land-use model which yielded and integrated nitrogen attenuation of 52%, since pond and stream attenuation in the watershed model use conservative attenuation factors (see Table IV-6). The directly measured nitrogen loads from the rivers were used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

Table IV-7. Comparison of water flow and nitrogen discharges from Mashpee River to Mashpee River (lower) and Santuit River to Shoestring Bay. The "Stream" data is from the MEP stream gauging effort. Watershed data is based upon the MEP watershed modeling effort by USGS.

Stream Discharge Parameter	Mashpee River Discharge to Mashpee River (lower)[b]	Santuit River Discharge to Shoestring Bay[c]	Data Source
Total Days of Record [a]	365	365	(1)
Flow Characteristics:			
Stream Average Discharge (m3/d)	26,223	13,164	(1)
Contributing Area Long-term Average Discharge (m3/d)	45,220[b]	20,093[c]	(2)
Discharge Stream 2002-03 vs. Long-term Discharge	58%	66%	
Nitrogen Characteristics:			
Stream Average Nitrate + Nitrite Concentration (mg N/L)	0.318	0.702	(1)
Stream Average Total N Concentration (mg N/L)	0.593	1.184	(1)
Nitrate + Nitrite as Percent of Total N (%)	54%	59%	(1)
Total Nitrogen (TN) Average Measured Stream Discharge (kg/d)	15.56	15.58	(1)
TN Average Contributing Area Attenuated Load (kg/d)	22.59	18.06	(2)
TN Average Contributing Area UN-attenuated Load (kg/d)	53.89	32.04	(3)
Attenuation of Nitrogen in Pond/Stream (%)	71%	51%	(4)

[a] from 09/24/02 to 09/24/03 (Mashpee River and Santuit River gauges)
[b] flow and N load to Mashpee River include Mashpee – Wakeby Pond Contributing Area,
[c] flow and N load to Santuit River include Santuit Pond Contributing Area

(1) MEP gauge site data
(2) Calculated from MEP watershed delineations to Mashpee – Wakeby Pond, and Santuit Pond; the fractional flow path from each sub-watershed which contribute to Mashpee River and Santuit River Flow; and the annual recharge rate.
(3) As in footnote #2, with the addition of pond and stream conservative attenuation rates.
(4) Calculated based upon the measured TN discharge from the river vs. the unattenuated watershed load.

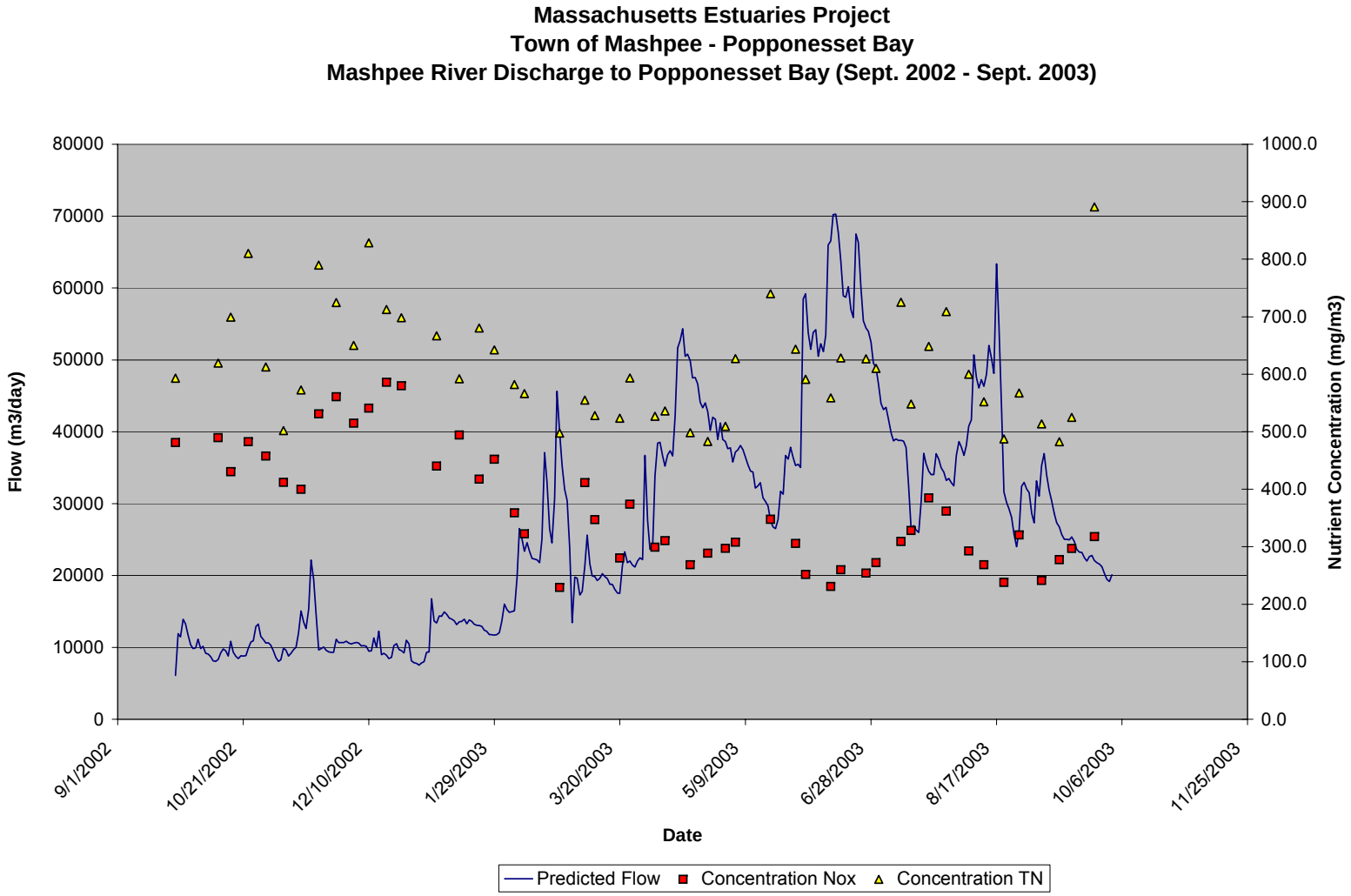


Figure IV-8. Mashpee River annual discharge developed from a stream gauge maintained above the tidal reach of the lower Mashpee River estuarine waters. Nutrient samples (Nox – Nitrate+Nitrite) were collected weekly and analyzed for inorganic and organic nitrogen species. These data were used to determine both annual flow and total nitrogen transport for determining nitrogen attenuation (see Table IV-7).

IV.2.3 Freshwater Discharge and Attenuation of Watershed Nitrogen: Santuit River to Shoestring Bay

Santuit Pond is one of the larger ponds within the study area and unlike many of the freshwater ponds, the Santuit Pond has stream outflow to the Santuit River, rather than discharging solely to the aquifer on the down-gradient shore. As for the Mashpee River (see IV.2.2 above) this stream outflow may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. Nitrogen attenuation also occurs within the wetlands and stream-bed associated with the Santuit River. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the Santuit River above the gauge site and the measured annual discharge of nitrogen.

At the Santuit River gauge site (Figure IV-7), a continuously recording vented calibrated water level gauge was installed to yield the level of water for the determination of freshwater flow. Calibration of the gauge was checked monthly. The gauge on the Santuit River was installed on December 3, 2001 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Due to the desire to have simultaneous measurement of river discharge from the Mashpee and Santuit Rivers, stage data collection was extended until October 3, 2003 (to match the Mashpee River). The 12 month uninterrupted record used in this analysis encompasses the summer 2003 field season.

River flow (volumetric discharge) was measured monthly using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Santuit River site based upon these measurements and measured water levels at the gauge site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. These measurements allowed for the determination of both total volumetric discharge and nitrogen mass discharge to the headwaters of Shoestring Bay (Figure IV-9 and Table IV-8).

Total nitrogen concentrations within the Santuit River outflow were relatively high, 1.18 mg N L^{-1} (2 times that observed in the Mashpee River). However the total nitrogen load was similar to the Mashpee River given that the flow was ~1/2 as high. Average daily total nitrogen discharge from the Santuit River to the estuary was 15,584 g/day (15.6 kg/d) with a measured total annual TN load of 5,688 kg/yr. As in the Mashpee River, nitrate was the predominant form of nitrogen (59%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the outflowing stream waters also suggests that plant production within the upgradient freshwater ecosystems is not nitrogen limited.

From the measured nitrogen load discharged by the Santuit River to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is significant nitrogen attenuation of upper watershed derived nitrogen during transport to Shoestring Bay. Based upon the lower measured nitrogen load (15.6 kg N d^{-1}, 5688 kg yr^{-1}) discharged from the Santuit River and nitrogen mass entering from the associated watershed (40.0 kg N d^{-1}, 14,615 kg yr^{-1}), the integrated measure of nitrogen attenuation by the pond/river ecosystem is 51%. This is consistent with the land-use model which yielded and integrated nitrogen attenuation of 44%, since pond and stream attenuation in the watershed model use conservative attenuation factors (Table IV-6). Directly measured nitrogen loads from the rivers were used in the Linked Watershed-Embayment Modeling of water quality (Chapter VI).

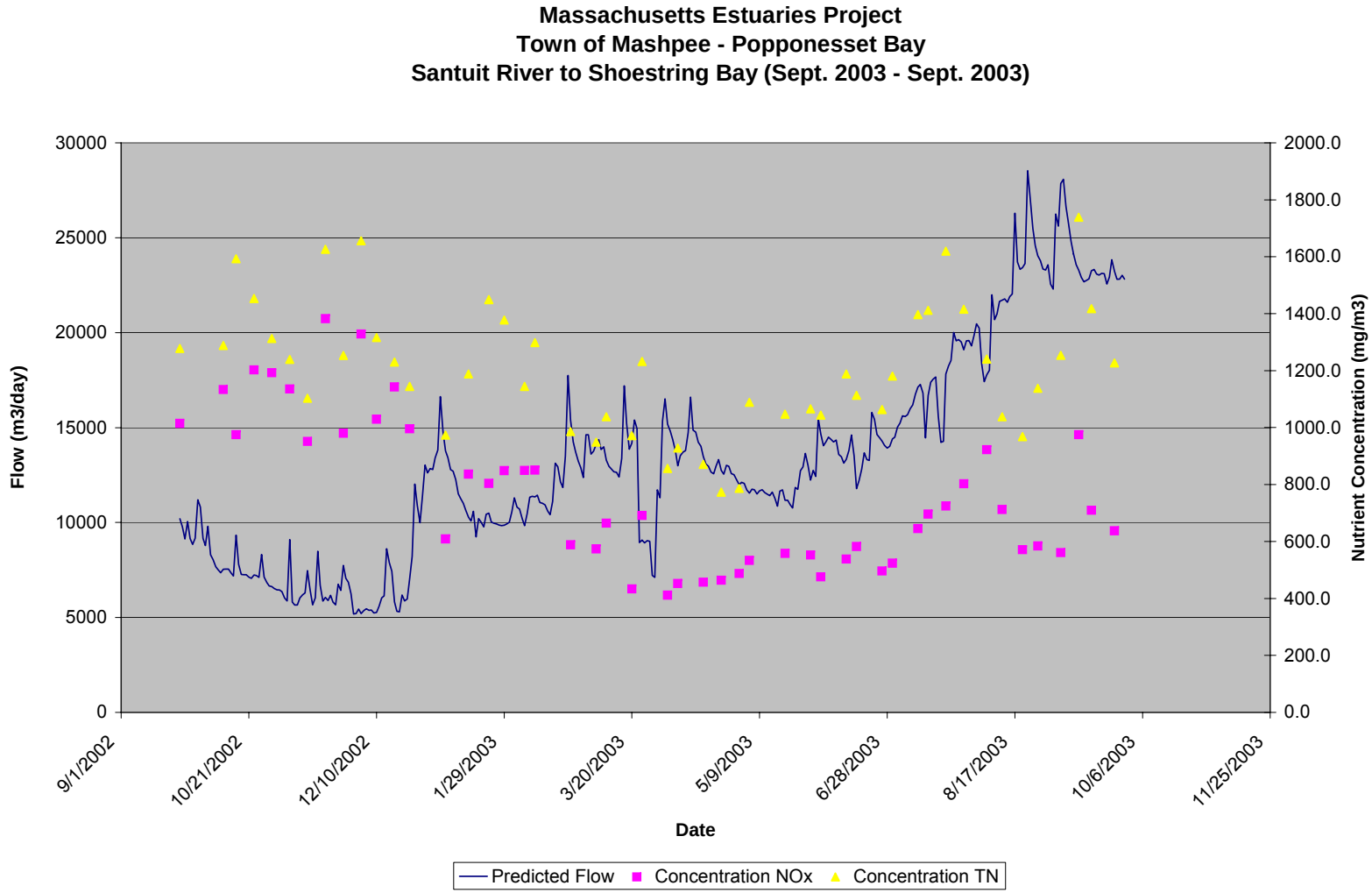


Figure IV-9. Santuit River annual discharge developed from a stream gauge maintained in the outflow from Santuit Pond discharging to Shoestring Bay. Nutrient samples (Nox – Nitrate+Nitrite) were collected approximately weekly and analyzed for inorganic and organic nitrogen species. These data were used to determine both annual flow and total nitrogen transport for determining nitrogen attenuation (see Table IV-5).

Table IV-8. Summary of Flow and Nutrient loads from both the Mashpee River discharging to tidally influenced Mashpee River (lower) and the Santuit River discharging to Shoestring Bay

SYSTEM	PERIOD	DISCHARGE (m3/yr)	ATTENUATED LOAD (Kg/yr)	
			Nox	TN
MASHPEE RIVER	September 24, 2002 - September 24, 2003	**9571405**	**3045**	**5680**
SANTUIT RIVER	September 24, 2002 - September 24, 2003	**4805008**	**3374**	**5688**

IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS

The overall objective of the Benthic Nutrient Flux Task was to quantify the summertime exchange of nitrogen, between the sediments and overlying waters within each major basin area within the Popponesset Bay System. The mass exchange of nitrogen between watercolumn and sediments is a fundamental factor in controlling nitrogen levels within coastal waters. These fluxes and their associated biogeochemical pools relate directly to carbon, nutrient and oxygen dynamics and the nutrient related ecological health of these shallow marine ecosystems. In addition, these data are required for the proper modeling of nitrogen in shallow aquatic systems, both fresh and salt water.

IV.3.1 Sediment-Watercolumn Exchange of Nitrogen

As stated in above sections, nitrogen loading and resulting levels within coastal embayments are the critical factors controlling the nutrient related ecological health and habitat quality within a system. Nitrogen enters the Popponesset Bay embayment predominantly in highly bioavailable forms from the surrounding upland watershed and more refractory forms in the inflowing tidal waters. If all of the nitrogen remained within the watercolumn (once it entered), then predicting watercolumn nitrogen levels would be simply a matter of determining the watershed loads, dispersion, and hydrodynamic flushing. However, as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bioavailable form nitrate. This nitrate and other bioavailable forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved forms into phytoplankton “particles”. Most of these “particles” remain in the watercolumn for sufficient time to be flushed out to a downgradient larger waterbody (like Nantucket Sound). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence), a fraction of the phytoplankton with their associated nitrogen “load” become incorporated into the surficial sediments of the bays.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within small enclosed basins (e.g. Ockway Bay, Shoestring Bay, etc). To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary.

Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic (oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter with its nitrogen content, that bioavailable nitrogen is returned to the embayment watercolumn for another round of uptake by phytoplankton. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that we have investigated, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. Failure to account for this recycled nitrogen generally results in significant errors in determination of threshold nitrogen loadings. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

IV.3.2 Method for Determining Sediment-Watercolumn Nitrogen Exchange

For the Popponesset Bay System, in order to determine the contribution of sediment regeneration to nutrient levels during the most sensitive summer interval (July-August), sediment samples were collected and incubated under *in situ* conditions. Sediment samples were collected from 8 sites (Figure IV-10) in August 1998, June, July, and early September 1999. Measurements of total dissolved nitrogen, nitrate + nitrite, ammonium were made in time-series on each incubated core sample. As part of a separate research investigation, the rate of oxygen uptake was also determined and measurements of sediment bulk density, organic nitrogen, and carbon content. These measurements were made by the Coastal Systems Program at SMAST-UMD working with the Town of Mashpee.

Rates of nitrogen release were determined using undisturbed sediment cores incubated for 24 hours in temperature-controlled baths. Sediment cores (15 cm inside diameter) were collected by SCUBA divers and cores transported by a small boat. Cores were maintained from collection through incubation at *in situ* temperatures. Bottom water was collected and filtered from each core site to replace the headspace water of the flux cores prior to incubation. The number of core samples from each site (see Figure IV- 10) per incubation were as follows:

- Station 1 – 3 cores (Popponesset Bay main bay)
- Station 2 – 3 cores (Popponesset Bay main bay)
- Station 3 – 1 core (Ockway Bay)
- Station 4 – 2 cores (Ockway Bay)
- Station 5 – 2 cores (Mashpee River)
- Station 6 – 2 cores (Mashpee River)
- Station 7 – 2 cores (Shoestring Bay)
- Station 8 – 1 core (Shoestring Bay)

Sampling was distributed throughout the embayment system and the results for each site combined for calculating the net nitrogen regeneration rates for the water quality modeling effort.

Sediment-watercolumn exchange follow the methods of Jorgensen (1977), Klump and Martens (1983), and Howes *et al.* (1995) for nutrients and metabolism. Upon return to the field laboratory (private residence located on the shores of Ockway Bay) the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with filtered water), filtered into acid leached polyethylene bottles and held on ice for nutrient analysis. Ammonium (Scheiner 1976) and ortho-phosphate (Murphy and Reilly 1962) assays were conducted within 24 hours and the remaining sample frozen (-20°C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia *et al.* 1977). Rates were determined from linear regression of analyte concentrations through time.

Chemical analyses were performed by the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST) at the University of Massachusetts in New Bedford, MA. The laboratory follows standard methods for saltwater analysis and sediment geochemistry.

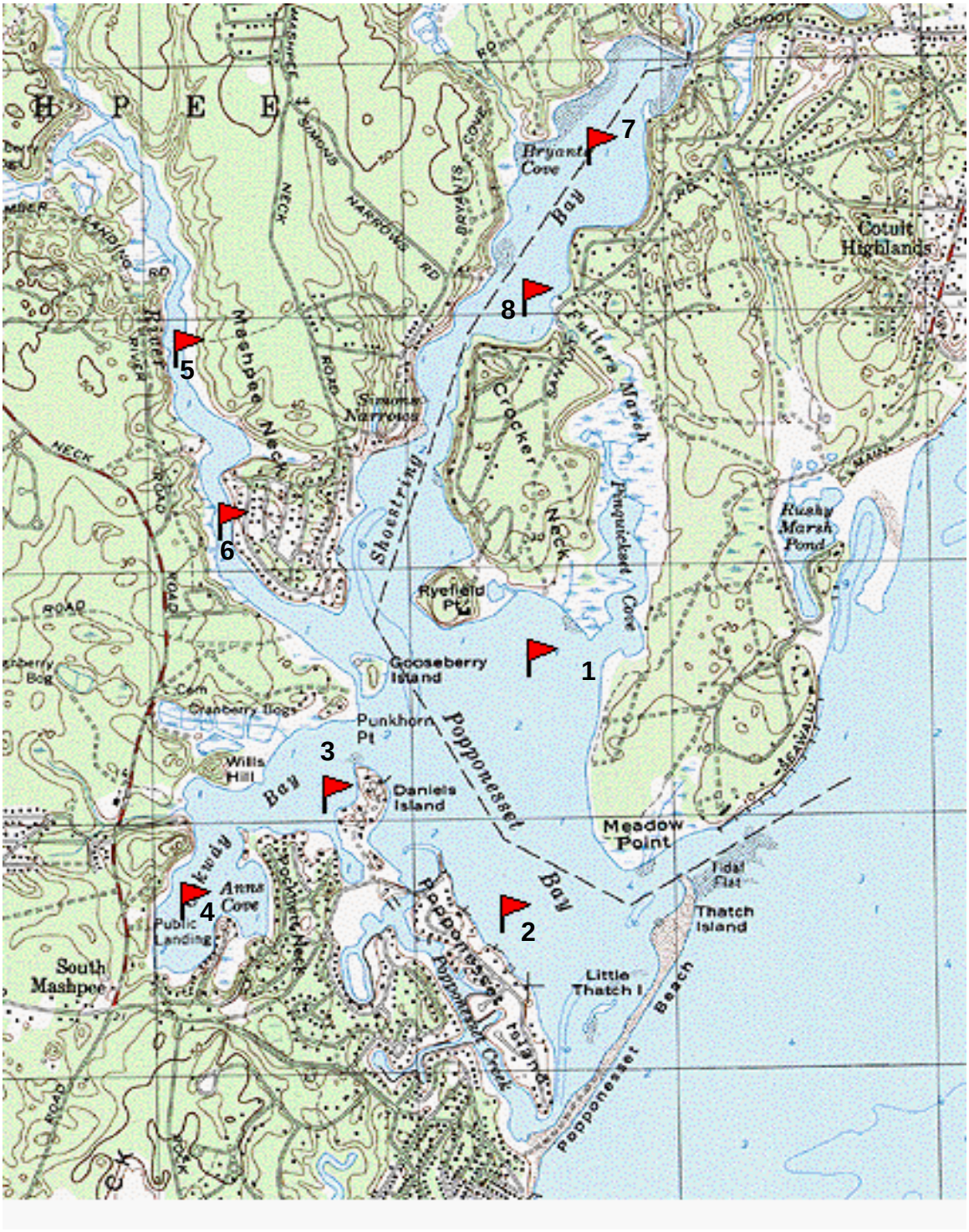


Figure IV-10. Popponesset Bay System locations (red flags) of sediment sample collection for determination of nitrogen regeneration rates. Numbers are for reference in Table IV-9.

Table IV-9. Rates of net nitrogen return from sediments to the overlying waters of the Popponesset Bay System. These values are combined with the basin areas to determine total nitrogen mass in the water quality model (see Chapter VI). Measurements represent June – early September rates.

		Sediment Nitrogen Release		
Sub-Embayment	Station	Mean mg N m^{-2} d^{-1}	std. dev. mg N m^{-2} d^{-1}	N
Mashpee River, Upper-Mid	5	85.40	10.52	8
Mashpee River, Lower	6	59.22	36.42	8
Shoestring Bay, Upper	7	-13.81	15.83	8
Shoestring Bay, Lower	8	-17.05	20.20	4
Ockway Bay, Upper	4	15.85	25.14	8
Ockway Bay, Lower	3	-11.45	9.67	3
Popponesset Bay, Upper	1	4.37	2.98	12
Popponesset Bay, Lower	2	-12.52	12.42	12

IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments

Watercolumn nitrogen levels are the balance of inputs from direct sources (land, rain etc), losses (denitrification, burial), regeneration (watercolumn and benthic), and uptake (e.g. photosynthesis). As stated above, during the warmer summer months the sediments of shallow embayments typically act as a net source of nitrogen to the overlying waters and help to stimulate eutrophication in organic rich systems. However, some sediments may be net sinks for nitrogen and some may be in "balance" (organic N particle settling = nitrogen release). Sediments may also take up dissolved nitrate directly from the watercolumn and convert it to dinitrogen gas (termed "denitrification"), hence effectively removing it from the ecosystem. This process is typically a small component of sediment denitrification in embayment sediments, since the watercolumn nitrogen pool is typically dominated by organic forms of nitrogen, with very low nitrate concentrations. However, this process can be very effective in removing nitrogen loads in some systems, particularly in salt marshes, where overlying waters support high nitrate levels.

In addition to nitrogen cycling, there are ecological consequences to habitat quality of organic matter settling and mineralization within sediments, which relate primarily to sediment and watercolumn oxygen status. However, for the modeling of nitrogen within an embayment it is the relative balance of nitrogen input from watercolumn to sediment versus regeneration which is critical. Similarly, it is the net balance of nitrogen fluxes between water column and sediments during the modeling period that must be quantified. For example, a net input to the sediments represents an effective lowering of the nitrogen loading to down-gradient systems and net output from the sediments represents an additional load.

The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the organic levels within the sediment (oxic/anoxic) and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake throughout the summer months, even though organic nitrogen is being mineralized and released to the overlying water as well. The rate of nitrate uptake simply dominates the overall sediment nitrogen cycle.

In order to model the nitrogen distribution within an embayment it is important to be able to account for the net nitrogen flux from the sediments within each part of each system. This requires that an estimate of the particulate input and nitrate uptake be obtained for comparison to the rate of nitrogen release. Only sediments with a net release of nitrogen contribute a true additional nitrogen load to the overlying waters, while those with a net input to the sediments serve as an "in embayment" attenuation mechanism for nitrogen.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure IV-11).

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates.

In order to determine the net nitrogen flux between watercolumn and sediments, all of the above factors were taken into account. The net input or release of nitrogen within a specific embayment was determined based upon the measured ammonium release, measured nitrate uptake or release, and estimate of particulate nitrogen input. Dissolved organic nitrogen fluxes were not used in this analysis, since they were highly variable and generally showed a net balance within the bounds of the method.

Sediment sampling was conducted within each of the sub-embayments of the Popponesset Bay System in order to obtain the nitrogen regeneration rates required for parameterization of the water quality model (Figure IV-10). The distribution of cores was established to cover gradients in sediment type, flow field and phytoplankton density. The rate measurements conducted on the 4 sampling dates were averaged. For each core the nitrogen flux rates (described in the section above) were evaluated relative to measured sediment organic carbon and nitrogen content and bulk density and an analysis of each site's tidal flow velocities. The maximum bottom water flow velocity at each coring site was determined from the hydrodynamic model. These data were then used to determine the nitrogen balance within each sub-embayment.

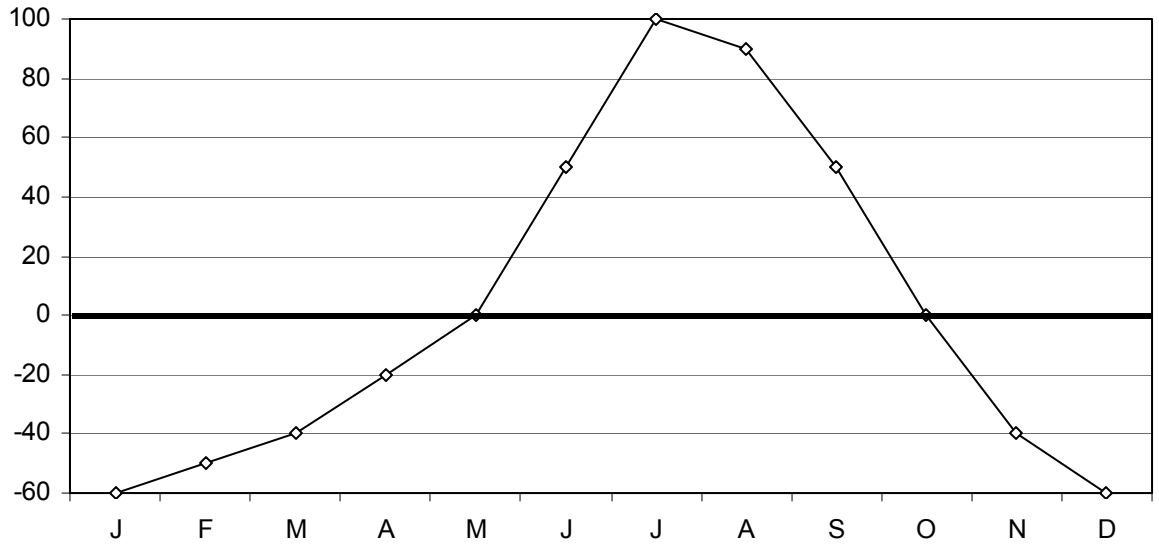


Figure IV-11. Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.

The magnitude of the settling of particulate organic carbon and nitrogen into the sediments was accomplished by determining the average depth of water within each sediment site and the average summer particulate carbon and nitrogen concentration within the overlying water. Two levels of settling were used. If the sediments were organic rich and a fine grained and the hydrodynamic data showed low tidal velocities, then a water column particle residence time of 8 days was used (based upon phytoplankton and particulate carbon studies of poorly flushed basins). If the sediments indicated a coarse grained sediments and low organic content and high velocities, then half this settling rate was used. Adjusting the measured sediment releases was essential in order not to over-estimate the sediment nitrogen source and to account for those sediment areas which are net nitrogen sinks for the aquatic system. This approach was validated in outer Cape Cod embayments (Town of Chatham) by examining the relative fraction of the sediment carbon turnover (total sediment metabolism) which would be accounted for by daily particulate carbon settling. This analysis indicated that sediment metabolism in the highly organic rich sediments of the wetlands and depositional basins is driven primarily by stored organic matter (ca. 90%). Also, in the more open lower portions of larger embayments, storage appears to be low and a large proportion of the daily carbon requirement in summer is met by particle settling (approximately 33% to 67%). This range of values and their distribution is consistent with ecological theory and field data from shallow embayments.

Net nitrogen release or uptake from the sediments within the Popponesset Bay System for use in the water quality modeling effort (Chapter VI) are presented in Table IV-9. It is clear that the sediments within the tidal reach of the Mashpee River represent a significant summer source of nitrogen to the overlying waters. This partially reflects the high phytoplankton production within (Chapter VII) and high nitrogen loading to this sub-embayment. In addition, the Mashpee River appears to function as a salt marsh system with a large single tidal channel. Other basins, more typical of embayments, showed relative small positive or negative net

nitrogen fluxes. This appears to result from the relatively high mass of particulate nitrogen settling within this system, due to the high phytoplankton production in the nitrogen rich embayment waters.

Higher nitrogen net fluxes from sediments of the Mashpee River versus the other basins likely results in part from differences in basin depth and tidal exchange (cf. Table V-9 for local residence times). There is also an indication that the very reducing (anoxic) nature of the Mashpee River sediments may be increasing the percentage of nitrogen which is released from the sediments versus the amount of nitrogen being lost to denitrification via the pathway of mineralization→ nitrification → denitrification. The coupled nitrification-denitrification step in the pathway is significantly influenced by the availability of oxygen within the surficial sediments for nitrifying bacteria. That the anoxic/sulfidic nature of the Mashpee River sediment is affecting enhancement of nitrogen release is supported by estimates of potential nitrogen loss versus the amount of measured loss. Using this rough approximation, more nitrogen is released from the Mashpee River sediments than from the other sites. Note that this approach yields general patterns and cannot be used to determine accurate nitrogen removal rates

V. HYDRODYNAMIC MODELING

V.1 INTRODUCTION

To support the Town of Mashpee with their Comprehensive Wastewater Management Planning (CWMP), an evaluation of tidal flushing has been performed for the Popponesset Bay estuarine system. The field data collection and hydrodynamic modeling effort contained in this report, provides the first step towards evaluating the water quality of these estuarine systems, as well as understanding nitrogen loading "thresholds" for each system. The hydrodynamic modeling effort serves as the basis for the total nitrogen (water quality) model, which will incorporate upland nitrogen load, as well as benthic regeneration within bottom sediments.

Shallow coastal embayments are the initial recipients of freshwater flow and the nutrients they carry. An embayment's semi-enclosed structure increases the time that nutrients are retained in them before being flushed out to adjacent waters, and their shallow depths both decrease their ability to dilute nutrient (and pollutant) inputs and increase the secondary impacts of nutrients recycled from the sediments. Degradation of coastal waters and development are tied together through inputs of pollutants in runoff and groundwater flows, and to some extent through direct disturbance, i.e. boating, oil and chemical spills, and direct discharges from land and boats. Excess nutrients, especially nitrogen, promote phytoplankton blooms and the growth of epiphytes on eelgrass and attached algae, with adverse consequences including low oxygen, shading of submerged aquatic vegetation, and aesthetic problems.

Estuarine water quality is dependent upon nutrient and pollutant loading and the processes that help flush nutrients and pollutants from the estuary (e.g., tides and biological processes). Relatively low nutrient and pollutant loading and efficient tidal flushing are indicators of high water quality. The ability of an estuary to flush nutrients and pollutants is proportional to the volume of water exchanged with a high quality water body (i.e. Nantucket Sound). Several embayment-specific parameters influence tidal flushing and the associated residence time of water within an estuary. For Popponesset Bay, the most important parameters are:

- Tide range
- Inlet configuration
- Estuary size, shape, and depth, and
- Longshore transport of sediment

The Popponesset Bay estuarine system (Figure V-1) is a tidally dominated embayment open to Nantucket Sound. The system separates the towns of Mashpee and Barnstable along the south coast of Cape Cod, Massachusetts. The system consists principally of subembayments Popponesset Bay, Ockway Bay, Mashpee River, and Shoestring Bay, as well as numerous other smaller coves, creeks, and marshes. It is relatively shallow on average, exceptions being deeper channels that provide flow paths between the Nantucket Sound and the embayments. The approximate tidal range within the system is 2.5 feet, with Nantucket Sound tidal variations providing the hydraulic forcing that drives water movement throughout the system.

The objective of this analysis is to develop a numerical model to simulate accurately the hydrodynamic characteristics of the Popponesset Bay system. The calibrated model can be used to understand tidal circulation, as well as be extended to calculate system flushing rates. Further, the hydrodynamic model provides basis for water quality modeling, enabling the Towns



Figure V-1. Map of the Popponesset Bay estuary (from United States Geological Survey topographic map, Cotuit quadrangle).

(Mashpee and Barnstable) to understand how pollutant loadings into the estuary will affect the biochemical environment and its ability to sustain a healthy marine habitat.

Since the water elevation difference between Nantucket Sound and each of the estuarine systems is the primary driving force for tidal exchange, the local tide range naturally limits the volume of water flushed during a tidal cycle. Tidal damping (reduction in tidal amplitude) through the Popponesset Bay system is negligible indicating “well-flushed” systems. Based on the tidal characteristics alone, this might indicate that the Popponesset Bay embayments (e.g. the Mashpee River) are “healthy” relative to embayments with more occluded inlets; however,

land development in the watershed serving the estuarine system has created significant nutrient loading, especially in the northern half of the system. Consequently, estuarine water quality is more dependent on nutrient loading than tidal characteristics for the Popponesset Bay system.

In addition to tidal forcing characteristics, the regional geomorphology influences flushing characteristics within the Popponesset Bay system. Offshore shoal migration and alongshore sediment transport patterns along the south shore of Mashpee and Cotuit (e.g., beach sand movement along Popponesset Beach spit) have caused numerous changes to the inlet over the past 50 to 70 years.

This section summarizes the development of hydrodynamic models for the Popponesset Bay estuarine system. For the estuarine system, the calibrated model offers an understanding of water movement through the estuary. Tidal flushing information will be utilized as the basis for a quantitative evaluation of water quality. Nutrient loading data combined with measured environmental parameters within the various sub-embayments become the basis for an advanced water quality model based on total nitrogen concentrations. This type of model provides a tool for evaluating existing estuarine water quality, as well as determining the influence of various methods for improving overall estuarine health.

In general, water quality studies of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. For example, the spread of pollutants may be analyzed from tidal current information developed by the numerical models.

To calibrate the hydrodynamic model, field measurements of water elevations and bathymetry were required. For the Popponesset Bay system tide data was acquired within Nantucket Sound (two gages were installed offshore of the groin field to the east of the inlet) and within major sub-embayments of the estuary. All temperature-depth recorders (TDRs or tide gages) were installed for a 30-day period to measure tidal variations through an entire neap-spring cycle. In this manner, attenuation of the tidal signal as it propagates through the various sub-embayments was evaluated accurately.

V.2 GEOMORPHIC AND ANTHROPOGENIC EFFECTS TO THE ESTUARINE SYSTEM

The southern coast of Cape Cod in the vicinity of Popponesset Bay is a moderately dynamic region, where natural wave and tidal forces continue to reshape the shoreline. As beaches continue to migrate, episodic breaching of the barrier beach system creates new inlets that alter the pathways of water entering the estuary. Storm-driven inlet formation often leads to hydraulically efficient estuarine systems, where seawater exchanges more rapidly with water inside the estuary. However, this episodic inlet formation is balanced by the gradual wave-driven migration of the barrier beach separating the estuaries from the ocean. As beaches elongate, the inlet channels to the estuaries often become long, sinuous, and hydraulically inefficient. Periodically, overwash from storm events will erode the barrier beach enough at a point to allow again the formation of a new inlet. It is then possible that the new inlet will stabilize and become the main inlet for the system, while the old inlet eventually fills in. Several

examples of this process along the Massachusetts coast include Allen's Pond (Westport), New Inlet/Chatham Harbor/Pleasant Bay (Chatham), and Nauset inlet (Orleans).

As described in Aubrey and Goud (1983), the loss of nearly one-half of the barrier beach between 1954 and the early 1980s led to concerns regarding future barrier spit migration. Figures V-2 and V-3 illustrate changes to the barrier spit over the 30 year period between 1951 and 1981. According to Aubrey and Gaines (1982), the present spit length has been historically the stable configuration. It wasn't until after about 1860 that the spit began to grow past its present location. The USGS map from 1893 (Figure V-4) shows the barrier beach in a condition where the spit is elongated slightly beyond present day conditions, where the flood shoal is emergent (Thatch Island).

Based on tidal hydrodynamics alone, present-day conditions represent a more efficient flow pathway than the elongated channel that existed in the three decades preceding the 1954 hurricane. Similar to most tidal inlets, the natural position of the inlet is a balance between hydrodynamic efficiency and littoral transport along the open coast. As the barrier spit elongated between the early 1900s and the mid-1950s as a result of regional littoral drift, the inlet channel become less efficient, where the tide height within Popponesset Bay decreased and the lag time between high tide in the estuary and Nantucket Sound increased. This increase in tidal attenuation was remedied in 1954, when a hurricane breached the barrier spit, creating an efficient inlet in the vicinity of the present inlet. Once the spit had breached, the remnants of the spit east of the inlet gradually overwashed and rejoined the shoreline (primarily in the vicinity of Rushy Marsh). This inlet spit growth and breaching process has been documented extensively for the southeastern coast of Massachusetts (e.g. Fitzgerald, 1993).

In addition to natural phenomena affecting estuarine hydrodynamics, man-made alterations have impacted tidal exchange in the Popponesset Bay system. Examples of anthropogenic modifications include the 1916 dredging within the main portion of Popponesset Bay, as well as the 1962 dredging associated with the large-scale development at New Seabury. The location of existing and proposed dredge channels within the Popponesset Bay system is shown in Figure V-5. Since the inlet has no jetties, the position of the main inlet migrated naturally for much of the past 100 years. Over the past decade, maintenance dredging likely has stabilized the inlet position at the present location.

Manmade coastal structures along the Mashpee shoreline consist primarily of seawalls and/or revetments along the updrift shoreline (west of Popponesset Beach). These structures likely have reduced the natural littoral sediment supply to the barrier beach system. In effect, this reduction in sediment supply may decrease spit growth and the associated needs for maintenance dredging. Long-term plans for the New Seabury shoreline facing Nantucket Sound include a large-scale beach nourishment project aimed at offsetting the impact of coastal structures on the local littoral system. If designed properly, this proposed beach nourishment program should have a negligible impact on inlet stability.

Although man has modified much of the Mashpee coastline, most of the large-scale changes to the estuarine systems have been caused by nature. For example, the 1954 breach of Popponesset Beach created a much more efficient inlet channel. Most of the manmade modifications to Popponesset Bay or the adjacent coastline have caused small changes to overall estuarine health. While past dredging efforts may have had a slight positive impact to tidal flushing, this influence is minor relative to natural large-scale changes.

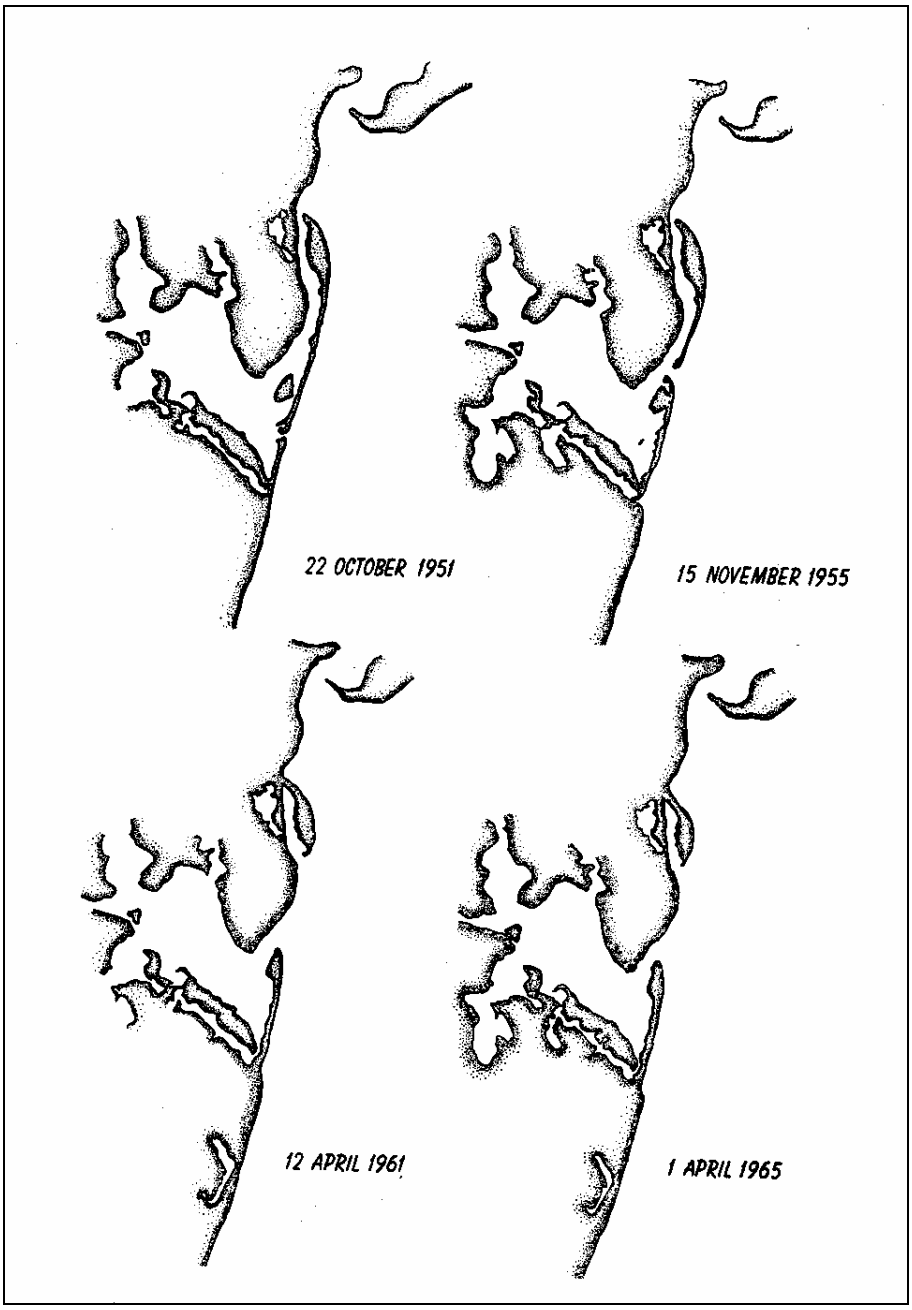


Figure V-2. Outlines of vertical aerial photographs illustrating stages of shoreline evolution in the Popponesset Spit region between 1951 and 1965 (from Aubrey and Goud, 1983).

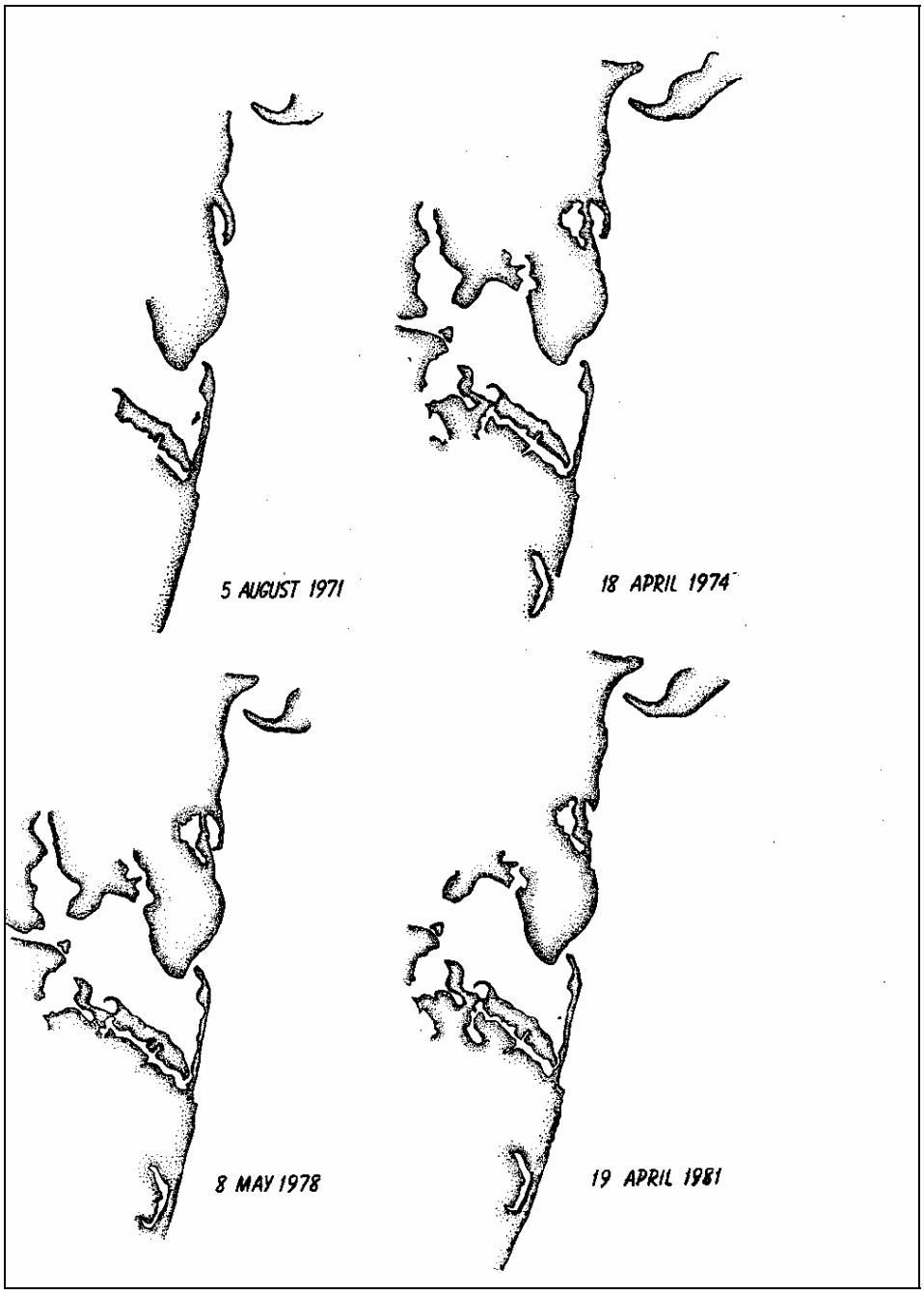


Figure V-3. Outlines of vertical aerial photographs illustrating stages of shoreline evolution in the Popponesset Spit region between 1971 and 1981 (from Aubrey and Goud, 1983).

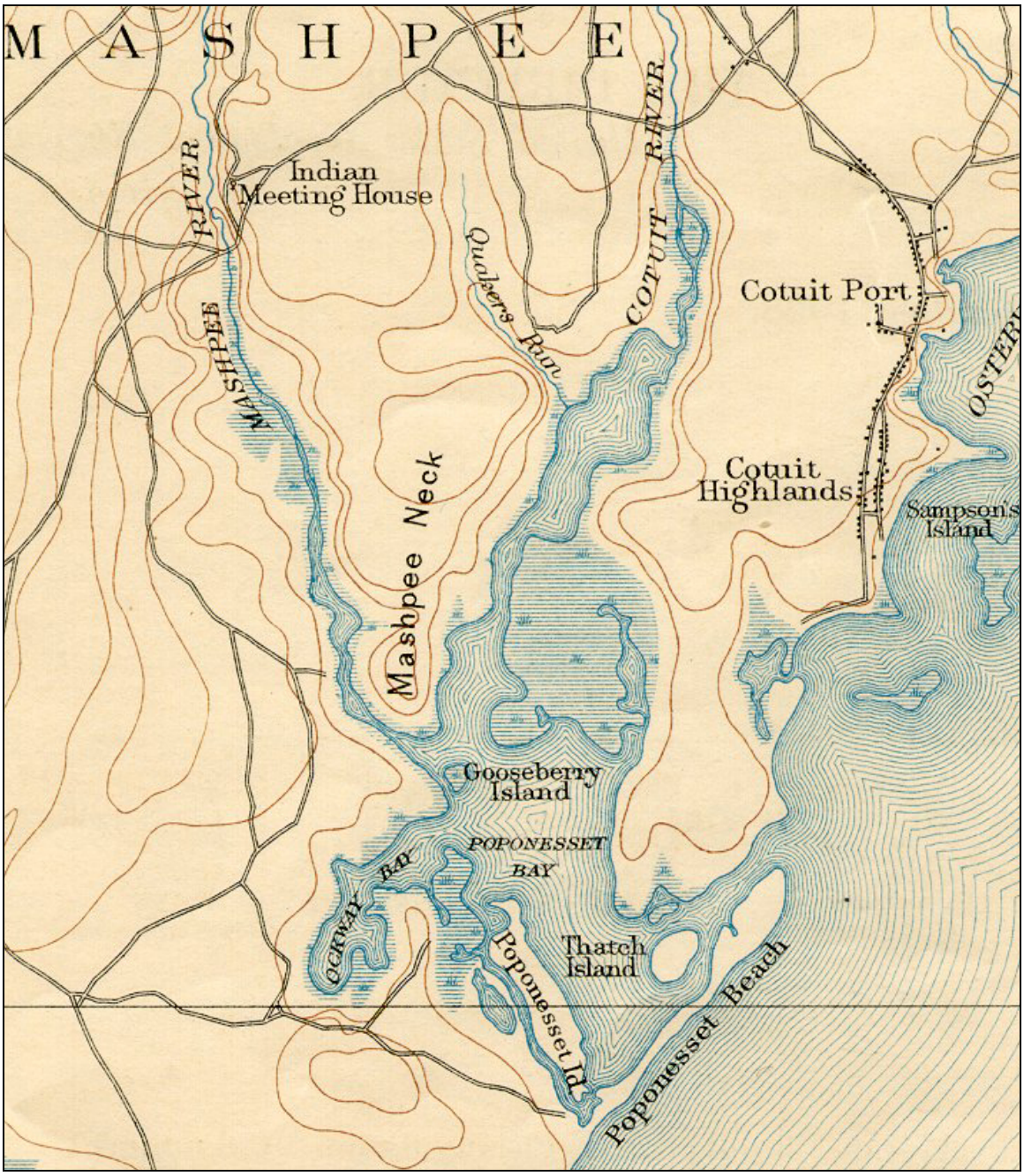


Figure V-4. Portion of the 1893 USGS topographic map (Cotuit Quadrangle) showing the position of the inlet at a similar location as the present inlet.

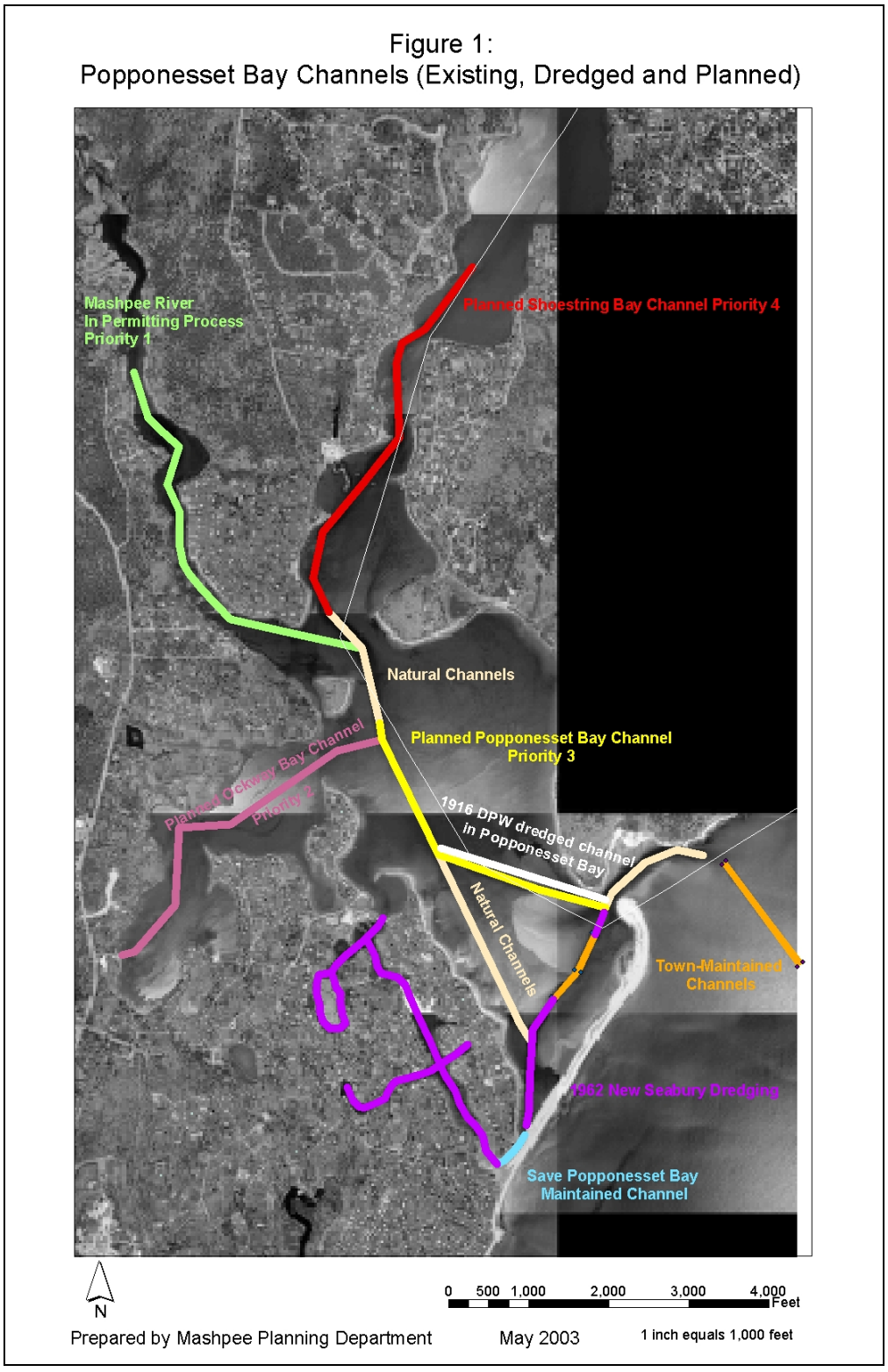


Figure V-5. Past and proposed future dredged channels within the Popponesset Bay estuarine system. Much of the previous improvement dredging within the system was performed during the 1960s development of New Seabury (shown in purple).

V.3 FIELD DATA COLLECTION AND ANALYSIS

Accurate modeling of system hydrodynamics is dependent upon measured conditions within the estuary for two important reasons:

- To define accurately the system geometry and boundary conditions for the numerical model
- To provide 'real' observations of hydrodynamic behavior to calibrate and verify the model results

The system geometry is defined as the shoreline of the system, including all coves, creeks, and marshes, as well as accompanying depth (or bathymetric) information. The three-dimensional surface of the estuary should be mapped as accurately as possible, since the resulting hydrodynamic behavior is strongly dependent upon features such as channel widths and depths, sills, marsh elevations, and inter-tidal flats. Hence, this study included an effort to collect bathymetric information in the field.

Boundary conditions for the numerical model consist of variations of water surface elevation in Nantucket Sound. These variations result principally from tides, and provide the dominant hydraulic forcing for the system. A pressure sensor was installed near the mouth of Popponesset Bay to measure the Nantucket Sound tides. This tidal function was used as the principal forcing function, or boundary condition, to the model.

Additional pressure sensors were installed at selected interior locations to measure variations of water surface elevation within subembayments. These measurements were used to calibrate and verify the model results, and to assure that the important physics were properly simulated.

V.3.1 Data Acquisition

V.3.1.1 Water Elevation

Variations in water surface elevation were measured at five locations around Popponesset Bay Estuary (Figure V-6):

- Offshore of the inlet to Popponesset Bay (location #1)
- Popponesset Island (location #2)
- Ockway Bay (location #3)
- Mashpee River (location #4)
- Shoestring Bay (location #5)

These variations were measured using small, self-contained pressure/ temperature sensors (typically referred to as tide gauges). These sensors use electronic recording circuits to sense external temperature and pressure, and write the measurements to internal memory recorders. The units are installed rigidly to pier pilings or other fixed objects, and remain in place throughout a monthly tidal cycle (more than 29 days).

The units were installed in early October, 1999, and recovered in early November, 1999. Data presented in this report spans October 4 to November 3, 1999. All recorders captured 100% of the data. Tide gauges in Shoestring Bay and Popponesset Island were surveyed into



Figure V-6. Map of the study region identifying locations of the tide gauges used to measure water level variations throughout the system. Five (5) gauges were deployed for one month between October 4 and November 5, 1999. Each black square represents the approximate locations of the tide gauges (1) Offshore of the inlet to the northeast of Thatch Island, (2) on the eastern shore of Popponesset Island, (3) within Anns Cove (Ockway Bay), (4) in the Mashpee River, and (5) on the western shore of Shoestring Bay.

local vertical datum using standard engineering rod-and-level techniques. Local benchmarks were obtained from FEMA Flood Insurance maps and National Geodetic Survey data sheets. Surveying at one gauge to a known datum allows estimation of the elevation of the remaining gauges.

Two types of sensors were utilized of this study: Brancker TG-205 recorders (at locations 1, 2, 4, and 5), and Coastal Leasing MicroTide recorders (location 3). In addition, a Coastal Leasing MicroTide sensor was used to record atmospheric pressure variations. The Brancker recorders utilize a 0-30 psia Druck strain gauge pressure sensor; resolution is 0.03% full scale and its accuracy is 0.1% full scale, or about 0.03 psi. This translates to an accuracy of about 0.8 inches of seawater. The MicroTide units possess the same accuracy standards as the Brancker units.

Two problems with the measurements were identified upon recovery; these problems did not affect the accuracy of the study. The first problem resulted from galvanic corrosion of the pressure port plumbing on the Brancker gauge installed in the Mashpee River. Corrosion caused the port to become slightly clogged during the last four-to-five days of the study, inhibiting the response of the gauge to changes in water elevation. Data returned from this gauge for the first four weeks of the study showed no adverse effects from this problem. The second problem was installation of the Ockway Bay gauge. While the gauge was mounted to a pier along the shoreline, the pressure port was located approximately 1 foot above the seabed. The gauge became exposed during extreme low-water events, hence the tidal curve becomes truncated during extreme low tides. This will affect the tidal constituent analysis, reporting harmonic constituents that may be decreased by as much as 3%-5%.

Upon recovery, the raw data were transferred from the instrument recorders to PC hard disks for processing and analysis. The raw data were first converted to engineering units (pounds per square inch, or psi) using each sensors factory-supplied calibration coefficients. Once in pressure units, the data were corrected for variations due to atmospheric pressure. These atmospheric pressure observations were collected near Ockway Bay using a Coastal Leasing MicroTide pressure sensor. After correction for atmospheric pressure variations, the data were then converted to head-of-water units, assuming a constant water density value of 1025 kg/m^3. These water elevation variation values for Shoestring Bay and Popponesset Island were then rectified to the NGVD 1929 vertical datum using survey measurements. The measurements obtained at each location are presented as Figure V-7.

Tide records of greater than 29 days ensure a complete evaluation of spring and neap tidal conditions within the estuarine system. Although a one-month record does not necessarily include extreme high or low tides, it does provide an accurate basis for typical tidal conditions governed by both lunar and solar gravitational attraction. In Nantucket Sound, additional attenuation of the tidal signal is caused by the geomorphology of the nearshore region. For numerical modeling of hydrodynamics, the typical tide conditions associated with a one-month record are appropriate for driving tidal flows within the estuarine system.

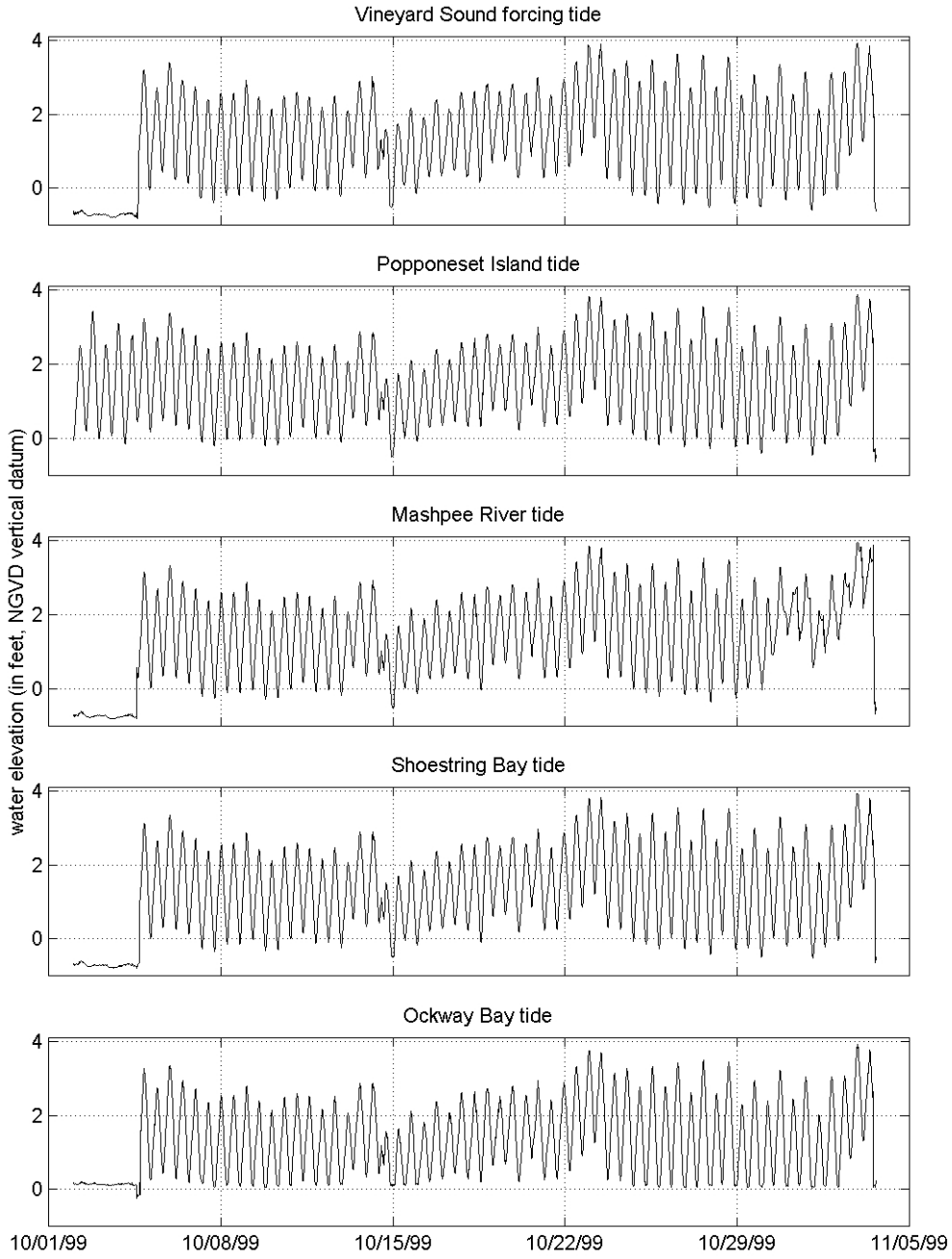


Figure V-7. Water elevation variations as measured at the five locations within the Popponesset Bay estuary. Atmospheric effects have been removed from the records. The gauge at Popponesset Island was deployed approximately three days prior to the other gauges.

V.3.1.2 Bathymetry

Bathymetry, or depth, of each subembayment was measured during a field survey October 28, 1999. The survey was completed using a small vessel equipped with a precision fathometer interfaced to a differential GPS receiver. The fathometer had a depth resolution of approximately 0.1 foot, and the differential GPS provides position measurements accurate to

approximately 1-3 feet. Digital data output from both the echo sounder and GPS were logged to a laptop computer, which integrated the data to produce multiple data sets consisting of water depth as a function of geographic position (latitude/longitude). The surveys were performed within each sub-embayment to develop plan view contour maps of system geometry.

The data files of water depth as a function of geographic position were merged with water surface elevation measurements to correct the measured depths to the NGVD 1929 vertical datum. Once corrected, the data were then merged into larger 'xyz' files containing x-y horizontal position (in Massachusetts State Plan 1983 coordinates) and vertical elevation of the bottom (z) relative to NGVD29. These xyz files were then interpolated into the finite element mesh used for the hydrodynamic simulations. The interpolated bathymetric data is presented in Figure V-8. The bathymetry survey and tidal measurements were performed after the 1999 dredging of the Popponesset Bay inlet.

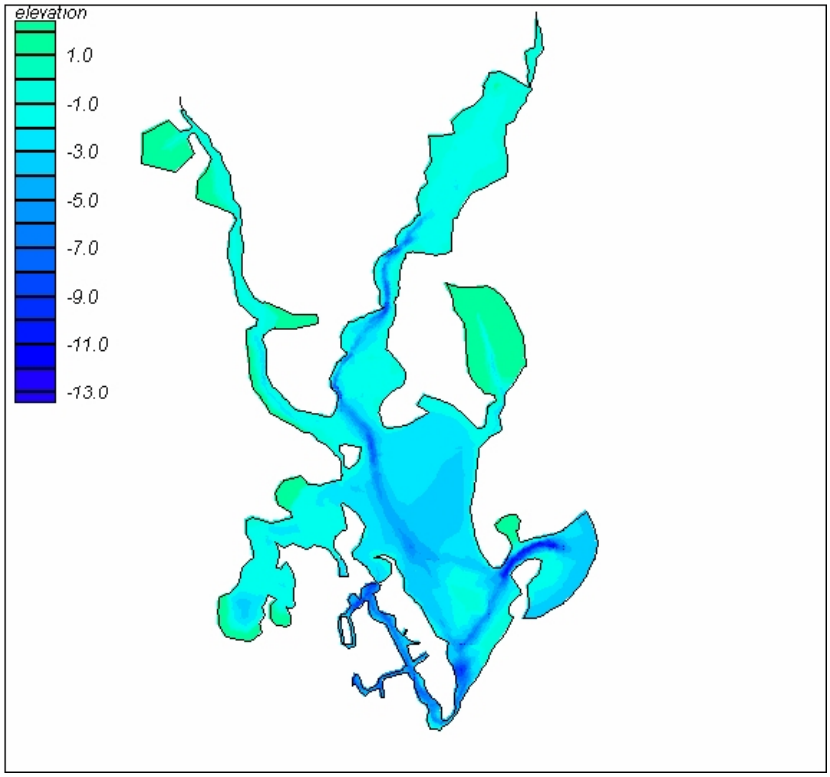


Figure V-8. Bathymetric data interpolated to the finite element mesh of hydrodynamic model.

V.3.2 Discussion of Results

V.3.2.1 Bathymetry Analysis

Analyses of the tide and bathymetric data provided insight into the hydrodynamic characteristics of each system. Harmonic analysis of the tidal time series produced tidal amplitude and phase of the major tidal constituents, and provided assessments of hydrodynamic 'efficiency' of each system in terms of tidal attenuation. This analysis also yielded an assessment of the relative influence of non-tidal or residual factors, processes (such as wind forcing) on the hydrodynamic characteristics of each system.

The Popponesset Bay system is open to Nantucket Sound. The inlet is affected significantly by longshore sand transport (the predominant transport is west to east), which tends to accrete Popponesset Spit towards Cotuit Highlands. This longshore sediment transport can impede hydrodynamic exchange at the mouth. Groins constructed along the Cotuit side of the shoreline armor the downdrift side of the inlet; the Popponesset Beach side (updrift side) is unarmored. The offshore region near the entrance to the system is quite shallow, with mild slopes extending offshore. The entrance channel is narrow and relatively deep, approximately 10 to 15 feet below NGVD and features strong tidal currents. Inside the system, the Popponesset Bay embayment possesses relatively deep water along the western edge, and shallower depths on the eastern edge. Popponesset Creek, on backside of Popponesset Island has been modified by dredging; in some areas the creek depth is more than 8 feet below NGVD. The northeast portion of Popponesset Bay embayment splits into Ockway Bay, a shallow embayment of soft sediments and sluggish flow, and the entrances to Shoestring Bay (Santuit River) and Mashpee River. The Mashpee River is long and narrow, with relatively shallow depths in the channel of order 3 to 5 feet below NGVD. A deep channel (6 to 10 feet below NGVD) along the western edge of Shoestring Bay leads to a northern basin where the depths are shallow and sediments relatively soft. Marsh areas exist within the system, most significantly the Pinquickset Marsh on the northeast corner of the embayment, but also in areas of Ockway Bay and upper (northern) portions of the Mashpee River.

V.3.2.2 Tidal Harmonic Analysis

Harmonic analyses were performed on the time series from each gage location in an effort to separate the various tidal components and identify the important properties. In addition, it allows an understanding of the relative contribution that various physical processes (i.e. tides, winds, etc.) have on water level variations within the estuary. Harmonic analysis is a mathematical procedure that fits sinusoidal functions of known frequency to the measured signal. The amplitudes and phase of 23 tidal constituents result from this procedure.

Table V-1 presents the amplitudes of the eight largest tidal constituents. The M_2, or the familiar twice-a-day lunar semi-diurnal, tide is the strongest contributor to the signal with an amplitude of 1.2 feet in Nantucket Sound. The range of the M_2 tide is twice the amplitude, or about 2.4 feet. The diurnal tides, K_1 (solar) and O_1 (lunar), possess amplitudes of approximately 0.15-0.20 feet. The N_2 tide, a lunar constituent with a semi-diurnal period, rivals the diurnal constituents with an amplitude of 0.30 feet. The M_4 tide, a higher frequency harmonic of the M_2 lunar tide (twice the frequency of the M_2), results from frictional dissipation of the M_2 tide in shallow water. The M_4 is significant in Vineyard and Nantucket Sounds, and is responsible for the unusual 'double high' tide signature prominent along the Falmouth shoreline to the west. This M_4 constituent tends to decrease eastward in Nantucket Sound, but at Popponesset Bay is still 0.18 feet, approximately one-fifth the amplitude of the M_2.

Table V-1. Tidal Constituents for Popponesset Bay System 1999.

	Amplitude (feet)							
Constituent	M_2	M_4	M_6	S_2	N_2	K_1	O_1	Msf
Period (hours)	12.42	6.21	4.14	12.00	12.66	23.93	25.82	354.61
Nantucket Sound (Inlet)	1.20	0.18	0.06	0.10	0.30	0.15	0.20	0.25
Popponesset Island	1.14	0.08	0.06	0.08	0.28	0.14	0.19	0.24
Ockway Bay	1.10	0.07	0.05	0.08	0.27	0.13	0.18	0.24
Shoestring Bay	1.15	0.06	0.07	0.07	0.29	0.13	0.19	0.24
Mashpee River	1.05	0.04	0.07	0.15	0.22	0.11	0.18	0.27

The observed astronomical tide is therefore the sum of several individual tidal constituents, with a particular amplitude and frequency. For demonstration purposes a graphical example of how these constituents add together is shown in Figure V-9.

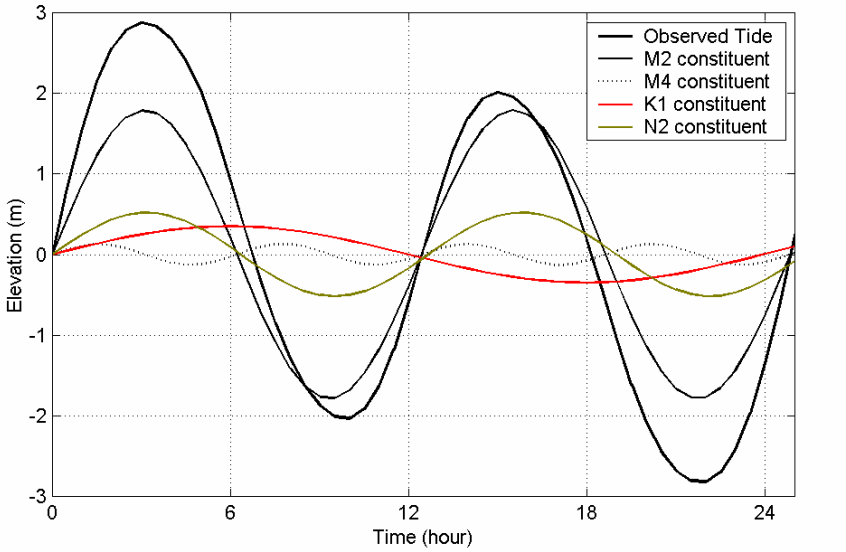


Figure V-9. Example of observed astronomical tide as the sum of its primary constituents.

Table V-1 also shows how the constituents vary as the tide propagates into the estuaries. Most estuaries exhibit tidal damping, that is, a reduction of the tide range relative to the offshore forcing tide. Note the reduction in the M_2 amplitude between Nantucket Sound and Popponesset Island (M_2 amplitude of 1.2 feet in Nantucket Sound versus 1.14 feet at Popponesset Island, just inside the inlet, a reduction of 5%). Tidal amplitude decreases are also shown in Ockway Bay and Mashpee River. In general, the amplitude reduction of the M_2 constituent is relatively small through the system, with the largest reduction across the inlet.

To better quantify the changes to the tide from the inlet to inside the system, the standard tide datums were computed from the 29-day records. These datums are presented in Table V-2. For most NOAA tide stations, these datums are computed using 19 years of tide data, the definition of a tidal epoch. For this study, a significantly shorter time span of data was available; however, these datums still provide a useful comparison of tidal dynamics within the system. The Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) levels represent the mean of the daily highest and lowest water levels. The Mean High Water (MHW) and Mean Low Water (MLW) levels represent the mean of all the high and low tides of a record, respectively. The Mean Tide Level (MTL) is simply the mean of MHW and MLW.

The tides in Nantucket Sound are semi-diurnal, meaning that there are typically two tide cycles in a day. There is usually a small variation in the level of the two daily tides. This variation can be seen in the differences between the MHHW and MHW, as well as the MLLW and MLW levels. With the relatively small tide range of the Popponessett Bay, the influence of atmospheric forcing also can be seen in the tide records. For example, the maximum tide reading in the Mashpee River is higher than the remainder of the system, where this anomalous reading likely was due to local wind set-up.

Table V-2. Tide datums computed from records collected in Popponesset Bay from October 4 to November 3, 1999. Datum elevations are given relative to NGVD.

Tide Datum	Offshore (feet)	Poppones set Island (feet)	Shoestring Bay (feet)	Mashpee River (feet)	Ockway Bay (feet)
Maximum Tide	3.94	3.88	3.93	3.96	3.91
MHHW	3.02	2.98	2.96	2.97	2.95
MHW	2.77	2.74	2.70	2.73	2.69
MTL	1.51	1.51	1.45	1.56	1.46
MLW	0.14	0.23	0.14	0.35	0.29
MLLW	-0.59	0.03	-0.07	0.12	0.16
Minimum Tide	-0.83	-0.51	-0.64	-0.50	0.03

Table V-3 presents the phase delay of the M_2 tide at all tide gauge locations, in other words, the travel time required for the tidal wave to propagate throughout the system. The data suggest that it takes approximately 5 minutes for the tide wave to travel from Popponesset Island to Ockway Bay, about 7-8 minutes to go from Popponesset Island to Shoestring, and more than 11 minutes to propagate from Popponesset Island to the Mashpee River. The important result from Table V-3 is that it takes about a half-hour for the tide to move from Nantucket Sound through the inlet. This suggests that the inlet may be responsible for significant modification of the tide wave. Modification of the wave, or tidal distortion, can alter the hydrodynamic characteristics of a system and resulting efficiency with which the system flushes pollutants. Long delays signify reduced hydrodynamic exchange, while small delays indicate an efficient, well-flushed system. The results from Table V-3 suggest that hydrodynamic circulation is quite efficient within the system, that is, between Popponesset Bay and the subembayments; however, the relatively longer delay between Nantucket Sound and Popponesset Island suggests exchange through the inlet is the primary source of inefficiency.

Table V-3. M_2 Phase Delays from Nantucket Sound through the Popponesset Bay System

Location	Delay (minutes)
Popponesset Bay	28.75
Ockway Bay	33.57
Shoestring Bay	36.48
Mashpee River	40.37

Table V-4 shows the relative variance of tidal versus non-tidal (or residual) processes at different locations in the systems. Variance is directly proportional to energy. Non-tidal processes include wind responses, for example wind set-up and set-down, or sub-tidal oscillations originating in Nantucket Sound. In addition, the water levels within the estuary can be affected by freshwater input, either through groundwater or surface runoff during rain events. The table shows the percentage of non-tidal energy at various points within the estuary, and that the relative percentage increases with increasing distance into the system. At Popponesset Island, only about 14% of the signal variance can be attributed to non-tidal events. In the

Mashpee River, nearly 25% of the signal was due to non-tidal processes. The larger influence of non-tidal processes within the Mashpee River likely is due to local effects of wind which can produce significant non-tidal variations of the sea surface, hence increasing the energy of non-tidal processes. Fresh water inflow also could produce variations, especially after substantial precipitation, although these effects are difficult to quantify through a constituent analysis of short-term tidal data. The results from Table V-4 indicate that hydrodynamic circulation in each of the subembayments is dependent primarily upon tidal processes, yet wind and other non-tidal effects are of significant concern as well. For the hydrodynamic modeling effort described below, the actual tide signal in Nantucket Sound was used to force the model; therefore, the effects of non-tidal energy are included in the modeling analysis.

Table V-4. Percentages of Tidal versus Non-Tidal Variance Popponesset Bay System (units of ft^2)

Location	Total Variance	Tidal Variance	Residual Variance	% Residual
Nantucket Sound	1.024	0.889	0.135	13.2%
Popponesset Bay	0.903	0.778	0.124	13.8%
Ockway Bay	0.856	0.732	0.124	14.4%
Shoestring Bay	0.933	0.792	0.141	15.1%
Mashpee River	0.887	0.668	0.219	24.7%

Figure V-10 shows the results of the tidal versus the non-tidal separation procedure for the tide gauge at Popponesset Island. While the measurements show that tides dominate the variations of water level within the estuary, it was clear that non-tidal processes also affected changes in the water surface. While the tidal range was nearly four feet (maximum), the measurements suggest that non-tidal processes, probably winds, can produce water surface variations of +/- 1 foot, a significant fraction of the tide range. These processes can have important hydrodynamic repercussions, specifically a major influence in horizontal mixing within the estuary. In a sense, major wind storms provide benefits for estuaries with limited tide ranges, such as those along the southwest Cape shore (i.e. Falmouth finger ponds, Waquoit and Popponesset Bays). Strong winds have energy sufficient to increase substantially horizontal circulation and improve flushing in areas where tidal-induced circulations are poor.

Table V-5 presents additional analytical information regarding the hydrodynamic behavior of the estuary. The amplitude ratio and relative phase values can indicate the degree of tidal distortion, or modification, of the tide entering the estuary, and provide insight into the physical processes responsible for the observed signals (Freidrichs and Aubrey, 1985). Two results of Table V-5 deserve attention: the first is the reduction of the M_4/M_2 ratio with distance into the estuary, and second are relative phase values in the vicinity of 270°. Both of these values suggest Popponesset Bay estuary can be described as an 'ebb-dominant' estuary, in contrast to many other estuaries on Cape Cod that can be described as 'flood-dominant' estuaries.

Table V-5. Amplitude Ratio and Relative Phase

Location	M_4/M_2 ratio	$2M_2$-M_4 phase
Nantucket Sound	0.148	262°
Popponesset Bay	0.072	270°
Ockway Bay	0.065	294°
Shoestring Bay	0.053	284°
Mashpee River	0.042	291°

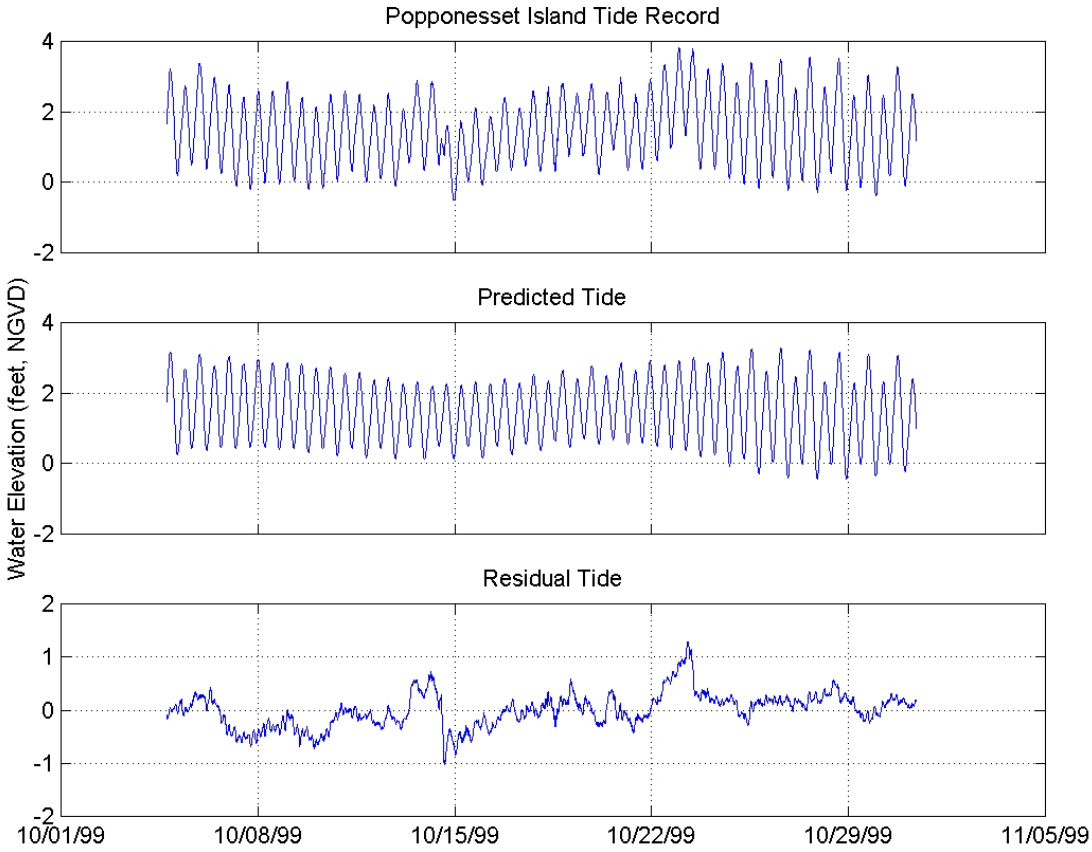


Figure V-10. Results of the harmonic analysis and the separation of the tidal from the non-tidal, or residual, signal measured at Popponesset Island.

A detailed scientific explanation of these parameters is presented in Freidrichs and Aubrey (1985). In general, the results of this analysis indicate that the Popponesset Bay system is ebb-dominant, where the estuary tends to have a flood tide that is longer in duration than the ebb tide. Due to this asymmetry in the tide phases, and the need to conserve volume within the estuary, ebb currents will tend to be stronger than flood currents because the same (or similar) volume must pass through the inlet over a shorter time period. The 'ebb-dominant' estuary, with its stronger ebb currents, will tend to have a net transport of sediments out of the system and into Nantucket Sound. Flood-dominant systems tend to accumulate sediments.

V.4 HYDRODYNAMIC MODELING

The focus of this study was the development of a numerical model capable of accurately simulating hydrodynamic circulation within this estuary. Once calibrated, the model was used to calculate water volumes for selected subembayments (e.g., Ockway Bay, Mashpee River, and Shoestring Bay) as well as determine the volumes of water exchanged during each tidal cycle. These parameters are used to calculate system residence times, or flushing rates. Use of a calibrated numerical model is the most accurate and reliable method to determine system flushing rates.

V.4.1 Model Theory

This study of the Popponesset Bay system utilized a state-of-the-art computer model to evaluate tidal circulation and flushing. The particular model employed was the RMA-2 model developed by Resource Management Associates (King, 1990). It is a two-dimensional, depth-averaged finite element model, capable of simulating transient hydrodynamics. The model is widely accepted and tested for analyses of estuaries or rivers. Applied Coastal staff members have utilized RMA-2 for numerous flushing studies on Cape Cod, including West Falmouth Harbor, Falmouth's 'finger' ponds, Pleasant Bay estuary, as well as previous studies of Popponesset Bay.

In its original form, RMA-2 was developed by William Norton and Ian King under contract with the U.S. Army Corps of Engineers (Norton et al., 1973). Further development included the introduction of one-dimensional elements, state-of-the-art pre- and post-processing data programs, and the use of elements with curved borders. Recently, the graphic pre- and post-processing routines were updated by Brigham Young University through a package called the Surfacewater Modeling System or SMS (BYU, 1998). SMS is a front- and back-end software package that allows the user to easily modify model parameters (such as geometry, element coefficients, and boundary conditions), as well as view the model results and download specific data types. While the RMA model is essentially used without cost or constraint, the SMS software package requires site licensing for use.

RMA-2 is a finite element model designed for simulating one- and two-dimensional depth-averaged hydrodynamic systems. The dependent variables are velocity and water depth, and the equations solved are the depth-averaged Navier-Stokes equations. Reynolds assumptions are incorporated as an eddy viscosity effect to represent turbulent energy losses. Other terms in the governing equations permit friction losses (approximated either by a Chezy or Manning formulation), Coriolis effects, and surface wind stresses. All the coefficients associated with these terms may vary from element to element. The model utilizes quadrilaterals and triangles to represent the prototype system. Element boundaries may either be curved or straight.

The time dependence of the governing equations is incorporated within the solution technique needed to solve the set of simultaneous equations. This technique is implicit; therefore, unconditionally stable. Once the equations are solved, corrections to the initial estimate of velocity and water elevation are employed, and the equations are re-solved until the convergence criteria is met.

V.4.2 Model Setup

There are three main steps required to implement RMA-2V:

- Grid generation
- Boundary condition specification
- Calibration

The extent of each finite element grid was generated using digital aerial photographs from the MassGIS online orthophoto database. A time-varying water surface elevation boundary condition (measured tide) was specified at the entrance of the system based on the tide gauge data collected in Nantucket Sound. Once the grid and boundary conditions were set, the model was calibrated to ensure accurate predictions of tidal flushing. Various friction and eddy viscosity coefficients were adjusted, through several (15+) model calibration simulations for each system, to obtain agreement between measured and modeled tides. The calibrated model provides the requisite information for future detailed water quality modeling.

V.4.2.1 Grid Generation

The grid generation process for the model was simplified by the use of the SMS package. The digital shoreline and bathymetry data were imported to SMS, and a finite element grid was generated to represent the estuary with 3584 elements and 10227 nodes (Figure V-11). All regions in the system were represented by two-dimensional (depth-averaged) elements. The finite element grid for the system provided the detail necessary to evaluate accurately the variation in hydrodynamic properties within the estuary. Fine resolution was required to simulate the numerous channel constrictions that significantly impact the estuarine hydrodynamics. The SMS grid generation program was used to develop quadrilateral and triangular two-dimensional elements throughout the estuary. Reference water depths at each node of the model were interpreted from bathymetry data obtained in the field surveys. The model computed water elevation and velocity at each node in the model domain.

Grid resolution was governed by two factors: 1) expected flow patterns, and 2) the bathymetric variability in each region. Relatively fine grid resolution was employed where complex flow patterns were expected. For example, smaller node spacing in each creek and/or channel was designed to provide a more detailed analysis in these regions of rapidly varying flow. Also, elements through channels were designed to account for the rapid changes in bathymetry caused by shoaling and scour processes. Widely spaced nodes were defined for much of the marsh and inter-tidal flats, where flow patterns did not change dramatically. Appropriate implementation of wider node spacing and larger elements reduced computer run time with no sacrifice of accuracy.

V.4.2.2 Boundary Condition Specification

Three types of boundary conditions were employed for the RMA-2 model: 1) "slip" boundaries, 2) freshwater inflow, and 3) tidal elevation boundaries. All of the elements with land borders have "slip" boundary conditions, where the direction of flow was constrained shore-parallel. The model generated all internal boundary conditions from the governing conservation equations. Freshwater recharge was specified at the upper end of the Mashpee River and Shoestring Bay (Santuit River), although these values were quite small relative to the tidal prism.

The model was forced using water elevations measurements obtained just offshore of the inlet in Nantucket Sound (see discussion in the previous section). This measured time series consists of all physical processes affecting variations of water level: tides, winds, and other non-tidal oscillations of the sea surface. The rise and fall of the tide in the Sound is the primary driving force for estuarine circulation. Dynamic (time-varying) model simulations specified a new water surface elevation at the offshore boundary every 10 minutes. The model specifies the water elevation at the offshore boundary, and uses this value to calculate water elevations at every nodal point within the system, adjusting each value according to solutions of the model equations. Changing water levels in Nantucket Sound produce variations in surface slopes within the estuary; these slopes drive water either into the system (if water is higher offshore) or out of the system (if water levels fall in the Sound).

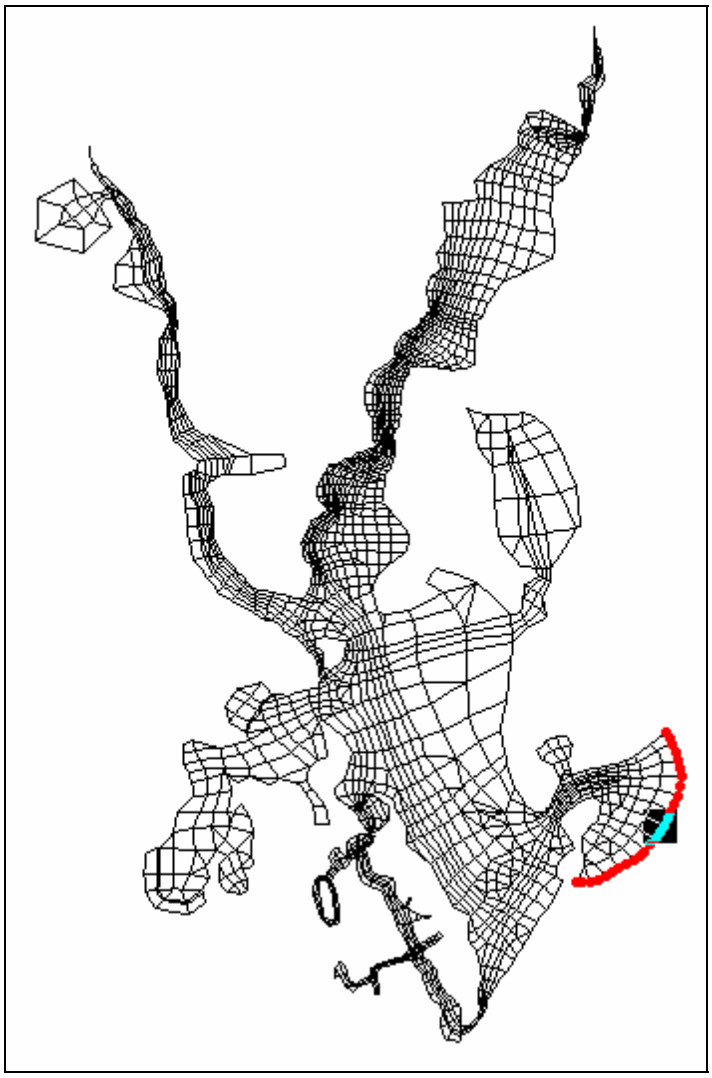


Figure V-11. The model finite element mesh developed for Popponesset Bay. The model seaward boundary (red bold line) was specified with a forcing function consisting of water elevation measurements obtained in Nantucket Sound.

V.4.2.3 Calibration

After developing the finite element grid and specifying boundary conditions, the model was calibrated. Calibration ensured the model predicted accurately what was observed during the field measurement program. Numerous model simulations were required to calibrate the model, with each run varying specific parameters such as friction coefficients, turbulent exchange coefficients, fresh water inflow, and subtle modifications to the system bathymetry (for example, variations to marsh plain surface area and elevation) to achieve a best fit to the data.

Calibration of the flushing model required a close match between the modeled and measured tides in each of the sub-embayments where tides were measured (e.g. Mashpee River, Shoestring Bay, etc). Initially, a seven-day period was calibrated to obtain visual agreement between modeled and measured tides. To refine the calibration procedure, water elevations were outputted from the simulation at the same locations in the estuary where tide

gauges were installed. The two data curves, model and measured, were overlaid on a graph for visual comparison. In addition, the data were processed to calculate harmonic constituents (of both data sets) over the seven-day period. The amplitude and phase of four constituents (M_2, M_4, M_6, and K_1) were compared and the corresponding errors for each were calculated. In addition, the standard error between the two curves was calculated. The intent of the calibration procedure is to minimize the standard error between the curves, as well as to minimize the error in amplitude and phase of the individual constituents. In general, minimization of the M_2 amplitude and phase becomes the highest priority, since this is the dominant constituent. Emphasis is also placed on the M_4 constituent, as this constituent has the greatest impact on the degree of tidal distortion within the system, and provides the unique shape of the modified tide wave at various points in the system.

The calibration was performed for a seven-day period, beginning 1100 hours EST October 23, 1999 and ending October 30, 1999. This representative time period was selected because it included tidal conditions where the wind-induced portion of the signals (i.e. the residual) was minimal, hence more typical of purely tidal circulation within the estuary. The selected time period also spanned the transition from neap (bi-monthly minimum) to spring (bi-monthly maximum) tide ranges, which is representative of average tidal conditions in the embayment system. Throughout the selected seven-day period, the tide ranged approximately 3.5 feet from low to high tides. The ability to model a range of flow conditions is a primary advantage of a numerical tidal flushing model. Modeled tides were evaluated for time (phase) lag and height damping of dominant tidal constituents. The calibrated model was used to analyze existing detailed flow patterns and compute residence times.

V.4.2.3.1 Friction Coefficients

Friction inhibits flow along the bottom of estuary channels or other flow regions where water depths can become shallow and velocities relatively high. Friction is a measure of the channel roughness, and can cause both significant amplitude attenuation and phase delay of the tidal signal. Friction is approximated in RMA-2 as a Manning coefficient. First, the Manning's coefficients were matched to bottom type. Manning's friction coefficient values of 0.025 were specified for all elements. These values correspond to typical Manning's coefficients determined experimentally in smooth earth-lined channels with no weeds (low friction) to winding channels with pools and shoals with higher friction (Henderson, 1966). On the marsh plains, damping of flow velocities typically is controlled more by "form drag" associated with marsh plants than the bottom friction described above. However, simulation of this "form drag" is performed using Manning's coefficients as well, with values ranging from 2-to-10 times friction coefficients used in channels. Final calibrated friction coefficients for the marsh were selected as 0.05. Small changes in these values did not change the accuracy of the calibration.

Variation of the friction parameters during the calibration effort showed that the system was not sensitive to small changes in friction values. A greater change to the estuary response was observed in the model when turbulent exchange values were increased within the inlet channel. The strong flow speeds within the entrance channel will be sensitive to changes in turbulent exchange. As turbulent exchange coefficients increase, tidal energy is removed from the system. Increases in turbulent exchange values through the inlet were found to increase the phase delay of the tide (i.e. high tide arrived later in the Bay) and to decrease the tidal amplitude. Final calibrated friction coefficients are summarized in Table V-6.

Table V-6. Manning's Roughness coefficients used in simulations of modeled embayments.		
System	Embayment	Bottom Friction
Popponesset Bay	Nantucket Sound	0.025
	Inlet	0.025
	Meadow Point	0.050
	Popponesset Bay	0.025
	Popponesset Creek	0.025
	Pinquicket Cove	0.025
	Pinquicket Marsh	0.050
	Shoestring Bay	0.025
	Mashpee River	0.025
	Mashpee River Marsh	0.050
	Ockway Bay	0.025
	Ockway Bay Marsh	0.050

V.4.2.3.2 Turbulent Exchange Coefficients

Turbulent exchange coefficients approximate energy losses due to internal friction between fluid particles. The significance of turbulent energy losses increases where flow is swift, such as inlets and bridge constrictions. According to King (1990), these values are proportional to element dimensions (numerical effects) and flow velocities (physics). The model was mildly sensitive to turbulent exchange coefficients, specifically in the entrance channel of strong turbulent flow. In other regions where the flow was generally weak, for example broad regions of eastern Popponesset Bay, the model was insensitive to changes in turbulent exchange coefficients. Typically, model turbulence coefficients were set between 50 and 100 lb-sec/ft^2. Higher values (up to 200 lb-sec/ft^2) were used on the marsh plain, to ensure solution stability.

The calibration procedure proved that, in addition to changes in friction and turbulence coefficients, the model was also quite sensitive to changes in system geometry. This fact is not unexpected, and is the reason why accurate bathymetry and topography data are required for these models. While the bathymetry data set obtained for this study was extensive: spatial coverage and vertical resolution of upland marshes and creek areas were not well documented. For example, it was found that the changes in the marsh surface area would affect model response. Similarly, variations in the elevation of the marsh plain could also elicit model changes.

V.4.2.3.3 Wetting and Drying/Marsh Porosity Processes

Modeled hydrodynamics were complicated by wetting/drying cycles on the marsh plain included in the model of the Popponesset system. Cyclically wet/dry areas of the marsh will tend to store waters as the tide begins to ebb and then slowly release water as the water level drops within the creeks and channels. This store-and-release characteristic of these marsh regions was partially responsible for the distortion of the tidal signal, and the elongation of the ebb phase of the tide. On the flood phase, water rises within the channels and creeks initially until water surface elevation reaches the marsh plain, when at this point the water level remains nearly constant as water 'fans' out over the marsh surface. The rapid flooding of the marsh surface corresponds to a flattening out of the tide curve approaching high water. Marsh porosity

is a feature of the RMA-2 model that permits the modeling of hydrodynamics in marshes. This model feature essentially simulates the store-and-release capability of the marsh plain by allowing grid elements to transition gradually between wet and dry states. This technique allows RMA-2 to change the ability of an element to hold water, like squeezing a sponge. The marsh porosity feature of RMA-2 is typically utilized in estuarine systems where the marsh plain has a significant impact on the hydrodynamics of a system.

V.4.2.3.4 Comparison of Modeled Tides and Measured Tide Data

Many experimental model runs were performed to determine how changes to various parameters (e.g. friction and turbulent exchange coefficients) affected the model results. These trial runs achieved excellent agreement between the model simulations and the field data, with standard errors on the order of 1 inch. Examples of the simulated tide curves for each of the four inner-estuary locations are shown in Figure V-12.

Once the model was calibrated, a validation model run was performed to test the accuracy of the calibrated model. A new time period was selected for the validation run, from October 4 through October 11, 1999. The period was selected because it included different tidal conditions than contained in the calibration time period. During the validation time period, the tide range was approximately 3 feet or less, slightly reduced relative to the calibration time period in late October. Comparison of the model output and data observations for this simulation is shown in Figure V-13.

A further tidal constituent verification was undertaken for the validation period. The constituent calibration values are presented in Table V-7, and reveal excellent agreement between modeled and measured tides. Standard errors between the model and observed conditions were less than 1 inch on average for all locations, suggesting the model accurately predicts tidal hydrodynamics within the Popponesset Bay system. Measured tidal constituent amplitudes and time lags (ϕ_{lag}) for the validation time period differ from those in Tables V-1 and V-3 because constituents were computed for only seven days, rather than the entire thirty-day period represented in Tables V-1 and V-3. Errors associated with tidal constituent height were on the order of hundredths of feet, which was of the same order of magnitude as the accuracy of the tide gage (0.03 ft). The greatest errors were noticed in Ockway Bay. These errors were likely a result of the deployment problem (i.e. the sensor becoming dry at extreme low tides and, therefore not measuring the full range of the tide) and not due to model inaccuracies.

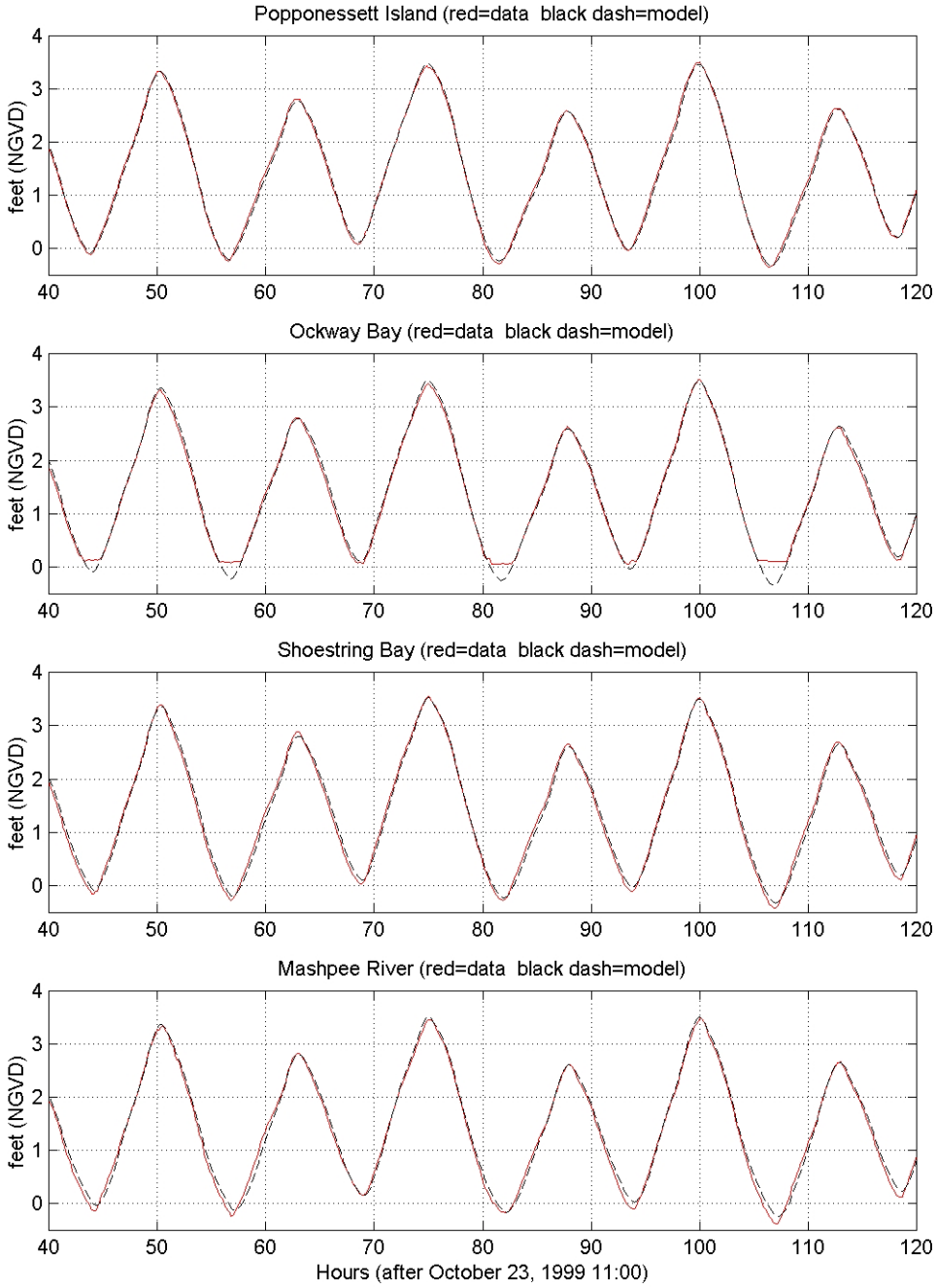


Figure V-12. Comparison of water surface variations simulated by the model (dashed black line) to those measured within the system (red solid line) for the calibration time period at four interior locations.

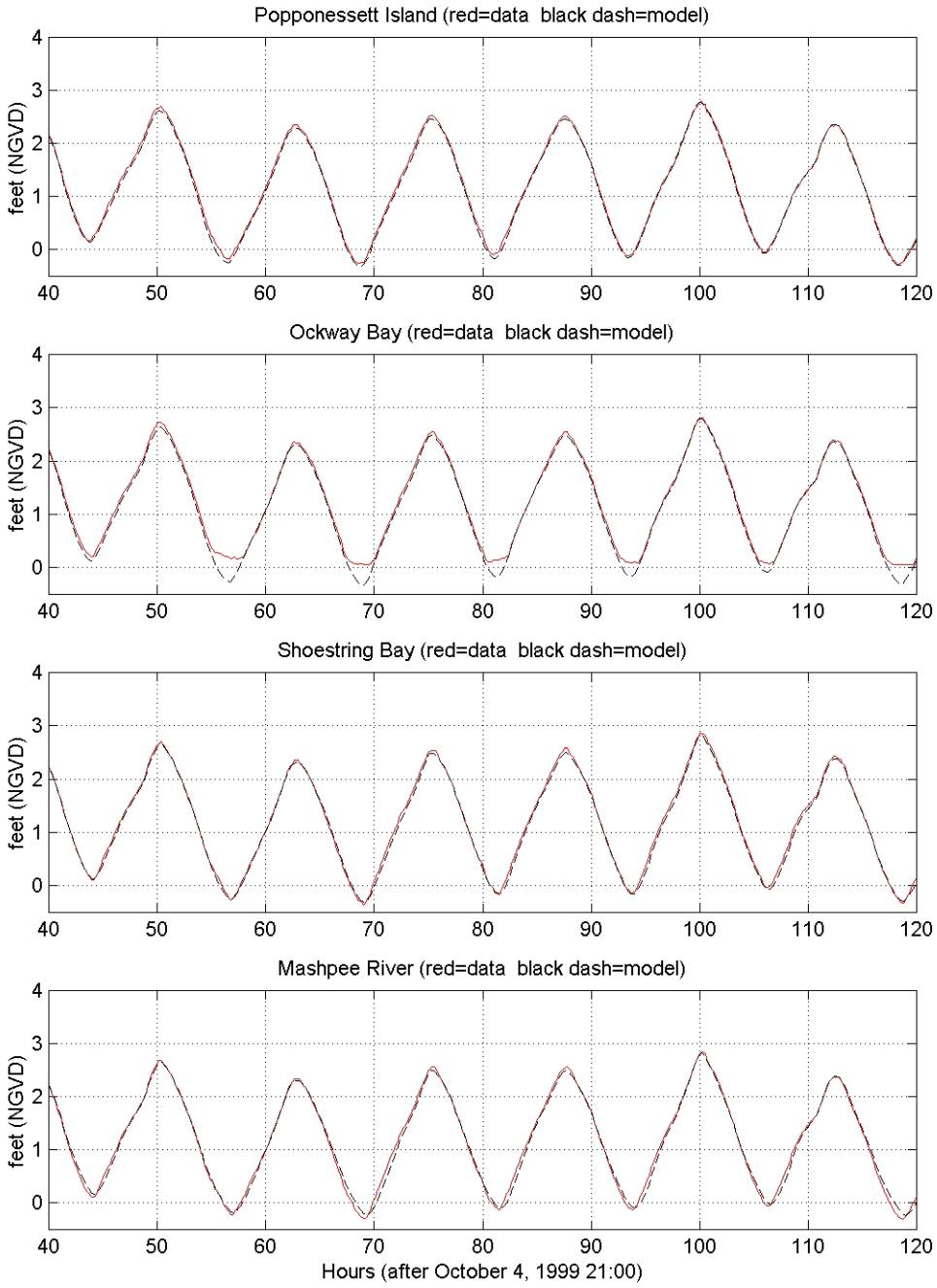


Figure V-13. Comparison of water surface variations simulated by the model (dashed black line) to those measured within the system (red solid line) for the verification time period at four interior locations.

Table V-7. Comparison of Tidal Constituents calibrated RMA2 model versus measured tidal data for the period October 4-11, 1999.

Model Verification Run						
Location	Constituent Amplitude (ft)				Phase (degrees)	
	M_2	M_4	M_6	K_1	ΦM_2	ΦM_4
Popponesset Island	1.188	0.119	0.080	0.031	17.1	120.3
Ockway Bay	1.193	0.103	0.089	0.032	19.4	124.9
Shoestring Bay	1.193	0.072	0.091	0.033	22.9	126.5
Mashpee River	1.177	0.035	0.081	0.034	24.9	111.1
Measured Tidal Data						
Location	Constituent Amplitude (ft)				Phase (degrees)	
	M_2	M_4	M_6	K_1	ΦM_2	ΦM_4
Popponesset Island	1.179	0.115	0.084	0.041	12.5	111.0
Ockway Bay	1.154	0.090	0.067	0.043	15.4	100.6
Shoestring Bay	1.195	0.086	0.100	0.044	16.5	116.5
Mashpee River	1.186	0.082	0.096	0.043	17.2	115.7
Error						
Location	Constituent Amplitude (ft)				Phase (minutes)	
	M_2	M_4	M_6	K_1	ΦM_2	ΦM_4
Popponesset Island	0.009	0.004	0.004	0.010	9.5	9.6
Ockway Bay	0.039	0.013	0.022	0.011	8.3	25.2
Shoestring Bay	0.002	0.014	0.009	0.011	13.4	10.4
Mashpee River	0.009	0.047	0.015	0.009	15.9	4.8

V.4.2.3.5 Model Circulation Characteristics

The final calibrated and validated model serves as a useful tool for investigating the circulation characteristics of the Popponesset Bay system. Using model inputs of bathymetry and tide data, current velocities and flow rates can be determined at any point in the model domain. This is a very useful feature of a hydrodynamic model, where a limited amount of collected data can be expanded to determine the physical attributes of the system in areas where no physical data record exists.

From the model run of the Popponesset Bay system, ebb velocities in the channels are slightly larger than velocities during maximum flood. In the inlet to Popponesset Bay from Nantucket Sound, the maximum depth-averaged flood velocities in the model are approximately 2.6 feet/sec, while maximum ebb velocities are about 3.6 feet/sec. A close-up of the model output is presented in Figure V-14, which shows contours of flow velocity, along with velocity vectors which indicate the direction and magnitude of flow, for a single model time-step, at the portion of the tide where maximum flood velocities occur.

In addition to depth averaged velocities, the total flow rate of water flowing through a channel can be computed with the hydrodynamic model. For the flushing analysis in the next section, flow rates were computed across four separate transects in the Popponesset Bay system: at the inlet channel to Popponesset Bay, at the inlet to Mashpee River, and at the inlet to Shoestring Bay, and at the inlet to Ockway Bay. The variation of flow as the tide floods and ebbs is seen in the plot of system flow rates in Figure V-15. Maximum flow rates occur during ebb tides in this system, an indication that this estuary system is ebb dominant. During spring tides, the maximum flood flow rates reach 5200 ft^3/sec at the Popponesset Bay inlet. Maximum ebb flow rates during spring tides are slightly higher, or about 6400 ft^3/sec.

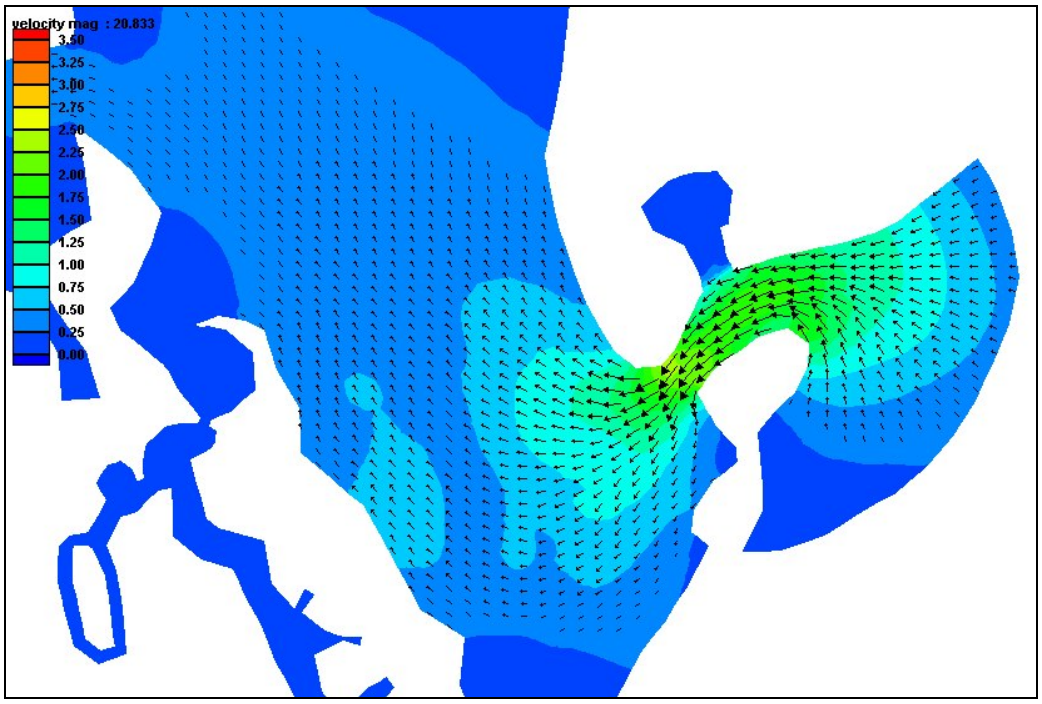


Figure V-14. Example of hydrodynamic model output for a single time step where maximum flood velocities occur for this tide cycle. Color contours indicate flow velocity, and vectors indicate the direction and magnitude of flow.

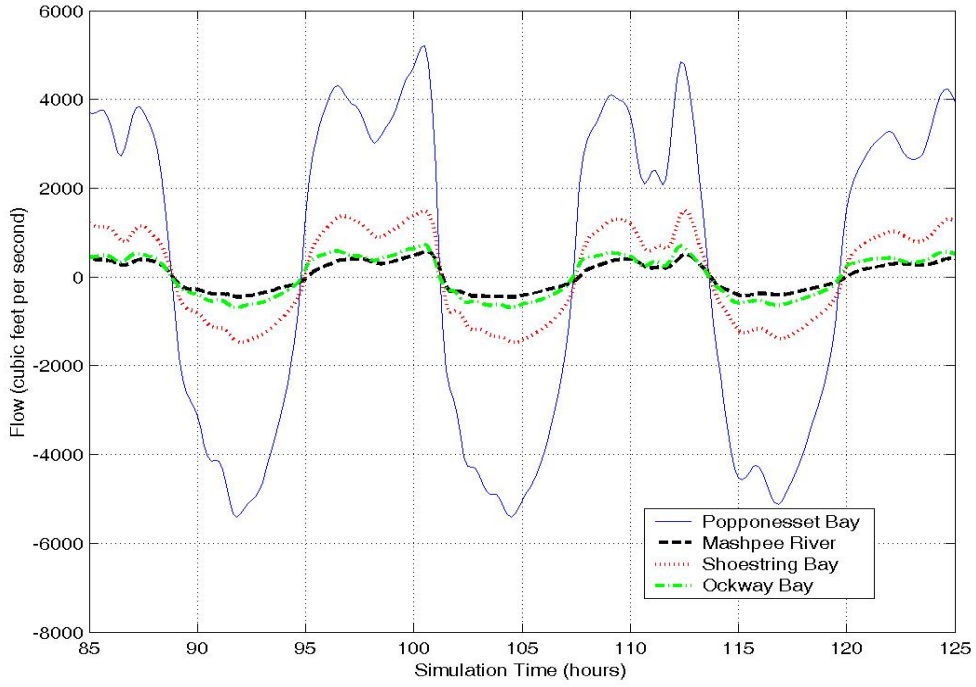


Figure V-15. Time variation of computed flow rates for three transects in the Popponesset Bay system. Model period shown corresponds to spring tide conditions, where the tide range is the

largest, and resulting flow rates are correspondingly large compared to neap tide conditions. Positive flow indicates flooding tide, while negative flow indicates ebbing tide.

V.5 FLUSHING CHARACTERISTICS

Since the magnitude of freshwater inflow is much smaller in comparison to the tidal exchange through each inlet, the primary mechanism controlling estuarine water quality within the modeled Popponesset Bay system is tidal exchange. A rising tide offshore in Nantucket Sound creates a slope in water surface from the ocean into the modeled systems. Consequently, water flows into (floods) the system. Similarly, each estuary drains into the open waters of Nantucket Sound on an ebbing tide. This exchange of water between each system and the ocean is defined as tidal flushing. The calibrated hydrodynamic model is a tool to evaluate quantitatively tidal flushing of each system, and was used to compute flushing rates (residence times) and tidal circulation patterns.

Flushing rate, or residence time, is defined as the average time required for a parcel of water to migrate out of an estuary from points within the system. For this study, **system residence times** were computed as the average time required for a water parcel to migrate from a point within the each embayment to the entrance of the system. System residence times are computed as follows:

$$T_{system} = \frac{V_{system}}{P} t_{cycle}$$

where T_{system} denotes the residence time for the system, V_{system} represents volume of the (entire) system at mean tide level, P equals the tidal prism (or volume entering the system through a single tidal cycle), and t_{cycle} the period of the tidal cycle, typically 12.42 hours (or 0.52 days). To compute system residence time for a sub-embayment, the tidal prism of the sub-embayment replaces the total system tidal prism value in the above equation.

In addition to system residence times, a second residence, the **local residence time**, was defined as the average time required for a water parcel to migrate from a location within a sub-embayment to a point outside the sub-embayment. Using Shoestring Bay as an example, the **system residence time** is the average time required for water to migrate from Shoestring Bay, through Popponesset Bay, and into Nantucket Sound, where the **local residence time** is the average time required for water to migrate from Shoestring Bay to just Popponesset Bay (not all the way to the Sound). Local residence times for each sub-embayment are computed as:

$$T_{local} = \frac{V_{local}}{P} t_{cycle}$$

where T_{local} denotes the residence time for the local sub-embayment, V_{local} represents the volume of the sub-embayment at mean tide level, P equals the tidal prism (or volume entering the local sub-embayment through a single tidal cycle), and t_{cycle} the period of the tidal cycle (again, 0.52 days).

Residence times are provided as a first order evaluation of estuarine water quality. Lower residence times generally correspond to higher water quality; however, residence times may be misleading depending upon pollutant/nutrient loading rates and the overall quality of the receiving waters. As a qualitative guide, **system residence times** are applicable for systems

where the water quality within the entire estuary is degraded and higher quality waters provide the only means of reducing the high nutrient levels. For the Popponesset Bay system this approach is applicable, since it assumes the main system has relatively low quality water relative to Nantucket Sound.

The rate of pollutant/nutrient loading and the quality of water outside the estuary both must be evaluated in conjunction with residence times to obtain a clear picture of water quality. Efficient tidal flushing (low residence time) is not an indication of high water quality if pollutants and nutrients are loaded into the estuary faster than the tidal circulation can flush the system. Neither are low residence times an indicator of high water quality if the water flushed into the estuary is of poor quality. Advanced understanding of water quality will be obtained from the calibrated hydrodynamic model by extending the model to include a total nitrogen dispersion model (Section VI). The water quality model will provide a valuable tool to evaluate the complex mechanisms governing estuarine water quality in the Popponesset Bay system.

Since the calibrated RMA-2 model simulated accurate two-dimensional hydrodynamics in the system, model results were used to compute residence times. Residence times were computed for the entire estuary, as well the three main sub-embayments within the system. In addition, **system** and **local residence times** were computed to indicate the range of conditions possible for the system. Residence times were calculated as the volume of water (based on mean volumes computed for the simulation period) in the entire system divided by the average volume of water exchanged with each sub-embayment over a flood tidal cycle (tidal prism). Units then were converted to days. The volume of the each sub-embayment, as well as their respective tidal prisms, were computed as cubic feet (Table V-8).

Residence times were averaged for the tidal cycles comprising a representative 7.25 day period (14 tide cycles), and are listed in Table V-9. The modeled time period used to compute the flushing rates was different from the modeled calibration period, and included the transition from neap to spring tide conditions. Model divisions used to define the system sub-embayments include 1) the entire system, 2) Mashpee River, 3) Shoestring Bay, and 4) Ockway Bay. The model calculated flow crossing specified grid lines for each sub-embayment to compute the tidal prism volume. Since the 7-day period used to compute the flushing rates of the system represent average tidal conditions, the measurements provide the most appropriate method for determining mean flushing rates for the system sub-embayments.

Table V-8. Embayment mean volumes and average tidal prism during simulation period.

Embayment	Mean Volume (ft^3)	Tide Prism Volume (ft^3)
Popponesset Bay System	119,443,200	86,946,000
Mashpee River	6,562,500	6,875,000
Shoestring Bay	25,195,000	21,707,000
Ockway Bay	12,457,800	9,755,000

Table V-9. Computed System and Local residence times for embayments in the Popponesset Bay system.

Embayment	System Residence Time (days)	Local Residence Time (days)
Popponesset Bay System	0.71	0.71
Mashpee River	8.99	0.49

Shoestring Bay	2.85	0.60
Ockway Bay	6.34	0.66

The computed flushing rates for the Popponesset Bay system show that as a whole, the system flushes well. A flushing time of 0.71 days for the entire estuary indicates that on average, water is resident in the system less than one day. Mashpee River has the greatest system residence time, approximately 9 days. By the definition of system residence time, smaller sub-embayments have longer residence times; therefore, residence times may be misleading for small, remote parts of the estuary. Instead, it is useful to compute a local residence time for each sub-embayment. A local residence time represents the time required for a water parcel to leave the particular sub-embayment. For instance, the local residence time for Ockway Bay represents the time required for a water parcel to be flushed from the sub-embayment into Popponesset Bay. Local residence times are computed as the volume of the sub-embayment divided by the tidal prism of that sub-embayment, and units are converted to days.

Local residence times are significantly lower than residence times based on the volume of the entire estuary. For example, flow entering Shoestring Bay on an average tidal cycle flushes through Popponesset Bay inlet in 6.3 days, but flushes into Popponesset Bay in 0.6 days. Generally, a local residence time is only useful where the adjacent embayment has high water quality. For embayments located in the upper reaches of the system (Ockway Bay, Mashpee River, and Shoestring Bay), the receiving waters that exchange tidal flow with the various sub-embayments show signs of ecological stress, indicative of poor water quality. Therefore, system residence times may be more appropriate for future planning scenarios.

Generally, possible errors in computed residence times can be linked to two sources: the bathymetry information and simplifications employed to calculate residence time. In this study, the most significant errors associated with the bathymetry data result from the process of interpolating the data to the finite element mesh, which was the basis for all the flushing volumes used in the analysis. In addition, limited topographic measurements were available on the marsh plains. Minor errors may be introduced in residence time calculations by simplifying assumptions. Flushing rate calculations assume that water exiting an estuary or sub-embayment does not return on the following tidal cycle. For regions where a strong littoral drift exists, this assumption is valid. For the purposes of this study, a coastal area exhibiting “strong littoral drift” is defined as a system that has noticeable longshore tidal currents and frequent wave-induced mixing of estuarine waters entering the coastal region. However, water exiting a small sub-embayment on a relatively calm day may not completely mix with estuarine waters. In this case, the “strong littoral drift” assumption would lead to an under-prediction of residence time. Since littoral drift along the Nantucket Sound shorelines in Mashpee/Barnstable typically is strong and local winds induce tidal mixing within the regional estuarine systems, the “strong littoral drift” assumption only will cause minor errors in residence time calculations. Based on our knowledge of estuarine processes, we estimate that the combined errors due to bathymetric inaccuracies represented in the model grid and the “strong littoral drift” assumption are within 10% to 15% of “true” residence times.

VI. WATER QUALITY MODELING

VI.1 DATA SOURCES FOR THE MODEL

Several different data types and calculations are required to support the water quality modeling effort. These include the output from the hydrodynamics model, calculations of external nitrogen loads from the watersheds, measurements of internal nitrogen loads from the sediment (benthic flux), and measurements of nitrogen in the water column.

VI.1.1 Hydrodynamics and Tidal Flushing in the Embayments

Extensive field measurements and hydrodynamic modeling of the embayments were an essential preparatory step to the development of the water quality model. The result of this work, among other things, was a set of five files of calibrated model output representing the transport of water within each of the five embayment systems. Files of node locations and node connectivity for the RMA-2V model grids were transferred to the RMA-4 water quality model; therefore, the computational grid for the hydrodynamic model also was the computational grid for the water quality model. The period of hydrodynamic output for the water quality model calibration was a 12-tidal cycle period in autumn 1999 that includes the fortnightly variation between spring and neap tide ranges. For each modeled scenario (e.g., present conditions, build-out) the model was run for a 30-day spin-up period, to allow the model to reach a dynamic "steady state", and ensure that model spin-up would not affect the final model output.

VI.1.2 Nitrogen Loading to the Embayments

Three primary nitrogen loads to sub-embayments are recognized in this modeling study: external loads from the watersheds, nitrogen load from direct rainfall on the embayment surface, and internal loads from the sediments. Additionally, there is a fourth load to the Popponesset Bay sub-embayments, consisting of the background concentrations of total nitrogen in the waters entering from Nantucket Sound. This load is represented as a constant concentration along the seaward boundary of the model grid.

VI.1.3 Measured Nitrogen Concentrations in the Embayments

In order to create a model that realistically simulates the total nitrogen concentrations in a system in response to the existing flushing conditions and loadings, it is necessary to calibrate the model to actual measurements of water column nitrogen concentrations. The refined and approved data for each monitoring station used in the water quality modeling effort are presented in Table VI-1. Station locations are indicated in Figure VI-1. The multi-year averages present the "best" comparison to the water quality model output, since factors of tide, temperature and rainfall may exert short-term influences on the individual sampling dates and even cause inter-annual differences. Three years of baseline field data is the minimum required to provide a baseline for MEP analysis. For the Popponesset Bay System water quality data was collected by the Popponesset Bay Water Quality Monitoring Program, which was established by the Town of Mashpee with the Coastal Systems Program at SMAST-UMASS-Dartmouth in 1997. The multiple departments and groups taking part in this effort were coordinated by the Mashpee Waterways Commission (see Chapter II). For most of the 15 sampling stations, seven years of data were available. Average summer total nitrogen within the waters at each station was used to calibrate the model. Extremely high or low values (<5% of samples), as determined by a departure criterion of >3 standard deviations from the mean, were not included in the averages. Deletion of data outliers was deemed appropriate, since the water quality module of the Linked Watershed-Embayment Model represents typical or average summertime conditions throughout the embayment.

Table VI-1. Measured and modeled Nitrogen concentrations for the Popponesset Bay system used in the model calibration plots of Figure VI-2. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means. Overall mean is presented as "data mean" with the standard deviation (s.d.) and number of total samples (N).

Sub-Embayment	monitoring station	1997 mean	1998 mean	1999 mean	2000 mean	2001 mean	2002 mean	2003 mean	data mean	s.d. all data	N	model min	model max	Model avg
Mashpee River - head (MRh)	PB 1	0.798	0.633	0.787	0.831	0.990	1.137	0.756	0.859	0.200	26	0.690	0.893	0.771
Mashpee River - Upper (MRu)	PB2	1.006	0.726	1.022	0.798	1.082	1.153	0.892	0.958	0.242	24	0.774	0.944	0.855
Mashpee River - Mid (MRm)	PB3	0.651	0.764	0.669	0.596	0.740	1.120	0.733	0.739	0.216	25	0.510	0.941	0.783
Mashpee River - Lower (MRl)	PB4	0.603	0.668	0.564	0.485	0.695	0.694	0.736	0.627	0.134	25	0.341	0.889	0.561
Shoestring Bay - head (SBh)	SR 5	-	1.193	0.860	0.878	1.278	1.132	1.377	1.135	0.380	20	0.956	1.166	1.067
Shoestring Bay - upper (SBu)	PB5	0.730	0.878	0.606	0.594	0.678	0.580	0.870	0.690	0.169	26	0.644	0.754	0.692
Shoestring Bay - mid (SBm)	PB 6	0.617	0.695	0.644	0.671	0.668	0.707	0.884	0.688	0.140	28	0.498	0.713	0.620
Shoestring Bay - lower (SBl)	PB 7	0.518	0.551	0.467	0.506	0.507	0.527	0.592	0.520	0.113	27	0.379	0.670	0.524
Ockway Bay - upper (OBu)	PB 9	0.552	0.569	0.498	0.486	1.003	0.785	0.734	0.677	0.217	27	0.537	0.570	0.551
Ockway Bay - lower (OBl)	PB 10	0.485	0.508	0.426	0.467	0.765	0.592	0.512	0.536	0.177	27	0.328	0.556	0.464
Popponesset Bay – head (PBh)	PB 8	0.476	0.589	0.444	0.592	0.772	0.595	0.732	0.581	0.151	24	0.306	0.667	0.451
Popponesset Bay – upper (PBu)	PB 11	0.307	0.521	0.434	0.417	0.579	0.567	0.506	0.485	0.111	23	0.289	0.533	0.374
Popponesset Bay - mid (PBm)	PB 12	0.343	0.492	0.393	0.473	0.539	0.554	0.486	0.456	0.102	25	0.282	0.485	0.325
Popponesset Creek (POC)	PB 13	0.369	0.376	0.351	0.486	0.591	0.456	0.479	0.422	0.107	23	0.355	0.376	0.366
Pinquickset Cove (PQC)	PB 15	-	-	-	-	-	0.470	0.640	0.527	0.097	6	0.331	0.447	0.407
Nantucket Sound (NAS)	PB 14	0.260	0.282	0.297	0.326	0.368	0.351	0.375	0.315	0.055	22	0.283	0.320	0.288

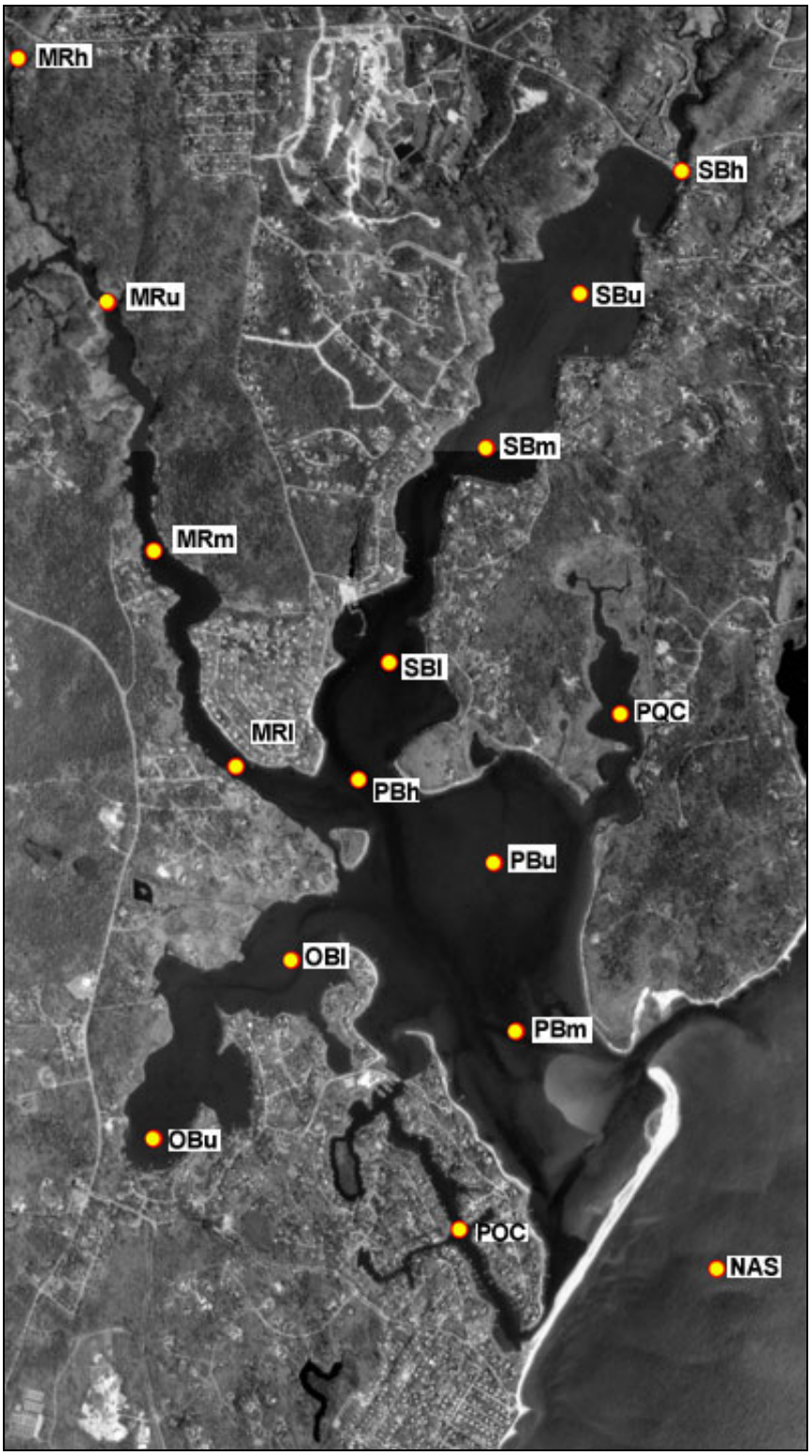


Figure VI-1. Estuarine water quality monitoring station locations in Popponesset Bay. Station labels correspond to those provided in Table VI-1.

VI.2 MODEL DESCRIPTION AND APPLICATION

A two-dimensional finite element water quality model, RMA-4 (King, 1990), was employed to study the effects of nitrogen loading in the Popponesset estuarine system. The RMA-4 model has the capability for the simulation of advection-diffusion processes in aquatic environments. It is the constituent transport model counterpart of the RMA-2 hydrodynamic model used to simulate the fluid dynamics of the Popponesset system. Like RMA-2 numerical code, RMA-4 is a two-dimensional, depth averaged finite element model capable of simulating time-dependent constituent transport. The RMA-4 model was developed with support from the US Army Corps of Engineers (USACE) Waterways Experiment Station (WES), and is widely accepted and tested. Applied Coastal staff have utilized this model in water quality studies of other Cape Cod embayments, including West Falmouth Harbor and the "finger" ponds of Falmouth, MA (Ramsey *et al*., 2000), and embayment systems in Chatham, MA (Howes *et al*., 2003).

The overall approach involves modeling total nitrogen as a non-conservative constituent, where bottom sediments act as a source or sink of nitrogen, based on local biochemical characteristics. This modeling represents summertime conditions, when algal growth is at its maximum. Total nitrogen modeling is based upon various data collection efforts and analyses presented in previous sections of this report. Nitrogen loading information was derived from the Cape Cod Commission watershed loading analysis (based on the USGS watersheds), as well as the measured bottom sediment nitrogen fluxes. Water column nitrogen measurements were utilized as model boundaries and as calibration data. Hydrodynamic model output (discussed in Section V) provided the remaining information (tides, currents, and bathymetry) needed to parameterize the water quality model of Popponesset Bay.

VI.2.1 Model Formulation

The formulation of the model is for two-dimensional depth-averaged systems in which concentration in the vertical direction is assumed uniform. The depth-averaged assumption is justified since vertical mixing by wind and tidal processes prevent significant stratification in the Popponesset Bay sub-embayments. The governing equation of the RMA-4 constituent model can be most simply expressed as a form of the transport equation, in two dimensions:

$$\left(\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y}\right) = \left(\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x} + \frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y} + \sigma\right)$$

where c in the water quality constituent concentration; t is time; u and v are the velocities in the x and y directions, respectively; D_x and D_y are the model dispersion coefficients in the x and y directions; and σ is the constituent source/sink term. Since the model utilizes input from the RMA-2 model, a similar implicit solution technique is employed for the RMA-4 model.

The model is therefore used to compute spatially and temporally varying concentrations c of the modeled constituent (i.e., total nitrogen), based on model inputs of 1) water depth and velocity computed using the RMA-2 hydrodynamic model; 2) mass loading input of the modeled constituent; and 3) user selected values of the model dispersion coefficients. Dispersion coefficients used for each system sub-embayment were developed during the calibration process. During the calibration procedure, the dispersion coefficients were incrementally changed until model concentration outputs matched measured data.

RMA-4 model can be utilized to predict both spatial and temporal variations in total

nitrogen. At each time step the model computes constituent concentrations over the entire finite element grid and utilizes a continuity of mass equation to check these results. Similar to the hydrodynamic model, the water quality model evaluates model parameters at every element at 10-minute time intervals throughout the grid system. For this application, the RMA-4 model was used to predict tidally averaged total nitrogen concentrations throughout the Popponesset Bay system.

VI.2.2 Water Quality Model Setup

Required inputs to the RMA-4 model include a computational mesh, computed water elevations and velocities at all nodes of the mesh, constituent mass loading, and spatially varying values of the dispersion coefficient. Because the RMA-4 model is part of a suite of integrated computer models, the finite-element meshes and the resulting hydrodynamic simulations previously developed for Popponesset Bay also were used for the water quality constituent modeling portion of this study.

Based on measured flowrates from SMAST and groundwater recharge rates from the USGS, the Popponesset Bay hydrodynamic model was set-up to include the latest estimates of surface water flows from Mashpee River, Quaker Run River and Santuit River. Surface freshwater inputs from these streams are significant compared to the tidal prisms of the embayments to which they discharge. The Mashpee River has a measured flowrate of 10.7 ft^3/sec (26,223 m^3/day), which is 7.0% of the volume exchanged daily by the tide in the estuarine portion of the River. The Santuit and Quaker Run Rivers have average flows of 5.4 ft^3/sec and 1.5 ft^3/sec (13,164 m^3/day and 3,730 m^3/day) respectively, which total to 1.9% of the daily tidal exchange in Shoestring Bay.

For each model, an initial total N concentration equal to the concentration at the open boundary was applied to the entire model domain. The model was then run for a simulated month-long (30 day) spin-up period. At the end of the spin-up period, the model was run for an additional 6 tidal-day (150 hour) period. Model results were recorded only after the initial spin-up period. The time step used for the water quality computations was 10 minutes, which corresponds to the time step of the hydrodynamics input for Popponesset Bay.

VI.2.3 Boundary Condition Specification

Mass loading of nitrogen into each model included 1) sources developed from the results of the watershed analysis, 2) estimates of direct atmospheric deposition, 3) summer benthic regeneration, 4) point source inputs developed from measurements of the freshwater portions of the Santuit and Mashpee Rivers. Nitrogen loads from each separate sub-embayment watershed were distributed across the sub-embayment. For example, the combined watershed, direct atmospheric deposition, and benthic regeneration loads for Shoestring Bay were evenly distributed at grid cells that formed the perimeter of the embayment.

The loadings used to model present conditions in the Popponesset Bay system are given in Table VI-2. Watershed and depositional loads were taken from the results of the analysis of Section IV. Summertime benthic flux loads were computed based on the analysis of sediment cores in Section IV. The area rate (g/sec/m^2) of nitrogen flux from that analysis was applied to the surface area coverage computed for each sub-embayment (excluding marsh coverages, when present), resulting in a total flux for each embayment (as listed in Table VI-2). Due to the highly variable nature of bottom sediments and other estuarine characteristics of coastal embayments in general, the measured benthic flux for existing conditions also is variable. For present conditions, some sub-embayments (e.g., Mashpee River) have approximately the same

loading rate from benthic regeneration as from the watershed. For other sub-embayments (e.g., Shoestring Bay), the benthic flux is relatively low or negative indicating a net uptake of nitrogen in the bottom sediments.

In addition to mass loading boundary conditions set within the model domain, concentrations along the model open boundary was specified. The model uses concentrations at the open boundary during the flooding tide periods of the model simulations. Constituent concentrations of the incoming water are set at the value designated for the open boundary. The boundary concentration in Nantucket Sound was set at 0.285 mg/L, based on SMAST data from the Nantucket Sound. The open boundary total nitrogen concentration represents long-term average summer concentrations found within Nantucket Sound.

The boundary condition for Popponesset Bay that was used in the Draft Final Report was 0.305 mg N/L. The reason that 0.315 mgN/L (Station PB14) was not used was that (1) the data were highly variable from year to year and (2) there was concern from a many of Technical Staff the station was within the ebb tidal "plume" from Popponesset Bay. Therefore, a lower offshore boundary condition (0.305mgN/L) was used, based on a variety of estimates. However, subsequent to completion of the Draft Final Report, the core Technical Group convened to specifically address this issue. The consensus was that (1) the "plume" concern about station PB14 cannot be discounted and (2) the "best" estimate of the Nantucket Sound Boundary was the long-term monitoring station off of Green Pond. This station has been monitored since 1987 and has consistently yielded a value of 0.285 mgN/L. Therefore, the modeling in the Final Report reflects this new boundary condition. Note that the boundary condition basically lowers the nitrogen background, but does not affect the other modeling parameters (a change is boundary concentration is basically subtracting a constant from all values).

Table VI-2. Sub-embayment and surface water loads used for total nitrogen modeling of the Popponesset Bay system, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent **present loading conditions** for the listed sub-embayments.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux (kg/day)
Popponesset Bay	1.82	4.01	-5.04
Popponesset Creek	4.94	-	-0.64
Pinquickset Cove	0.76	0.29	-0.33
Ockway Bay - lower	-	-	-1.60
Ockway Bay - upper	3.15	1.09	3.37
Mashpee River	12.11	0.66	11.47
Shoestring Bay	9.21	2.23	-11.85
Surface Water Sources			
Mashpee River	15.56	-	-
Santuit River (Shoestring Bay)	15.58	-	-
Quaker Run River (Shoestring Bay)	5.98	-	-

VI.2.4 Model Calibration

Calibration of the Popponesset Bay total nitrogen model proceeded by changing model dispersion coefficients so that model output of nitrogen concentrations matched measured data. Generally, several model runs of each system were required to match the water column

measurements. Dispersion coefficient (*E*) values were varied through the modeled systems by setting different values of *E* for each grid material type, as designated in Section V. Observed values of *E* (Fischer, *et al.*, 1979) vary between order 10 and order 1000 m^2/sec for large riverine estuary systems characterized by relatively wide channels (compared to channel depth) with moderate currents. Generally, the relatively quiescent Popponesset Bay sub-embayments are small compared to the riverine estuary systems evaluated by Fischer, *et al.*, (1979); therefore the values of *E* also are relatively lower. Observed values of *E* in these calmer areas typically range between order 10 and order 0.001 m^2/sec (USACE, 2001). The final values of *E* used in each sub-embayment of the modeled systems are presented in Table VI-3. These values were used to develop the "best-fit" total nitrogen model calibration. For the case of TN modeling, "best fit" can be defined as minimizing the error between the model and data at all sampling locations, utilizing reasonable ranges of dispersion coefficients within each sub-embayment.

Table VI-3. Values of longitudinal dispersion coefficient, E, used in calibrated RMA4 model runs of salinity and nitrogen concentration for the Popponesset Bay system.

Embayment Division	E m^2/sec
Popponesset Bay	2.0
Popponesset Inlet	5.0
Nantucket Sound	5.0
Lower Mashpee River	10.0
Upper Mashpee River	0.5
Lower Shoestring Bay	10.0
Upper Shoestring Bay	4.0
Lower Ockway Bay	1.0
Upper Ockway Bay	0.25
Popponesset Creek	5.0
Pinquickset Cove	0.25
Santuit River	0.4
Quaker Run River	0.4

Comparisons between model output and measured nitrogen concentrations are shown in Figure VI-2. In the plot, means of the water column data and a range of two standard deviations of the annual means at each individual station are plotted against the modeled maximum, mean, and minimum concentrations output from the model at locations which corresponds to the SMAST monitoring stations. Because the water samples are taken during ebbing tides, calibration targets in each sub-embayment were set such that the means of the measured data would fall within the range between the modeled maximum and modeled mean concentration, for stations where there is a wide range of modeled concentrations. This technique was used on embayments like the Mashpee River. At other locations (e.g., Ockway Bay), where the model exhibited less variability than the measured data, a calibration target near the mean of the water column data was selected.

Calibrated model output is shown in Figure VI-3. In this figure, color contours indicate nitrogen concentrations throughout the model domain. The output in these figures show average total nitrogen concentrations, computed using the full 6-tidal-day model simulation output period.

VI.2.5 Model Salinity Verification

In addition to the model calibration based on nitrogen loading and water column measurements, numerical water quality model performance is typically verified by modeling salinity. This step was performed for Popponesset Bay using Salinity data collected at the same stations as the nitrogen data. The only required inputs into the RMA4 salinity model of Popponesset bay, in addition to the RMA2 hydrodynamic model output, were salinities at the model open boundary and at the freshwater stream discharges. The open boundary salinity was set at 28.5 ppt. For the stream inputs, salinities were set at 1 ppt. Fresh water flow rates for the streams were the same as those used for the total nitrogen model, as presented earlier in this section.

A comparison of modeled and measured salinities is presented in Figure VI-4, with a contour plot of model output shown in Figure VI-5. Though model dispersion coefficients were not changed from those values selected through the nitrogen model calibration process, the model adequately represents salinity gradients in the Popponesset Bay system. The salinity verification provides a further independent confirmation that model dispersion coefficients and represented freshwater inputs to the model correctly simulate the real physical system.

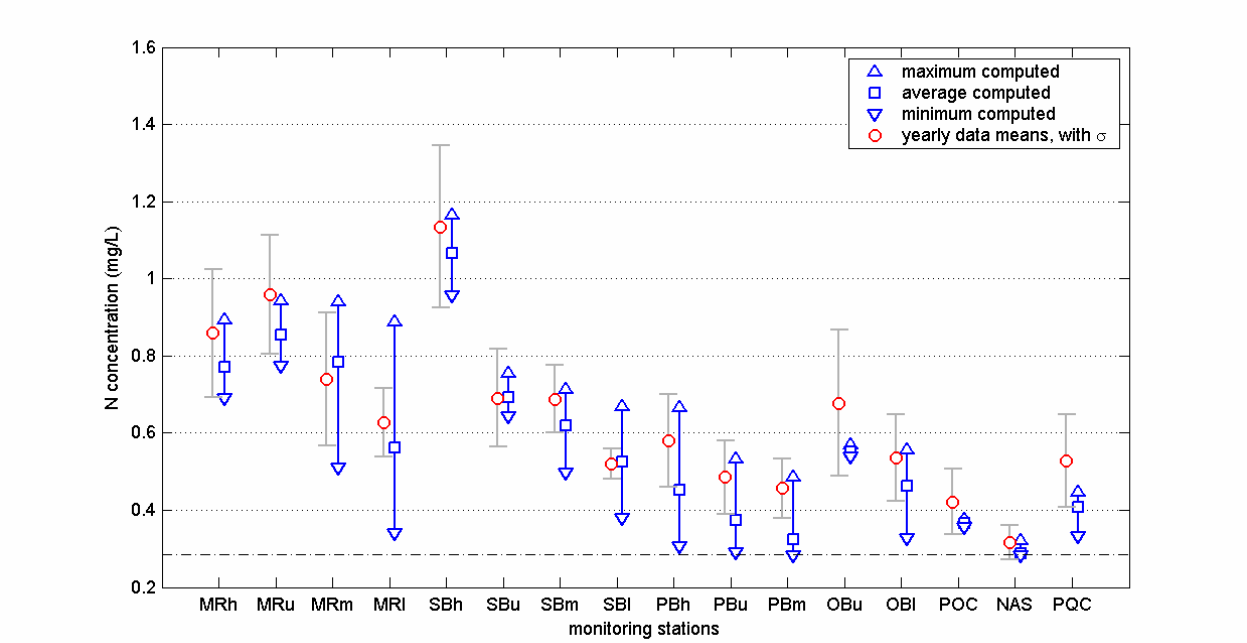


Figure VI-2. Comparison of measured total nitrogen concentrations and calibrated model output at stations in the Popponesset Bay system. Stations labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed concentration for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the annual data means. The background concentration (0.285 mg/L) in Nantucket Sound is indicated by the black dot-dashed line.

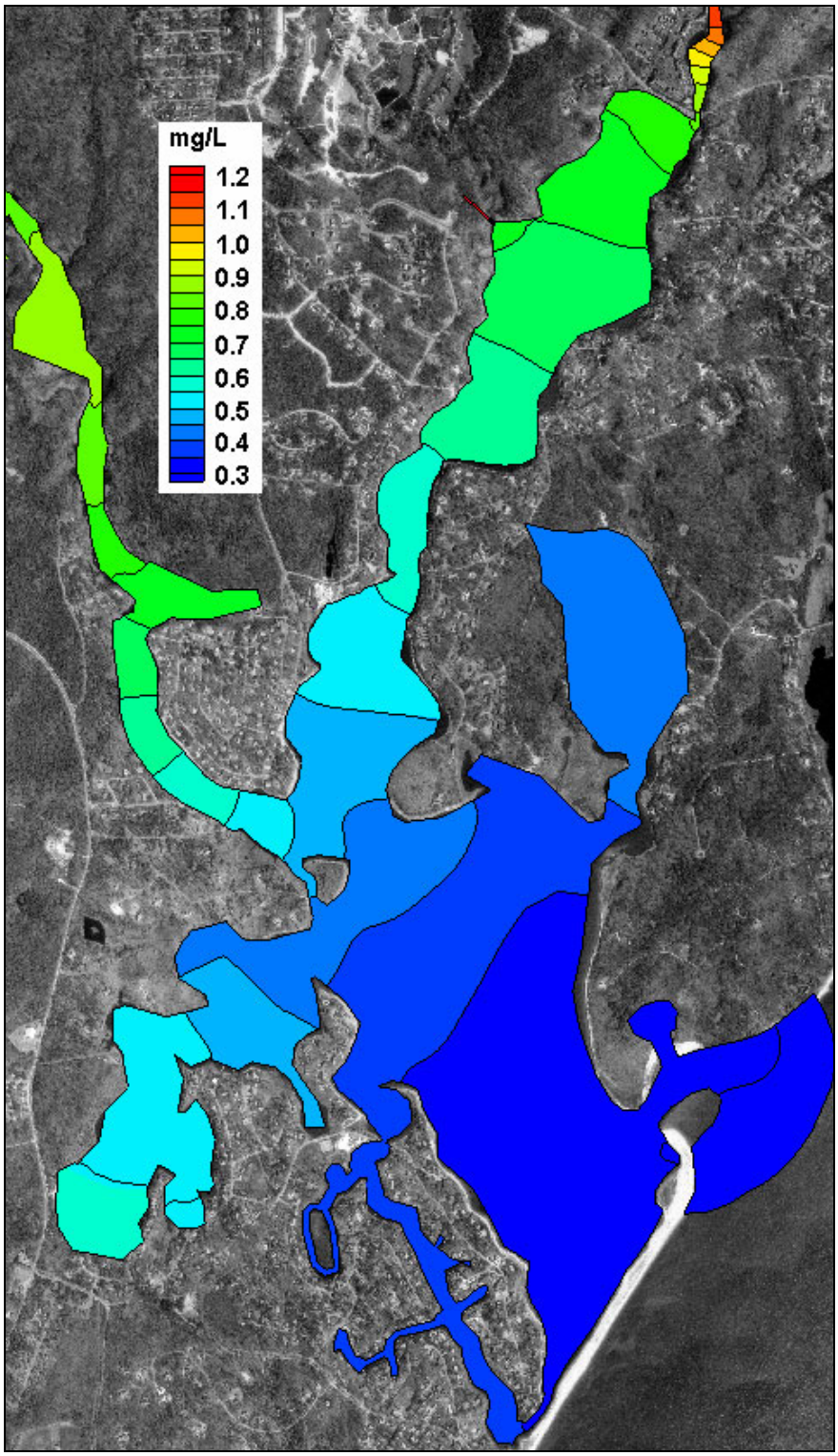


Figure VI-3. Contour plot of average total nitrogen concentrations from results of the present conditions loading scenario, for Popponesset Bay.

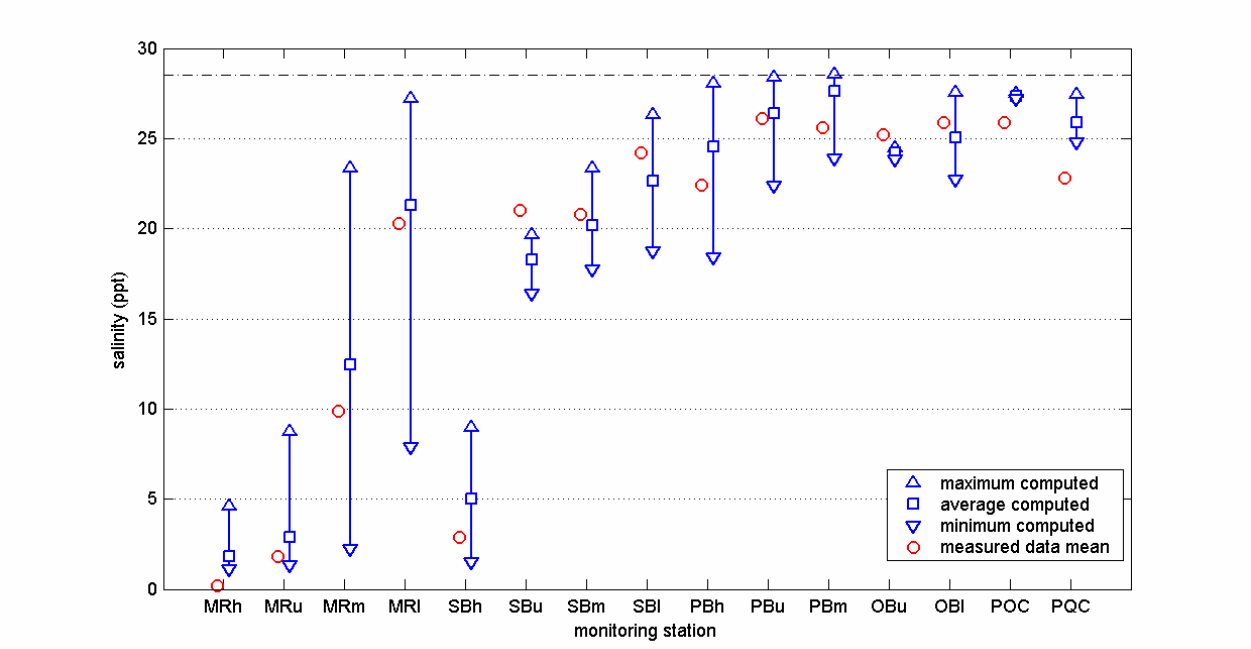


Figure VI-4. Comparison of measured and calibrated model output at stations in the Popponesset Bay system. Stations labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed salinity for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers). The background salinity (28.5 ppt) in Nantucket Sound is indicated by the black dot-dashed line.

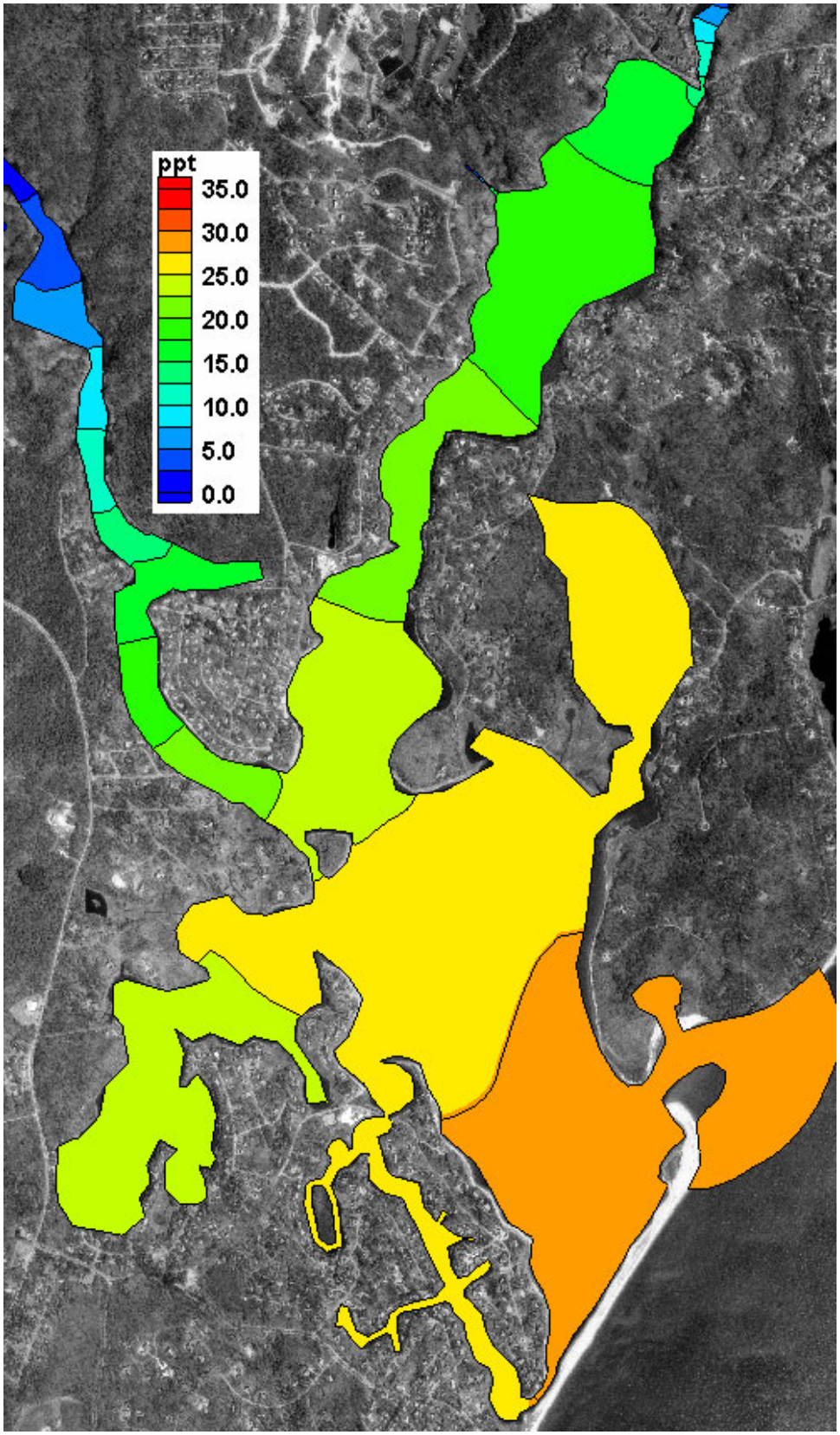

ppt
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0

Figure VI-5. Contour Plot of modeled salinity (ppt) in Popponesset Bay.

VI.2.6 Build-Out and No Anthropogenic Load Scenarios

To assess the influence of nitrogen loading on total nitrogen concentrations within each of the embayment systems, two standard water quality modeling scenarios were run: a "build-out" scenario based on potential development (described in more detail in Section IV) and a "no anthropogenic load" or "no load" scenario assuming only atmospheric deposition on the watershed and sub-embayment, as well as a natural forest within each watershed. Comparisons of the alternate watershed loading analyses are shown in Table VI-4. Loads are presented in kilograms per day (kg/day) in this Section, since it is inappropriate to show benthic flux loads in kilograms per year due to seasonal variability.

In general, certain sub-embayments would be impacted more than others. The build-out scenario indicates that there would be less than a 9% increase in watershed nitrogen load to the lower portion of the Popponesset Bay system as a result of potential future development. Other watershed areas would experience much greater load increases, for example the loads to Shoestring Bay and Ockway Bay would increase 25% and 35% respectively from the present day loading levels. A maximum increase in watershed loading resulting from future development would occur in the freshwater section of the Mashpee River, where the increase would be 139%. For the no load scenarios, almost all of the load entering the watershed is removed; therefore, the load is generally lower than existing conditions by over 90%.

Table VI-4. Comparison of sub-embayment watershed loads used for modeling of present, build out, and no-anthropogenic ("no-load") loading scenarios of the Popponesset Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	build out (kg/day)	build out % change	no load (kg/day)	no load % change
Popponesset Bay	1.82	1.98	+8.9%	0.08	-95.6%
Popponesset Creek	4.94	5.35	+8.4%	0.10	-97.9%
Pinquickset Cove	0.76	0.98	+28.7%	0.11	-85.7%
Ockway Bay	3.15	4.25	+35.0%	0.24	-76.0%
Mashpee River	12.11	17.57	+45.1%	0.62	-79.4%
Shoestring Bay	9.21	11.47	+24.5%	0.34	-75.5%
Surface Water Sources					
Mashpee River	15.56	37.15	+138.7%	4.68	-69.9%
Santuit River (Shoestring Bay)	15.58	21.46	+37.7%	1.27	-91.8%
Quaker Run River (Shoestring Bay)	5.98	6.62	+10.6%	0.24	-96.0%

For the build out scenario, a breakdown of the total nitrogen load entering each sub-embayment is shown in Table VI-5. The benthic flux for the build-out scenarios is assumed to vary proportional to the watershed load, where an increase in watershed load will result in an increase (positive) in benthic flux.

Following development of the nitrogen loading estimates for the build out scenario, the water quality model was run to determine nitrogen concentrations within each sub-embayment. Total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios. The relative change in total nitrogen concentrations resulting from build out was relatively large as shown in Table VI-6, with greater than 30% increases in total Nitrogen concentrations in the upper portions of the Popponesset

Bay system. Color contours of model output for the build-out scenario are present in Figure VI-6. The range of nitrogen concentrations shown are the same as for the plot of present conditions in Figure VI-3, which allows direct comparison of nitrogen concentrations between loading scenarios.

Table VI-5. Build-out sub-embayment and surface water loads used for total nitrogen modeling of the Popponesset Bay system, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux (kg/day)
Popponesset Bay	1.98	4.01	-5.13
Popponesset Creek	5.35	-	-0.65
Pinquickset Cove	0.98	0.29	-0.33
Ockway Bay - lower	-	-	-1.81
Ockway Bay - upper	4.25	1.09	3.89
Mashpee River	17.57	0.66	21.30
Shoestring Bay	11.46	2.23	-13.34
Surface Water Sources			
Mashpee River	37.14	-	-
Santuit River (Shoestring Bay)	21.46	-	-
Quaker Run River (Shoestring Bay)	6.62	-	-

Table VI-6. Comparison of model average total N concentrations from present loading and the build-out scenario, with percent change, for the Popponesset Bay system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions).

Sub-Embayment	monitoring station	present (mg/L)	build-out (mg/L)	% change
Mashpee River - head (MRh)	PB 1	0.771	1.650	113.9%
Mashpee River - Upper (MRu)	PB2	0.855	1.736	102.9%
Mashpee River - Mid (MRm)	PB3	0.783	1.361	73.8%
Mashpee River - Lower (MRl)	PB4	0.561	0.818	45.9%
Shoestring Bay - head (SBh)	SR 5	1.067	1.473	38.1%
Shoestring Bay - upper (SBu)	PB5	0.692	0.955	38.0%
Shoestring Bay - mid (SBm)	PB 6	0.620	0.856	38.1%
Shoestring Bay - lower (SBl)	PB 7	0.524	0.701	33.8%
Ockway Bay - upper (OBu)	PB 9	0.551	0.714	29.4%
Ockway Bay - lower (OBl)	PB 10	0.464	0.586	26.3%
Popponesset Bay - head (PBh)	PB 8	0.451	0.578	28.2%
Popponesset Bay - upper (PBu)	PB 11	0.374	0.442	18.1%
Popponesset Bay - mid (PBm)	PB 12	0.325	0.354	9.1%
Popponesset Creek (POC)	PB 13	0.366	0.407	11.4%
Pinquickset Cove (PQC)	PB 15	0.407	0.495	21.5%

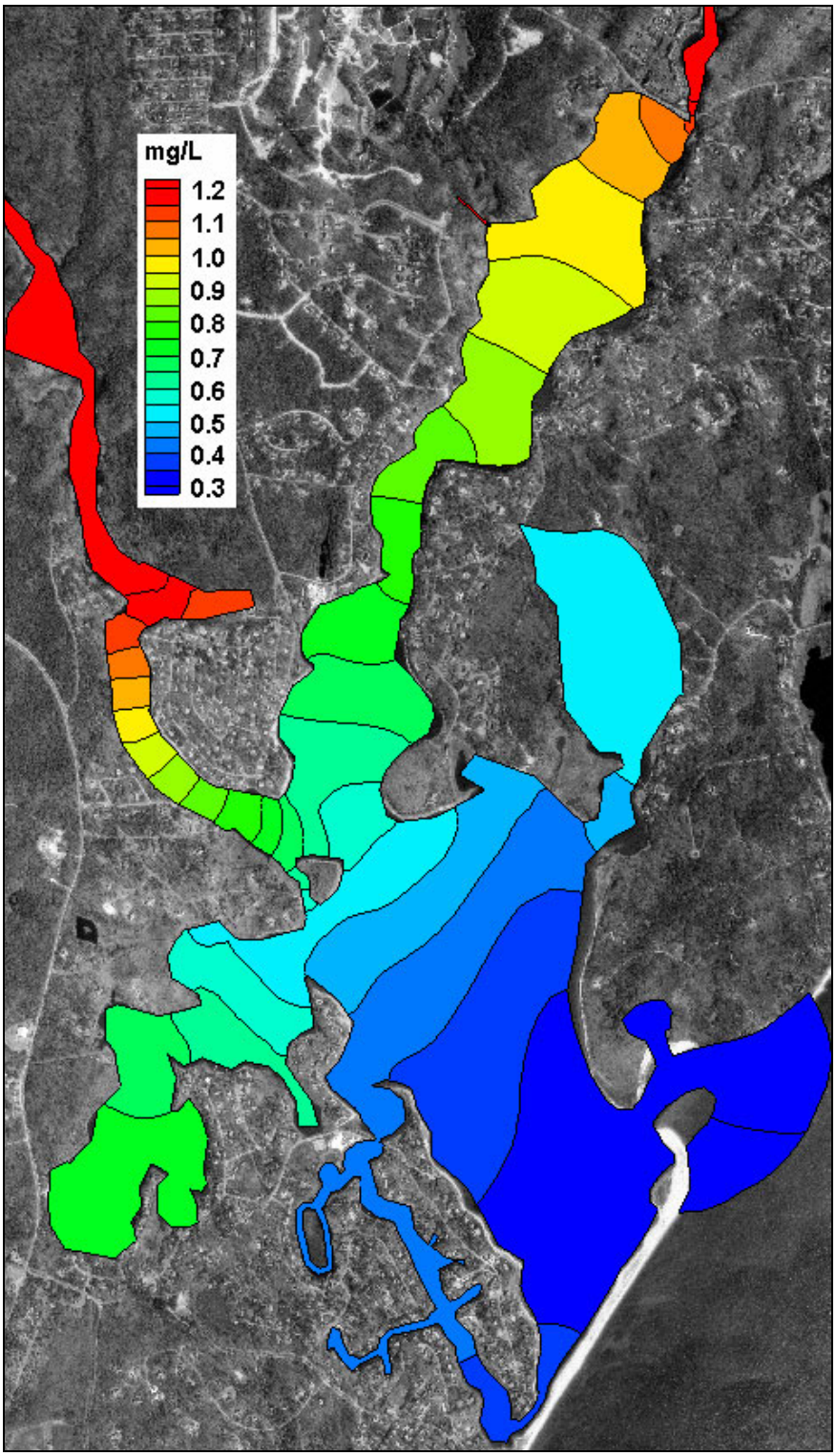


Figure VI-6. Contour Plot of modeled total nitrogen concentrations (mg/L) in Popponesset Bay, for projected build out loading conditions.

A breakdown of the total nitrogen load entering each sub-embayment for the no anthropogenic load scenarios is shown in Table VI-7. The benthic flux input to each embayment was reduced (toward zero) based on the reduction in the watershed load. Compared to the modeled present conditions and build-out scenario, atmospheric deposition directly to each sub-embayment becomes a greater percentage of the total nitrogen load as the watershed load and related benthic flux decrease.

Following development of the nitrogen loading estimates for the no load scenario, the water quality model was run to determine nitrogen concentrations within each sub-embayment. Again, total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios. The relative change in total nitrogen concentrations resulting from "no load" was significant as shown in Table VI-8, with reductions greater than 35% occurring the upper portions of the system. These results are shown pictorially in Figure VI-7.

For the no load scenario, the sub-embayment concentrations are generally governed by the total nitrogen concentrations observed in Nantucket Sound. There is a negative gradient in total nitrogen concentrations from the inlet to Popponesset Bay to the upper reaches. This is different from the modeled present and build-out conditions, where concentrations increase from the inlet to the upper reaches of the system. The slight negative gradient in the modeled "no-load" scenario results because the surface freshwater inputs have little load themselves, and dilute concentrations at the heads of Shoestring Bay and the Mashpee River.

Table VI-7. "No anthropogenic loading" sub-embayment and surface water loads used for total nitrogen modeling of the Popponesset Bay system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux (kg/day)
Popponesset Bay	0.08	4.01	-4.83
Popponesset Creek	0.10	-	-0.61
Pinquickset Cove	0.11	0.29	-0.31
Ockway Bay - lower	-	-	-1.03
Ockway Bay - upper	0.24	1.09	2.00
Mashpee River	0.62	0.66	6.56
Shoestring Bay	0.34	2.23	-4.43
Surface Water Sources			
Mashpee River	4.68	-	-
Santuit River (Shoestring Bay)	1.27	-	-
Quaker Run River (Shoestring Bay)	0.24	-	-

Table VI-8. Comparison of model average total N concentrations from present loading and the no anthropogenic ("no load") scenario, with percent change, for the Popponesset Bay system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions).

Sub-Embayment	monitoring station	present (mg/L)	no load (mg/L)	% change
Mashpee River - head (MRh)	PB 1	0.771	0.235	-69.6%
Mashpee River - Upper (MRu)	PB2	0.855	0.264	-69.2%
Mashpee River - Mid (MRm)	PB3	0.783	0.294	-62.5%
Mashpee River - Lower (MRl)	PB4	0.561	0.291	-48.2%
Shoestring Bay - head (SBh)	SR 5	1.067	0.129	-87.9%
Shoestring Bay - upper (SBu)	PB5	0.692	0.244	-64.8%
Shoestring Bay - mid (SBm)	PB 6	0.620	0.261	-58.0%
Shoestring Bay - lower (SBl)	PB 7	0.524	0.274	-47.8%
Ockway Bay - upper (OBu)	PB 9	0.551	0.319	-42.2%
Ockway Bay - lower (OBl)	PB 10	0.464	0.296	-36.1%
Popponesset Bay - head (PBh)	PB 8	0.451	0.281	-37.7%
Popponesset Bay - upper (PBu)	PB 11	0.374	0.283	-24.3%
Popponesset Bay - mid (PBm)	PB 12	0.325	0.285	-12.3%
Popponesset Creek (POC)	PB 13	0.366	0.282	-22.8%
Pinquickset Cove (PQC)	PB 15	0.407	0.284	-30.2%

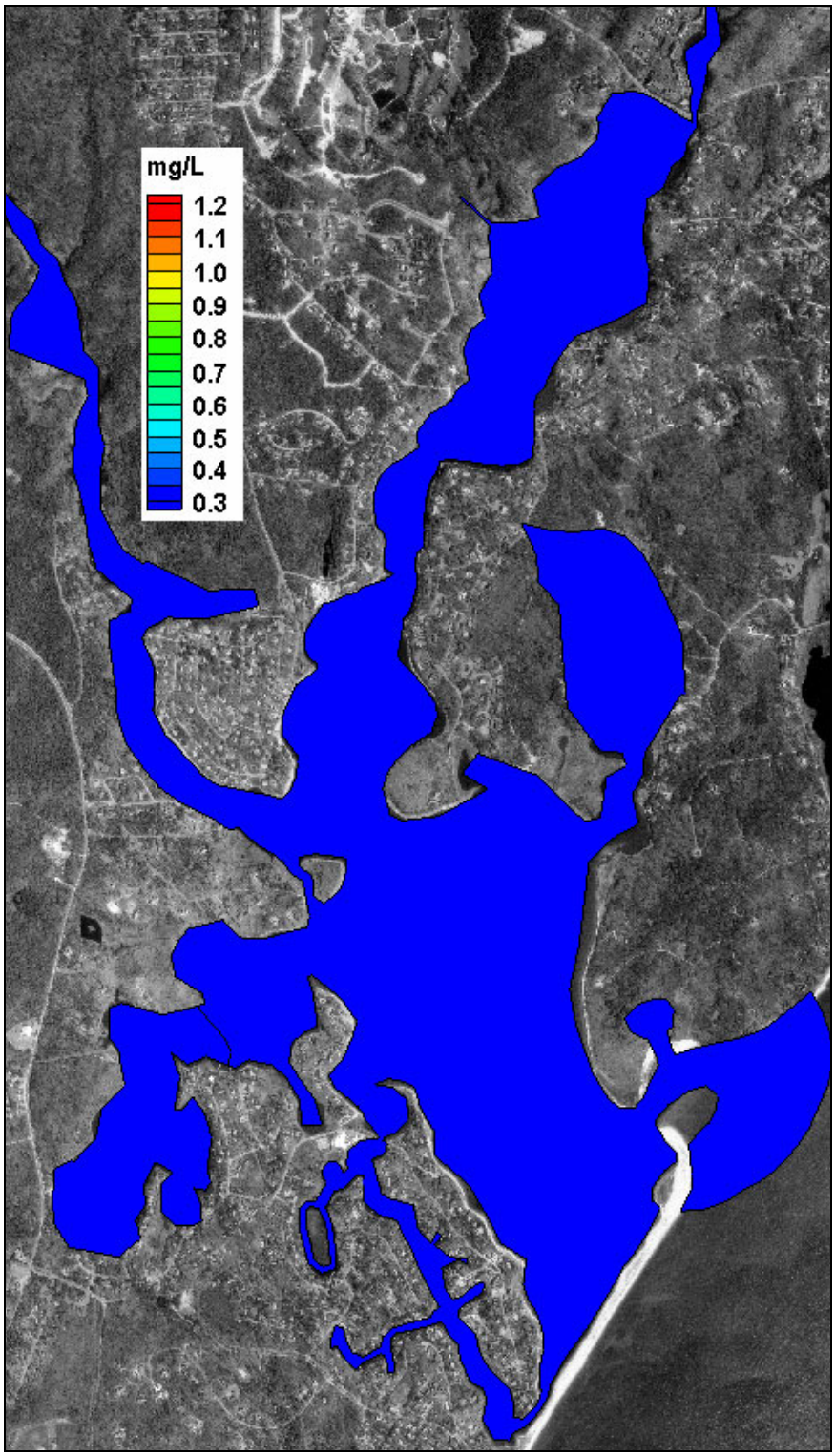


Figure VI-7. Contour Plot of modeled total nitrogen concentrations (mg/L) in Popponesset Bay, for no anthropogenic loading conditions.

VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll, and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (fish, shellfish, infauna) which it supports. For the Popponesset Bay embayment system in the Towns of Mashpee and Barnstable, Cape Cod, MA, our assessment is based upon data from the water quality monitoring database and our surveys of eelgrass distribution, benthic animal communities and sediment characteristics, and dissolved oxygen records conducted during the summers of 1998 and 1999. These data form the basis of an assessment of this system's present health, and when coupled with a full water quality synthesis and projections of future conditions based upon the water quality modeling effort, will support complete nitrogen threshold development for these systems (Chapter VIII).

VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS

There are a variety of indicators that can be used in concert with water quality monitoring data for evaluating the ecological health of embayment systems. The best biological indicators are those species which are non-mobile and which persist over relatively long periods, if environmental conditions remain constant. The concept is to use species which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

As a basis for a nitrogen thresholds determination, MEP focused on major habitat quality indicators: (1) bottom water dissolved oxygen and chlorophyll a (Section VII.2), (2) eelgrass distribution over time (Section VII.3) and (3) benthic animal communities (Section VII.4). Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate cause being nitrogen loading). However, oxygen conditions can change rapidly and frequently show strong tidal and diurnal patterns. Even severe levels of oxygen depletion may occur only infrequently, yet have important effects on system health. To capture this variation, the MEP Technical Team deployed dissolved oxygen sensors within the upper tributary sub-embayments, as well as closer to the inlet to Popponesset Bay, to record the frequency and duration of low oxygen conditions during the critical summer period. The MEP habitat analysis uses eelgrass as a sentinel species for indicating nitrogen over-loading to coastal embayments. Eelgrass is a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. Mapping of the eelgrass beds within the Popponesset Bay System was conducted for comparison to historic records (DEP Eelgrass Mapping Program, C. Costello). Temporal trends in the distribution of eelgrass beds are used by the MEP to assess the stability of the habitat and to determine trends potentially related to water quality. Eelgrass beds can decrease within embayments in response to a variety of causes, but throughout almost all of the embayments within southeastern Massachusetts, the primary cause appears to be related to increases in embayment nitrogen levels. Within the Popponesset Bay System, temporal changes in eelgrass distribution provides a strong basis for evaluating recent increases (nitrogen loading) or decreases (increased flushing-new inlet) in nutrient enrichment.

In areas that do not support eelgrass beds, benthic animal indicators were used to assess the level of habitat health from "healthy" (low organic matter loading, high D.O.) to "highly stressed" (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment

samples were identified and the environments ranked based upon the fraction of healthy, transitional, and stressed indicator species. The analysis is based upon life-history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes *et al.* 1997). These data are coupled with the level of diversity (H') and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

VII.2 BOTTOM WATER DISSOLVED OXYGEN

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 3.8 mg L^{-1}. Massachusetts State Water Quality Classification indicates that SA (high quality) waters maintain oxygen levels above 6 mg L^{-1}. The tidal waters of the Popponesset Bay System are currently listed under this Classification as SA. It should be noted that the Classification system represents the water quality that the embayment should support, not the existing level of water quality. It is through the MEP and TMDL processes that management actions are developed and implemented to keep or bring the existing conditions in line with the Classification.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates in summer than winter (Figure VII-1). It is not surprising that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute levels (mg L^{-1}) are found during the summer in southeastern Massachusetts embayments when water column respiration rates are greatest. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen conditions within shallow embayments (Taylor and Howes, 1994). To more accurately capture the degree of bottom water dissolved oxygen depletion during the critical summer period, autonomously recording oxygen sensors were moored 30 cm above the embayment bottom within key regions of the Popponesset Bay System (Figure VII-2). The sensors (YSI 6600) were first calibrated in the laboratory and then checked with standard oxygen mixtures at the time of initial instrument mooring deployment. In addition periodic calibration samples were collected at the sensor depth and assayed by Winkler titration (potentiometric analysis, Radiometer) during each deployment. Each instrument mooring was serviced and calibration samples collected at least biweekly and sometimes weekly during a minimum deployment of 30 days within the interval from July through mid-September. All of the mooring data from the Popponesset Bay embayment system was collected during 1997, 1998 and 1999.

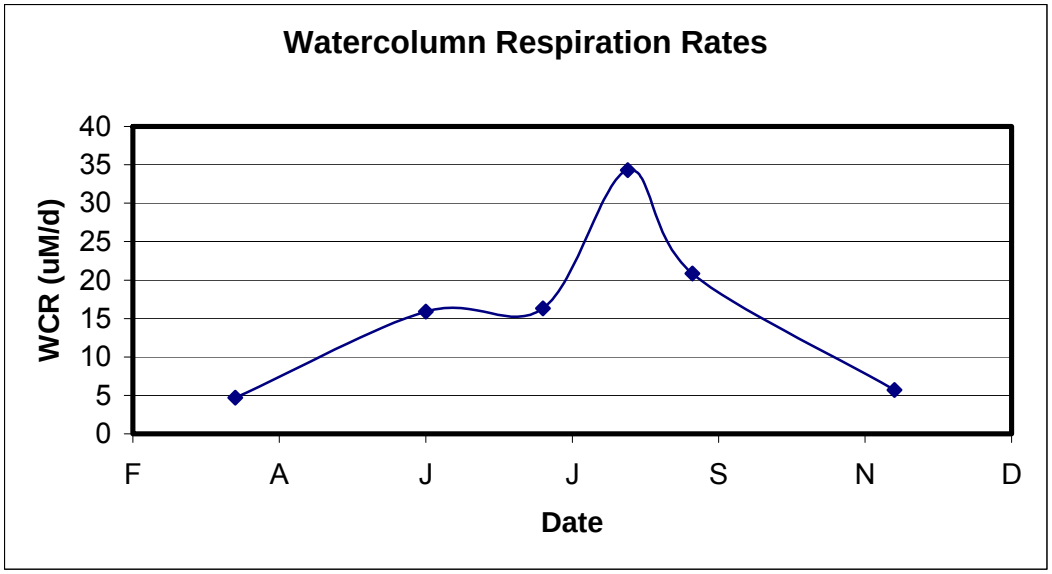


Figure VII-1. Average watercolumn respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System at the stations shown in Figure VII-11 (Schlezinger and Howes, unpublished data). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Similar to other embayments in southeastern Massachusetts, the sub-embayments to the overall Popponesset Bay System evaluated in this assessment showed high frequency variation, apparently related to diurnal and sometimes tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site, underscores the need for continuous monitoring within these systems. More important, both the level of oxygen depletion and the magnitude of daily oxygen excursion indicate highly nutrient enriched waters and impaired habitat quality at all but the lower-most mooring site (Popponesset Upper-Daniels Island, Figure VII-3 versus Figures VII-4 through VII-9).

The dissolved oxygen records indicate that the upper region of the Popponesset Bay Central Basin (the area generally associated with the Popponesset Bay Outer – Daniels Island DO mooring station) is currently maintaining adequate oxygen levels. However, the other regions of the Bay show significant depletions during summer. The oxygen depletion data indicate that the upper-most region of the central basin (south of Gooseberry Island), the region defined by the entrances to the Mashpee River and Shoestring Bay, and Shoestring Bay are exhibiting similar levels of oxygen depletion. Ockway Bay is showing greater levels of oxygen depletion, while the lower and upper regions of the Mashpee River are exhibiting oxygen excursions and depletion levels consistent with extremely high levels of organic matter loading.

Dissolved oxygen records were analyzed to determine the percent of the deployment time (18-45 days) that oxygen was below various benchmark concentrations (Table VII-1). These data indicate not just the minimum or maximum levels of this critical nutrient related constituent, but the intensity of the low oxygen circumstances. However, it should be noted that the frequency of oxygen depletion needs to be integrated with the actual temporal pattern of oxygen levels, specifically as it relates to daily oxygen excursions. From the oxygen records it is

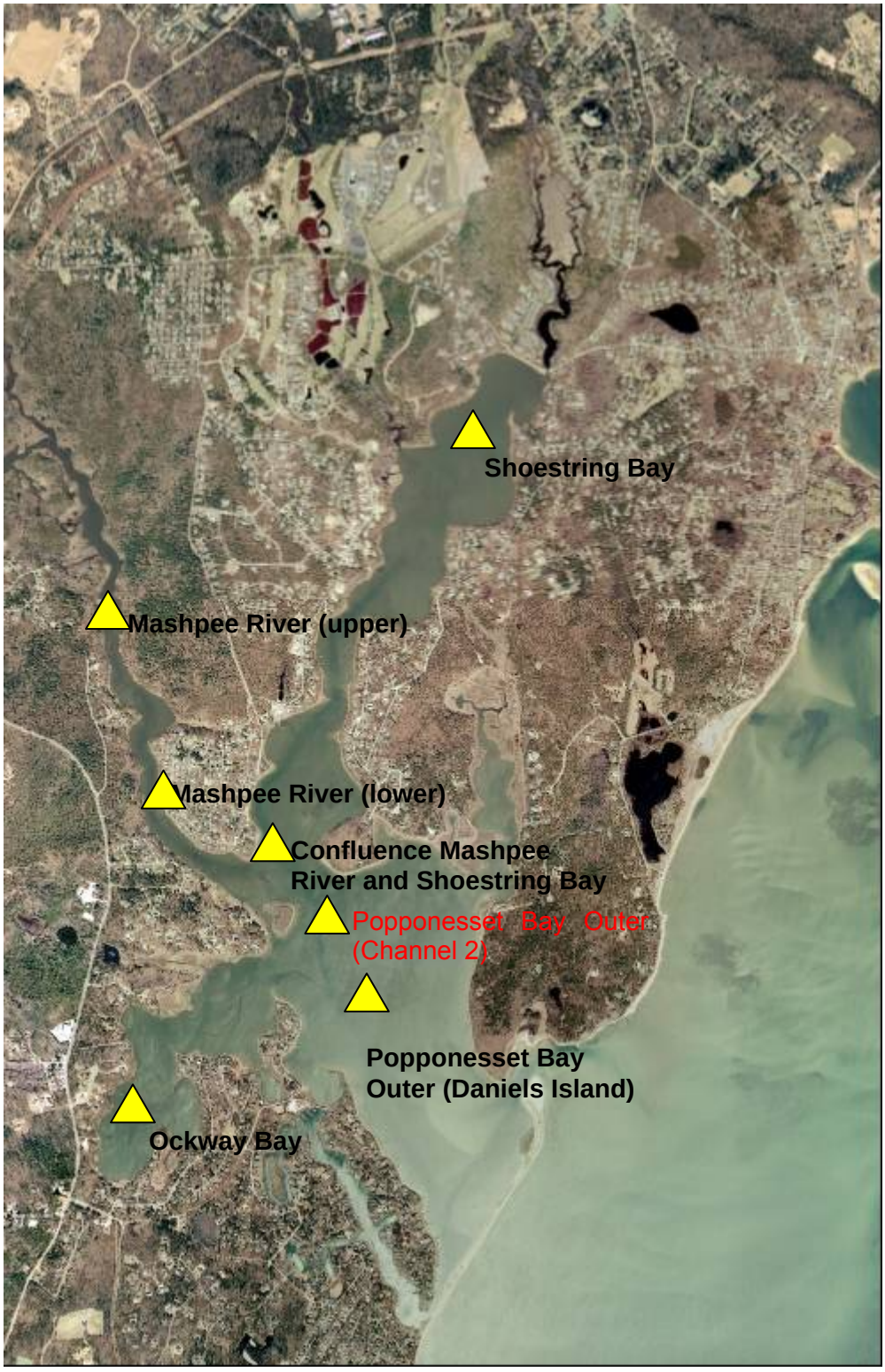


Figure VII-2. Aerial Photograph of the Popponesset Bay system in Mashpee showing locations of Dissolved Oxygen mooring deployments conducted in Summer 1998 and 1999.

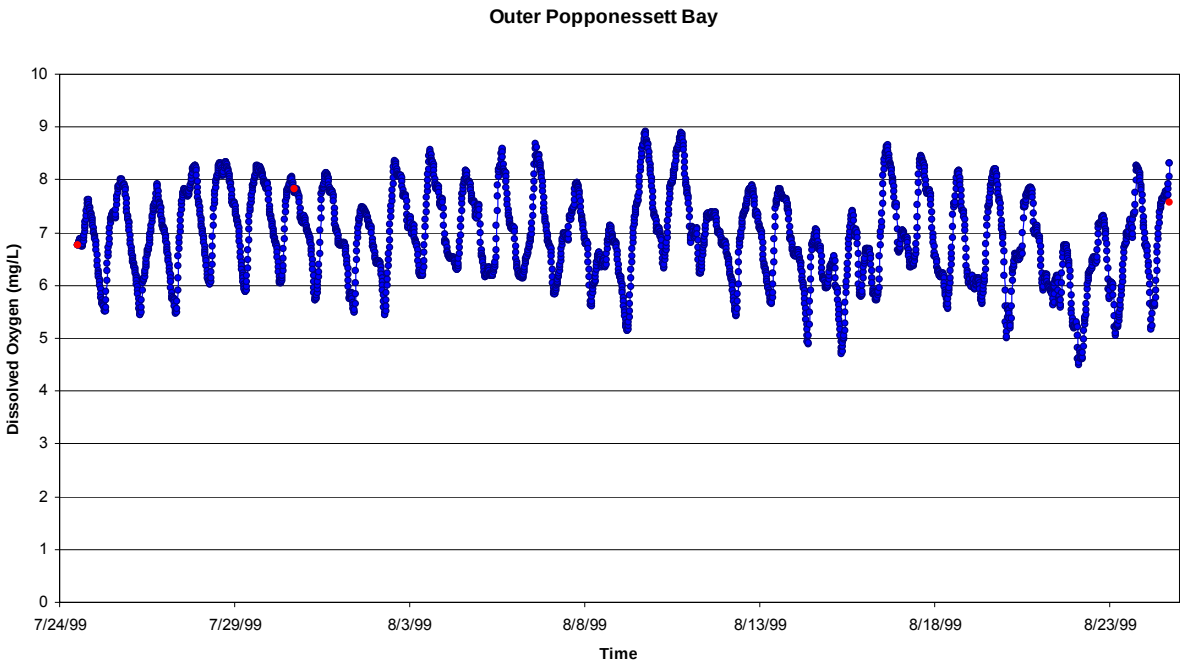


Figure VII-3. Bottom water record of dissolved oxygen at Outer Popponesset Bay station by Daniels Island, Summer 1999. Calibration samples represented as red dots.

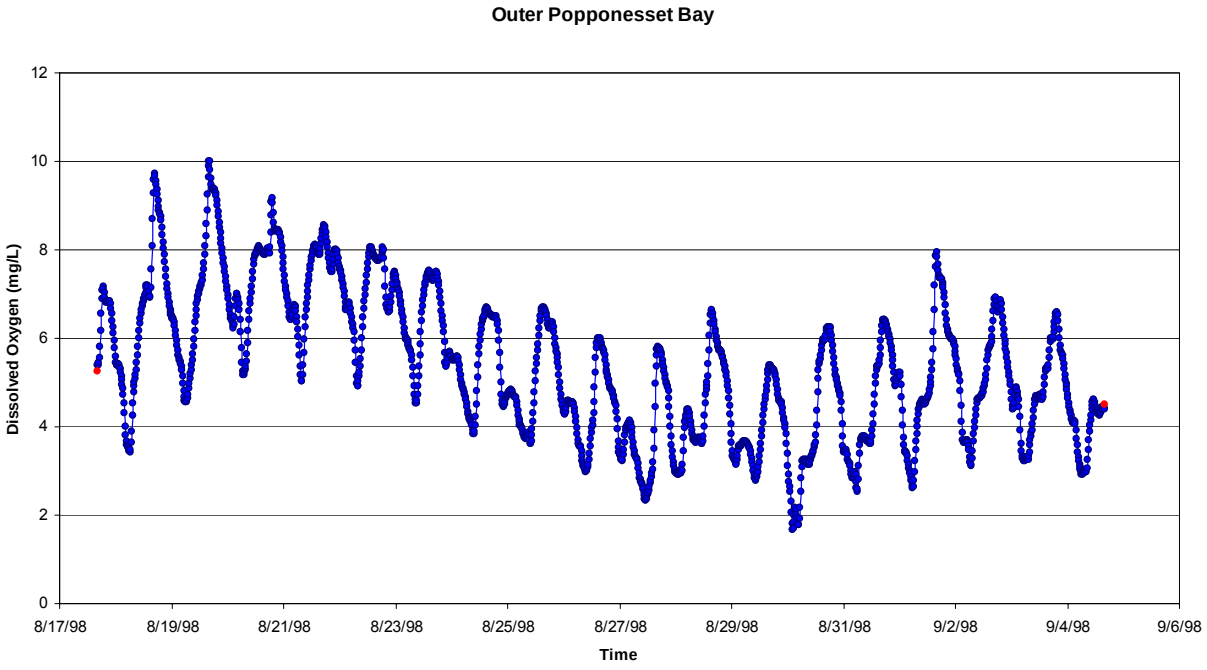


Figure VII-4. Bottom water record of dissolved oxygen in Outer Popponesset Bay station in Channel 2, Summer 1998. Calibration samples represented as red dots.

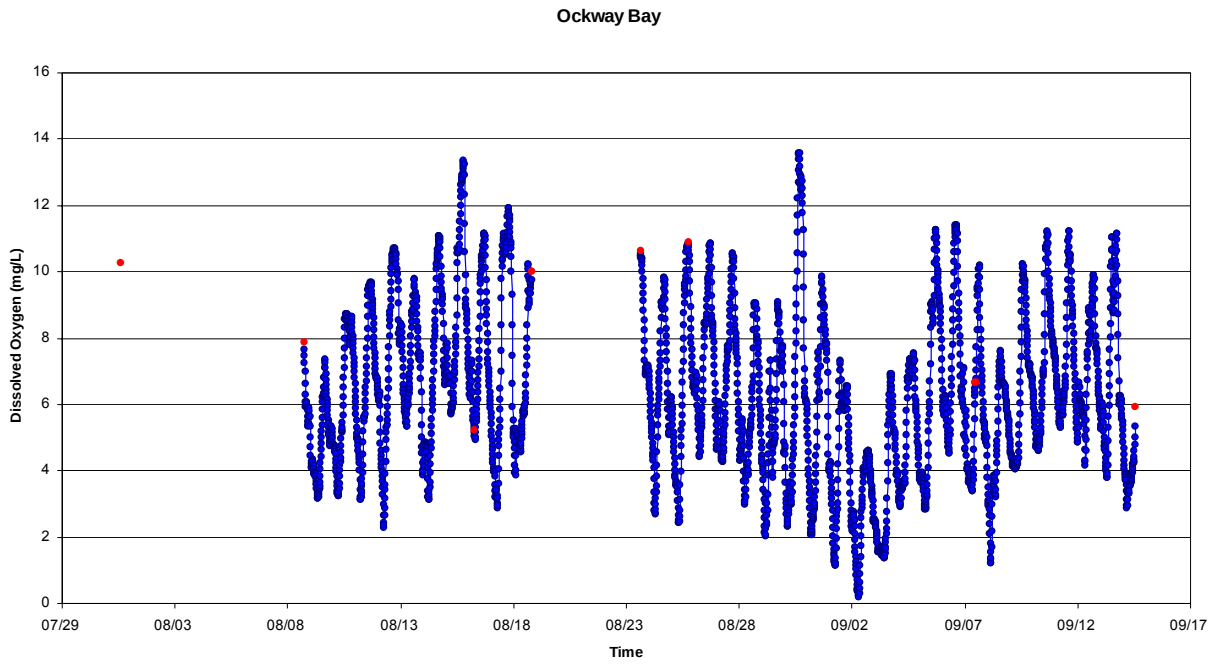


Figure VII-5. Bottom water record of dissolved oxygen in Ockway Bay, Summer 1997. Calibration samples represented as red dots.

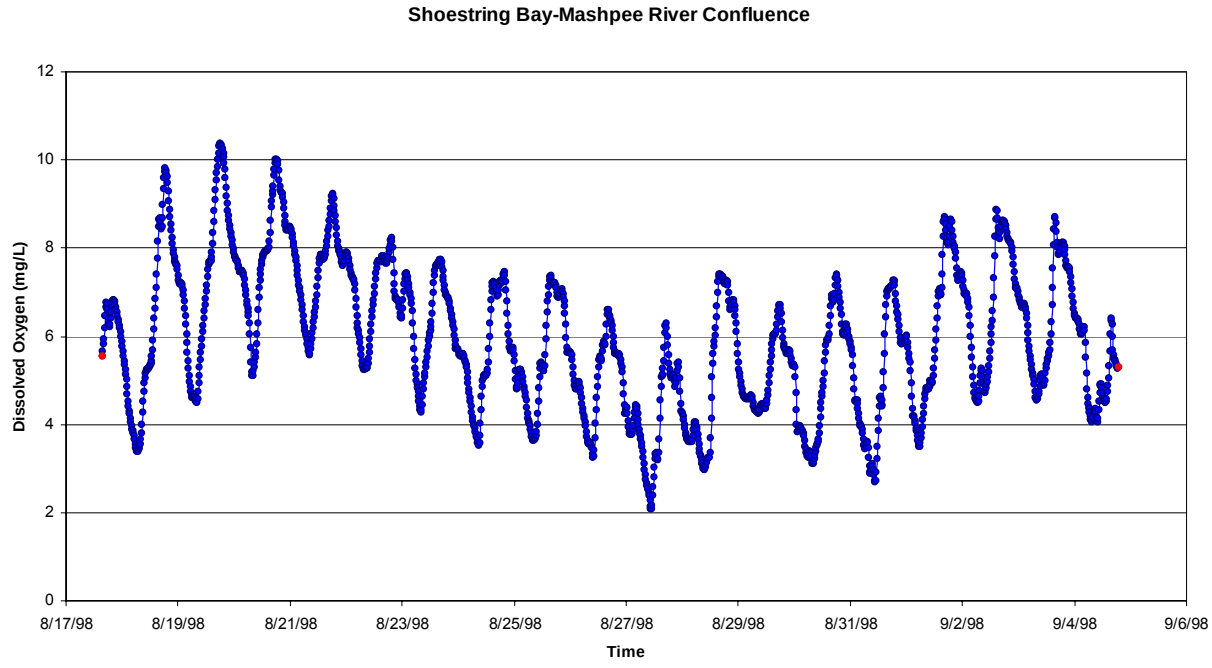


Figure VII-6. Bottom water record of dissolved oxygen at the confluence of the Mashpee River (lower) and Shoestring Bay, Summer 1998. Calibration samples represented as red dots.

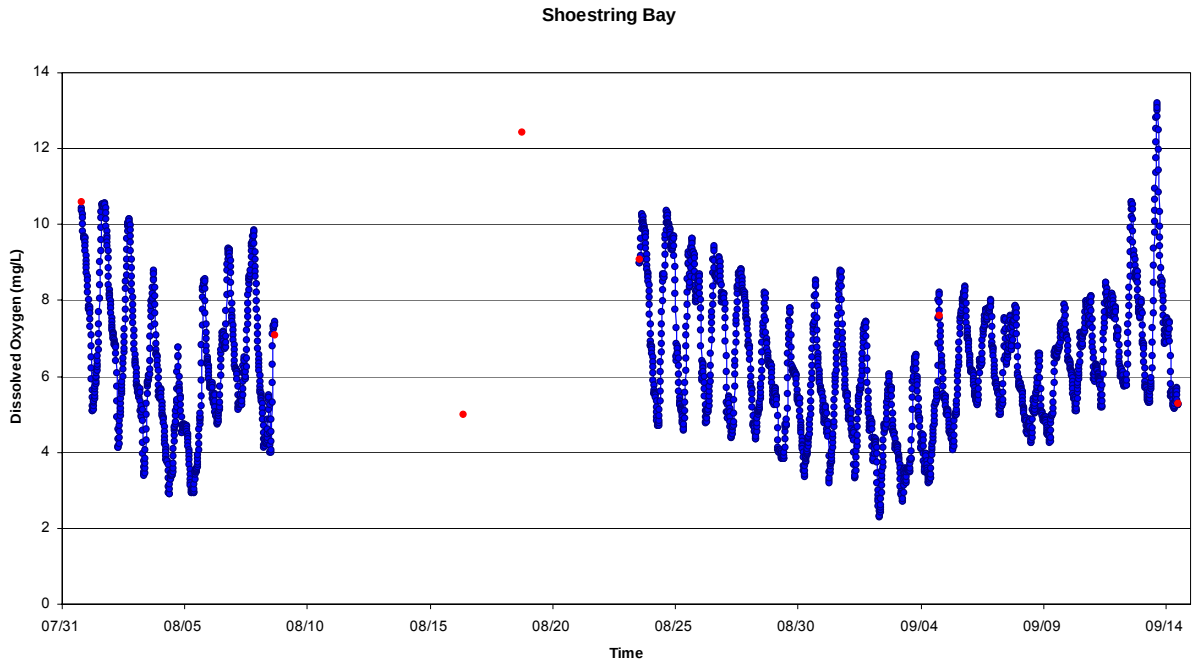


Figure VII-7. Bottom water record of dissolved oxygen in Shoestring Bay, Summer 1997. Calibration samples represented as red dots.

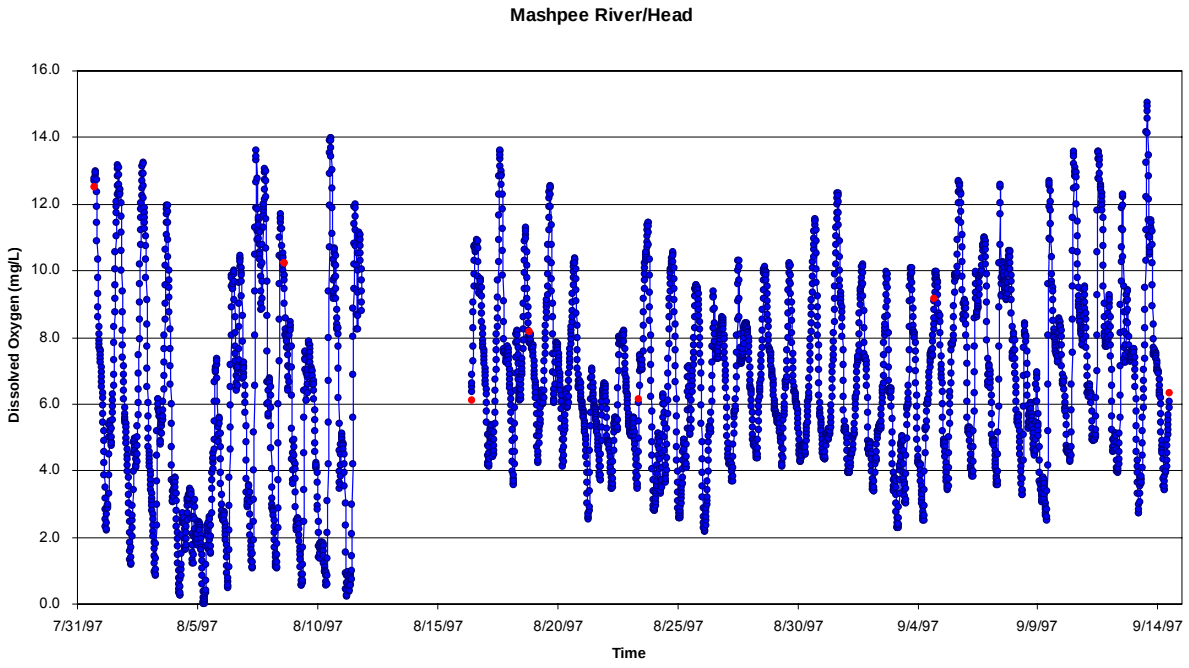


Figure VII-8. Bottom water record of dissolved oxygen in upper Mashpee River, Summer 1997. Calibration samples represented as red dots.

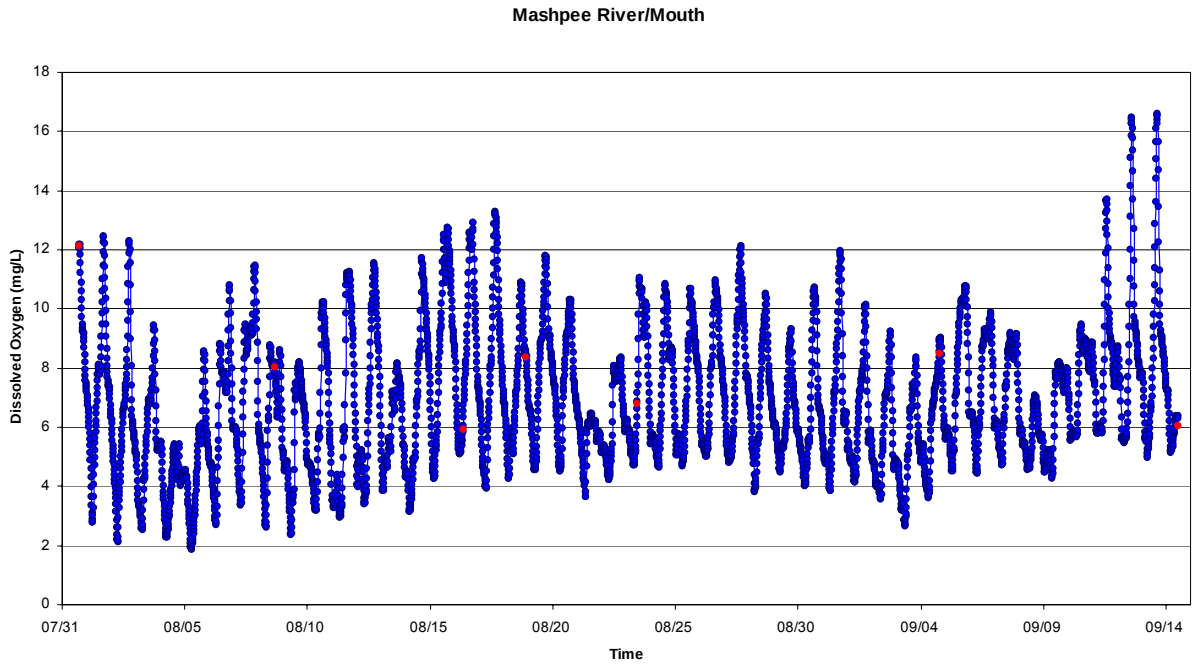


Figure VII-9. Bottom water record of dissolved oxygen in Mashpee River (lower) at the mouth, Summer 1999. Calibration samples represented as red dots.

Table VII-1. Percent of time during deployment that bottomwater oxygen levels recorded by the *in situ* sensors were below various benchmark oxygen levels.

Massachusetts Estuaries Project
Town of Mashpee: 1998-1999

	Dissolved Oxygen: Continuous Record, Summer 1997-1999				
	Deployment Days	**<6 mg/L (% of days)**	**<5 mg/L (% of days)**	**<4 mg/L (% of days)**	**<3 mg/L (% of days)**
Mashpee River Upper	44.8	51%	40%	27%	20%
Mashpee River/ Mouth	44.8	43%	22%	8%	2%
Mashpee River/Shoestring Bay	18.2	52%	31%	13%	2%
Ockway Bay	32.0	47%	33%	19%	8%
Shoestring Bay	29.8	48%	25%	9%	1%
Popponesset Bay Channel 2	18.0	60%	41%	24%	6%
Popponesset Bay Daniels Isle	31.2	15%	1%	0%	0%

clear that the Mashpee River has the greatest extent of oxygen depletion and the oxygen excursion indicates a high degree of nutrient enrichment (as is supported by the chlorophyll a data, see below). However, use of only the duration of oxygen below for example 4 mg l^{-1} would underestimate oxygen stress in this system. The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae), oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems. This is the case in the Mashpee River and to a lesser extent in the other basins.

Chlorophyll a data collected by the water quality monitoring program was of sufficient size to allow a frequency analysis similar to that for dissolved oxygen (Table VII-2). It is clear that the upper regions of the Popponesset Bay System periodically have large phytoplankton blooms and that the general gradient in chlorophyll levels is consistent with the observed distribution in oxygen depletion of bottom waters. The Mashpee River and Shoestring Bay supported phytoplankton blooms >15 ug L^{-1} on about one third of the sampling dates (sum of frequencies 15-20, 20-25, >25 ug L^{-1}, Table VII-2). Ockway Bay and upper Popponesset Bay showed lesser blooms and the central region of Popponesset Bay exhibited only moderate-low chlorophyll levels.

Combining the dissolved oxygen and chlorophyll a data yield a clear pattern of nutrient related habitat quality (based on these parameters only, see eelgrass and infaunal indicators below). At present, the central basin of Popponesset Bay supports relatively healthy habitat conditions of consistently high bottom water dissolved oxygen and modest phytoplankton blooms during summer. In contrast, the other regions of the System have moderate to high levels of nitrogen related impairment. Shoestring Bay shows both periodic oxygen declines and significant phytoplankton blooms, while Ockway Bay has similar oxygen declines, but apparently less phytoplankton biomass. Dissolved oxygen measurements in the Mashpee River also indicate nutrient impairment, with extreme oxygen excursions and night-time oxygen depletion on a consistent basis, and significant phytoplankton blooms. The major issue with the Mashpee River is the extent to which its structure as a salt marsh system ameliorates the impact of these water quality features. However, even as a salt marsh, these levels of chlorophyll a and oxygen excursion indicate a moderate level of impairment. Based upon the dissolved oxygen and chlorophyll data the ranking of the Popponesset Bay System components is as follows:

- Popponesset Bay Central Basin – high quality
- Popponesset Bay upper/confluence, Shoestring & Ockway Bays – significantly impaired
- Mashpee River – significantly impaired to degraded (relative to embayments)
  -- moderately to significantly impaired (relative to salt marshes).

Table VII-2. Frequency of grab samples for summer chlorophyll a levels above various benchmark levels within each of the tributary sub-embayments to the Popponesset Bay System. Data collected by the Popponesset Bay Water Quality Monitoring Program and Coastal Systems Program, SMAST. Geometric averages were used to estimate "average" conditions, given the periodic phytoplankton blooms.

		Frequency						Statistics		
Sub-Embayment	Sta ID	<5 ug/L %	5-10 ug/L %	10-15 ug/L %	15-20 ug/L %	20-25 ug/L %	>25 ug/L %	Geo Mean ug/l	Geo s.d. ug/L	N
Popponesset Bay System										
Mashpee River	1997-2003									
Upper (PB2)	PB2	23	27	19	12	4	15	11.2	3.1	26
Mid	PB3	11	30	26	19	4	11	12.8	2.7	27
Lower	PB4	14	46	25	7	4	4	8.8	2.0	28
Shoestring Bay	1997-2003									
Upper	PB5	11	30	26	11	4	19	12.3	2.0	27
Mid	PB6	7	39	25	18	7	4	11.2	1.6	28
Lower	PB7	14	57	7	7	14	0	8.2	1.7	28
Ockway Bay	1997-2003									
Upper	PB9	17	55	19	6	4	0	7.7	1.6	27
Lower	PB10	29	54	7	7	0	4	6.5	1.8	28
Pinquickset Cove	2002-2003									
Mid	PB15	57	0	14	0	14	14	7.6	2.7	7
Popponesset Bay	1997-2003									
Upper	PB8	12	67	7	2	5	7	8.0	1.8	27
Mid	PB11	29	58	4	0	0	8	6.8	2.1	24
Lower	PB12	48	41	7	0	0	4	5.1	1.8	27
Popponesset Crk	PB13	50	43	4	0	0	4	5.3	1.8	28

VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS

Eelgrass surveys and analysis of historical data was conducted for the Popponesset Bay System by the DEP Eelgrass Mapping Program as part of the MEP Technical Team. Surveys were conducted in 1995 and 2001, as part of this program. Additional analysis of available high resolution aerial photos from 1951 was used to reconstruct the eelgrass distribution prior to any substantial development of the watershed. The 1951 data were only anecdotally validated, while the 1995 and 2001 maps were field validated. The primary use of the data is to indicate (a) if eelgrass once or currently colonizes a basin and (b) if large-scale system-wide shifts have occurred. Integration of these data sets provides a view of temporal trends in eelgrass distribution from 1951 to 1995 to 2001 (Figure VII-10); the period in which watershed nitrogen loading significantly increased to its present level. This temporal information can be used to determine the stability of the eelgrass community.

At present, eelgrass is not present within the Popponesset Bay System. In addition, to the DEP mapping, this has been confirmed by the multiple MEP staff conducting the infaunal and

sediment sampling and the mooring studies. The current lack of eelgrass beds is expected given the high chlorophyll a and low dissolved oxygen levels and watercolumn nitrogen concentrations within this system. However, it appears that a substantial area of the central basin supported eelgrass beds in 1951. In addition, there were smaller beds within the upper region of the main basin, at the mouth to Shoestring Bay. The pattern of these beds is consistent with the pattern of nitrogen related habitat quality which is currently observed within the System. It appears that as the Bay became nutrient enriched, that these sites could no longer support eelgrass beds. However, it is likely that if nitrogen loading were to decrease that eelgrass could first be restored in the lower portion of the main basin and with further reductions, be restored to the 1951 pattern.

It is significant that eelgrass was not detected in Shoestring Bay or Ockway Bay in the 1951 data. It appears that these systems are not supportive of this type of habitat. Given the structure of these sub-embayments and their sediment types, it appears that these are natural depositional basins and may not be conducive to supporting rooted macrophytes. The lack of eelgrass in the Mashpee River is consistent with its role as a salt marsh system, which drains completely at low tide in some regions and which is “naturally” organic rich. For these reasons, salt marshes typically do not support eelgrass beds within their main channels.

In systems like Popponesset Bay, the general pattern is for highest nitrogen levels to be found within the innermost basins, with concentrations declining moving toward the tidal inlet. This pattern is also observed in nutrient related habitat quality parameters, like phytoplankton, turbidity, oxygen depletion, etc. The consequence is that eelgrass bed decline typically follows a pattern of loss in the innermost basins (and sometimes also from the deeper waters of other basins) first. The temporal pattern is a “retreat” of beds toward the region of the tidal inlet.

Other factors which influence eelgrass bed loss in embayments may also be at play in Popponesset Bay, though the loss seems completely in-line with nitrogen enrichment. However, a brief listing of non-nitrogen related factors is useful. Eelgrass bed loss does not seem to be directly related to mooring density, as the Bay supports few boat moorings. Similarly, pier construction and boating pressure may be adding additional stress in nutrient enriched areas, but do not seem to be the overarching factor. It is not possible at this time to determine the potential effect of shellfishing on eelgrass bed distribution, although it must be small as there is little shellfishing on an areal basis in the Bay.

As for the apparent decline along Popponesset Spit and just off the inlet, there are 2 major likely causes. First, coastal processes in this area are highly dynamic. This is particularly true in the nearshore to the spit, where there have been several storm overwash events and the need for beach nourishment to maintain the spit. There was a major hurricane in 1954 just after the 1951 survey, which surely affected the area. Directly off the inlet there has been periodic maintenance dredging, without which the tidal flushing of the Bay would be reduced, magnifying the eutrophic conditions of the entire system. Note in Figure V-2 the significant reduction in the length of Popponesset Spit through the area in question, since 1951. The second cause may be related to the nitrogen plume emanating from Popponesset Bay on the ebb tide. This plume can result in elevated nitrogen levels, though the elevated nitrogen plume levels would be lower than what would typically lead to eelgrass bed loss. Boat traffic cannot be ruled out either.

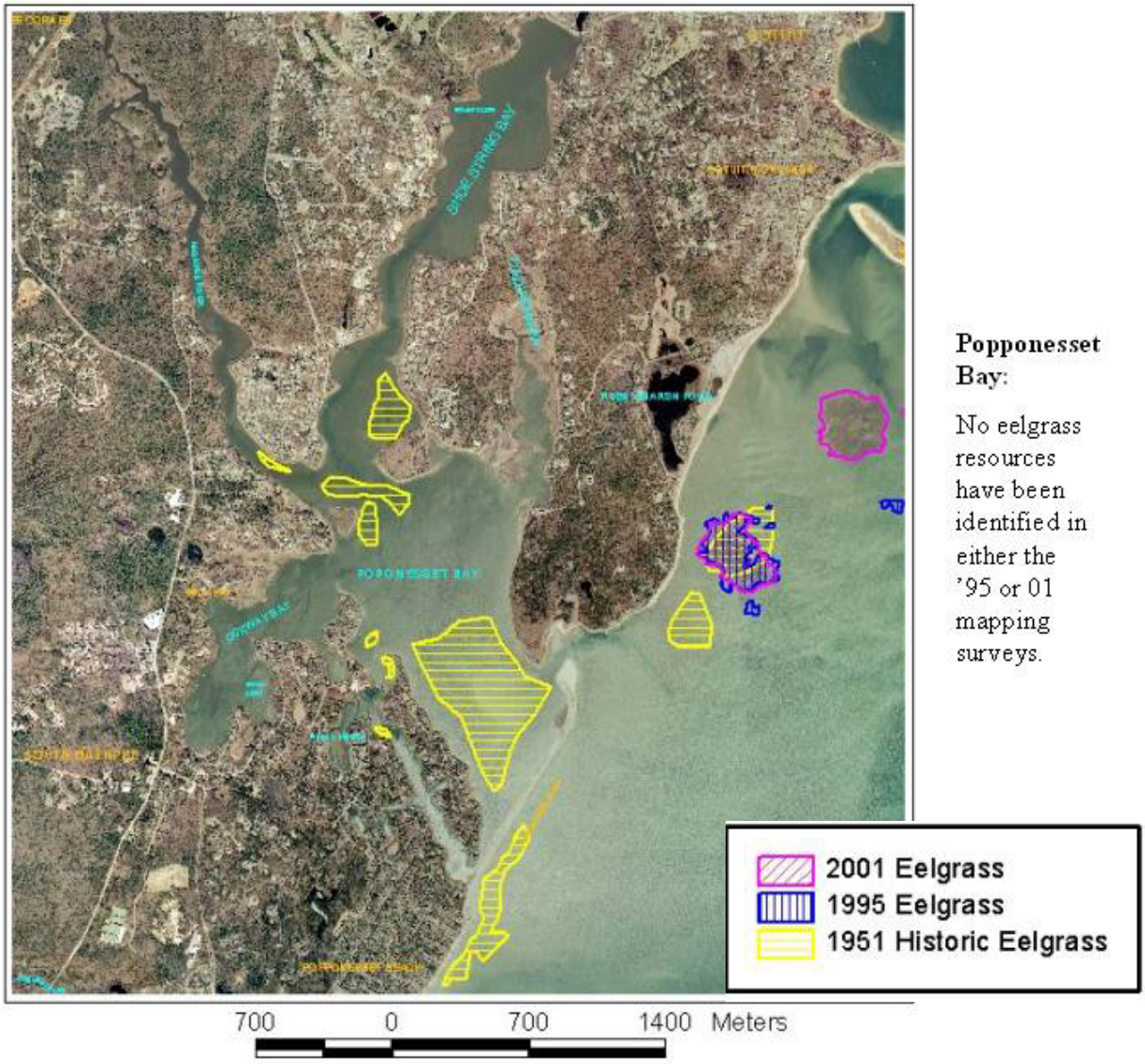


Figure VII-10. Eelgrass bed distribution within the Popponesset Bay System. The 1951 coverage is depicted by the yellow outline inside of which circumscribes the eelgrass beds. The blue (1995) and purple (2001) areas were mapped by DEP. All data was provided by the DEP Eelgrass Mapping Program.

It is not possible to determine a general idea of short- and long-term rates of change in eelgrass coverage from the mapping data, since there is only one survey with eelgrass. However, it is possible to utilize the 1951 coverage data as an indication that an eelgrass bed might be recovered on the order of 100 acres, if nitrogen management alternatives were implemented (Table VII-3). Even more area is possible, if the upper portion of the central basins, which did not contain eelgrass in 1951, could also be restored. Note that restoration of this habitat will necessarily result in restoration of other resources in Shoestring and Ockway Bays and in the region of the mouth to the Mashpee River.

The relative pattern of these data is consistent with the results of the benthic infauna analysis and the observed eelgrass loss is typical of nutrient enriched shallow embayments (see below).

Table VII-3. Changes in eelgrass coverage in the Popponesset Bay sub-systems within the Town of Mashpee over the past half century (C. Costello).

Embayment	1951 (acres)	1995 (acres)	2001 (acres)	% Difference (1951 to 2001)
Popponesset Main Bay	**85.41**	**0**	**0**	**100 %**
Shoestring Bay	**10.64**	**0**	**0**	**100 %**
Mashpee River	**0.83**	**0**	**0**	**100 %**
Ockway Bay	**0**	**0**	**0**	
Pinquickset Cove	**0**	**0**	**0**	
There is presently no eelgrass within the Popponesset Bay System				

VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling was conducted at 8 locations throughout the Popponesset Bay System (Figure VII-11). In some cases multiple assays were conducted. In all areas and particularly those that do not support eelgrass beds (hence all of the Popponesset Bay System), benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity and evenness of the community. It should be noted that, given the loss of eelgrass beds, the Popponesset Bay System is clearly impaired by nutrient overloading. However, to the extent that it can still support healthy infaunal communities, the benthic infauna analysis is important for determining the level of impairment (moderately impaired→significantly impaired→severely degraded). This assessment is also important for the establishment of site-specific nitrogen thresholds (Chapter VIII).

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas, as shown by the oxygen and chlorophyll records and eelgrass coverage, have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5.

The Infauna Study indicated that all areas with the exception of the lower station within the central basin of Popponesset Bay are presently moderately to severely degraded (Table VII-4). Upper Ockway Bay was found to support the poorest infaunal communities within the system, based upon the very low number of species and individuals. Although the 2 species found (compared to 31 in the central basin) were indicative of healthy conditions, the low numbers (20's compared to 400-500 typically) indicated that this system cannot support a community. The indication of better habitat in the Mashpee River, although listed as significantly impaired, results from it supporting a community indicative of a riverine salt marsh. The stress indicator species present were dominated by *Cyathura polita,* which is tolerant of the salinity stress and helps to define this as a marsh system. However, the total numbers of individuals and diversity tends to be low, indicative of a significantly impaired resource. Shoestring Bay and the uppermost portion of the Popponesset Bay central basin both showed a resource that was categorized between moderate and significant impairment. The numbers of individuals was generally high (500-600 per 0.018 m^2) representing a moderate number of species. Diversity was also moderate to high and distributed between indicators of healthy and stressed conditions (Table VII-5), again indicative of moderate impairment. In contrast, the Lower Popponesset Bay station supports a relatively healthy infaunal community, with nearly double the species of other sites and high numbers of individuals (~500 per 0.018 m^2). The high diversity and general evenness are consistent with a healthy community. The indication of moderate impairment stems from the presence of stress indicator species. The overall results indicate a system capable of supporting diverse healthy communities in the region nearest the tidal inlet, with most of the system having infaunal habitat that is significantly impaired under present nitrogen loading conditions.



Figure VII-11. Aerial photograph of Popponesset Bay showing location of benthic infaunal sampling stations (red symbol).

Table VII-4. Benthic Infaunal Community Assessment for Popponesset Embayments. Samples collected Fall of 1998. All data is represented as per 0.018 m^2. Indicator assessment based upon life history information. Classification is based upon DEP-SMAST proposed thresholds. Some species are unclassified so the Total Species do not always equal the Indicators.

Popponesset Bay System			Benthic Infaunal Community - Indicators						
Sub-Embayment	Total #Species	Total #Individuals	Healthy #Species	Healthy #Individual	Transition #Species	Transition #Individuals	Stressed #Species	Stressed #Individuals	Classification
Mashpee River									
Mid - B5 Rep 1	6	98	0	0	3	57	3	41	Significant Impairment
Rep 2	7	195	1	1	2	79	4	115	Significant Impairment
Lower – B6 Rep 1	12	223	6	31	2	41	4	151	Significant Impairment
Ockway Bay									
Inner - B4 Rep 1	2	26	2	26	0	0	0	0	Severe Degradation[1]
Rep 2	2	10	2	10	0	0	0	0	Severe Degradation[1]
Rep 3	2	11	2	11	0	0	0	0	Severe Degradation[1]
Outer – B3 Rep 1	12	68	6	18	2	5	3	30	Significant Impairment
Rep 2	14	126	6	30	3	26	3	60	Significant Impairment
Shoestring Bay									
Inner - B7 Rep 1	15	666	6	161	3	92	4	405	Moderate-Significant Imp[2]
Rep 2	16	645	6	274	3	50	5	312	Moderate-Significant Imp[2]
Rep 3	16	474	7	171	4	95	4	205	Moderate-Significant Imp[2]
Mid – B8 Rep 1	15	534	5	133	6	225	4	176	Moderate-Significant Imp[2]
Popponesset Bay									
Upper – B1 Rep 1	8	500	2	6	3	332	2	160	Moderate-Significant Imp[2]
Rep 2	6	642	1	2	3	340	2	300	Moderate-Significant Imp[2]
Rep 3	9	962	3	22	3	394	2	544	Moderate-Significant Imp[2]
Rep 4	11	88	5	16	2	5	3	57	Moderate-Significant Imp[2]
Lower - B2 Rep 1	31	489	18	105	5	180	5	200	Healthy – Moderate Imp[3]

1 Based upon the virtual absence of animals in numbers of individuals and species.
2 Based upon the total number of species and individuals and the large contribution of stress species
3 Based upon the total number of species (healthy) and total number of individuals and the fraction of transition and stress species

Table VII-5. Benthic infaunal community data for the Popponesset Bay embayment system. Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations (Samples represent surface area of 0.018 m2).

Sub-Embayment	Location	Total Actual Species	Total Actual Individuals	Species Calculated @75 Indiv.	Weiner Diversity (H')	Evenness (E)
Popponesset Bay System						
Mashpee River	Mid - PB5					
	Rep 1	6	98	4	1.59	0.61
	Rep 2	7	195	6	1.75	0.62
	Lower - PB6					
	Rep 1	12	223	8	1.76	0.49
Ockway Bay	Inner - PB4					
	Rep 1	2	26	N/A	0.24	0.24
	Rep 2	2	10	N/A	0.47	0.47
	Rep 3	2	11	N/A	0.44	0.44
	Outer - PB3					
	Rep 1	12	68	N/A	3.05	0.85
	Rep 2	15	128	14	3.02	0.77
Shoestring Bay	Inner - PB7					
	Rep 1	15	666	11	2.69	0.69
	Rep 2	17	645	10	2.70	0.66
	Rep 3	16	474	10	2.55	0.64
	Mid - PB8					
	Rep 1	15	534	9	2.71	0.69
Popponesset Bay	Upper - PB1					
	Rep 1	8	500	6	1.63	0.54
	Rep 2	6	642	5	1.66	0.64
	Rep 3	9	962	6	1.76	0.55
	Rep 4	11	88	10	2.48	0.72
	Lower - PB2					
	Rep 1	31	489	17	3.39	0.68

VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS

VIII.1. ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires integration of key habitat parameters (infauna and eelgrass), sediment characteristics, and nutrient related water quality information (particularly dissolved oxygen and chlorophyll a). Additional information on temporal changes within each sub-embayment and its watershed further strengthen the analysis. These data were collected to support threshold development for the Popponesset Bay System by MEP Team and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels from the long-term baseline water quality monitoring program. At present the bulk of the Popponessett Bay System is showing significantly impaired habitat quality (Chapter VII).

Eelgrass: Since the system once supported eelgrass beds (~100 acres in 1951) and now has lost all eelgrass coverage, the highest habitat evaluation currently possible is moderate impairment (Howes et. al 2003). The level of impairment after the loss of eelgrass can be determined from the dissolved oxygen and phytoplankton biomass (chlorophyll) and infaunal communities. The current lack of eelgrass beds is expected given the high chlorophyll a and low dissolved oxygen levels and watercolumn nitrogen concentrations within this system. However, it appears that a substantial area of the central basin supported eelgrass beds in 1951. In addition, there were smaller beds within the upper region of the main basin, at the mouth to Shoestring Bay. The pattern of these beds is consistent with the pattern of nitrogen related habitat quality, which is currently observed within the System. It appears that as the Bay became nutrient enriched, that these sites could no longer support eelgrass beds. However, it is likely that if nitrogen loading were to decrease, eelgrass could first be restored in the lower portion of the main basin and with further reductions, be restored to the 1951 pattern.

It is significant that eelgrass was not detected in Shoestring Bay and Ockway Bay in the 1951 data. It appears that these systems are not supportive of this type of habitat. Given the structure of these sub-embayments and their sediment types, it appears that these are natural depositional basins and may not be conducive to supporting rooted macrophytes. It is also possible that the tidal flushing of the Popponesset Bay System has historically varied from unrestricted to restricted as the inlet has migrated. This variation may have created nutrient related habitat quality issues within Ockway and Shoestring Bays, even under the low watershed nitrogen loading levels generally associated with the 1951 population. The lack of eelgrass in the Mashpee River is consistent with its role as a salt marsh system, which drains completely at low tide in the upper regions and which is “naturally” organic rich. For these reasons, salt marshes typically do not support eelgrass beds within their main channels.

Water Quality: At present, the central basin of Popponesset Bay supports relatively healthy habitat conditions of consistently high bottom water dissolved oxygen and modest phytoplankton blooms during summer. In contrast, the other regions of the System have moderate to high levels of nitrogen related impairment. Shoestring Bay shows both periodic oxygen declines and significant phytoplankton blooms, while Ockway Bay has similar oxygen declines, but apparently less phytoplankton biomass. Dissolved oxygen measurements in the Mashpee River also indicate nutrient impairment, with extreme oxygen excursions and night-time oxygen depletion on a consistent basis, and significant phytoplankton blooms. The major issue with the Mashpee River is the extent to which its structure as a salt marsh system ameliorates the impact of these water quality features. However, even as a salt marsh, these

levels of chlorophyll a and oxygen excursion indicate a moderate level of impairment. Based upon the dissolved oxygen and chlorophyll data the ranking of the Popponesset Bay System components is as follows:

- Popponesset Bay Central Basin – high quality
- Popponesset Bay upper/confluence, Shoestring & Ockway Bays – significantly impaired
- Mashpee River – significantly impaired to degraded (relative to embayments)
  -- moderately to significantly impaired (relative to salt marshes).

Infaunal Communities: The Infauna Study indicated that all areas, except for the lower station within the central basin of Popponesset Bay, are presently moderately to severely degraded (Table VII-5). Upper Ockway Bay was found to support the poorest infaunal communities within the system, based upon the very low number of species and individuals. Although the 2 species found (compared to 31 in the central basin) were indicative of healthy conditions, the low numbers (20's compared to 400-500 typically) indicated that this system is not supporting a productive or diverse benthic community. The indication of better habitat, although listed as significantly impaired, is seen in the Mashpee River results. The River is currently supporting a community indicative of a riverine salt marsh. However, the total numbers of individuals and diversity tend to be low, indicative of an impaired resource (significant impaired on the overall classification scale). Shoestring Bay and the uppermost portion of the Popponesset Bay central basin both showed a resource between moderate and significant impairment. The numbers of individuals was generally high and were distributed among a moderate number of species. Diversity was also moderate to high and distributed between indicators of healthy and stressed conditions (Table VII-5), again indicative of moderate impairment. In contrast the Lower Popponesset Bay station supports a relatively healthy infaunal community, with nearly double the species of other sites and high numbers of individuals. The high diversity (H') and general evenness (E) are consistent with a healthy community. The indication of moderate impairment stems from the presence of stress indicator species. The overall results indicate an embayment system capable of supporting diverse healthy communities in the region nearest the tidal inlet, with most of the system having infaunal habitat that is significantly impaired under present nitrogen loading conditions.

Overall, all of the indicators show a consistent pattern of moderate impairment of the lower portion of the central basin of Popponesset Bay, primarily based upon its loss of eelgrass. While the upper central bay and Shoestring Bay are moderately to significantly impaired and Ockway Bay is significantly impaired to severely degraded based primarily upon the infaunal community data and the extent and duration of bottom water dissolved oxygen depletion. The Mashpee River appears to be functioning as a riverine salt marsh. However, due to its impoverished benthic community in the upper reach and the extreme dissolved oxygen excursions and phytoplankton blooms, it appears to be nutrient overloaded at present.

VIII.2. THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout and embayment system, is to first identify a sentinel location within the embayment and second to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality. The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level is

determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

Within the Popponesset Bay System the region between the upper portion of the central basin to Popponesset Bay and the mouth of Shoestring Bay was selected as the sentinel region (PBh in Figure VI-1). This location was selected because (1) it was the upper extent of the eelgrass coverage in 1951, (2) restoration of nitrogen conditions supportive of eelgrass at this location will necessarily result in even higher quality conditions throughout the whole of the central basin, and (3) restoration of nitrogen concentrations at this site should result in conditions similar to 1951 within Shoestring and Ockway Bays. Shoestring Bay and Ockway Bay should then be supportive of high quality habitat for benthic infaunal communities (confirmed as described below).

The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.38 mg TN L^{-1}. It was not possible to make this determination based upon an analysis of the relationship of measured nitrogen levels to existing eelgrass beds in Popponesset Bay, as all beds have been lost. Instead, the value stems from (1) the analysis of Stage Harbor, Chatham which also exchanges tidal water with Nantucket Sound (for which a MEP target has already been set), (2) analysis of nitrogen levels within the eelgrass bed in adjacent Waquoit Bay, near the inlet (measured TN of 0.395 mg N L^{-1}, tidally corrected <0.38 mg N L^{-1}), and (3) a similar analysis in West Falmouth Harbor. The sentinel station under present loading conditions supports a measured nitrogen level at mid-ebb tide of 0.581 mg TN L^{-1} and a tidally corrected average concentration of 0.451 mg TN L^{-1}. Based upon sequential reductions in watershed nitrogen loading in the analysis described in the section below (VIII-3), the sentinel station achieved an average TN level of 0.371 mg L^{-1} , the mouth of Ockway Bay, 0.376 mg TN L^{-1} and the whole of the Popponesset Bay basin <0.331 mg TN L^{-1}. This indicates that significant eelgrass habitat restoration would occur within the regions of the 1951 coverage. It is possible also to evaluate the response in benthic infaunal habitat. At present, the regions supporting the highest quality infaunal habitat have tidally averaged concentrations (mg TN L^{-1}) from 0.692 in the moderate-significantly impaired Shoestring Bay sites, to 0.451 in the similar upper Popponesset Bay site to 0.325 at the watercolumn site closest to the infaunal sampling site in the lower Bay basin. This latter concentration is likely too low and results from the fact that the model results are at the lower end of the allowable fit to the measured data at this site. The measured TN concentration is currently 0.456 mg TN L^{-1}. In any case, the data suggest that there is likely a range of total nitrogen that can support healthy infauna within this system. Based upon the infaunal analysis (Chapter VII) coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN L-1 are likely supportive of high infaunal habitat quality in this system. It should be noted that these values were not used for setting nitrogen thresholds in this embayment system. These values merely provide a check on the acceptability of conditions in Shoestring and Ockway Bays, as well as Lower Mashpee River, at the point that the threshold level is attained at the sentinel station. The results of the Linked Watershed-Embayment modeling, when the nitrogen threshold is attained (Section VIII-3), yield TN levels in these regions within the acceptable range: upper to lower Shoestring Bay, 0.522 to 0.412 mg TN L^{-1}; upper Ockway Bay, 0.421 mg TN L^{-1}; and mid to lower Mashpee River, 0.525 to 0.422 mg TN L^{-1}. Therefore, it appears that achieving the nitrogen target at the sentinel location is restorative of eelgrass habitat throughout the Popponesset Bay central basin and restorative of infaunal habitat throughout Shoestring and Ockway Bays, as well as the lower portion of the Mashpee River.

VIII.3. DEVELOPMENT OF TARGET NITROGEN LOADS

The tidally averaged total nitrogen thresholds derived in Section VIII-1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel region for the Popponesset Bay System. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the communities. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

As shown in Table VIII-1, the nitrogen load reductions within the Popponesset Bay System necessary to achieve the threshold nitrogen concentrations were relatively high, 100% removal of septic load (associated with direct groundwater discharge to the embayment) required within four sub-embayments (Popponesset Creek, Ockway Bay, Mashpee River, and Shoestring Bay). In addition, a portion of the septic load entering the estuarine system via Mashpee and Santuit Rivers also must be removed to meet the threshold nitrogen concentrations. For the load reduction scenario evaluated, the Mashpee River and Santuit River required removal of approximately 41% and 35% of their septic load, respectively. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figures VIII-1 and VIII-2.

Tables VIII-2 and VIII-3 provide additional loading information associated with the thresholds analysis. Table VIII-2 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-1. In general, removal of 100% of the septic load from Popponesset Creek, Ockway Bay, Mashpee River, and Shoestring Bay results in an 80% to 85% reduction in total nitrogen load from these sub-watersheds. Table VIII-3 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. For Table VIII-3, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to Nantucket Sound.

The basis for the watershed nitrogen removal strategy utilized to achieve the embayment thresholds may have merit, since this example nitrogen remediation effort is focused on watersheds where groundwater is flowing directly into the estuary. For nutrient loads entering the sub-embayments through surface flow, natural attenuation in freshwater bodies (i.e., streams and ponds) can significantly reduce the load that finally reaches the estuary. Presently, this attenuation is occurring due to natural ecosystem processes and the extent of attenuation being determined by the mass of nitrogen which discharges to these systems. The nitrogen reaching these systems is currently "unplanned", resulting primarily from the widely distributed non-point nitrogen sources (e.g. septic systems, lawns, etc.). Future nitrogen management should take advantage of natural nitrogen attenuation to ensure the most cost-effective nitrogen reduction strategies. However, "planned" use of natural systems has to be done carefully and with the full analysis to ensure that degradation of these systems will not occur. One clear finding of the MEP has been the need for analysis of the potential of restored wetlands or ecologically engineered ponds/wetlands to enhance nitrogen attenuation. Attenuation by ponds in agricultural systems has also been found to work in some cranberry systems, as well. The

lower freshwater and salt water reaches of the Mashpee and Santuit Rivers provide opportunities for enhancing natural attenuation of their nitrogen loads. Restoration or enhancement of wetlands and ponds associated with the lower ends of rivers and streams discharging to estuaries is seen as providing a dual service of lowering infrastructure costs associated with wastewater management and increasing aquatic resources associated within the watershed and upper estuarine reaches.

Although the above modeling results provide one manner of achieving the selected threshold levels for the sentinel site within this estuarine system, the specific examples do not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment. As the restoration process continues, the MEP will work with the Towns of Mashpee and Barnstable to develop additional specific water quality modeling scenarios, to be run to evaluate other nitrogen removal strategies. One such proposed scenario, removing the discharges from the existing wastewater facilities from the watershed (pipeline), was partially evaluated by the MEP Team. At present only a tiny fraction (<0.5%) of the watershed nitrogen loading is discharged by the existing treatment facilities. Removing this load would have a very small impact. However, with increased sewering and treatment of wastewater, discharge within the groundwatershed directly discharging to Nantucket Sound has merit. The existing MEP analysis and model provides for the determination of potential discharge sites and the concomitant improvement of the nutrient related habitat quality within the Popponesset Bay System.

Table VIII-1. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Popponesset Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Popponesset Bay	1.58	1.58	0.0%
Popponesset Creek	4.00	0.00	-100.0%
Pinquickset Cove	0.58	0.58	0.0%
Ockway Bay	2.39	0.00	-100.0%
Mashpee River	9.61	0.00	-100.0%
Shoestring Bay	6.94	0.00	-100.0%
Surface Water Sources			
Mashpee River	9.96	5.85	-41.3%
Santuit River (Shoestring Bay)	11.69	7.58	-35.2%
Quaker Run River (Shoestring Bay)	4.69	4.69	0.0%
TOTAL	51.12	19.96	-61.0%

Table VIII-2. Comparison of sub-embayment ***total watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Popponesset Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Popponesset Bay	1.82	1.82	0.0%
Popponesset Creek	4.94	0.95	-80.7%
Pinquickset Cove	0.76	0.76	0.0%
Ockway Bay	3.15	0.76	-76.0%
Mashpee River	12.11	2.50	-79.4%
Shoestring Bay	9.21	2.26	-75.5%
Surface Water Sources			
Mashpee River	15.56	11.45	-26.4%
Santuit River (Shoestring Bay)	15.58	11.47	-26.4%
Quaker Run River (Shoestring Bay)	5.98	5.98	0.0%
TOTAL	69.11	37.95	-45.2%

Table VIII-3. Threshold sub-embayment and surface water loads used for total nitrogen modeling of the Popponesset Bay system, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux (kg/day)
Popponesset Bay	1.82	4.01	-4.91
Popponesset Creek	0.95	-	-0.62
Pinquickset Cove	0.76	0.29	-0.33
Ockway Bay - lower	-	-	-1.13
Ockway Bay - upper	0.76	1.09	2.24
Mashpee River	2.50	0.66	9.47
Shoestring Bay	2.26	2.23	-8.73
Surface Water Sources			
Mashpee River	11.45	-	-
Santuit River (Shoestring Bay)	11.47	-	-
Quaker Run River (Shoestring Bay)	5.98	-	-
TOTAL	37.9	8.28	

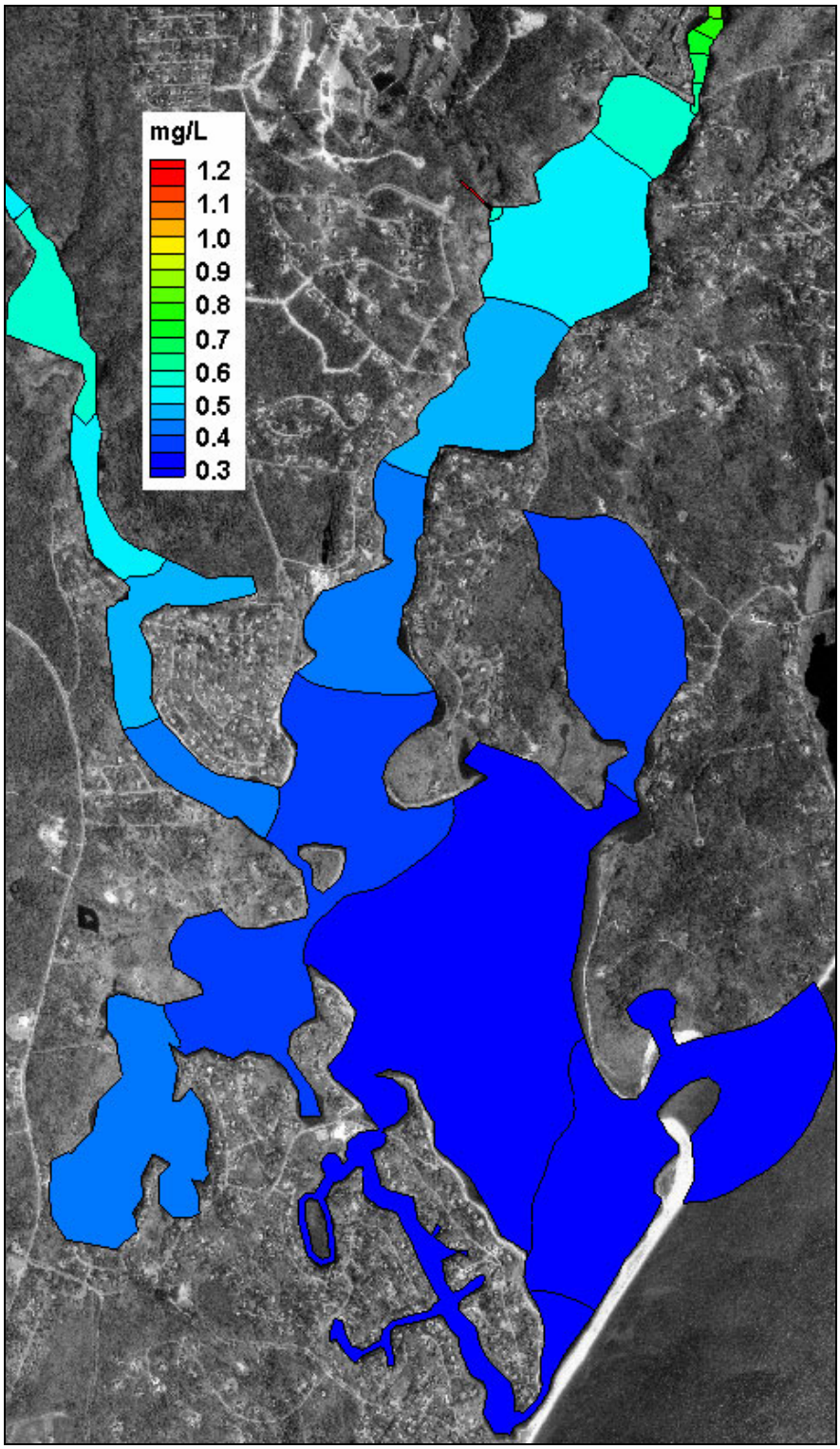


Figure VIII-1. Contour plot of modeled total nitrogen concentrations (mg/L) in the Popponesset Bay system, for threshold conditions (0.38 mg/L at lower Mashpee River, Lower Shoestring Bay, and mid Ockway Bay).

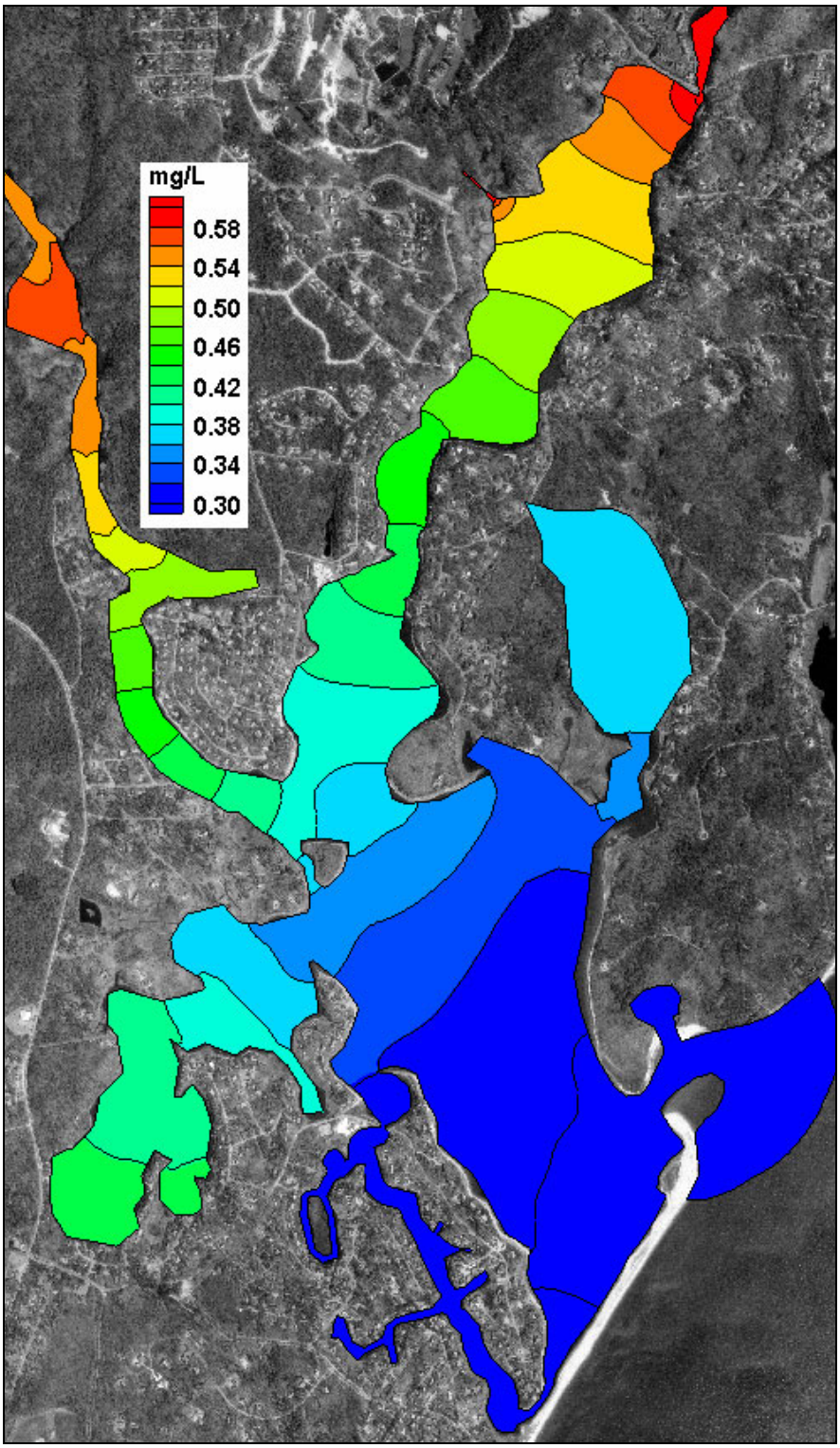


Figure VIII-2. Same results as for Figure VIII-1, but shown with finer contour increments for emphasis. Contour plot of modeled total nitrogen concentrations (mg/L) in the Popponesset Bay system, for threshold conditions (0.38 mg/L at lower Mashpee River, Lower Shoestring Bay, and mid Ockway Bay).

IX. DREDGING IMPACTS TO WATER QUALITY

Keystones of the MEP include modeling support upon request of municipalities and the analysis of non-traditional approaches to nitrogen mitigation. In the case of the Popponesset Bay System, channel dredging was evaluated to determine potential effects on nutrient related water quality. Dredging of inlets and channels is conducted for a variety of reasons throughout southeastern Massachusetts and even within a single system. For example, within New Bedford Inner Harbor dredging has recently been conducted in one region for removal of PCB contaminated sediments and in another region for navigation associated with port activities. In the case of the Popponesset Bay System, maintenance dredging of the inlet has been conducted over the past several years for navigation and for the general health of the system and additionally for beach nourishment (Popponesset Spit). The Mashpee Waterways Commission has developed various dredging plans for dredging within the Bay System, some of which are currently underway, some for which permits are being sought and some for future design (Figure IX-1). The various dredging projects are conducted by both municipal and private entities.

The Popponesset Bay System has had a significant amount of dredging over the past century. In 1916 the DPW dredged a channel from the inlet to mid-bay (Figure IX-1) for navigation. Vestiges of this channel remain today. One of the major dredging projects was conducted by New Seabury in 1962. This effort was related to the development of the Popponesset Creek Watershed and significantly increased the depth within this part of the system, which remains today. Over the past 50 years, dredging has been more for maintenance purposes. Both for the tidal inlet (Town-maintained channels) and related to navigation between Popponesset Bay and Popponesset Creek (Save Popponesset Bay channel). Disposal of appropriate dredged material has been used to stabilize Popponesset Spit, which is subject to erosion and storm overwash. At present, the maintenance projects continue, but there has been an effort by the Town of Mashpee (Waterways Commission) to develop a dredging plan for the interior basins, due to the very shallow nature of Popponesset Bay. The dredge plan has prioritized navigational dredging into priority channels of (1) Mashpee River (in permitting process), (2) Ockway Bay (to public boat ramp), (3) Popponesset Bay central channel, and (4) Shoestring Bay. It is worth noting that the major logistical issue to be resolved in this effort is the disposal of the fine organic enriched dredged material and the major environmental issue involves the effects on the System's nutrient related habitat quality. In this Chapter we address the latter issue.

An evaluation of two dredging alternatives was performed using the hydrodynamic and water quality models developed for Popponesset Bay. The evaluation was performed to determine potential impacts to water quality throughout the Popponesset Bay system resulting from dredging the proposed navigation channels. As a result of discussions with the Mashpee Waterways Commission (Hanks, 2004), the two modeled dredging alternatives selected were 1) dredging an approximately 50 ft wide channel to -3 ft MLW in the Mashpee River (Alternative 1); and 2) dredging an additional -5 ft MLW channel between the lower Mashpee River and Popponesset Bay inlet (Alternative 2). Channel layouts for these two alternatives are shown in Figure IX-2. The navigation channel layout in the lower portion of Popponesset Bay for Alternative 2 follows the approximate route of a channel first dredged in 1916.

Popponesset Bay Channels (Existing, Dredged and Proposed)

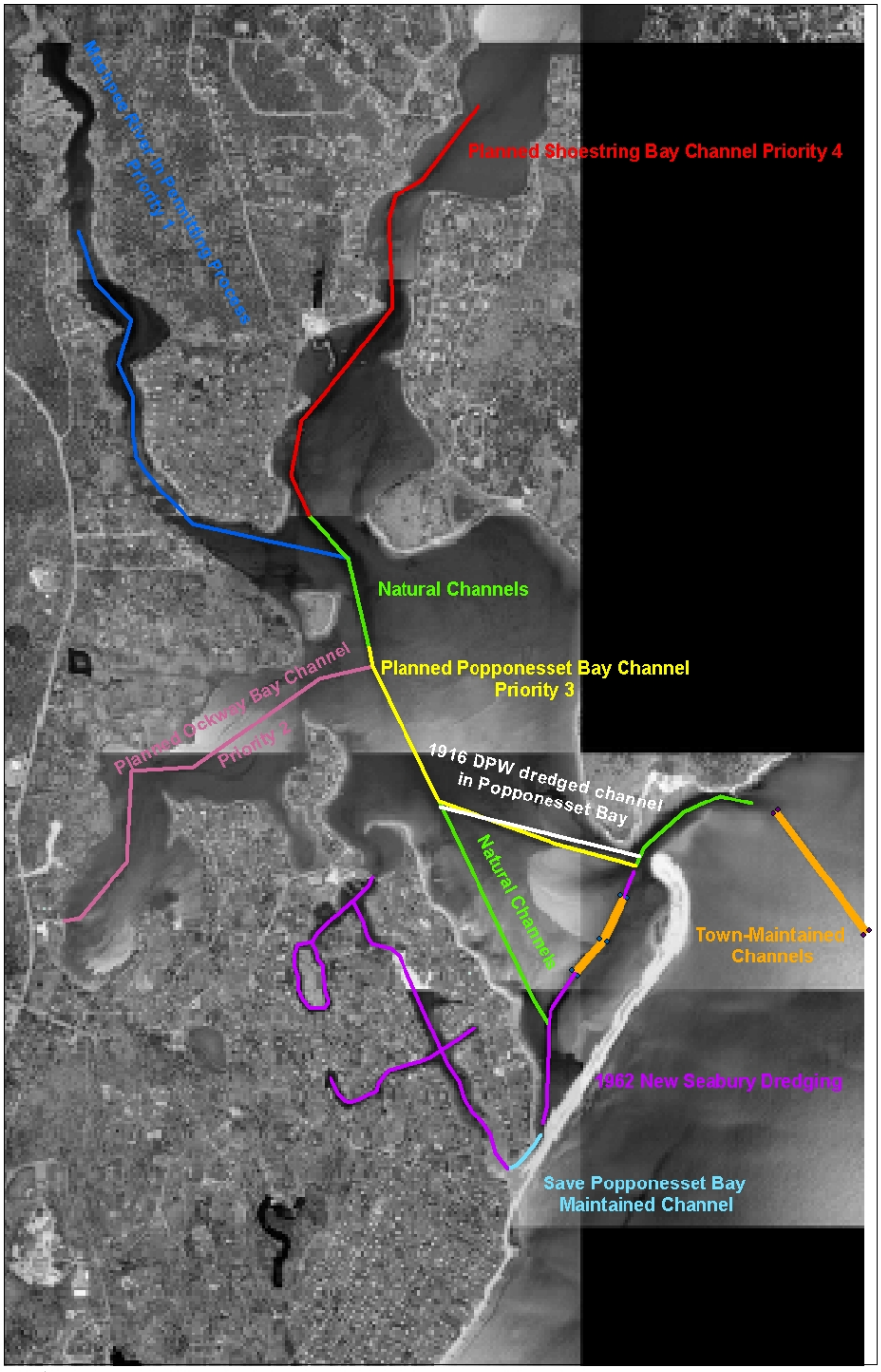


Figure IX-1. Historical and proposed dredging plans for the Popponesset Bay system.

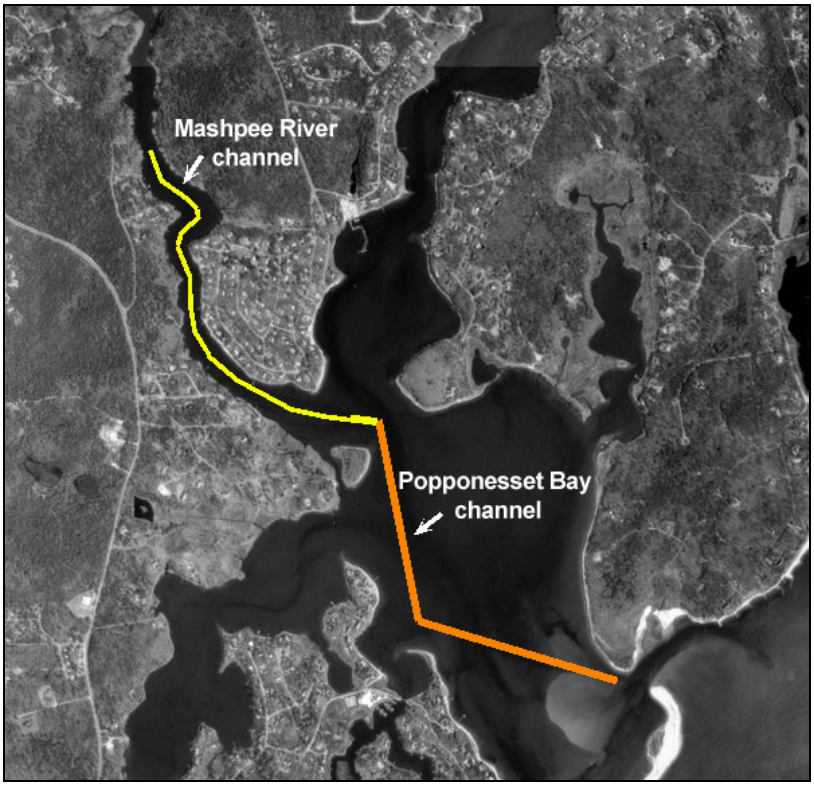


Figure IX-2. Channel layouts for two dredging alternatives in Popponesset Bay: 1) Alternative 1 (yellow line), dredging a -3 ft MLW channel in the Mashpee River, and 2) Alternative 2 (yellow and orange lines), dredging an additional -5 ft MLW channel between the lower Mashpee River and Popponesset Bay inlet.

Modeling these two alternatives first required that the computational grid of Popponesset Bay be modified to incorporate the dredged channels. Next, the hydrodynamic model was rerun using the grid developed for each separate alternative. With the updated hydrodynamic solutions, the total nitrogen model was then rerun, using the same diffusion coefficients used for the modeling of present conditions (Section VI).

Model results showing N concentration changes resulting from Alternatives 1 and 2 are presented in Figures IX-3 and IX-4. Output from the two modeled scenarios shows that the two dredging alternatives have essentially the same effect on N concentrations in Popponesset Bay. Changes in average modeled N concentrations along the Mashpee River for the two modeled alternatives are presented in Figure IX-5, and Table IX-1.

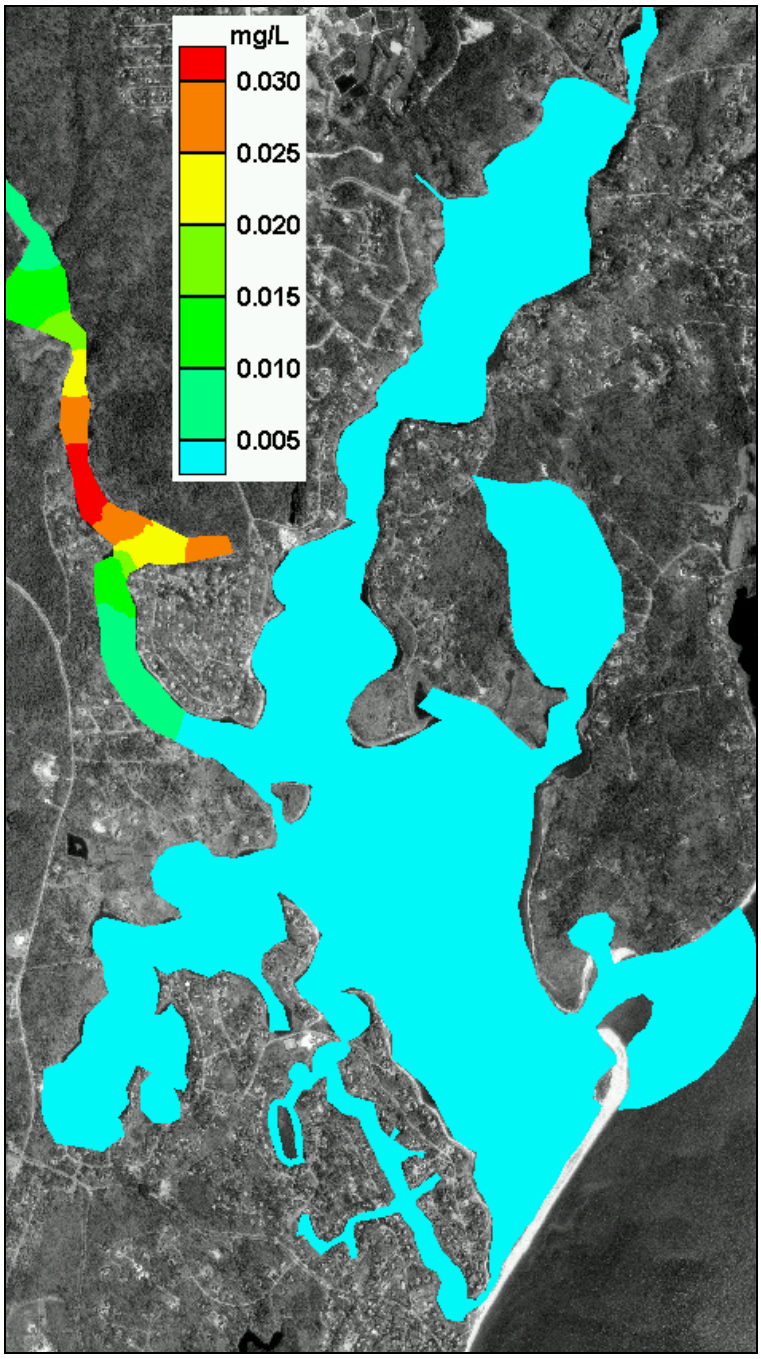


Figure IX-3. Color contours indicating change in nitrogen concentrations (mg/L) resulting from dredging the Mashpee River (Alternative 1). Contours greater than zero indicate N concentration increases over present modeled conditions.

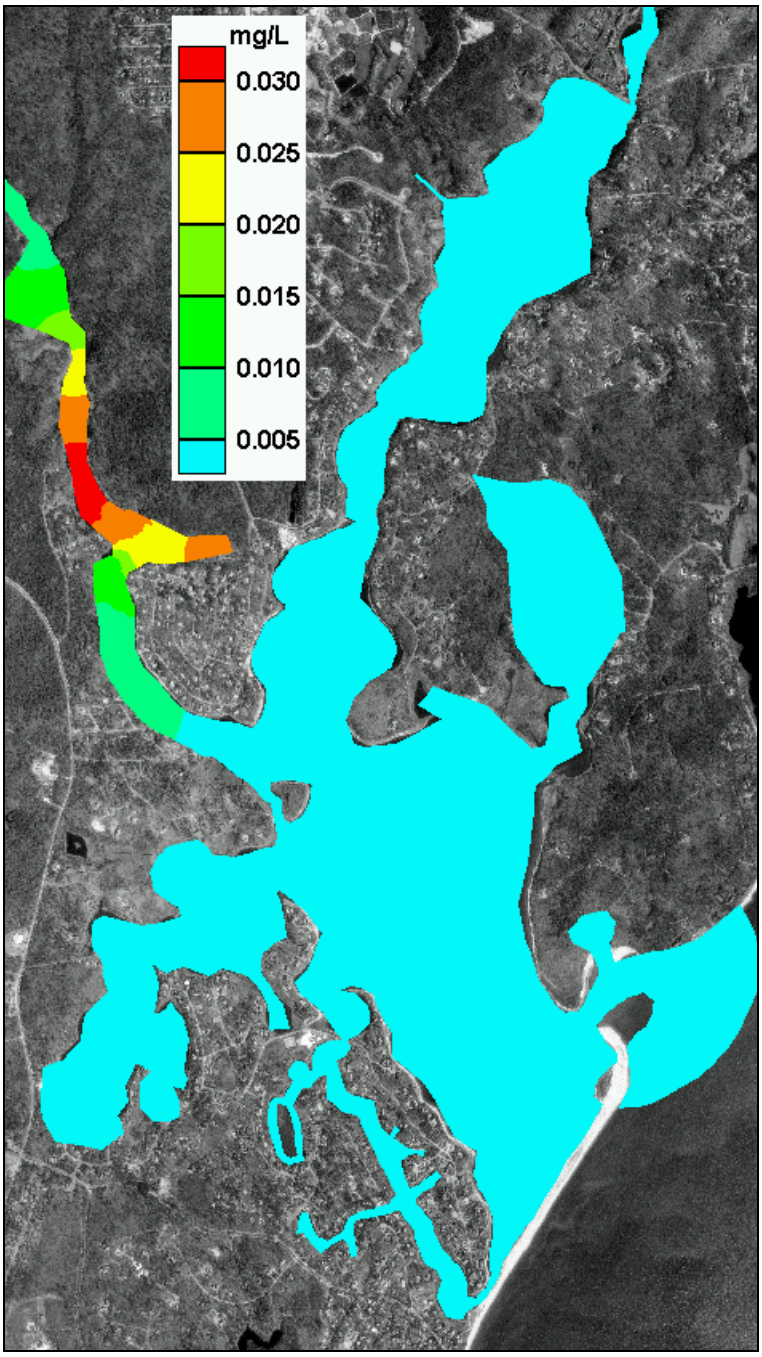


Figure IX-4. Color contours indicating change in nitrogen concentrations (mg/L) resulting from dredging the Mashpee River together with the 1916 channel in Popponesset Bay. (Alternative 2). Contours greater than zero indicate N concentration increases over present modeled conditions.

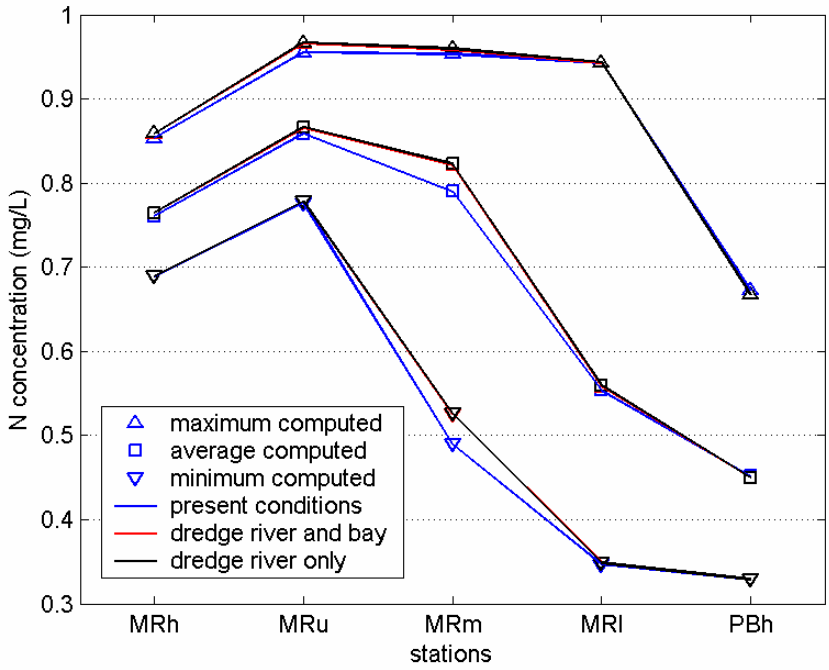


Figure IX-5. Comparison of modeled maximum, average and minimum total N concentrations for present conditions (blue line), and two dredging alternatives (Alternative 1, dredging Mashpee River inlet, black line; Alternative 2, dredging Mashpee River and Popponesset Bay channels). Stations are along the Mashpee River, from the Mashpee River headwater (MRh) to the upper reach of Popponesset Bay (PBh), see Figure VI-1. Because the two dredging alternatives cause the same concentration changes in the Mashpee River, the lines representing conditions for Alternative 1 and 2 are indistinguishable from each other in this plot.

Table IX-1. Comparison of changes in average computed average total N concentrations resulting from two dredging alternatives: 1) Alternative 1, dredging a -3 ft MLW channel in the Mashpee River, and 2) Alternative 2, dredging an additional -5 ft MLW channel between the lower Mashpee River and Popponesset Bay inlet. Positive values indicate increased concentration over present conditions. Stations references are the same as Figure VI-1.

Station Name	SMAST Station Indicator	Alternative 1: dredge Mashpee River only	Alternative 2: dredge River and Bay
		N % change	N % change
Mashpee River head - MRh	PB1	+0.5%	+0.5%
Mashpee River upper - MRu	PB2	+0.9%	+0.8%
Mashpee River mid - MRm	PB3	+4.2%	+4.0%
Mashpee River lower - MRl	PB4	+1.0%	+0.8%
Popponesset Bay head - PBh	PB8	+0.4%	+0.5%

Model results indicate that dredging the proposed channel in the Mashpee River will increase N concentrations along the river, with the greatest increase occurring at the mid-way point of the tidal portion of the river. The reason that nitrogen concentrations increase is due to the increase in mean tide volume of the Mashpee River sub-embayment. Because the tide prism change from pre- and post-dredge conditions is negligible compared to the change in mean tide volume of the sub-embayment (i.e., a 9.0% increase in mean tide volume results from dredging the channel, but there is only a 0.5% increase in tidal prism), tidal excursion (i.e., the distance a parcel of water travels during a half tide cycle) in the river decreases. As a result, residence times in the river increase, which, in turn, increases N concentrations in the river. The change is greatest at the mid-point of the estuarine reach of the river because of the diluting effects of the large freshwater discharge at the head of the river and the lower concentration waters from Popponesset Bay at the opposite end of the sub-embayment, combined with the watershed and benthic N loads which are distributed along the length of the river (which have a concentrating effect).

Results for Alternative 2 indicate that the proposed channel in the lower portion of the bay would have negligible effects on nitrogen concentrations in the main basin of Popponesset Bay. The reason there is little change is that the dredged channel does not significantly affect tidal exchange (i.e., change the volume of the tidal prism) in the Popponesset Bay system. In order for there to be significant reductions in nitrogen concentrations in a coastal embayment, it is usually necessary to increase the tide prism volume. Embayments that would benefit most from dredging likely would have significant attenuation of tidal energy, possibly caused by an under-sized inlet to the ocean. For the Popponesset Bay system, possible improvements to water quality as a result of dredging are small, since tidal attenuation through the system is minimal (see Section V).

Although the results of the modeling for the two dredging scenarios indicated a slight increase in total nitrogen concentrations, it likely is possible to develop dredging scenarios that have no increase in total nitrogen concentrations. In general, the dredging conditions evaluated caused a more significant increase in the mean sub-embayment volume than the increase in tidal flushing could offset, allowing high-nutrient water to reside longer within the Mashpee River. Therefore, to avoid potential negative impacts to water quality, future dredging efforts within the Popponesset Bay system (except for the inlet) should focus on keeping the overall sub-embayment volume fixed at present-day conditions. Dredging scenarios that do not increase sub-embayment volume would require dredged material to remain within the sub-embayment. One option would be to utilize dredge spoils for wetland restoration.

The conditions described above are appropriate for sub-embayments where tidal attenuation is negligible. For the Popponesset Bay system, it is unlikely that dredging will improve water quality within the three main sub-embayments: Ockway Bay, Shoestring Bay, and Mashpee River. However, the hydrodynamic modeling indicated that tidal attenuation is small, but not negligible, across the main inlet to Popponesset Bay. Therefore, the main channel connecting to Nantucket Sound should be maintained to its existing cross-section to avoid further degradation of estuarine health. Although no dredging alternatives were evaluated through the main inlet, the combined hydrodynamic and water quality model provides an ideal tool for evaluating future proposed dredging scenarios.

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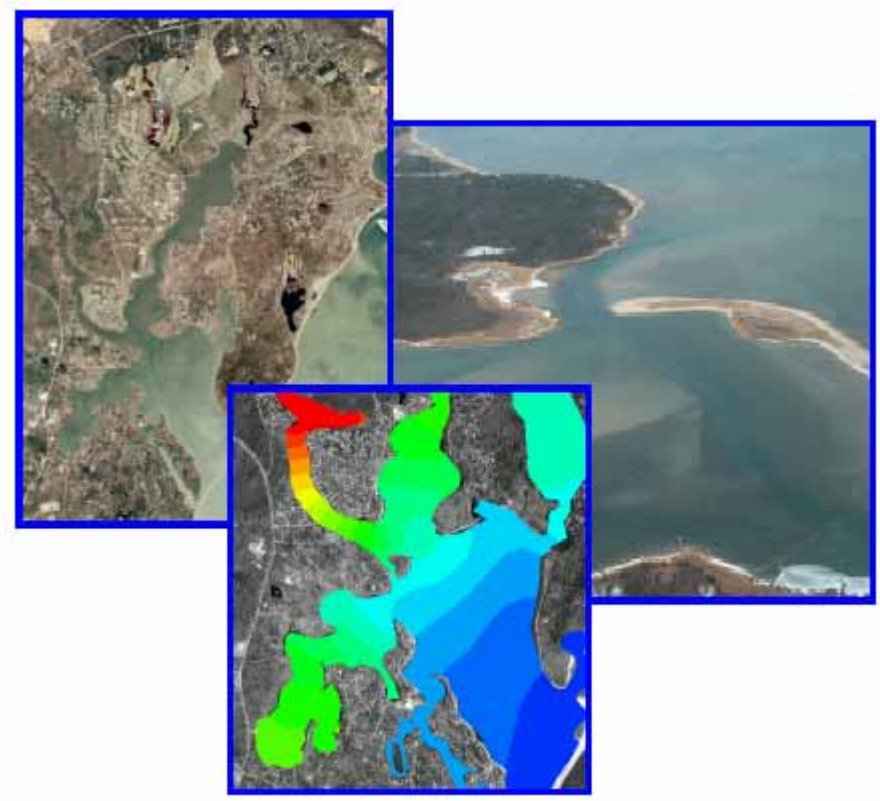
Appendix U

MassDEP TMDL Report for Popponesset Bay; MassDEP, April 10, 2006.

FINAL
Popponesset Bay
Total Maximum Daily Loads
For Total Nitrogen
(Report # 96-TMDL-4
Control #217.0)



COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
STEPHEN R. PRITCHARD, SECRETARY
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
ROBERT W. GOLLEDGE, JR., COMMISSIONER
BUREAU OF RESOURCE PROTECTION
GLEN HAAS, ACTING ASSISTANT COMMISSIONER

April 10, 2006

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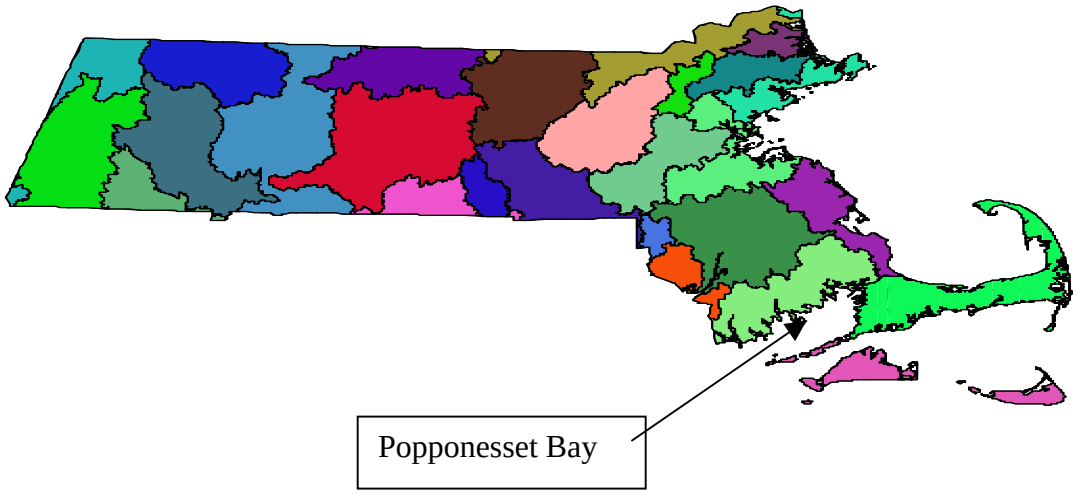
Popponesset Bay
Total Maximum Daily Loads
For Total Nitrogen



Key Feature: Total Nitrogen TMDL for Popponesset Bay
Location: EPA Region 1
Land Type: New England Coastal
303d Listing:

Mashpee River	MA96-24_2002	0.08 sq mi	Nutrients & Pathogens
Shoestring Bay	MA96-08_2002	0.31 sq mi	Nutrients & Pathogens
Popponesset Bay	MA96-40_2002	0.67 sq mi	Nutrients

Data Sources: University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Cape Cod Commission, Town of Mashpee, Town of Barnstable
Data Mechanism: Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model
Monitoring Plan: Towns of Mashpee and Barnstable monitoring program (possible assistance from SMAST)
Control Measures: Sewering, Storm Water Management, Attenuation by Impoundments and Wetlands, Fertilizer Use By-laws

EXECUTIVE SUMMARY

Problem Statement

Excessive nitrogen (N) originating primarily from on-site wastewater disposal (both conventional septic systems and innovative/alternative systems) has led to significant decreases in the environmental quality of coastal rivers, ponds, and harbors in many communities in southeastern Massachusetts. In the Towns of Mashpee and Barnstable the problems in coastal waters include:

- Loss of eelgrass beds, which are critical habitats for macroinvertebrates and fish
    - Undesirable increases in macro algae, which are much less beneficial than eelgrass
    - Periodic extreme decreases in dissolved oxygen concentrations that threaten aquatic life
    - Reductions in the diversity of benthic animal populations
    - Periodic algae blooms

With proper management of nitrogen inputs these trends can be reversed. Without proper management more severe problems might develop, including:

- Periodic fish kills
- Unpleasant odors and scum
- Benthic communities reduced to the most stress-tolerant species, or in the worst cases, near loss of the benthic animal communities

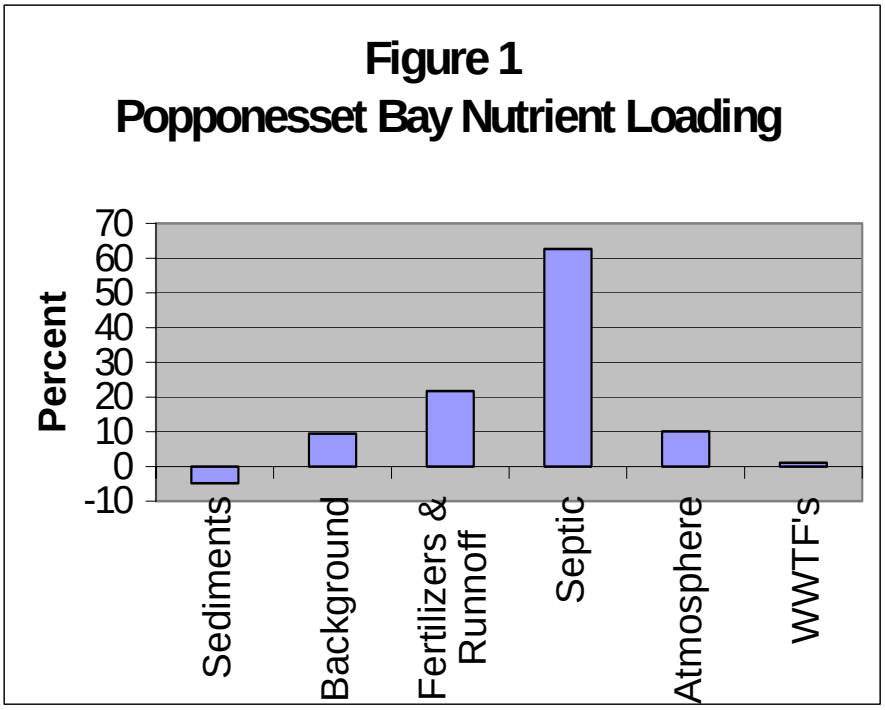
Coastal communities, including Mashpee and Barnstable, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings will result in complete replacement of eelgrass by macro-algae, a higher frequency of extreme decreases in dissolved oxygen concentrations and fish kills, widespread occurrence of unpleasant odors and visible scum, and a complete loss of benthic macroinvertebrates throughout most of the embayments. As a result of these environmental impacts, commercial and recreational uses of Popponesset Bay's coastal waters will be greatly reduced, and could cease altogether.

Sources of nitrogen

Nitrogen enters the waters of coastal embayments from the following sources:

- The watershed
    - On-site subsurface wastewater disposal systems
    - Natural background
    - Runoff
    - Fertilizers
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments

Most of the present N load originates from individual subsurface wastewater disposal (septic) systems, primarily serving individual residences, as seen in the following figure.



Target Threshold Nitrogen Concentrations and Loadings

The N loadings (the quantity of nitrogen) to the Popponesset Bay sub-embayments presently range from 0.76 kg/day in Pinquickset Cove, to 39.99 kg/day in the Mashpee River. The resultant concentrations of N in the sub-embayments range from 0.422 mg/L (milligrams of nitrogen per liter) in Popponesset Bay to 0.958 mg/L in the Mashpee River.

In order to restore and protect the Popponesset Bay, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below the thresholds that cause the observed environmental impacts. The Massachusetts Estuaries Project (MEP) has determined that, for Popponesset Bay, an N concentration of 0.38 mg/L is protective. The mechanism for achieving these target N concentrations is to reduce the N loadings to the sub-embayments. The MEP has determined through mathematical modeling that the Total Maximum Daily Loads (TMDL) of N that will meet the target thresholds N loads in the 5 sub-embayments, which make up the Popponesset Bay System range from 1 to 26 kg/day. The purpose of this document is to present TMDLs for each sub-embayment and to provide guidance to the Towns on possible ways to reduce the N loadings to implement the proposed TMDLs.

Implementation

The primary goal of implementation will be lowering the concentrations of N by greatly reducing the loadings from on-site subsurface wastewater disposal systems through a variety of centralized or decentralized methods such as sewering with nitrogen removal technology, advanced treatment of septage, upgrade/repairs of failed on-site systems, and/or installation of N-reducing on-site systems.

These strategies, plus ways to reduce N loadings from stormwater runoff and fertilizers, are explained in detail in the "MEP Embayment Restoration Guidance for Implementation Strategies", which is available on the DEP website at (http://www.mass.gov/dep/water/resources/restore.htm). The appropriateness of any of the alternatives will depend on local conditions, and will have to be determined on a case-by-case basis, using an adaptive management approach.

Finally, growth within the communities of Mashpee, Barnstable, and Sandwich (part of the upper Mashpee River watershed only), which would exacerbate the problems associated with N loadings, should be guided by considerations of water quality-associated impacts.

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Introduction

Section 303(d) of the Federal Clean Water Act requires each state (1) to identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. The TMDL allocation establishes the maximum loadings (of pollutants of concern), from all contributing sources, that a water body may receive and still meet and maintain its water quality standards and designated uses, including compliance with numeric and narrative standards. The TMDL development process may be described in four steps, as follows:

1. Description of water bodies and priority ranking: determination and documentation of whether or not a water body is presently meeting its water quality standards and designated uses.

2. Problem Assessment: assessment of present water quality conditions in the water body, including estimation of present loadings of pollutants of concern from both point sources (discernable, confined, and concrete sources such as pipes) and non-point sources (diffuse sources that carry pollutants to surface waters through runoff or groundwater).

3. Linking water quality and pollutant sources: determination of the loading capacity of the water body. EPA regulations define the loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. If the water body is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings.

4. Total Maximum Daily Loads: specification of load allocations, based on the loading capacity determination, for non-point sources and point sources, that will ensure that the water body will not violate water quality standards.

After public comment and final approval by the EPA, the TMDL will serve as a guide for future implementation activities. The DEP will work with the Towns to develop specific implementation strategies to reduce N loadings, and will assist in developing a monitoring plan for assessing the success of the nutrient reduction strategies.

In the Popponesset Bay System, the pollutant of concern for this TMDL (based on observations of eutrophication) is the nutrient nitrogen. Nitrogen is the limiting nutrient in coastal and marine waters, which means that as its concentration is increased, so is the amount of plant matter. This leads to nuisance populations of macro-algae and increased concentrations of phytoplankton and epiphyton which impair eelgrass beds and imperil the healthy ecology of the affected water bodies.

The TMDLs for total N for the five coastal sub-embayments within the Popponesset Bay System are based primarily on data collected, compiled, and analyzed by University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Towns of Mashpee and Barnstable, the Cape Cod Commission, and others, as part of the Massachusetts Estuaries Program (MEP). The data was collected over a study period from 1997 to 2003. This study period will be referred to as the "Present Conditions" in the TMDL since it is the most recent data available. The accompanying MEP Technical Report presents the results of the analyses of these five coastal sub-embayments using the MEP Linked Watershed-Embayment Nitrogen Management Model (Linked Model). The analyses were performed to assist the Towns with decisions on current and future wastewater planning, wetland restoration, anadromous fish runs, shellfisheries, open-space, and harbor maintenance programs. A critical element of this approach is the assessments of water quality monitoring data (particularly nitrogen, the limiting nutrient), historical changes in eelgrass

distribution, time-series water column oxygen measurements, and benthic community structure studies that were conducted on each sub-embayment. These assessments served as the basis for generating N loading thresholds for use as goals for watershed N management. The TMDLs are based on the site-specific thresholds generated for each sub-embayment. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision-making process in the Towns of Mashpee, Barnstable, and Sandwich.

Description of Water Bodies and Priority Ranking

The Popponesset Bay System in Mashpee and Barnstable Massachusetts, at the southwestern edge of Cape Cod, faces Nantucket Sound to the south, and consists of a number of small sub-embayments of varying size and hydraulic complexity, characterized by limited rates of flushing, shallow depths and heavily developed watersheds. These sub-embayments constitute important components of the Towns' natural and cultural resources. The nature of enclosed sub-embayments in populous regions brings two opposing elements to bear: 1) as protected marine shoreline they are popular regions for boating, recreation, and land development and 2) as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the sub-embayments within the Popponesset Bay System are at risk of further eutrophication from high nutrient loads in the groundwater and runoff from their watersheds. Because of excessive nutrients, 3 sub-embayments are already listed as waters requiring TMDLs (Category 5) in the MA 2002 Integrated List of Waters, as summarized in Table 1A. This report will provide target loads and concentrations necessary to meet water quality standards. Where present conditions already achieve standards this report will serve to provide a concentration and load necessary to protect the resource into the future.

Table 1A. Popponesset Bay sub-embayments in Category 5 of the Massachusetts 2002 Integrated List[1]

NAME	SEGMENT ID	DESCRIPTION	SIZE	Pollutant Listed
Popponesset Bay System				
Mashpee River	MA96-24_2002	Quinaquisset Avenue to mouth at Shoestring Bay (formerly to mouth of Popponesset Bay), Mashpee	0.08 sq mi	Nutrients & Pathogens
Shoestring Bay	MA96-08_2002	Quinaquisset Avenue to Popponesset Bay (line from Ryefield Point, Barnstable to Punkhorn Point, Mashpee, including Gooseberry Island), Barnstable/Mashpee	0.31 sq mi	Nutrients & Pathogens
Popponesset Bay	MA96-40_2002	From line connecting Ryefield Point, Barnstable to Punkhorn Point, Mashpee,to inlet of Nantucket Sound (including Ockway Bay and Pinquickset Cove), Mashpee/Barnstable	0.67 sq mi	Nutrients

[1] These segments are also classified as Category 5 on the Draft 2004 Integrated List.

A complete description of all 5 sub-embayments is presented in Chapters I and IV of the MEP Technical Report from which the majority of the following information is drawn. TMDLs were calculated for all 5 sub-embayments listed below. Analytical and modeling efforts were conducted by grouping these 5 sub-embayments, into a single embayment system, which flows into Nantucket Sound to the south.

- Popponesset Bay System:
  1. Mashpee River 2. Shoestring Bay 3. Ockway Bay
  4. Pinquickset Cove 5. Popponesset Bay

The sub-embayments addressed by this document are determined to be high priorities based on 3 significant factors: (1) the initiative that these Towns have taken to assess the conditions of the entire Popponesset embayment system, (2) the commitment made by these Towns to restoring and preserving the sub-embayments, and (3) the extent of eutrophication in the sub-embayments. In particular, these sub-embayments are at risk of further degradation from increased N loads entering through groundwater and surface water from their increasingly developed watersheds. In both marine and freshwater systems, an excess of nutrients results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources. The general conditions related to the major indicators of habitat impairment, due to excess nutrient loadings, are tabulated in Table 1B. Observations are summarized in the Problem Assessment section below, and detailed in Chapter VII, Assessment of Embayment Nutrient Related Ecological Health, of the MEP Technical Report.

Table 1B. General summary of conditions related to the major indicators of habitat impairment observed in Popponesset Bay System.

Popponesset Bay System Sub-embayments	Eel Grass Loss[1]	Dissolved Oxygen	Chlorophyll *a*[2]	Benthic Fauna[3]
Mashpee River	100%	<6 mg/l (51% of time) <4 mg/L (27% of time) **SD**	>10ug/l (up to 60% of time) >20ug/L (up to 19% of time) **SD**	**SI**
Shoestring Bay	100%	<6 mg/l (48% of time) <4 mg/L (9% of time) **SD**	>10ug/l (up to 60% of time) >20ug/L (up to 23% of time) **SD**	**SI**
Ockway Bay	**NS**	<6 mg/l (47% of time) <4mg/L (19% of time) **SD**	>10ug/L (up to 29% of time) >20ug/L (up to 4% of time) **SD**	**SI**
Pinquickset Cove	No data	No mooring data	>10ug/L (up to 42% of time) >20ug/L (up to 28% of time) **SD**	No data
Popponesset Bay	100%	<6mg/l (60% of time) <4mg/l (24% of time) **GF**	>10ug/L (up to 21% of time) >20ug/L (up to 12% of time) **SD**	**SI**

[1] There is presently no eelgrass within the Popponesset Bay System, although it was documented in a 1951 survey

[2] Algal blooms are consistent with chlorophyll *a* levels above 20 ug/L

[3] Based on observations of the type of species, number of species, and number of individuals

GF – Good to Fair – little or no change from normal conditions *
MI – Moderately Impaired – slight to reasonable change from normal conditions *
SI – Significantly Impaired- considerably and appreciably changed from normal conditions *
SD – Severe Degraded – critically or harshly changed from normal conditions *
NS - Non-supportive habitat, no eelgrass was present in 1951 Survey data.
*** -** these terms are more fully described in MEP report "Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators"
December 22, 2003 (http://www.mass.gov/dep/smerp/files/nitroest.pdf)

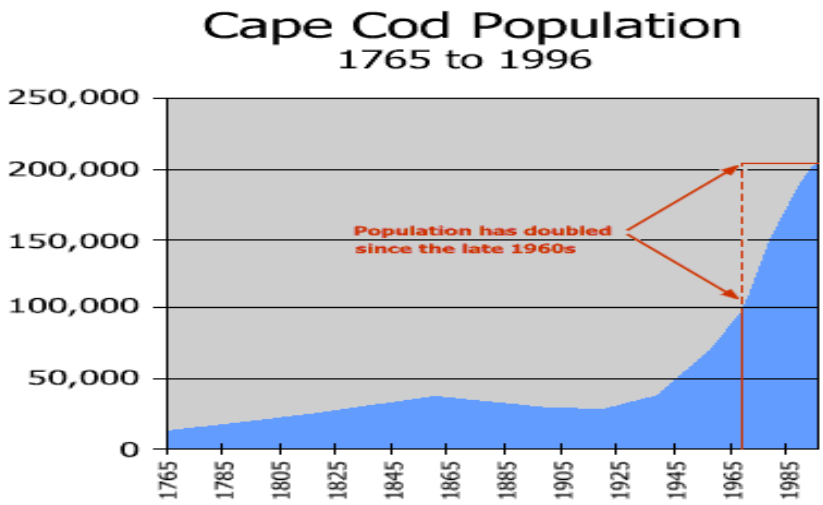
Problem Assessment

The watersheds of Popponesset Bay's estuaries have all had rapid and extensive development of single-family homes and the conversion of seasonal into full time residences. This is reflected in a substantial transformation of land from forest to suburban use between the years 1951 to 2000. Water quality problems associated with this development result primarily from on-site wastewater treatment systems, and to a lesser extent, from runoff - including fertilizers - from these developed areas.

On-site subsurface wastewater disposal system effluents discharge to the ground, enter the groundwater system and eventually enter the surface water bodies. In the sandy soils of Cape Cod, effluent that has entered the groundwater travel towards the coastal waters at an average rate of one foot per day. The nutrient load to the groundwater system is directly related to the number of subsurface wastewater disposal systems, which in turn are related to the population. The population of Mashpee and Barnstable, as with all of Cape Cod, has increased markedly since 1950. In addition, summertime residents and visitors swell the population of the entire Cape by about 300% according to the Cape Cod Commission (http://www.capecodcommission.org/data/trends98.htm#population).

The increase in year round residents is illustrated in the following graph:

Figure2



Sources:

1) Cape Cod Commission. (1997). Cape Trends: Cape Cod demographic and economic trends 1997 [online].

2) Wilkie, Richard W. and Jack Tager, [eds.]. 1991. Historical Atlas of Massachusetts. University of Massachusetts Press. Amherst, MA.152 pp.

Prior to the 1950's there were few homes and many of those were seasonal. During these times water quality was not a problem and eel grass beds were plentiful. Dramatic declines in water quality, and the quality of the estuarine habitats, throughout Cape Cod, have paralleled its population growth since these times. The problems in these particular sub-embayments generally include periodic decreases of dissolved oxygen, decreased diversity of benthic animals, and periodic algal blooms. Eelgrass beds, which are critical habitats for macroinvertebrates and fish, have completely disappeared from these waters. Furthermore, the eelgrass was replaced by macro algae, which are

undesirable, because they do not provide high quality habitat for fish and invertebrates. In the most severe cases habitat degradation could lead to periodic fish kills, unpleasant odors and scums, and near loss of the benthic community and/or presence of only the most stress-tolerant species of benthic animals.

Coastal communities, including Mashpee and Barnstable, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as commercial fin fishing and shellfishing. The continued degradation of these coastal sub-embayments, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources.

Habitat and water quality assessments were conducted on each sub-embayment based upon water quality data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The five sub-embayment systems in this study display a range of habitat quality. In general, the habitat quality of the Popponesset Bay System is highest near the tidal inlet on Nantucket Sound and poorest in the inland-most tidal reaches. This is indicated by gradients of the various indicators. Nitrogen concentrations are highest inland and lowest near the mouths. A high resolution aerial photography survey from 1951 indicates there were significant eelgrass beds in the central basin as well as eelgrass beds within the upper basin near the mouth of Shoestring Bay. Subsequent field surveys in 1995 and 2001 have both shown the complete loss of all eelgrass beds throughout the Popponesset Bay System. This makes the presence or loss of eelgrass a difficult parameter to use in evaluating water quality within the sub-embayments. Infaunal study results indicate a system capable of supporting diverse healthy communities in the region nearest the tidal inlet, with most of the system having infaunal habitat that is significantly impaired under present N loading conditions. Currently the central basin of Popponesset Bay supports relatively healthy habitat conditions of consistently high bottom water dissolved oxygen and modest phytoplankton blooms during the summer months. The other sub-embayments within the system have moderate to high levels of nitrogen-related impairment. Shoestring Bay shows both periodic oxygen declines and significant phytoplankton blooms, while Ockway Bay has similar oxygen declines, but apparently less phytoplankton biomass. Upper Mashpee River dissolved oxygen measurements showed <3 mg/L during 20% of the days tested. Chlorophyll *a* concentrations are the highest in the inland reaches. Shoestring Bay and Mashpee River both have phytoplankton blooms, which are common and large (chlorophyll *a* concentrations >20 ug/L). Overall the Popponesset Bay central basin has relatively high water quality, Popponesset Bay upper basin and confluence with Shoestring Bay and Ockway Bay is significantly impaired, and the Mashpee River sub-embayment is significantly impaired.

Pollutant of Concern, Sources, and Controllability

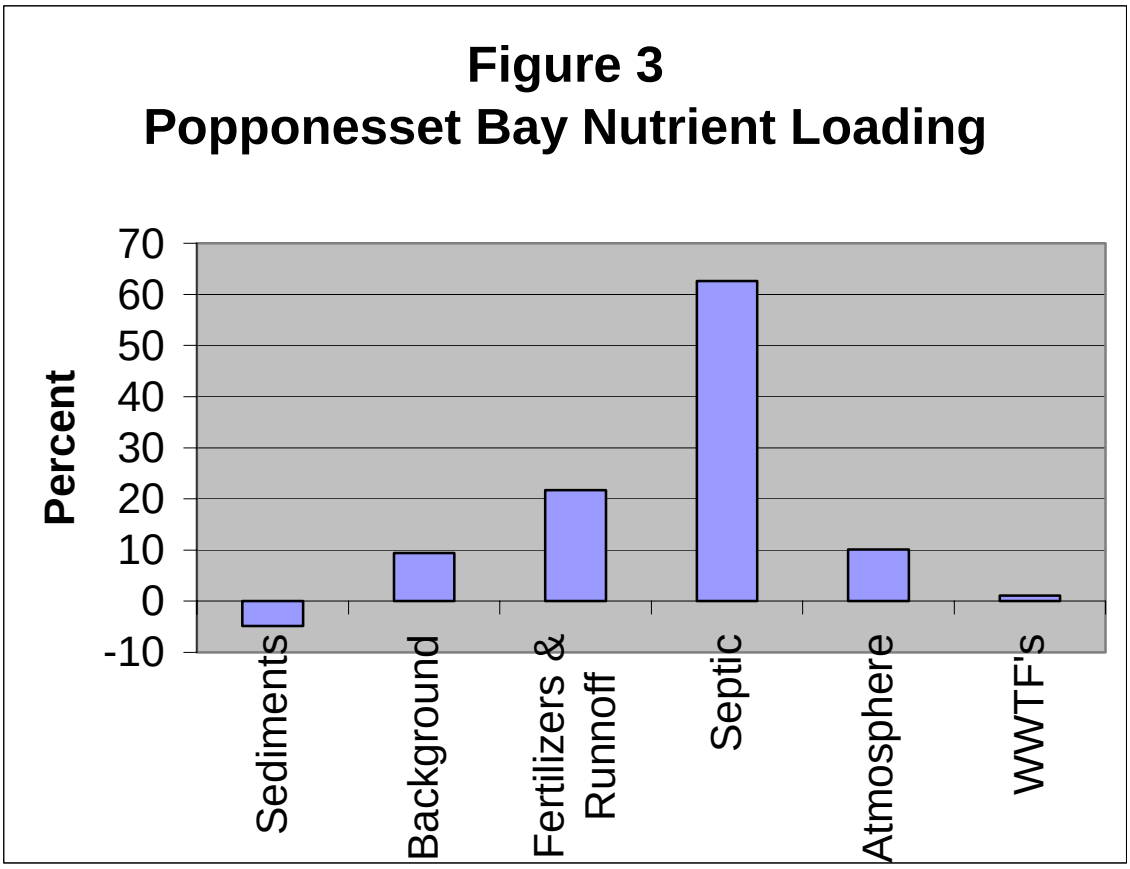
In the coastal embayments of the Towns of Mashpee and Barnstable, as in most marine and coastal waters, the limiting nutrient is nitrogen. Nitrogen concentrations above natural levels contribute to undesirable conditions, including the severe impacts described above, through the promotion of excessive growth of plants and algae, including nuisance vegetation.

Each of the embayments covered in this TMDL has had extensive data collected and analyzed through the Massachusetts Estuaries Program (MEP) and with the cooperation and assistance from the Town of Mashpee, the Town of Barnstable, the USGS, and the Cape Cod Commission. Data collection included both water quality and hydrodynamics as described in Chapters I, IV, V, and VII of the MEP Technical Report.

These investigations revealed that loadings of nutrients, especially N, are much larger than they would be under natural conditions, and as a result the water quality has deteriorated. A principal indicator of decline in water quality is the disappearance of eelgrass from its entire natural habitat in these sub-embayments. This is a result of nutrient loads causing excessive growth of algae in the water (phytoplankton) and algae growing on eel grass (epiphyton), both of which result in the loss of eelgrass through the reduction of available light levels.

As is illustrated by Figure 3, most of the N affecting Popponesset Bay's sub-embayments originates from on-site subsurface wastewater disposal systems, with considerably less N originating from natural background sources, runoff, fertilizers, waste water treatment facilities, and atmospheric deposition. Although this figure shows that overall the sediments are a N sink, examination of individual sub-embayments indicates that some of them have sediments that provide significant sources of N (Table 3).

Percent contribution of various sources and sinks of nitrogen in Popponesset Bay's embayments



The level of "controllability" of each source, however, varies widely:

Atmospheric nitrogen cannot be adequately controlled locally – it is only through region and nation-wide air pollution control initiatives that reductions are feasible;

Sediment nitrogen control by such measures as dredging is not feasible on a large scale. However, the concentrations of N in sediments, and thus the loadings from the sediments, will decline over time

if sources in the watershed are removed, or reduced to the target levels discussed later in this document. Increased dissolved oxygen will help keep nitrogen from fluxing;

Fertilizer – related nitrogen loadings can be reduced through bylaws and public education;

Stormwater sources of N can be controlled by best management practices (BMPs), bylaws and stormwater infrastructure improvements;

Septic system sources of nitrogen are the largest controllable sources. These can be controlled by a variety of case-specific methods including: sewering and treatment at centralized or decentralized locations, upgrading/repairing failed systems, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing nitrogen-reducing on-site wastewater treatment systems.

Natural Background is the background load as if the entire watershed was still forested and contains no anthropogenic sources. It cannot be controlled locally.

WWTFs effluent nitrogen can be reduced by advanced treatment processes that include denitrification.

Landfill leachate nitrogen is included in the land use loading source, can best be controlled by collecting and treating the leachate, but can also be controlled by capping the landfill to prevent percolation of rainwater through the landfill (and thus capturing and transporting contaminants into the groundwater). The Mashpee landfill capping was completed in 1998.

Cost/benefit analyses will have to be conducted on all of the possible N loading reduction methodologies in order to select the optimal control strategies, priorities, and schedules.

Description of the Applicable Water Quality Standards

Water quality standards of particular interest to the issues of cultural eutrophication are dissolved oxygen, nutrients, aesthetics, excess plant biomass, and nuisance vegetation. The Massachusetts water quality standards (314 CMR 4.0) contain numeric criteria for dissolved oxygen, but have only narrative standards that relate to the other variables, as described below:

314 CMR 4.05(5)(a) states "Aesthetics – All surface waters shall be free from pollutants in concentrations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances, produce objectionable odor, color, taste, or turbidity, or produce undesirable or nuisance species of aquatic life."

314 CMR 4.05(5)(c) states, "Nutrients – Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication".

314 CMR 4.05(b) 1:

(a) Class SA

1. Dissolved Oxygen -
a. Shall not be less than 6.0 mg/l unless background conditions are lower;
b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 75% of saturation due to a discharge; and

c. site-specific criteria may apply where background conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

(b) Class SB

1. Dissolved Oxygen -
a. Shall not be less than 5.0 mg/L unless background conditions are lower;
b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 60% of saturation due to a discharge; and
c. site-specific criteria may apply where back-ground conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

Thus, the assessment of eutrophication is based on site specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is recommended by the US Environmental Protection Agency in their draft Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (EPA-822-B-01-003, Oct 2001). The Guidance Manual notes that lakes, reservoirs, streams, and rivers may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management. However, individual estuarine and coastal marine waters have unique characteristics, and development of individual water body criteria is typically required.

It is this framework, coupled with an extensive outreach effort that the Department, with the technical support of SMAST, is employing to develop nutrient TMDLs for coastal waters.

Methodology - Linking Water Quality and Pollutant Sources

Extensive data collection and analyses have been described in detail in the MEP Technical Report. Those data were used by SMAST to assess the loading capacity of each embayment. Physical (Chapter V), chemical and biological (Chapters IV, VII, and VIII**)** data were collected and evaluated. The primary water quality objective was represented by conditions that:

1) restore the natural distribution of eelgrass because it provides valuable habitat for shellfish and finfish
2) prevent algal blooms
3) protect benthic communities from impairment or loss
4) maintain dissolved oxygen concentrations that are protective of the estuarine communities.

The details of the data collection, modeling and evaluation are presented and discussed in Chapters IV, V, VI, VII and VIII of the MEP Technical Report. The main aspects of the data evaluation and modeling approach are summarized below, taken from pages 4 through 7 of that report.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. It fully links watershed inputs with embayment circulation and N characteristics, and is characterized as follows:

- requires site specific measurements within the watershed and each sub-embayment;

- uses realistic “best-estimates” of N loads from each land-use (as opposed to loads with built-in “safety factors” like Title 5 design loads);

- spatially distributes the watershed N loading to the embayment;

- accounts for N attenuation during transport to the embayment;

- includes a 2D or 3D embayment circulation model depending on embayment structure;

- accounts for basin structure, tidal variations, and dispersion within the embayment;

- includes N regenerated within the embayment;

- is validated by both independent hydrodynamic, N concentration, and ecological data;

- is calibrated and validated with field data prior to generation of “what if” scenarios.

The Linked Model has been applied previously to watershed N management in 15 embayments throughout Southeastern Massachusetts. In these applications it became clear that the model can be calibrated and validated, and has use as a management tool for evaluating watershed N management options.

The Linked Model, when properly calibrated and validated for a given embayment, becomes a N management planning tool as described in the model overview below. The model can assess solutions for the protection or restoration of nutrient-related water quality and allows testing of management scenarios to support cost/benefit evaluations. In addition, once a model is fully functional it can be refined for changes in land-use or embayment characteristics at minimal cost. In addition, since the Linked Model uses a holistic approach that incorporates the entire watershed, embayment and tidal source waters, it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

The Linked Model provides a quantitative approach for determining an embayment's: (1) N sensitivity, (2) N threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2 of the MEP Technical Report). This methodology integrates a variety of field data and models, specifically:

• Monitoring - multi-year embayment nutrient sampling

• Hydrodynamics -

- embayment bathymetry (depth contours throughout the embayment)
- site specific tidal record (timing and height of tides)
- water velocity records (in complex systems only)
- hydrodynamic model

• Watershed Nitrogen Loading

- watershed delineation
- stream flow and N load
- land-use analysis (GIS)
- watershed N model

• Embayment TMDL - Synthesis

- linked Watershed-Embayment Nitrogen Model
- salinity surveys (for linked model validation)
- rate of N recycling within embayment
- dissolved oxygen record
- Macrophyte survey
- Infaunal survey (in complex systems)

Application of the Linked Watershed-Embayment Model

The approach developed by the MEP for applying the linked model to specific sub-embayments, for the purpose of developing target N loading rates, includes:

1) selecting one or two sub-embayments within the embayment system, located close to the inland-most reach or reaches, which typically has the poorest water quality within the system. These are called "sentinel" sub-embayments;

2) using site-specific information and a minimum of 3 years of sub-embayment-specific data to select target/threshold N concentrations for each sub-embayment. This is done by refining the draft threshold N concentrations that were developed as the initial step of the MEP process. The target concentrations that were selected generally occur in higher quality waters near the mouth of the embayment system;

3) running the calibrated water quality model using different watershed N loading rates, to determine the loading rate, which will achieve the target N concentration within the sentinel sub-embayment. Differences between the modeled N load required to achieve the target N concentration, and the present watershed N load, represent N management goals for restoration and protection of the embayment system as a whole.

Previous sampling and data analyses, and the modeling activities described above, resulted in four major outputs that were critical to the development of the TMDLs. Two outputs are related to N **concentration**:

- the present N concentrations in the sub-embayments
- site-specific target (threshold) concentrations

and, two outputs are related to N **loadings:**

- the present N loads to the sub-embayments
- load reductions necessary to meet the site specific target N concentrations

A brief overview of each of the outputs follows:

Nitrogen concentrations in the sub-embayments

a) Observed "present" conditions:

Table 2 presents the range of average concentrations of N measured in the sub-embayments from 1997 through 2003. Concentrations of N are the highest in the Mashpee River (0.958 mg/L). Nitrogen in the other sub-embayments ranges in concentration from 0.456 to 0.690 mg/L, resulting in overall ecological habitat quality ranging from moderately healthy to severely degraded. The individual yearly means and standard deviations of the averages are presented in Tables A-1 of Appendix A.

b) Modeled site-specific target threshold nitrogen concentrations:

A major component of TMDL development is the determination of the maximum concentrations of N (based on field data) that can occur without causing unacceptable impacts to the aquatic environment. Prior to conducting the analytical and modeling activities described above, SMAST selected appropriate nutrient-related environmental indicators and tested the qualitative and quantitative relationship between those indicators and N concentrations. The Linked Model was then used to determine site-specific threshold N concentrations by using the specific physical, chemical and biological characteristics of each sub-embayment.

Table 2. Observed present nitrogen concentrations and calculated target threshold nitrogen concentrations derived for the Popponesset Bay Sub-embayments

Embayment System And Sub-embayments	Range of Average Observed System Nitrogen Concentration [1] (mg/L)	System Threshold Nitrogen Concentration (mg/L)
Popponesset Bay		0.38
Mashpee River	0.958-0.627[2]	
Shoestring Bay	0.690-0.520[2]	
Ockway Bay	0.677-0.536[2]	
Pinquickset Cove	0.527	
Popponesset Bay	0.485-0.422[2]	

[1] calculated as the average of the separate yearly means of 1997-2003 data. Individual yearly means and standard deviations of the average are presented in Tables A-1 Appendix A
[2]listed as a range since it was sampled as several segments(see Table A-1 Appendix A)

As shown in Table 2, the site-specific target (threshold) N concentration is 0.38 mg/L for all of the Popponesset Bay embayment.

The findings of the analytical and modeling investigations for this embayment system are discussed and explained below:

The threshold N level for an embayment represents the average water column concentration of N that will support the high habitat quality being sought. The water column N level is ultimately controlled by the integration of the watershed N load, the N concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column N concentration is modified by the extent of sediment uptake and/or regeneration and by direct atmospheric deposition.

The threshold N levels for the embayment in this study were developed to restore or maintain SA

waters or high habitat quality. In the embayment, high habitat quality was defined as supportive of eelgrass and diverse benthic animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed N loads (Tables ES-1 and ES-2 of the MEP Technical Report) to the Popponesset Bay System from the Towns of Mashpee and Barnstable were comprised primarily of septic system N loading. Analysis of the overall septic system load to the 5 sub-embayments in the Popponesset Bay System indicate that 70% of the N load is from this source.

The threshold N level for the Popponesset Bay System was determined as follows:

- The target N concentration for restoration of eelgrass in this system was determined to be 0.38 mg/L Total Nitrogen (TN). The value stems from (1) the analysis of Stage Harbor, Chatham which also exchanges tidal water with Nantucket Sound and for which a target has already been set), (2) analysis of N levels within the vestigial eelgrass bed in adjacent Waquoit Bay, near the inlet (measured TN of 0.395 mg/L, this value is tidally averaged to <0.38 mg/L), and (3) a similar analysis in West Falmouth Harbor. Threshold values relating to eelgrass restoration were based upon these other Cape Cod systems with similar N dynamics, since there are presently no remaining eelgrass beds in the Popponesset Bay System (or even adjacent Three Bays).

- The sentinel station was located within the upper region of the central basin to Popponesset Bay at the mouth of Shoestring Bay, at the uppermost eelgrass bed detected in the 1951 data. Under present loading conditions the sentinel station supports a measured N level at mid-ebb tide of 0.581 mg/L TN and a tidally corrected average concentration of 0.451 mg/L TN. This location was selected as a sentinel station because: (1) it was the upper extent of the eelgrass coverage in 1951, (2) restoration of N conditions supportive of eelgrass at this location will necessarily result in even higher quality conditions throughout the whole of the central basin, and (3) restoration of N concentrations at this site should result in conditions similar to 1951 within Shoestring and Ockway Bays. Shoestring Bay and Ockway Bay should then be supportive of high quality habitat for benthic infaunal communities. Based upon current conditions, the infaunal analysis (Chapter VII, MEP Technical Report) coupled with the N data (measured and modeled), indicated that N levels on the order of 0.4 to 0.5 mg/L TN are supportive of high quality infauna habitat within the Popponesset Bay System.

- Based upon sequential reductions in watershed N loading in the analysis described in the Section VIII-3 of the MEP Technical Report, the sentinel station is projected to achieve an average TN level of 0.371 mg/L , the mouth of Ockway Bay 0.376 mg/l TN, and the whole of the Popponesset Bay basin <0.331 mg/L TN.

The data suggest that there is likely a range of total N, which can support a healthy infaunal community within this system. Since Shoestring and Ockway Bays did not support eelgrass in the 1951 data, evaluation was based upon benthic animal habitat.

- The results of the Linked Watershed-Embayment modeling indicated that when the N threshold level is attained at the sentinel station (Section VIII-3 of the MEP Technical report), TN levels in Shoestring and Ockway Bays will be consistent with high quality infauna habitat: upper and lower Shoestring Bay, 0.522 and 0.412 mg/L TN respectively; upper Ockway Bay, 0.421 mg/L TN; and mid and lower Mashpee River, 0.525 and 0.422 mg/L TN.

- The model shows that achieving the N target at the sentinel station will be restorative of eelgrass habitat throughout the Popponesset Bay central basin and restorative of infaunal habitat throughout Shoestring and Ockway Bays and the lower portion of the Mashpee River.

- It is important to note that the analysis of future N loading to the Popponesset Bay System focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the analysis (as described in Chapter VI of the MEP Technical Report) indicates that significant increases in N loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round usage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine N management must include management approaches to prevent increased N loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The overwhelming conclusion of the analysis of the Popponesset Bay System is that restoration will necessitate a reduction in the present (2003) N inputs and management options to negate additional future N inputs.

Nitrogen loadings to the sub-embayments

a) Present loading rates:

In the Popponesset Bay System overall, the highest N loading from controllable sources is from septic systems, which is also the highest N loading source in each sub-embayment. On-site septic system loadings range from 0.58 kg/day to as high as 26.46 kg/day. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) is significant in the Mashpee River sub-embayment. As discussed previously, however, the direct control of N from sediments is not considered feasible. However, the magnitude of the benthic contribution is related to the watershed load. Therefore, reducing the incoming load should reduce the benthic flux over time. The total N loading from all sources ranges from 0.84 kg/day in Pinquickset Cove to 52.71 kg/day in the Mashpee River. A further breakdown of N loading, by source, is presented in Table 3. The data on which Table 3 is based can be found in Table ES-1 of the MEP Technical Report.

Table 3. Nitrogen loadings to the Popponesset Bay sub-embayments from within the watersheds (natural background, land use-related runoff, and septic systems), from WWTFs from the atmosphere, and from nutrient-rich sediments within the embayments.

Popponesset System Sub-embayments	Natural Background [1] Watershed Load (kg/day)	Present Land Use Load [2] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load (kg/day)	Present Atmospheric Deposition (kg/day)	Present Benthic Flux [3] (kg/day)	Total nitrogen load from all sources (kg/day)
Mashpee River	5.86	10.38[a]	23.62	0.15	0.66	15.34	56.01
Shoestring Bay	2.05	7.77	23.00	0.47	2.23	-11.85	23.67
Ockway Bay	0.24	0.76	2.39	0.00	1.09	1.78	6.26
Pinquickset Cove	0.11	0.19	0.58	0.00	0.29	-0.33	0.84
Popponesset Bay	0.18	1.19	5.56	0.00	4.01	-5.68	5.26

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of fertilizer and runoff only
[3] nitrogen loading from the sediments
[a] includes residual plume from the capped Mashpee Landfill (0.39 kg/day)

b) Nitrogen loads necessary for meeting the site-specific target nitrogen concentrations.

As previously indicated, the present N loadings to the Popponesset Bay sub-embayments must be reduced in order to restore conditions and to avoid further nutrient-related adverse environmental impacts. The critical final step in the development of the TMDL is modeling and analysis to determine the loadings required to achieve the target N concentrations.

Table 4 lists the present controllable N loadings, target thresholds, and reductions necessary to achieve target concentrations (which will be described more fully in the following section). It should be noted once again that the goal of this TMDL is to achieve the target N concentration in the designated sentinel system. The loadings presented in Table 4 represent one, but not the only, loading reduction scenario that can meet the TMDL goal. In this scenario, the percentage reductions to meet threshold concentrations range from 1 % at Pinquickset Cove up to76% at Ockway Bay. Tables VIII-2 and VIII-3 of the MEP Technical Report (and reproduced in Appendix B of this document) summarize the present loadings from on-site subsurface wastewater disposal systems, and the reduced loads that would be necessary to achieve the threshold N concentrations in the Popponesset Bay System if on-site subsurface wastewater disposal system loads alone were targeted.

Table 4. Present Controllable Watershed nitrogen loading rates, calculated loading rates that are necessary to achieve target threshold nitrogen concentrations, and the percent reductions of the existing loads necessary to achieve the target threshold loadings.

Popponesset Bay System Sub-embayments	Present contollable watershed load [1] (kg/day)	Target Threshold Watershed Load [2] (kg/day)	Percent watershed load reductions needed to achieve threshold loads
Mashpee River	34.15	16.17	52.7
Shoestring Bay	31.24	19.72	36.9
Ockway Bay	3.15	0.76	75.9
Pinquickset Cove	0.77	0.76	1.3
Popponesset Bay	6.75	2.77	59.0

[1] Composed of combined fertilizer, runoff, WWTP effluent, and septic system loadings
[2] Target threshold watershed load is the load from the watershed needed to meet the embayment threshold N concentration of 0.38 mg/L identified in Table 2 above.

Total Maximum Daily Loads

As described in EPA guidance, a total maximum daily load (TMDL) identifies the loading capacity of a water body for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. The TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass and benthic animal community structure, the leading indicator of ecological health, thus meeting water quality goals for aquatic life support. Because there are no “numerical” water quality standards for N, the TMDLs for the Popponesset Bay sub-embayments are aimed at determining the loads that would correspond to sub-embayment-specific N concentrations determined to be protective of the water quality and ecosystems.

The effort includes detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time), for each sub-embayment. The results of the mathematical model are correlated with estimates of impacts on water quality, including negative impacts on eelgrass (the primary indicator), as well as dissolved oxygen, chlorophyll, and benthic infauna.The TMDL can be defined by the equation:

TMDL = BG + WLAs + LAs + MOS

Where

TMDL = loading capacity of receiving water
BG = natural background
WLAs = portion allotted to point sources
LAs = portion allotted to (cultural) non-point sources
MOS = margin of safety

Background Loading

Natural background N loading estimates are presented in Table 3 above. Background loading was calculated on the assumption that the entire watershed is forested, with no anthropogenic sources of N.

Wasteload Allocations

Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of storm water be included in the waste load component of the TMDL. On Cape Cod the vast majority of storm water percolates into the ground and aquifer and proceeds into the embayment systems through groundwater migration. The Linked Model accounts for storm water loadings and groundwater loading in one aggregate allocation as a non-point source – combining the assessments of waste water and storm water (including storm water that infiltrates into the soil and direct discharge pipes into water bodies) for the purpose of developing control strategies. Although the vast majority of storm water percolates into the ground, there are a few storm water pipes that discharge directly to water bodies that are subject to the requirements of the Phase II Storm Water NPDES Program. Therefore, any storm water discharges subject to the requirements of storm water Phase II NPDES permit must be treated as a waste load allocation. Since the majority of the nitrogen loading comes from septic systems, fertilizer and storm water that infiltrates into the groundwater, the allocation of nitrogen for any storm water pipes that discharge directly to any of the embayments is insignificant as compared to the overall groundwater load. Based on land use, the Linked Model accounts for loading for storm water, but does not differentiate storm water into a load and waste load allocation. Nonetheless, based on the fact that there are few storm water discharge pipes within NPDES Phase II communities that discharge directly to embayments or waters that are connected to the embayments, the waste load allocation for these sources is considered to be less than 0.29% (93.7 kg/year) as compared to the overall nitrogen load (31,885 kg/year) to the embayments. Looking at individual sub-embayments this load ranged from 0.09-1.59% compared to the individual nitrogen load to each sub-embayment (Appendix C). This is based on the percent of impervious surface within 200 feet of the waterbodies and the relative load from this area compared to the overall load (Table IV-5 of the MEP Technical Report). Although most stormwater infiltrates into the ground on Cape Cod, some impervious areas within approximately 200 of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of waste load allocation it was

assumed that all impervious surfaces within 200ft of the shoreline discharge directly to the waterbody. This load is obviously negligible when compared to other sources.

There are four wastewater treatment facilities that discharge to groundwater in the Popponesset Bay watershed, but they are not considered point sources under EPA definition. Two of these are in the Shoestring Bay sub-embayment and the other two are in the Mashpee River sub-embayment. EPA policy also requires that stormwater regulated under the NPDES program be identified and included as a wasteload allocation. As discussed, for the purpose of this TMDL, stormwater loadings are not differentiated into point and non-point sources, because most storm water discharges directly to the ground.

EPA and DEP authorized the Towns of Mashpee, Barnstable, and Sandwich for coverage under the NPDES Phase II General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003. The watershed of the Popponesset Bay System that is in Mashpee and Sandwich are located in an area subject to the requirements of the permit, as EPA has mapped these entire areas of the watershed as regulated areas. EPA did not designate the entire watershed area in Barnstable as a regulated urbanized area. While communities need to comply with the Phase II permit only in the mapped Urbanized Areas, the Town of Barnstable has decided to extend all the stormwater permit requirements throughout the entire town, including the Popponesset Bay System watershed area.

The Phase II general permit requires the permittee to determine whether the approved TMDL is for a pollutant likely to be found in storm water discharges from the MS4. The MS4 is required to implement the storm water waste load allocation, BMP recommendations or other performance requirements of a TMDL and assess whether the waste load allocation is being met through implementation of existing stormwater control measures or if additional control measures are necessary.

Load Allocations

Load allocations identify the portion the loading capacity allocated to existing and future nonpoint sources. In the case of the Popponesset Bay System, the nonpoint source loadings are primarily from on-site subsurface wastewater disposal systems. Additional N sources include: natural background, stormwater runoff (including N from fertilizers), the four WWTF's groundwater discharges, atmospheric deposition, and nutrient-rich sediments.

Generally, stormwater that is subject to the EPA Phase II Program would be considered a part of the wasteload allocation, rather than the load allocation. As presented in Chapter IV, V, and VI, of the MEP Technical Report, on Cape Cod the vast majority of stormwater percolates into the aquifer and enters the embayment system through groundwater. Given this, the TMDL accounts for stormwater loadings and groundwater loadings in one aggregate allocation as a non-point source, thus combining the assessments of wastewater and storm water for the purpose of developing control strategies. Ultimately, when the Phase II Program is implemented in Mashpee, Barnstable, and Sandwich, new studies, and possibly further modeling, will identify what portion of the stormwater load may be controllable through the application of BMPs.

The four WWTFs currently discharge about 0.62 kg N/day into the groundwater. This represents less than 1% of the nitrogen load into the Popponesset Embayment System (rounded off to 1% in Figure 4 below). This small percentage of N load is due to the fact that the amount of wastewater effluent discharged by these facilities is small and also that the groundwater discharge permits for three of the four facilities has such a low nitrogen limit that the facilities must use treatment technology

which will denitrify the effluent prior to discharge. Due to the fact that groundwater discharge permits must be renewed over time the fourth wastewater treatment facility will come under the same treatment technology requirements in the near future. If towns shifted loads from on-site systems that do not denitrify (septic systems do not normally denitrify) to these wastewater treatment facilities, it would lead to overall decline in N loadings to the sub-embayments.

The solid waste disposal (landfill) load was included based on data collected from the observation wells. Capping the landfill has eliminated the source of this load, thus the load itself will continue to decrease over time.

The sediment loading rates incorporated into the TMDL are lower than the existing sediment flux rates listed in Table 3 above because projected reductions of N loadings from the watershed will result in reductions of nutrient concentrations in the sediments, and therefore, over time, reductions in loadings from the sediments will occur. Benthic N flux is a function of N loading and particulate organic nitrogen (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed N loads, and are calculated by multiplying the present N flux by the ratio of projected PON to present PON, using the following formulae:

Projected N flux = (present N flux) (PON projected / PON present)

When:

$$PON_{projected} = (R_{load}) (D_{PON}) + PON_{present\ offshore}$$

When R_{load} = (projected N load) / (Present N load)

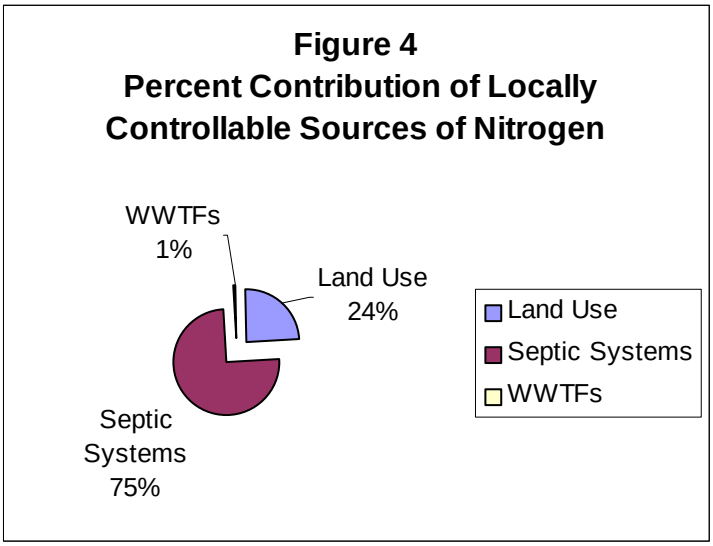
And D_{PON} is the PON concentration above background determined by:

$$D_{PON} = (PON_{present\ embayment} - PON_{present\ offshore})$$

The benthic flux modeled for the Popponesset Bay System is reduced from existing conditions based on the load reduction and the observed PON concentrations within each sub-embayment relative to Nantucket Sound (boundary condition). The benthic flux input to each sub-embayment was reduced (toward zero) based on the reduction of N in the watershed load.

The loadings from atmospheric sources incorporated into the TMDL, however, are the same rates presently occurring, because, as discussed above, local control of atmospheric loadings is not considered feasible.

Locally controllable sources of N within the watersheds are categorized as on-site subsurface wastewater disposal system wastes, land use (which includes stormwater runoff and fertilizers), and wastewater treatment facilities. The following figure emphasizes the fact that the overwhelming majority of locally controllable N comes from on-site subsurface wastewater disposal systems.



Margin of Safety

Statutes and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA para 303 (d)(20©, 40C.G.R. para 130.7©(1)]. The EPA's 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. The MOS for the Popponesset Bay System TMDL is implicit, and the conservative assumptions in the analyses that account for the MOS are described below.

1. Use of conservative data in the Linked Model

In the Popponesset Bay System embayments most of the current N load passes through surface water features, which reduce N concentrations. The load model uses attenuation factors for ground water passing through surface water features that are lower than those actually measured. Attenuation factors of 50% are used in the model when measured factors are in the vicinity of 70%. For the TMDL, a smaller than expected attenuation factor makes the allowable loading lower than it would otherwise be and constitutes a portion of the factor of safety.

In addition, using sub-embayments that are at, or near, the inland-most tidal reaches as sentinels for establishing the acceptable nitrogen load (i.e., the TMDL) provides a major margin of safety for "downstream" embayments, which are closer to the mouths. Finally, decreases in air deposition through continuing air pollution control efforts, are uncounted in this TMDL, and are thus another component of the margin of safety.

The hydrodynamic and water quality models have been assessed directly. In the many instances where the hydrodynamic model predictions of volumetric exchange (flushing) have also been directly measured by field measurements of instantaneous discharge, the agreement between modeled and observed values has been $\geq$95%. Field measurement of instantaneous discharge was performed using acoustic Doppler current profilers (ADCP) at key locations within the embayment (with regards to the water quality model, it was possible to conduct a quantitative assessment of the model results as fitted to a baseline dataset - a least squares fit of the modeled versus observed data showed an R^2>0.95, indicating that the model accounted for 95% of the variation in the field data). Since the water quality model incorporates all of the outputs from the other models, this excellent fit indicates a high degree of certainty in the final result. The high level of accuracy of the model provides a high

degree of confidence in the output, therefore, less of a margin of safety is required.

Similarly, the water column N validation dataset was also conservative. The Linked Model is validated to measured water column N. However, the model predicts average summer N concentrations. The very high or low measurements are marked as outliers. The effect is to make the N threshold more accurate and scientifically defensible. If a single measurement 2 times higher than the next highest data point in the series, raises the average 0.05 mg N/L, this would allow for a higher "acceptable" load to the embayment. Marking the very high outlier is a way of preventing a single and rare bloom event from changing the N threshold for a system. This effectively strengthens the data set so that a higher margin of safety is not required.

Finally, it is important to note that the reductions in benthic regeneration of N are most likely underestimates, i.e. conservative. The reduction is based solely on a reduced deposition of PON, due to lower primary production rates under the reduced N loading in these systems. As the N loading decreases and organic inputs are reduced, it is likely that rates of coupled remineralization-nitrification-denitrification and sediment oxidation will increase.

Benthic regeneration of N is dependant upon the amount of PON deposited to the sediments and the percentage that is regenerated to the water column versus denitrified or buried. The regeneration rate projected under reduced N loading conditions was based upon two assumptions:

a) the PON in the embayment in excess of that of inflowing tidal water (boundary condition) results from production supported by watershed N inputs and

b) the presently enhanced production would decrease in proportion to the reduction in the sum of watershed N inputs + plus direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON levels if watershed N loading + direct atmospheric deposition could be reduced to zero (an impossibility of course).

This proportional reduction assumes that the proportion of remineralized N will be the same as under present conditions, which is almost certainly an underestimate. As a result future N regeneration rates are overestimated, which adds to the margin of safety.

2. Conservative threshold sites/nitrogen concentrations

Conservatism was used in the selection of the threshold sites and N concentration. Sites were chosen that had benthic animal (infaunal) communities, and not those just starting to show impairment, which would have slightly higher N concentrations. Meeting the target thresholds in the sentinel sub-embayments will result in reductions of N concentrations in the rest of the systems, which is very conservative, thus adding to the margin of safety for those embayments as a whole.

In addition to the margin of safety within the context of setting the N threshold levels, described above, a programmatic margin of safety also derives from continued monitoring of these sub-embayments to support adaptive management. This continuous monitoring effort provides the ongoing data to evaluate the improvements that occur over the multi-year implementation of the N management plan. This will allow refinements to the plan to ensure that the desired level of restoration is achieved.

Seasonal Variation

Nutrient loads to the sub-embayments are based on annual loads for two reasons. Since the TMDLs for the waterbody segments are based on the most critical time period, i.e. the summer growing season, the TMDLs are protective for all seasons. The daily loads can be converted to annual loads by multiplying by 365 (the number of days in a year). Nutrient loads to the sub-embayments are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Second, as a practical matter, the types of controls necessary to control the N load, the nutrient of primary concern, by their very nature do not lend themselves to intra-annual manipulation since the majority of the N is from non-point sources. Thus, the annual loads make sense, since it is difficult to control non-point sources of nitrogen on a seasonal basis and that nitrogen sources can take considerable time to migrate to impacted waters.

TMDL Values for Popponesset Bay Sub-Embayments

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of each sub-embayment, were calculated by considering all sources of N grouped by natural background, point sources, and non-point sources. A more meaningful way of presenting the loadings data, from an implementation perspective, is presented in Table 5. In this table the N loadings from the atmosphere and nutrient-rich sediments are listed separately from the target watershed threshold loads, which are composed of natural background N along with locally controllable N from the WWTP, on-site subsurface wastewater disposal systems, stormwater runoff, and fertilizers. In the case of Popponesset Bay, the TMDLs were calculated by projecting reductions in locally controllable on-site subsurface wastewater disposal system, stormwater runoff, and fertilizer sources.

Table 5. The Total Maximum Daily Loads (TMDL) for the Popponesset Bay System, represented as the sum of the calculated target thresholds loads (from controllable watershed sources), atmospheric deposition, and sediment sources (benthic flux).

Popponesset System Sub-embayment	Target Watershed Threshold Load [1] (kg/day)	Atmospheric Deposition (kg/day)	Benthic Flux [2] (kg/day)	**TMDL [3] (kg/day)**
Mashpee River	16.2	0.7	9.4	**26**
Shoestring Bay	19.7	2.2	-8.7	**13**
Ockway Bay	0.8	1.1	1.1	**3**
Pinquickset Cove	0.8	0.3	-0.3	**1**
Popponesset Bay	2.8	4.0	-5.5	**1**

[1] Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table 2. Once again the goal of this TMDL is to achieve the identified N threshold concentration in the identified sentinel system. The target load identified in this table represents one alternative loading scenario to achieve that goal but other scenarios may be possible and approvable as well.

[2] Projected sediment N loadings obtained by reducing the present loading rates (Table 3) proportional to proposed watershed load reductions and factoring in the existing and projected future concentrations of PON.

[3] Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.

Implementation Plans

The critical element of this TMDL process is achieving the sub-embayment specific N concentrations presented in Table 2 above, that are necessary for the restoration and protection of water quality and eelgrass habitat within the Popponesset Bay sub-embayments. In order to achieve those target concentrations, N loading rates must be reduced throughout the Popponesset Bay System. Table 5, above, lists target watershed threshold loads for each sub-embayment. If those threshold loads are achieved, the overall Popponesset Bay System will be protected.

This loading reduction scenario is not the only way to achieve the target N concentrations. The Towns are free to explore other loading reduction scenarios through additional modeling as part of the Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated, however, that any alternative implementation strategies will be protective of the overall Popponesset Bay System, and that none of the sub-embayments will be negatively impacted. To this end, additional linked model runs can be performed by the MEP at a nominal cost to assist the planning efforts of the Towns in achieving target N loads that will result in the desired threshold concentrations.

The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, the DEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results.

Because the vast majority of controllable N load is from individual on-site subsurface wastewater disposal systems for private residences, the CWMP should assess the most cost-effective options for achieving the target N watershed loads, including but not limited to, sewering and treatment for N control of sewage and septage at either centralized or de-centralized locations, and denitrifying wastewater treatment systems for private residences.

The Towns, however, are urged to meet the target threshold N concentrations by reducing N loadings from any and all sources, through whatever means are available and practical, including reductions in stormwater runoff and/or fertilizer use within the watershed through the establishment of local by-laws and/or the implementation of stormwater BMPs, in addition to reductions in on-site subsurface wastewater disposal system loadings.

Although it is not explained in detail previously in this TMDL, it should be noted here that parts of the Town of Sandwich are in the watershed of the Popponesset Bay System. A portion of the upper Mashpee River sub-embayment watershed is located in Sandwich. Thus the development of any implementation plan should keep in mind that a third town needs to be included in coordinating efforts to maximize the reduction in TN loading.

DEP's MEP Implementation Guidance report (http://www.mass.gov/dep/water/resources/restore.htm) provides N loading reduction strategies that are available to the Towns of Mashpee, Barnstable and Sandwich and that could be incorporated into the implementation plans. The following topics related to N reduction are discussed in the Guidance:

- Wastewater Treatment
    - On-Site Treatment and Disposal Systems
    - Cluster Systems with Enhanced Treatment
    - Community Treatment Plants
    - Municipal Treatment Plants and Sewers
- Tidal Flushing

    - Channel Dredging
    - Inlet Alteration
    - Culvert Design and Improvements
- Stormwater Control and Treatment *
    - Source Control and Pollution Prevention
    - Stormwater Treatment
- Attenuation via Wetlands and Ponds
- Water Conservation and Water Reuse
- Management Districts
- Land Use Planning and Controls
    - Smart Growth
    - Open Space Acquisition
    - Zoning and Related Tools
- Nutrient Trading

* The Towns of Mashpee, Barnstable and Sandwich are three of 237 communities in Massachusetts covered by the Phase II stormwater program requirements.

Monitoring Plan for TMDL Developed Under the Phased Approach

The Department recommends that the Towns of Mashpee and Barnstable develop a detailed monitoring plan as part of the Comprehensive Wastewater Management Planning process and as part of the detailed plan for TMDL implementation. The monitoring plan should be designed to determine to what extent water quality improvements occur as a result of implementing this TMDL, and should be developed and conducted in phases according to the identification of N reduction options. The Department recognizes the long-term nature of the time horizon for full implementation of the TMDL; however, reasonable milestones in the shorter term are necessary.

Growth should be guided by a consideration of water quality-associated impacts.

Reasonable Assurances

DEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act (CWA), to implement and enforce the provisions of the TMDL, including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Both Mashpee and Barnstable have demonstrated this commitment through the comprehensive wastewater planning that they initiated well before the generation of the TMDL. The Towns expect to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers), and to prevent any future degradation of these valuable resources. Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations, availability of financial incentives and local, state and federal programs for pollution control. Storm water NPDES permit coverage will address discharges from municipally owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act; Title 5 regulations for on-site subsurface wastewater disposal systems, and other local regulations such as the Town of Rehoboth's stable regulations. Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement

between MA DEP and EPA. Other potential funds and assistance are available through Massachusetts' Department of Agriculture's Enhancement Program and the United States Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

Appendix A

Table A – 1: Summarizes the nitrogen concentrations for Popponesset Bay sub-embayments (from Chapter VI of the accompanying MEP Technical Report, Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts, July

Table VI-1. Measured and modeled Nitrogen concentrations for the Popponesset Bay system used in the model calibration plots of Figure VI-2. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means. Overall mean is presented as "data mean" with the standard deviation (s.d.) and number of total samples (N).

Sub-Embayment	monitoring station	1997 mean	1998 mean	1999 mean	2000 mean	2001 mean	2002 mean	2003 mean	data mean	s.d. all data	N	model min	model max	Model avg
Mashpee River - head (MRh)	PB 1	0.798	0.633	0.787	0.831	0.990	1.137	0.756	0.859	0.200	26	0.786	0.952	0.851
Mashpee River - Upper (MRu)	PB2	1.006	0.726	1.022	0.798	1.082	1.153	0.892	0.958	0.242	24	0.862	1.016	0.932
Mashpee River - Mid (MRm)	PB3	0.651	0.764	0.669	0.596	0.740	1.120	0.733	0.739	0.216	25	0.530	1.009	0.837
Mashpee River - Lower (MRl)	PB4	0.603	0.668	0.564	0.485	0.695	0.694	0.736	0.627	0.134	25	0.346	0.955	0.588
Shoestring Bay - head (SBh)	SR 5	-	1.193	0.860	0.878	1.278	1.132	1.377	1.135	0.380	20	0.965	1.166	1.071
Shoestring Bay - upper (SBu)	PB5	0.730	0.878	0.606	0.594	0.678	0.580	0.870	0.690	0.169	26	0.663	0.772	0.711
Shoestring Bay - mid (SBm)	PB 6	0.617	0.695	0.644	0.671	0.668	0.707	0.884	0.688	0.140	28	0.514	0.732	0.640
Shoestring Bay - lower (SBl)	PB 7	0.518	0.551	0.467	0.506	0.507	0.527	0.592	0.520	0.113	27	0.386	0.690	0.541
Ockway Bay - upper (OBu)	PB 9	0.552	0.569	0.498	0.486	1.003	0.785	0.734	0.677	0.217	27	0.552	0.586	0.567
Ockway Bay - lower (OBl)	PB 10	0.485	0.508	0.426	0.467	0.765	0.592	0.512	0.536	0.177	27	0.331	0.575	0.476
Popponesset Bay – head (PBh)	PB 8	0.476	0.589	0.444	0.592	0.772	0.595	0.732	0.581	0.151	24	0.307	0.694	0.464
Popponesset Bay – upper (PBu)	PB 11	0.307	0.521	0.434	0.417	0.579	0.567	0.506	0.485	0.111	23	0.290	0.552	0.381
Popponesset Bay - mid (PBm)	PB 12	0.343	0.492	0.393	0.473	0.539	0.554	0.486	0.456	0.102	25	0.282	0.501	0.328
Popponesset Creek (POC)	PB 13	0.369	0.376	0.351	0.486	0.591	0.456	0.479	0.422	0.107	23	0.359	0.381	0.370
Pinquickset Cove (PQC)	PB 15	-	-	-	-	-	0.470	0.640	0.527	0.097	6	0.335	0.460	0.416
Nantucket Sound (NAS)	PB 14	0.260	0.282	0.297	0.326	0.368	0.351	0.375	0.315	0.055	22	0.283	0.323	0.288

Appendix B

Table B –1 Summarizes the present on-site subsurface wastewater disposal system loads, and the loading reductions that would be necessary to achieve the TMDL by reducing on-site subsurface wastewater disposal system loads, ignoring all other sources.

Table VIII-1. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Popponesset Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Popponesset Bay	1.58	1.58	0.0%
Popponesset Creek	4.00	0.00	-100.0%
Pinquickset Cove	0.58	0.58	0.0%
Ockway Bay	2.39	0.00	-100.0%
Mashpee River	9.61	0.00	-100.0%
Shoestring Bay	6.94	0.00	-100.0%
Surface Water Sources			
Mashpee River	16.85	8.63	-48.8%
Santuit River (Shoestring Bay)	11.69	7.58	-35.2%
Quaker Run River (Shoestring Bay)	4.37	4.37	0.0%
TOTAL	58.01	22.74	-60.8%

Appendix C

Popponesset Bay Embayment System estimated wasteload allocation (WLA) from runoff of all impervious areas within 200 feet of waterbodies.

Subwatershed Name	Impervious subwatershed buffer areas[1]		Total Subwatershed Impervious areas		Total Impervious subwatershed load	Total subwatershed load	Impervious subwatershed buffer area WLA	
	Acres	%	Acres	%	Kg/year	Kg/year	Kg/year	%
Mashpee River	5.5	5.3	643.5	8.6	1411	13010	12.06	0.09
Shoestring Bay	10	12.4	426	10.1	986	13012	23.15	0.18
Ockway Bay	5.8	6.0	27.6	11.7	90	1549	18.91	1.22
Pinquickset Cove	0.9	3.6	8.4	4.2	10	385	1.07	0.28
Popponesset Bay	14.4	6.6	50.2	25	170	3929	62.31	1.59
TOTAL	40.6	9.8	1155.7	9.5	2667	31885	93.69	0.29

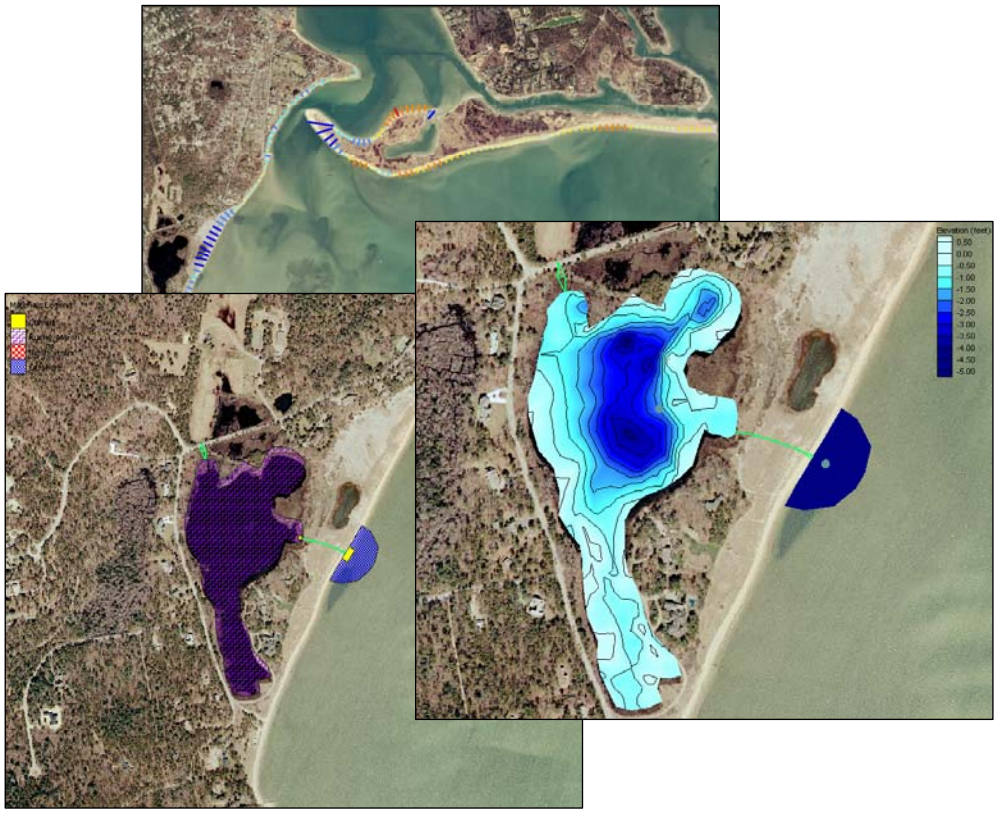
[1]The entire impervious area within a 200 foot buffer zone around all waterbodies as calculated from GIS. Due to the soils and geology of Cape Cod it is unlikely that runoff would be channeled as a point source directly to a waterbody from areas more than 200 feet away. Some impervious areas within approximately 200 of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of the wasteload allocation it was assumed that all impervious surfaces within 200ft of the shoreline discharge directly to the waterbody.

Appendix V

MEP Technical Report for Rushy Marsh; MEP, April 2006

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Rushy Marsh, Barnstable, Massachusetts



University of Massachusetts Dartmouth
School of Marine Science and Technology

Massachusetts Department of Environmental Protection

FINAL REPORT –APRIL 2006

Massachusetts Estuaries Project

LINKED WATERSHED-EMBAYMENT MODEL TO DETERMINE CRITICAL NITROGEN LOADING THRESHOLDS FOR RUSHY MARSH POND IN THE TOWN OF BARNSTABLE, MA

FINAL REPORT – APRIL 2006

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Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Rushy Marsh Barnstable, Massachusetts

Executive Summary

1. Background

This report presents the results generated from the implementation of the Massachusetts Estuaries Project's Linked Watershed-Embayment Approach to the Rushy Marsh embayment system, a coastal embayment within the Town of Barnstable, Massachusetts. Analyses of the Rushy Marsh embayment system was performed to assist the Town with up-coming nitrogen management decisions associated with the Towns' current and future wastewater planning efforts, as well as wetland restoration, anadromous fish runs, shell fishery, open-space, and harbor maintenance programs. As part of the MEP approach, habitat assessment was conducted on the embayment based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. Nitrogen loading thresholds for use as goals for watershed nitrogen management are the major product of the MEP effort. In this way, the MEP offers a science-based management approach to support the Town of Barnstable resource planning and decision-making process. The primary products of this effort are: (1) a current quantitative assessment of the nutrient related health of the Rushy Marsh embayment, (2) identification of all nitrogen sources (and their respective N loads) to embayment waters, (3) nitrogen threshold levels for maintaining Massachusetts Water Quality Standards within embayment waters, (4) analysis of watershed nitrogen loading reduction to achieve the N threshold concentrations in embayment waters, and (5) a functional calibrated and validated Linked Watershed-Embayment modeling tool that can be readily used for evaluation of nitrogen management alternatives (to be developed by the Town) for the restoration of the Rushy Marsh embayment system.

Wastewater Planning: As increasing numbers of people occupy coastal watersheds, the associated coastal waters receive increasing pollutant loads. Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The elevated nutrients levels are primarily related to the land use impacts associated with the increasing population within the coastal zone over the past half-century.

The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities. The primary nutrient causing the increasing impairment of our coastal embayments is nitrogen, with its primary sources being wastewater disposal, and nonpoint source runoff that carries nitrogen (e.g. fertilizers) from a range of other sources. Nitrogen related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their shallow nature and large shoreline area, are generally the first coastal systems to show the effect of nutrient pollution from terrestrial sources.

In particular, the Rushy Marsh embayment system within the Town of Barnstable is at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater from the increasingly developed watershed to this coastal salt pond. Eutrophication is a process that occurs naturally and gradually over a period of tens or hundreds of years. However, human-related (anthropogenic) sources of nitrogen may be introduced into ecosystems at an accelerated rate that cannot be easily absorbed, resulting in a phenomenon known as cultural eutrophication. In both marine and freshwater systems, cultural eutrophication results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources.

The Town of Barnstable has recognized the severity of the problem of eutrophication and the need for watershed nutrient management and is currently developing a Comprehensive Wastewater Management Plan, which it plans to rapidly implement. The Town of Barnstable has also completed and implemented wastewater planning in other regions of the Town not associated with the Rushy Marsh embayment system. The Town has nutrient management activities related to their tidal embayments, which have been associated with the MEP effort in Three Bays, Centerville River/Harbor and the Lewis Bay embayment systems. The Town of Barnstable and work groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. The completion of this multi-step process has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, which is a partnership effort between all MEP collaborators and the Town. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns' nutrient management groups to predict the impacts on water quality from a variety of proposed management scenarios.

Nitrogen Loading Thresholds and Watershed Nitrogen Management: Realizing the need for scientifically defensible management tools has resulted in a focus on determining the aquatic system's assimilative capacity for nitrogen. The highest-level approach is to directly link the watershed nitrogen inputs with embayment hydrodynamics to produce water quality results that can be validated by water quality monitoring programs. This approach when linked to state-of-the-art habitat assessments yields accurate determination of the "allowable N concentration increase" or "threshold nitrogen concentration". These determined nitrogen concentrations are then directly relatable to the watershed nitrogen loading, which also accounts for the spatial distribution of the nitrogen sources, not just the total load. As such, changes in nitrogen load from differing parts of the embayment watershed can be evaluated relative to the degree to which those load changes drive embayment water column nitrogen concentrations toward the "threshold" for the embayment system. To increase certainty, the "Linked" Model is independently calibrated and validated for each embayment.

Massachusetts Estuaries Project Approach: The Massachusetts Department of Environmental Protection (DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool to communities throughout southeastern Massachusetts (the Linked Watershed-Embayment Management Model) for nutrient management in their coastal embayment systems. Ultimately, use of the Linked Watershed-Embayment Management Model tool by municipalities in the region results in effective screening of nitrogen reduction approaches and eventual restoration and protection of valuable coastal resources. The MEP provides technical guidance in support of policies on nitrogen loading to embayments, wastewater management decisions, and establishment of nitrogen Total Maximum Daily Loads (TMDLs). A TMDL represents the greatest amount of a pollutant that a waterbody can accept and still meet water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation and fishing. The MEP modeling approach assesses available options for meeting selected nitrogen goals that are protective of embayment health and achieve water quality standards.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach, which links watershed inputs with embayment circulation and nitrogen characteristics.

The Linked Model builds on well-accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site-specific measurements within each watershed and embayment;
- uses realistic “best-estimates” of nitrogen loads from each land-use (as opposed to loads with built-in “safety factors” like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of “what if” scenarios.

The Linked Model Approach’s greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing “what if” scenarios for evaluating watershed nitrogen management options.

For a comprehensive description of the Linked Model, please refer to the *Full Report: Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. A more basic discussion of the Linked Model is also provided in Appendix F of the *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. The Linked Model suggests which management solutions will adequately protect or restore embayment water quality by enabling towns to test specific management scenarios and weigh the resulting water quality impact against the cost of that approach. In addition to the management scenarios modeled for this report, the Linked Model can be used to evaluate additional management scenarios and may be

updated to reflect future changes in land-use within an embayment watershed or changing embayment characteristics. In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries. Unlike many approaches, the Linked Model accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics and accommodates the spatial distribution of these processes. For an overview of several management scenarios that may be employed to restore embayment water quality, see *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm.

Application of MEP Approach: The Linked Model was applied to the Rushy Marsh embayment system by using site-specific data collected by the MEP and water quality data from the Water Quality Monitoring Program conducted by Three Bays Preservation in partnership with the Town of Barnstable, with technical guidance from the Coastal Systems Program at SMAST (see Chapter 2). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Barnstable Planning Department, and watershed boundaries delineated by USGS. This land-use data was used to determine watershed nitrogen loads within the Rushy Marsh embayment system and each systems sub-embayments as appropriate (current and build-out loads are summarized in Table IV-3). Water quality within a sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of this tidally influenced estuary included a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Once the hydrodynamics of the system was quantified, transport of nitrogen was evaluated from tidal current information developed by the numerical models.

A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for the Rushy Marsh embayment system. Once the hydrodynamic properties of the estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates. Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic model was then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis. Boundary nutrient concentrations in Vineyard Sound source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Rushy Marsh embayment system was used to calibrate the water quality model, with validation using measured nitrogen concentrations (under existing loading conditions). The underlying hydrodynamic model was calibrated and validated independently using water elevations measured in time series throughout the embayments.

MEP Nitrogen Thresholds Analysis: The threshold nitrogen level for an embayment represents the average water column concentration of nitrogen that will support the habitat quality being sought. The water column nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The water column nitrogen concentration is modified by the extent of sediment regeneration. Threshold nitrogen levels for the embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. High habitat quality was defined as supportive of

eelgrass and infaunal communities. Dissolved oxygen and chlorophyll a were also considered in the assessment.

The nitrogen thresholds developed in Section VIII-2 were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Rushy Marsh system. Tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel stations chosen for Rushy Marsh. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

The Massachusetts Estuaries Project's thresholds analysis, as presented in this technical report, provides the site-specific nitrogen reduction guidelines for nitrogen management of the Rushy Marsh embayment system in the Town of Barnstable. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayment. The MEP analysis has initially focused upon nitrogen loads from on-site septic systems as a test of the potential for achieving the level of total nitrogen reduction for restoration of each embayment system. The concept was that since septic system nitrogen loads generally represent 90% of the controllable watershed load to the Rushy Marsh embayment system and are more manageable than other of the nitrogen sources, the ability to achieve needed reductions through this source is a good gauge of the feasibility for restoration of these systems.

2. Problem Assessment (Current Conditions)

A habitat assessment was conducted throughout Rushy Marsh based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present, Rushy Marsh Pond is showing significantly impaired to severely degraded habitat quality. All of the habitat indicators are consistent with this evaluation of the whole of system (Chapter VII).

The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). The clear evidence of oxygen levels above atmospheric equilibration indicates that the Rushy Marsh System is eutrophic.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality within the estuary. Oxygen depletion was frequently to levels <4 mg/L (29 days) and periodically to < 3 mg/L (8 days). The oxygen data is consistent with high organic matter loads from phytoplankton production (chlorophyll a levels) indicative of nitrogen enrichment and eutrophication of this estuarine system, although the nitrogen enrichment stems primarily from the restriction of tidal exchange. The frequent significant level of oxygen depletion coupled to the frequent phytoplankton blooms is clear evidence of that Rushy Marsh Pond is presently nitrogen over-loaded eutrophic embayment.

Currently, eelgrass is not present within Rushy Marsh Pond. Rushy Marsh Pond is functionally a basin with fringing wetland, and the sediments are currently soft muds rich in organic matter, which in some locations overlay medium to fine sands. The current lack of eelgrass beds is expected given the high chlorophyll a and low dissolved oxygen levels and watercolumn nitrogen concentrations within this system. In addition, it does not appear that eelgrass beds were present in the system in 1951, as well. It appears that the restriction of the tidal exchange starting circa 1900 (as discussed in Chapter V), resulted in an absence of eelgrass sometime prior to 1951. The restriction of tidal exchange has resulted in an enrichment of estuarine waters in nitrogen to the extent that the system is currently eutrophic. Restoration of tidal exchange will be needed for habitat restoration of this system, as watershed nitrogen inputs are relatively low.

Given that eelgrass has not been documented for this system, it is not clear that even when the system was much better flushed, it supported eelgrass beds. However, observations of brackish water submerged aquatic vegetation in the shallow region of the western channel suggest that eelgrass habitat might be sustainable under lower effective nitrogen loading rates (i.e. higher flushing). To the extent that conditions could be improved to the level of eelgrass colonization in this system, the acreage would likely range from 4-12 acres, most likely in the southern channel and the margins of the main basin.

The Infauna Study indicated that presently, habitat capable of supporting benthic infaunal communities is virtually absent in Rushy Marsh Pond (Table VII-3). The infaunal survey found that summer conditions apparently are sufficient to prevent a community from developing in the central basin. In the shallower southern channel region, again only very few individuals and species were found. The low numbers of species and individuals indicates that benthic infaunal habitat has been severely degraded throughout Rushy Marsh Pond. The conditions proximately result from the high level of nitrogen and organic matter enrichment and associated oxygen depletion of bottom waters. Ultimately, the cause is the highly restricted tidal exchange and very low flushing rate of Pond waters (system residence time ~48 d). However, restoration of infaunal animal communities should occur at the point that habitat can be restored.

3. Conclusions of the Analysis

The threshold nitrogen level for an embayment represents the average watercolumn concentration of nitrogen that will support the habitat quality being sought. The watercolumn nitrogen level is ultimately controlled by the integration of the watershed nitrogen load, the nitrogen concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column nitrogen concentration is modified by the extent of sediment regeneration and by direct atmospheric deposition.

Threshold nitrogen levels for this embayment system were developed to restore or maintain SA waters or high habitat quality. In this system, high habitat quality was defined as possibly supportive of eelgrass and supportive of diverse benthic animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed nitrogen loads (Tables ES-1 and ES-2) for the Town of Barnstable Rushy Marsh embayment system was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 90% of the controllable watershed nitrogen load to the embayment was from wastewater.

A major finding of the MEP clearly indicates that a single total nitrogen threshold can not be applied to Massachusetts' estuaries, based upon the results of the Great, Green and Bournes Pond Systems, Popponesset Bay System, the Hamblin / Jehu Pond / Quashnet River analysis in eastern Waquoit Bay, the analysis of the adjacent Three Bays system and the Pleasant Bay and Nantucket Sound embayments associated with the Town of Chatham. This is almost certainly going to be true for the other embayments within the MEP area, as well.

The threshold nitrogen levels for the Rushy Marsh embayment system in Barnstable were determined as follows:

Rushy Marsh Threshold Nitrogen Concentrations

- Following the MEP protocol, since eelgrass has not been documented in Rushy Marsh Pond, restoration of infaunal habitat is the restoration goal. Infaunal animal habitat is a critical resource to the Rushy Marsh System and estuaries in general. Since there are virtually no infaunal animals remaining in the sub-tidal Rushy Marsh Pond sediments, comparisons to the muddy basins of other nearby estuarine systems were relied upon for setting the nitrogen threshold for healthy infaunal habitat at a nitrogen level of TN <0.5 mg TN L^{-1}. This level was found for Popponesset Bay where based upon the infaunal analysis coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN L-1 were found supportive of high infaunal habitat quality in this system. Similarly, in the Three Bays System, healthy infaunal areas are found at nitrogen levels of TN <0.42 mg TN L^{-1} (Cotuit Bay and West Bay), with impairment in areas where nitrogen levels of TN >0.5 mg TN L^{-1} (North Bay), and severe degradation at nitrogen levels of TN >0.6 mg TN L^{-1}..

- The nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations were not attainable with 100% removal of septic load (associated with direct groundwater discharge to the embayment) for the systems watershed. The limited circulation within the system prevents the threshold goals from be achieved. In order to meet the threshold concentrations in the system, alternative approaches beyond load reductions are required to increase circulation and water exchange with Nantucket Sound. .

It is important to note that the analysis of future nitrogen loading to the Rushy Marsh estuarine systems focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round useage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine nitrogen management must include management approaches to prevent increased nitrogen loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The overarching conclusion of the MEP analysis of the Rushy Marsh estuarine system is that restoration will necessitate a reduction in the present (2004) nitrogen inputs and management options to negate additional future nitrogen inputs.

Table ES-1. Existing total and sub-embayment nitrogen load to the estuarine waters of the Rushy Marsh Pond estuary system, observed nitrogen concentration, and sentinel system threshold nitrogen concentration.

Sub-embayments	Natural Background Watershed Load [1] (kg/day)	Present Land Use Load [2] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load [3] (kg/day)	Present Watershed Load [4] (kg/day)	Direct Atmospheric Deposition [5] (kg/day)	Present Net Benthic Flux (kg/day)	Present Total Load [6] (kg/day)	Observed TN Conc. [7] (mg/L)	Threshold TN Conc. (mg/L)
RUSHY MARSH POND SYSTEM										
Rushy Marsh Pond System Total	**0.08**	**0.10**	**0.35**	**0.00**	**0.45**	**0.20**	**-0.20**	**0.45**	**1.17-1.11**	**0.50[8]**

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer and runoff and natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined natural background, fertilizer, runoff, and septic system loadings
[5] atmospheric deposition to embayment surface only
[6] composed of natural background, fertilizer, runoff, septic system atmospheric deposition and benthic flux loadings
[7] average of 2002 – 2005 data.
Individual yearly means and standard deviations in Table VI-6.
[8] threshold for sentinel sites located at the mid point of Rushy Marsh Pond (RM2).

Table ES-2. Present Watershed Load, Threshold Load, and the percent reduction necessary to achieve the Threshold Load for the Rushy Marsh Pond system, Town of Cotuit, Massachusetts.

Sub-embayments	Present Watershed Load [1] (kg/day)	Target Threshold Watershed Load [2] (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net [3] (kg/day)	TMDL [4] (kg/day)	Percent watershed reductions needed to achieve threshold load levels
LITTLE POND SYSTEM						
Rushy Marsh Pond System Total	**0.45**	**0.09**	**0.20**	**-0.11**	**0.18**	**-79.1%**

(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.
(2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1.
(3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).
(4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.

ACKNOWLEDGMENTS

The Massachusetts Estuaries Project Technical Team would like to acknowledge the contributions of the many individuals who have worked tirelessly for the restoration and protection of the Rushy Marsh Pond Estuary. Without these stewards and their efforts, this project would not have been possible.

First and foremost, we would like to recognize the significant time and effort in data collection and discussion spent by members of the Three Bays/Rushy Marsh Water Quality Monitoring Program and SMAST "volunteers". These individuals gave generously of their time to collect nutrient samples from this system, without which the present analysis would not have been possible. Of particular note are Lindsey Counsell of Three Bays Preservation, Coordinator of the Monitoring Program, and John Jacobsen of the Town of Barnstable, Coordinator of the Town-wide Monitoring Program. Similarly, many in the Town of Barnstable helped in this effort, the Barnstable Department of Public Works, the Barnstable Conservation Division and the Barnstable Nutrient Management Committee. The technical team would like to specifically acknowledge the efforts of Three Bays Preservation and the Friends of Rushy Marsh for their energy and perseverance in the stewardship of this coastal resource.

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I. INTRODUCTION

The Rushy Marsh Embayment System is a simple estuary located within the Town of Barnstable on Cape Cod, Massachusetts with a southern shore bounded by water from Nantucket Sound (Figure I-1). Rushy Marsh is situated on the coast between the larger estuarine systems of Popponesset Bay and Three Bays. The watershed to Rushy Marsh is fully within the Town of Barnstable, making Barnstable the sole municipal steward of this small estuary. Virtually all watershed freshwater and nutrients enter Rushy Marsh via groundwater seepage, as there are no significant surface inflows to this system. As a result, there is little opportunity for nitrogen removal during transport from watershed source to estuarine waters.

Rushy Marsh Pond is a simple estuary, with a single embayment and highly restricted tidal inlet. The open water area of ~15 acres, makes Rushy Marsh Pond a great salt pond, similar to Oyster Pond in Falmouth. The present configuration of the Rushy Marsh Estuary is relatively new in the coastal landscape, as the southern coast of Cape Cod in the vicinity of Rushy Marsh is a moderately dynamic region, where natural wave and tidal forces continue to reshape the shoreline (see Chapters II and V). All the while, Rushy Marsh was formed by the flooding of a kettle pond as a result of rising sea level following the last glaciation approximately 18,000 years BP. The growth of salt marsh deposits along the northeastern portion of its shore, further enclosed the system, thus its classification as a lagoonal type estuary. This system appears to have persisted until the 1890's. USGS maps from 1893 show Rushy Marsh as a fully tidal estuary with salt marsh along its eastern and northern shores. An island exists off shore, Gull Island, which disappeared in about 1896 (Coast & Harbor Institute and Robert L. Fultz Associates 2002). During the 1900's the tidal inlet became restricted due to sedimentation deposits and the formation of a barrier beach. During this period Popponesset Spit elongated, then breached, with the northern portion finally attaching to the shoreline just north of Rushy Marsh around 1960. This formed a cove to Nantucket Sound running the length of and parallel to Rushy Marsh Pond. Over the next two decades this cove was filled by overwash and today all that remains is a small pond in the barrier beach (Figure I-1). However, the process of barrier beach formation and then overwash resulted in a freshening of Rushy Marsh Pond, even with efforts to keep the system tidal (pipes, culverts). By the turn of the century, the system was a brackish salt pond.

While Rushy Marsh Pond presently has a relatively low nitrogen load from its watershed, due to its small size and proportionally large undeveloped areas, it is still significantly impaired by nitrogen enrichment and is clearly eutrophic. This apparent paradox results from its very low tidal exchange rate, resulting from barrier beach processes restricting the inlet to Nantucket Sound. The low rate of tidal exchange serves to greatly increase the nitrogen sensitivity of this system, such that lower nitrogen inputs cause eutrophic conditions. In recent years the inlet periodically became closed and the pond level rose (due to groundwater inflow) to exceed sea level in the adjacent sound. This also resulted in a further decline in salinity to <1 ppt. The Town of Barnstable (through Conservation Department) working with Friends of Rushy Marsh and Three Bays Preservation partially restored tidal exchange (temporary fix). However, the persistent restricted tidal exchange has caused significant ecological degradation of the Rushy Marsh System. Even with the low watershed nitrogen loading, the low rate of nitrogen removal through tidal flushing results in high nitrogen levels, large phytoplankton blooms and periodic anoxia of bottom waters. In addition, the freshening of the pond waters has resulted in a loss of salt marsh area and a significant expansion of the areal coverage by the common reed, *Phragmites*. It is clear that restoration of Rushy Marsh Pond will require addressing the tidal restriction as one of the principal components, especially as the system has historically

operated as a tidal estuary and its proximity to Nantucket Sound prevents its management as a freshwater system due to periodic overwash of salt water (similar to Oyster Pond, Falmouth, see Howes et al., 2005).



Figure I-1. Study region for the Massachusetts Estuaries Project analysis of the Rushy Marsh Pond System. Tidal waters enter the Pond from Nantucket Sound. Freshwaters enter from the watershed primarily through direct groundwater discharge and direct precipitation. Note the small brackish pond in the barrier beach.

Although the nitrogen load to Rushy Marsh Pond is relatively low, nitrogen management should also be considered in the development of the restoration design. The Town of Barnstable has been among the fastest growing towns in the Commonwealth over the past two decades and does have a centralized wastewater treatment system located in Hyannis. However, the Rushy Marsh watershed is not connected to any municipal sewerage system, but relies on privately maintained septic systems for treatment and disposal of wastewater. As existing and probable increasing levels of nutrients impact Barnstable's coastal embayments, water quality degradation will accelerate, with further harm to invaluable environmental resources.

As the stakeholder to the Rushy Marsh Pond System, the Town of Barnstable and its citizens have been active in promoting restoration of this system. This local concern also led to the conduct of several studies (see Chapter II) to support restoration and the Town is presently willing to implement an appropriate plan. To this end, Friends of Rushy Marsh and Three Bays Preservation Inc. have been active in field data collection. One of the key projects undertaken by Three Bays Preservation was to establish, in 2002, a nitrogen related water quality monitoring program within Rushy Marsh Pond. The Three Bays/Rushy Marsh Water Quality Monitoring Program was provided technical assistance by the Coastal Systems Program at SMAST-UMD and over the past several years has been incorporated into Barnstable's Town-wide embayment monitoring program. This effort provides the quantitative watercolumn nitrogen data (2002-2005) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study.

Since the initial results of the Water Quality Monitoring Program and the coastal processes and land-use studies indicated that parts of the Rushy Marsh Estuary are currently impaired by nitrogen enrichment, the Town of Barnstable and Three Bays Preservation undertook additional site-specific data collection to support MEP's ecological assessment and modeling project. The effort was part of the Town's Wastewater Facilities Planning effort and was aimed at restoration of the estuarine resources. As a result of these efforts and to facilitate the development and implementation of restoration, it was appropriate to complete the evaluation of the Rushy Marsh salt pond system at this time.

The common focus of the Barnstable effort has been to gather site-specific data on the current nitrogen related water quality throughout the Rushy Marsh Pond System and determine its relationship to tidal flushing and watershed nitrogen loads. This multi-year effort has provided the baseline information required for determining the link between upland loading, tidal flushing, and estuarine water quality. The MEP effort builds upon the Water Quality Monitoring Program, and previous hydrodynamic and water quality analyses, and includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for each major sub-embayment. These critical nitrogen targets and the link to specific ecological criteria form the basis for the nitrogen threshold limits necessary to develop and implement management alternatives needed by the Town of Barnstable for estuarine restoration/protection. While the completion of this complex multi-step process of rigorous scientific investigation to support watershed based nitrogen management has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, the results stem directly from the efforts of large number of Town staff and volunteers over many years, most notably within the Departments of Conservation and Public Works and from members of the local non-governmental organizations (NGO's), Three Bays Preservation and Friends of Rushy Marsh. The modeling tools developed as part of this program provide the quantitative information necessary for the Town of Barnstable to develop and evaluate the most cost effective management alternatives to restore this coastal resource.

I.1 THE MASSACHUSETTS ESTUARIES PROJECT APPROACH

Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The nutrients are primarily related to changes in watershed land-use associated with increasing population within the coastal zone over the past half century. Many of Massachusetts' embayments have nutrient levels that are approaching or are currently over this assimilative capacity, which begins to cause declines in their ecological health. The result is the loss of fisheries habitat, eelgrass beds, and a general disruption of benthic communities and the food chain which they support. At higher levels, enhanced nitrogen loading from surrounding watersheds causes aesthetic degradation and inhibits even recreational uses of coastal waters. In addition to nutrient related ecological declines, an increasing number of embayments are being closed to swimming, shellfishing and other activities as a result of bacterial contamination. While bacterial contamination does not generally degrade the habitat, it restricts human uses. However like nutrients, bacterial contamination is frequently related to changes in land-use as watersheds become more developed. The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities.

The primary nutrient causing the increasing impairment of the Commonwealth's coastal embayments is nitrogen and the primary sources of this nitrogen are wastewater disposal, fertilizers, and changes in the freshwater hydrology associated with development. At present there is a critical need for state-of-the-art approaches for evaluating and restoring nitrogen sensitive and impaired embayments. Within Southeastern Massachusetts alone, almost all of the municipalities (as is the case with the Town of Barnstable) are grappling with Comprehensive Wastewater Planning and/or environmental management issues related to the declining health of their estuaries.

Municipalities are seeking guidance on the assessment of nitrogen sensitive embayments, as well as available options for meeting nitrogen goals and approaches for restoring impaired systems. Many of the communities have encountered problems with "first generation" watershed based approaches, which do not incorporate estuarine processes. The appropriate method must be quantitative and directly link watershed and embayment nitrogen conditions. This "Linked" Modeling approach must also be readily calibrated, validated, and implemented to support planning. Although it may be technically complex to implement, results must be understandable to the regulatory community, town officials, and the general public.

The Massachusetts Estuaries Project represents the next generation of watershed based nitrogen management approaches. The Massachusetts Department of Environmental Protection (MA DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool for watershed-embayment management for communities throughout Southeastern Massachusetts.

The Massachusetts Estuary Project is founded upon science-based management. The Project is using a consistent, state-of-the-art approach throughout the region's coastal waters and providing technical expertise and guidance to the municipalities and regulatory agencies tasked with their management, protection, and restoration. The overall goal of the Massachusetts Estuaries Project is to provide the DEP and municipalities with technical guidance to support policies on nitrogen loading to embayments. In addition, the technical reports prepared for each embayment system will serve as the basis for the development of

Total Maximum Daily Loads (TMDLs). Development of TMDLs is required pursuant to Section 303(d) of the Federal Clean Water Act. TMDLs must identify sources of the pollutant of concern (in this case nitrogen) from both point and non-point sources, the allowable load to meet the state water quality standards and then allocate that load to all sources taking into consideration a margin of safety, seasonal variations, and several other factors. In addition, each TMDL must contain an outline of an implementation plan. For this project, the DEP recognizes that there are likely to be multiple ways to achieve the desired goals, some of which are more cost effective than others and therefore, it is extremely important for each Town to further evaluate potential options suitable to their community. As such, DEP will likely be recommending that specific activities and timelines be further evaluated and developed by the Towns (sometimes jointly) through the Comprehensive Wastewater Management Planning process.

In appropriate estuaries, TMDL's for bacterial contamination will also be conducted in concert with the nutrient effort (particularly if there is a 303d listing). In these cases, the MEP (through SMAST) will produce a Technical Analysis and Report to support a bacterial TMDL for the system from which MA DEP develops the TMDL. The goal of the bacterial program is to provide information to guide targeted sampling for specific source identification and remediation.

In contrast to the bacterial program, the MEP nitrogen program also includes site-specific habitat assessments and watershed/embayment modeling approaches to develop and assess various nitrogen management alternatives for meeting selected nitrogen goals supportive of restoration/protection of embayment health.

The major MEP nitrogen management goals are to:

- provide technical analysis and supporting documentation to Towns as a basis for sound nutrient management decision making towards embayment restoration
- develop a coastal TMDL working group for coordination and rapid transfer of results,
- determine the nutrient sensitivity of each of the 89 embayments in Southeastern MA
- provide necessary data collection and analysis required for quantitative modeling,
- conduct quantitative TMDL analysis, outreach, and planning,
- keep each embayment's model "alive" to address future municipal needs.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. This approach represents the "next generation" of nitrogen management strategies. It fully links watershed inputs with embayment circulation and nitrogen characteristics. The Linked Model builds on and refines well accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;

- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied for watershed nitrogen management in approximately 15 embayments throughout Southeastern Massachusetts. In these applications it has become clear that the Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options.

The Linked Watershed-Embayment Model when properly parameterized, calibrated and validated for a given embayment becomes a nitrogen management planning tool, which fully supports TMDL analysis. The Model facilitates the evaluation of nitrogen management alternatives relative to meeting water quality targets within a specific embayment. The Linked Watershed-Embayment Model also enables Towns to evaluate improvements in water quality relative to the associated cost. In addition, once a model is fully functional it can be "kept alive" and updated for continuing changes in land-use or embayment characteristics (at minimal cost). In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

Linked Watershed-Embayment Model Overview: The Model provides a quantitative approach for determining an embayment's: (1) nitrogen sensitivity, (2) nitrogen threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is both calibrated and fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2). This methodology integrates a variety of field data and models, specifically:

- Watercolumn Monitoring - multi-year embayment nutrient sampling
- Hydrodynamics -
  - embayment bathymetry
  - site specific tidal record
  - current records (in complex systems only)
  - hydrodynamic model
- Watershed Nitrogen Loading
  - watershed delineation
  - stream flow (Q) and nitrogen load
  - land-use analysis (GIS)
  - watershed N model
- Embayment TMDL - Synthesis
  - linked Watershed-Embayment N Model
  - salinity surveys (for linked model validation)
  - rate of N recycling within embayment
  - D.O record
  - Macrophyte survey
  - Infaunal survey

I.2 SITE DESCRIPTION

Rushy Marsh Pond is a simple estuary, with a single embayment and highly restricted tidal inlet. The open water area of ~15 acres, makes Rushy Marsh Pond a great salt pond. The Rushy Marsh Estuarine System presently exchanges tidal water with Nantucket Sound through a 2' pipe running through the barrier beach in the general location of the historic natural

inlet (see Chapter V). The present "inlet" was installed to lower pond levels and to restore tidal exchange that had virtually ceased in late 2002 or early 2003. As mentioned above, the severe tidal restriction of this system has resulted in nitrogen related habitat declines and shifts in wetland communities. For the MEP analysis, Rushy Marsh Pond is the principal estuarine basin in the modeling and thresholds analysis.

Rushy Marsh Pond is currently a brackish embayment with limited tidal exchange with adjacent Nantucket Sound. The basin consists of a drowned kettle pond and is relatively deep (>2m) compared to nearby typical drowned river valley estuaries (e.g. Green Pond, Falmouth, 1m). At present, the embayment is eutrophic and has periodic summer phytoplankton blooms and anoxia. MEP surveys found sediments consistent with eutrophication, i.e. very soft organic/sulfidic muds. The result is a system virtually devoid of benthic animals. The associated wetlands have also been altered as a result of the varying inlet and tidal exchange rates. Salt marsh is no longer found bordering the pond. Brackish wetland plants, principally Phragmites, now fringe the basin with freshwater marsh slightly inland in the northern region. The loss of salt marsh is likely the result of both the freshening of the system (periodically to <1ppt) and to the periodic rise in standing water (several feet), which would "drown" the salt marsh zone under severe tidal restriction or complete blockage.

As management alternatives are being developed and evaluated, it is important to note that the Rushy Marsh System is naturally a relatively dynamic system and has undergone significant alterations to its hydrologic and biological systems over the past 100 years. Within such dynamic systems, restoration alternatives need to be evaluated relative to the system's "maximum level of sustainable environmental health" in addition to traditional standards..

While the nutrient related health of the Rushy Marsh Estuary as it exists today is linked to changes wrought by natural processes and human activities, it is the physical structure of the system laid down by the retreat of the Laurentide Ice Sheet that still controls much of the Systems' tolerance to nutrient inputs. The physical structure, shape and depth of a coastal embayment plays a major role in its susceptibility to ecological impacts from nutrient loading. Physical structure (geomorphology), which includes embayment bathymetry, inlet configuration and saltwater reaches, when coupled with the tidal range of the adjacent open waters, determines the system's rate of flushing. System flushing rate is generally the primary factor for removing nutrients from active cycling within coastal bays and harbors like Rushy Marsh Pond. As a result maximizing system flushing is one of the standard approaches for controlling the nutrient related health of coastal embayments.

The present configuration of the Rushy Marsh Estuary is relatively new in the coastal landscape, as the southern coast of Cape Cod in the vicinity of Rushy Marsh is a moderately dynamic region, where natural wave and tidal forces continue to reshape the shoreline (see Chapters II and V). All the while, Rushy Marsh was formed by the flooding of a kettle pond as a result of rising sea level following the last glaciation, approximately 18,000 years BP. The growth of salt marsh deposits along the northeastern portion of its shore further enclosed the system resulting in the system's classification as a lagoonal type estuary. This system appears to have persisted until the 1890's. USGS maps from 1893 show Rushy Marsh as a fully tidal estuary with salt marsh along its eastern and northern shores. An island exists off shore, Gull Island, which disappeared in about 1896 (Gaines and Fultz 2005). During the 1900's the tidal inlet became restricted due to sedimentation deposits and the formation of a barrier beach. During this period Popponesset Spit elongated, then breached, with the northern portion finally attaching to the shoreline just north of Rushy Marsh around 1960. This formed a cove to

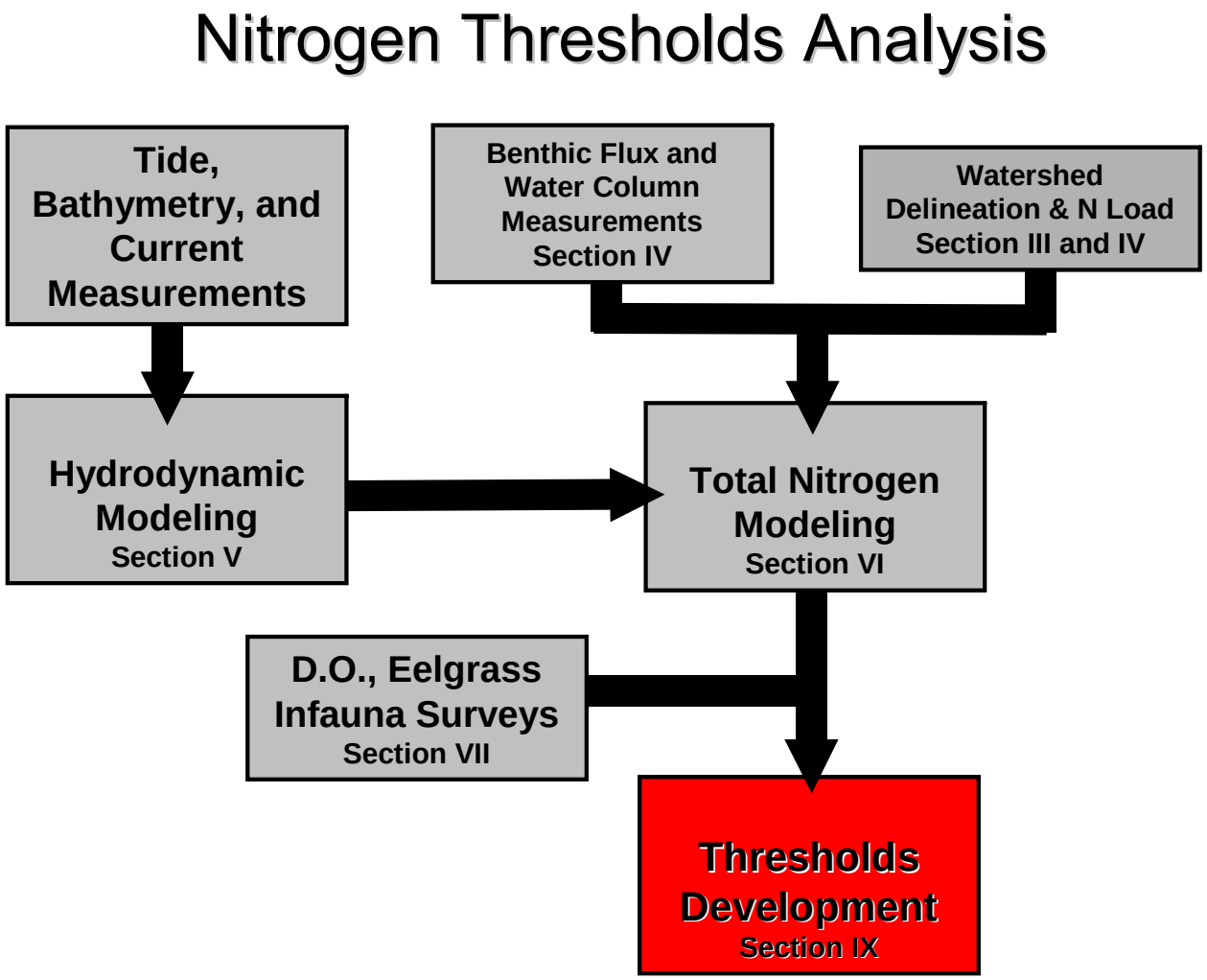


Figure I-2. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

Nantucket Sound running the length of and parallel to Rushy Marsh Pond. Over the next two decades this cove was filled by overwash and today all that remains is a small pond in the barrier beach. However, the process of barrier beach formation and then overwash resulted in a freshening of Rushy Marsh Pond, even with efforts to keep the system tidal (pipes, culverts). By the turn of the century, the system was a brackish salt pond.

While Rushy Marsh Pond presently has a relatively low nitrogen load from its watershed, due to its small size and proportionally large undeveloped areas, it is still significantly impaired by nitrogen enrichment and is clearly eutrophic. This apparent paradox results from its very low tidal exchange rate, resulting from barrier beach processes restricting the inlet to Nantucket Sound. The low rate of tidal exchange serves to greatly increase the nitrogen sensitivity of this system, so that lower nitrogen inputs are needed to cause eutrophic conditions. In recent years the inlet periodically became closed and the pond level rose (due to groundwater inflow) to exceed sea level in the adjacent sound. This also resulted in a further decline in salinity to <1 ppt. The Town of Barnstable (through Conservation Department) working with Friends of Rushy Marsh and Three Bays Preservation partially restored tidal exchange (temporary fix). However, the persistent restricted tidal exchange has caused significant ecological degradation of the Rushy Marsh System. Even with the low watershed nitrogen loading, the low rate of nitrogen removal through tidal flushing results in high nitrogen levels, large phytoplankton blooms and periodic anoxia of bottom waters. In addition, the freshening of the pond waters has resulted in a loss of salt marsh area and a significant expansion of the areal coverage by the common reed, *Phragmites*. It is clear that restoration of Rushy Marsh Pond will require addressing the tidal restriction as one of the principal components, especially as the system has historically operated as a tidal estuary and its proximity to Nantucket Sound prevents its management as a freshwater system due to periodic overwash of salt water (similar to Oyster Pond, Falmouth, see Howes et al., 2005).

By far the greatest changes to the Rushy Marsh Pond watershed have also occurred during the last 100 years. The most obvious change has been the dramatic shift in land-use to residential housing during the last half of the 1900's. With this shift and the advent of fertilized lawns, has come an increase in the amount of nitrogen, which enters the estuary during a period where its sensitivity has increased due to reductions in tidal exchange rates. The previous large shifts in land-use, primarily from forest to agriculture did not have the same resultant enhancement in nitrogen loading, as agriculture generally recycled nitrogen (as opposed to commercial fertilizers) and the population was <10% of today.

The MEP analysis focused on determining the extent to which the environmental health of the Rushy Marsh System will be enhanced by restoration of tidal exchange with the high quality waters of Nantucket Sound, relative to the potential need to manage watershed nutrient loading. The goal of the MEP and the local stakeholders is to restore the estuarine habitats within Rushy Marsh to meet the high level of quality designated by the State Water Quality Standards for the benefit of both present and future generations.

I.3 NUTRIENT LOADING

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the Rushy Marsh System, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even Cape Cod “rivers” are primarily

groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1996, Weiskel and Howes 1992, Smith *et al.* 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within Rushy Marsh Estuary presently follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. This point can be termed the “nutrient threshold” and in estuarine management this threshold sets the target nutrient level for restoration or protection. Because nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 and in press, Ramsey et al., 1995, Howes and Taylor, 1990, and the Falmouth Coastal Overlay Bylaw). While each approach may be different, they all focus on changes in nitrogen loading from watershed to embayment, and aim at projecting the level of increase in nitrogen concentration within the receiving waters. Each approach depends upon estimates of circulation within the embayment; however, few directly link the watershed and hydrodynamic models, and virtually none include internal recycling of nitrogen (as was done in the present effort). However, determination of the “allowable N concentration increase” or “threshold nitrogen concentration” used in previous studies had a significant uncertainty due to the need for direct linkage of watershed and embayment models and site-specific data. In the present effort we have integrated site-specific data on nitrogen levels and the gradient in N concentration throughout the Rushy Marsh System monitored by the Town of Barnstable/Three Bays Preservation Water Quality Monitoring Program, with site-specific habitat quality data (D.O., eelgrass, phytoplankton blooms, benthic animals) utilized to “tune” general nitrogen thresholds typically used by the Cape Cod Commission, Buzzards Bay Project, and Massachusetts State Regulatory Agencies.

Unfortunately, Rushy Marsh Pond is presently beyond its ability to assimilate additional nutrients without impacting their ecological health. This is in significant part due to the very restricted tidal exchange with Nantucket Sound waters. Nitrogen levels are elevated, eelgrass beds have not been observed within Rushy Marsh Pond for the past half century and there are large summer phytoplankton blooms and periodic anoxia of bottom waters. The result is that

nitrogen management of the Rushy Marsh Pond system is aimed at restoration, not protection or maintenance of existing conditions. In general, nutrient over-fertilization is termed "eutrophication" and when the nutrient loading is primarily from human activities, "cultural eutrophication". Although the influence of human-induced changes has increased nitrogen loading to the systems and contributed to the degradation in ecological health, it is sometimes possible that eutrophication within the Rushy Marsh System could potentially occur without man's influence and must be considered in the nutrient threshold analysis. While this finding would not change the need for restoration, it would change the approach and potential targets for management. As part of future restoration efforts, it is important to understand that it may not be possible to turn each embayment into a "pristine" system. In addition, to the impairment of Rushy Marsh Pond's sub-tidal habitats, there has been a loss of emergent salt marsh from the system stemming from the restricted tidal exchange in recent years. Restriction of the tidal inlet has resulted in freshening of the estuarine waters (sometimes to <1ppt) and an increase in both the mean tide level and during closures, the high water level. At present, the wetlands associated with Rushy Marsh are dominated by fresh and brackish water plants, with large areas of the common reed, *Phragmites*. It appears that the tidal restriction is affecting both the subtidal and intertidal resources, albeit through different mechanisms.

I.4 WATER QUALITY MODELING

Evaluation of upland nitrogen loading provides important "boundary conditions" (e.g. watershed derived and offshore nutrient inputs) for water quality modeling of the Rushy Marsh System; however, a thorough understanding of hydrodynamics is required to accurately determine nitrogen concentrations within each system. Therefore, water quality modeling of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. The spread of pollutants may be analyzed from tidal current information developed by the numerical models.

The MEP water quality evaluation examined the potential impacts of nitrogen loading into the Rushy Marsh Pond under a variety of nitrogen input (loading) and hydrodynamic conditions. A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations (both actual and projected under various inlet configurations) was employed. Once the hydrodynamic properties of the estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates.

Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic models were then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis, based upon watershed delineations by USGS using a modification of the West Cape model for sub-watershed areas designated by MEP. Almost all nitrogen entering the Rushy Marsh System is transported by freshwater, almost entirely through groundwater. Concentrations of total nitrogen and salinity of Nantucket Sound source waters and throughout Rushy Marsh Pond were taken from the Water Quality Monitoring Program (a coordinated effort between the Town

of Barnstable, Three Bays Preservation and the Coastal Systems Program at SMAST). Measurements of current salinity and nitrogen and salinity distributions throughout estuarine waters of the Systems (2002-2005) were used to calibrate and validate the water quality model (under existing loading conditions).

I.5 REPORT DESCRIPTION

This report presents the results generated from the implementation of the Massachusetts Estuaries Project linked watershed-embayment approach to the Rushy Marsh System for the Town of Barnstable. A review of existing water quality studies is provided (Section II). The development of the watershed delineations and associated detailed land use analysis for watershed based nitrogen loading to the coastal system is described in Sections III and IV. In addition, nitrogen input parameters to the water quality model are described. Since benthic flux of nitrogen from bottom sediments is a critical (but often overlooked) component of nitrogen loading to shallow estuarine systems, determination of the site-specific magnitude of this component also was performed (Section IV). Nitrogen loads from the watershed and sub-watershed surrounding the estuary were derived from Cape Cod Commission data and offshore water column nitrogen values were derived from an analysis of monitoring stations in Nantucket Sound (Section IV). Intrinsic to the calibration and validation of the linked-watershed embayment modeling approach is the collection of background water quality monitoring data (conducted by municipalities) as discussed in Section IV. Results of hydrodynamic modeling of embayment circulation are discussed in Section V and nitrogen (water quality) modeling, as well as an analysis of how the measured nitrogen levels correlate to observed estuarine water quality are described in Section VI. This analysis includes modeling of current conditions, conditions at watershed build-out, and with removal of anthropogenic nitrogen sources. In addition, an ecological assessment of the component sub-embayments was performed that included a review of existing water quality information and the results of a benthic analysis (Section VII). The modeling and assessment information is synthesized and nitrogen threshold levels developed for restoration of the Estuary in Section VIII. Additional modeling is conducted to produce an example of the type of watershed nitrogen reduction required to meet the determined Bay threshold for restoration. This latter assessment represents only one of many solutions and is produced to assist the Town in developing a variety of alternative restoration options for this system. Finally, analyses of the Rushy Marsh System were relative to potential alterations of circulation and flushing, including an analysis to identify hydrodynamic restrictions and an examination of various inlet options to improve nitrogen related water quality (and wetland communities). The results of the nitrogen modeling for each scenario have been presented (Section IX).

II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

In most marine and estuarine systems, such as Rushy Marsh Pond in the Town of Barnstable, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if nitrogen addition is controlled, then eutrophication is controlled. This approach has been formalized through the development of tools for predicting nitrogen loads from watersheds and the concentrations of water column nitrogen that may result. Additional development of the eutrophication management approaches via the reduction of nitrogen loads has also generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2003).

Until recently, these tools for predicting loads and concentrations tended to be generic in nature and overlooked some of the site-specific characteristics associated with a given water body. The present Massachusetts Estuaries Project (MEP) study focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species. The linked watershed-embayment model is built using embayment specific measurements, thus enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including Rushy Marsh Pond.

A number of studies have been performed regarding the south shore of Cape Cod geomorphology. Specific to Rushy Marsh Pond, two Woods Hole Oceanographic Institution reports: Aubrey and Gaines (1982) and Aubrey and Goud (1983) illustrated the historic processes governing tidal exchange over the past 100 years. For the Rushy Marsh estuarine system, the process of barrier spit elongation and breaching has had a significant influence on tidal exchange, even though the barrier spit is part of the adjacent Popponesset Bay System to the west. Over the past 100 years, the Popponesset Beach barrier elongation and breaching processes have governed the stability of the Rushy Marsh inlet. Between the late 1800s and 1950, the Popponesset barrier elongated past the Rush Marsh tidal inlet. Due to the influx of sediment associated with this barrier elongation, the natural tidal inlet to Rushy Marsh closed. As described in Aubrey and Goud (1983), the loss of nearly one-half of the Popponesset Beach barrier between 1954 and the early 1980s led to concerns regarding future barrier spit migration. According to Aubrey and Gaines (1982), the present spit length has been historically the stable configuration. It wasn't until after about 1860 that the spit began to grow past its present location.

As the barrier spit elongated between the early 1900s and the mid-1950s due to regional littoral drift, the inlet channel to Popponesset Bay became less efficient, where the tide height within Popponesset Bay decreased and the lag time between high tide in the estuary and Nantucket Sound increased. This increase in tidal attenuation was remedied in 1954, when a hurricane breached the barrier spit, creating an efficient inlet to Popponesset Bay in the vicinity of the present inlet. Once the spit had breached, the remnants of the spit east of the inlet gradually overwashed and rejoined the shoreline (primarily in the vicinity of Rushy Marsh). This inlet spit growth and breaching process has been documented extensively for the southeastern coast of Massachusetts (e.g. Fitzgerald, 1993).

The specific influence of barrier elongation and breaching upon the Rushy Marsh system was described in a report to the Town of Barnstable prepared by the Coast & Harbor Institute and Robert L. Fultz Associates (2002). Although the inlet to Rushy Marsh had naturally closed

in the early 1900s, the influx of littoral sediment caused by the 1954 breach of the Popponesset barrier further widened the barrier beach system fronting Rushy Marsh. Efforts to maintain an effective inlet near the southern end of the Pond have been complicated by the unstable nature of the shoreline, the relatively weak littoral drift that continues to supply sediment to this region, and the small potential tidal prism exiting Rushy Marsh. Based upon limited sampling of water quality parameters (dissolved oxygen, salinity, and turbidity), Coast & Harbor Institute and Robert L. Fultz Associates concluded that the pond productivity is moderate or low, and the poor water clarity might be a result of tannins in the water, rather than algal accumulation.

As the stakeholder to the Rushy Marsh Pond System, the Town of Barnstable and its citizens have been active in promoting restoration of this system. This local concern also led to the establishment, in 2002, of a nitrogen related water quality monitoring program for Rushy Marsh by Three Bays Preservation. The program was an extension of the effort for the adjacent Three Bays Estuary. The Three Bays/Rushy Marsh Water Quality Monitoring Program was provided technical assistance by the Coastal Systems Program at SMAST-UMD and over the past several years has been incorporated into Barnstable's Town-wide embayment monitoring program. The initial findings of the monitoring program are that Rushy Marsh Pond is currently impaired by nitrogen enrichment (i.e. eutrophic). As a result of the restriction of tidal exchange nitrogen entering the system is generally recycled rather being flushed out to Nantucket Sound. The result is elevated nitrogen levels, phytoplankton blooms, macroalgal accumulations and periodic depletion of dissolved oxygen in bottom waters. In addition, restriction of tidal exchange allows the pond to freshen and at present Rushy Marsh Pond is a brackish salt pond only periodically attaining ½ strength seawater salinities.

As part of on-going research and engineering efforts related to Rushy Marsh Pond, the geologic history of the pond was determined as was the recent history of shoreline change (See Section V). The short and long term trends in coastal processes as relate to the ecological health of Rushy Marsh Pond set an important background for the present restoration and management of this system. The Three Bays/Rushy Marsh Water Quality Monitoring Program provides the quantitative watercolumn nitrogen data (2002-2005) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study. In addition, for the MEP modeling analysis, the data from the previous studies were evaluated relative to the needs of the Linked Watershed-Embayment Model.

III. DELINEATION OF WATERSHEDS

III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). The USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. The USGS has a long history of developing regional models for the six-groundwater flow cells on Cape Cod. Through the years, advances in computing, lithologic information from well installations, water level monitoring, stream flow measurements, and reconstruction of glacial history have allowed the USGS to update and refine the groundwater models. The MODFLOW and MODPATH models utilized by to the USGS to organize and analyze the available data utilize up-to-date mathematical codes and create better tools to answer the wide variety of questions related to watershed delineation, surface water/groundwater interaction, groundwater travel time, and drinking water well impacts that have arisen during the MEP analysis of southeastern Massachusetts estuaries, including the Rushy Marsh embayment system. The Rushy Marsh Pond System and its watershed is fully located within the Town of Barnstable, Massachusetts and is situated between Popponesset Bay to the west and Three Bays to the east.

In the present investigation, the USGS was responsible for the application of its groundwater modeling approach to define the watershed or contributing area to the Rushy Marsh Pond system under evaluation by the Project Team. Unlike larger estuaries, Rushy Marsh did not require additional modeling to sub-divide the overall watershed into functional sub-units based upon: (a) defining inputs from contributing areas to each major portion within the embayment system, (b) defining contributing areas to major freshwater aquatic systems which generally attenuate nitrogen passing through them on the way to the estuary (lakes, streams, wetlands), and (c) defining 10 year time-of-travel distributions within each sub-watershed as a procedural check to gauge the potential mass of nitrogen from “new” development, which has not yet reached the receiving estuarine waters. The Rushy Marsh Pond embayment functions as a single horizontally mixed basin. There are no public water supply wells or “significant” streams or fresh ponds (e.g. >10 acres or which capture large amounts of groundwater) within its watershed. Furthermore, given the relatively small watershed, all of the recharged groundwater reaches the estuary in less than 10 years. Therefore a single watershed was used for the Linked Watershed-Embayment Management Model. Rushy Marsh Pond is similar to the larger Oyster Pond Estuary in Falmouth.

The relatively transmissive sand and gravel deposits that comprise most of Cape Cod create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by the land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994a,b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the sources of nitrogen that they carry requires determination of the portion of the watershed that contributes directly to the stream and the portion of the groundwater system that discharges directly into the estuary as groundwater seepage. In the case of Rushy Marsh Pond, direct groundwater discharge was the sole pathway, although a stream may have existed prior to road construction. A field survey did not find any surface water inflow to the Pond of sufficient flow (generally ~0.0005 m^3 s^{-1} is required) to support a MEP stream gauge.

III.2 MODEL DESCRIPTION

Contributing areas to the Rushy Marsh system and local freshwater bodies were delineated using a regional model of the Sagamore Lens (Walter and Whealan, 2005). The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh et al., 2000) was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program MODPATH4 (Pollock, 2000), which uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. This approach was used to determine the contributing areas to the Rushy Marsh Pond basin.

The Sagamore Flow Model grid consists of 246 rows, 365 columns and 20 layers. The horizontal model discretization, or grid spacing, is 400 by 400 feet. The top 17 layers of the model extend to a depth of 100 feet below NGVD 29 and have a uniform thickness of 10 ft. Layers 1-7 are stacked above NGVD 29 and layers 8 to 20 extend below. Layer 18 has a thickness of 40 feet and layer 19 extends to 240 feet below sea level. The bottom layer, layer 20, extends to the bedrock surface and has a variable thickness depending upon site characteristics. The rewetting capabilities of MODFLOW-2000, which allows drying and rewetting of model cells, was used to simulate the top of the water table, which varies in elevation depending on the location in the Lens. Since the Rushy Marsh Pond watershed is relatively distant from the top portion of the Sagamore Lens (i.e. it is near the coast), most of the uppermost layers of the groundwater model are inactive in its delineation.

The glacial sediments that comprise the aquifer of the Sagamore Lens consist of gravel, sand, silt, and clay that were deposited in a variety of depositional environments. The sediments generally show a fining downward with sand and gravel deposits deposited in glaciofluvial (river) and near-shore glaciolacustrine (lake) environments underlain by fine sand, silt and clay deposited in deeper, lower-energy glaciolacustrine environments. Most groundwater flow in the aquifer occurs in shallower portions of the aquifer dominated by coarser-grained sand and gravel deposits. The Rushy Marsh watershed is situated in the midst of the very-coarse grained Mashpee Pitted Plain deposits (Masterson et al., 1996). Lithologic data used to determine hydraulic conductivities used in the groundwater model were obtained from a variety of sources including well logs from USGS, local Town records and data from previous investigations. Final aquifer parameters were determined through calibration to observed water levels and stream flows. Hydrologic data used for model calibration included historic water-level data obtained from USGS records and local Towns and water level and streamflow data collected in May 2002.

The model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Large withdrawals of groundwater from pumping wells may have a significant influence on water tables and watershed boundaries and therefore the flow and distribution of nitrogen within the aquifer. After accounting for the 15% consumptive loss and measured discharge at municipal treatment facilities, water withdrawn from the modeled aquifer by public drinking water supply wells is evenly returned within designated residential areas utilizing on-site septic systems. Since the watershed to Rushy Marsh is lacking municipal sewers, this area is part of the Barnstable residential area in the groundwater model.

III.3 RUSHY MARSH POND CONTRIBUTORY AREA

Newly revised watershed and sub-watershed boundaries for the Rushy Marsh Estuary were determined by the United States Geological Survey (USGS). Model outputs of MEP watershed boundaries were "smoothed" to (a) correct for the grid spacing, (b) to enhance the accuracy of the characterization of the pond and coastal shorelines, and (c) to more closely match the sub-embayment segmentation of the tidal hydrodynamic model. The smoothing refinement was a collaborative effort between the USGS and the rest of the MEP Technical Team. This task was simplified for Rushy Marsh Pond as the contributing area is best represented as a single watershed and no great fresh ponds (>10 acres) are present. However, the USGS modeled output did require accounting for the grid spacing and incorporation of correct shoreline configuration (Figure III-1).

The daily discharge volume for the watershed was calculated by the groundwater model and the volume was used to assist in the salinity calibration of the tidal hydrodynamic models The MEP delineation determined that groundwater travel times were less than 10 yrs throughout the watershed.

The Rushy Marsh watershed from the USGS modeling effort is estimated to have an average annual freshwater discharge of 249,247 m^3 yr^{-1} to Rushy Marsh Pond. This estimate agrees well with estimates of freshwater input (watershed plus rainfall) calculated from a simple mixing model and measured dilution rates of Rushy Marsh Pond salinities (September 2002 through July 2003), when inputs of tidal water to the Pond were negligible. The freshwater estimate from the salinity dilution model was ~20% less than from the groundwater inflow and net rainwater inputs. However, this most likely results from salt diffusion from the pond sediments or slight amounts of tidal water entering over the sampling interval. The freshwater input estimates based upon salinity dilution were similar for both short (~1 month) and long (9 month) intervals. These data support the areal extent of the watershed delineation from the USGS groundwater model. The watershed delineation completed for the MEP project is the first for the Rushy Marsh Estuary.

The groundwater modeling approach to watershed delineation allows the Rushy Marsh delineation to be brought into congruence with adjacent watersheds and their supporting data. The evaluation of the Rushy Marsh watershed on the local and sub-regional scales (including the incorporation of new and old data) is important as it decreases the level of uncertainty in the final calibrated and validated linked watershed-embayment model used for the evaluation of nitrogen management alternatives. Errors in watershed delineations do not necessarily result in proportional errors in nitrogen loading as errors in loading depend upon the land-uses that are included/excluded within the contributing areas. Small errors in watershed area can result in large errors in loading if a large source is counted in or out. Conversely, large errors in watershed area that involve only natural woodlands have little effect on nitrogen inputs to the downgradient estuary.

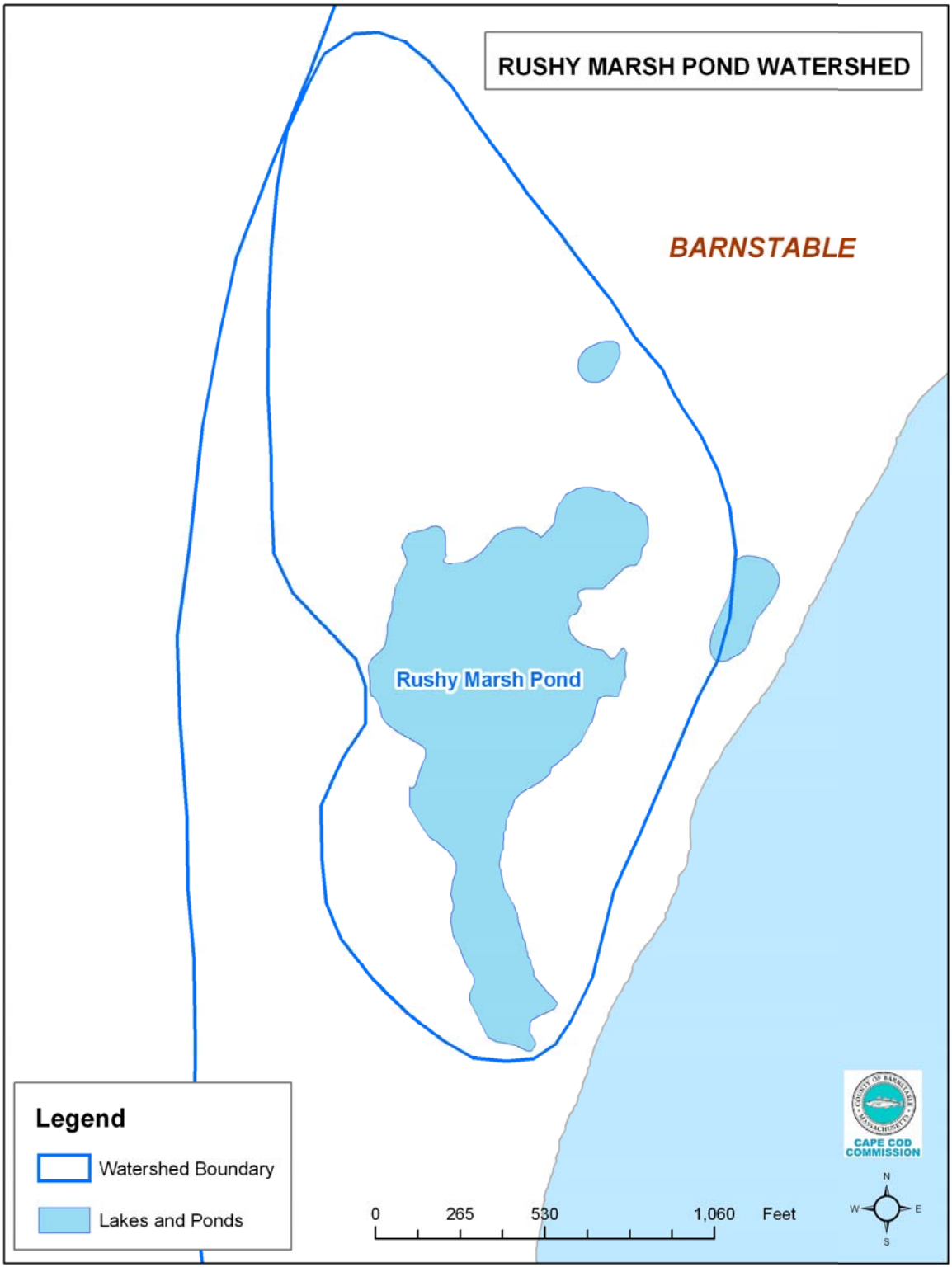


Figure III-1. Watershed delineation for the Rushy Marsh Estuary. All recharge reaches the estuary within ten years. A single watershed to the embayment was selected based upon the functional estuarine unit in the water quality model (see Chapter VI). The Popponesset Bay watershed is to the west.

IV. WATERSHED NITROGEN LOADING TO EMBAYMENT: LAND USE, STREAM INPUTS, AND SEDIMENT NITROGEN RECYCLING

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS

Management of nutrient related water quality and habitat health in coastal waters requires determination of the amount of nitrogen transported by freshwaters (surface water flow, groundwater flow) from the surrounding watershed to the receiving embayment of interest. In southeastern Massachusetts, the nutrient of management concern for estuarine systems is nitrogen and this is true for the Rushy Marsh Pond system. Determination of watershed nitrogen inputs to these embayment systems requires the (a) identification and quantification of the nutrient sources and their loading rates to the land or aquifer, (b) confirmation that a groundwater transported load has reached the embayment at the time of analysis, and (c) quantification of nitrogen attenuation that can occur during travel through lakes, ponds, streams and marshes. This latter natural attenuation process results from biological processes that naturally occur within ecosystems. Failure to account for attenuation of nitrogen during transport results in an over-estimate of nitrogen inputs to an estuary and an underestimate of the sensitivity of a system to new inputs (or removals). In addition to the nitrogen transport from land to sea, the amount of direct atmospheric deposition on each embayment surface must be determined as well as the amount of nitrogen recycling within the embayment, specifically nitrogen regeneration from sediments. Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms, which may be released to the overlying waters or lost to denitrification within the sediments. Burial of nitrogen is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters and leads to errors in predicting water quality if it is not included in determination of summertime nitrogen load.

The MEP Technical Team includes technical staff from the Cape Cod Commission (CCC). In coordination with other MEP technical team staff, CCC staff developed nitrogen loading rates (Section IV.1) to the Rushy Marsh embayment system (Section III). The Rushy Marsh contributing area is all within 10 years time-of-travel and includes only direct discharge to the estuary (e.g. no streams or great fresh ponds). The nitrogen loading effort also involved further refinement of watershed delineations to accurately reflect shoreline areas to the embayment (see Chapter III).

The initial task in the MEP land use analysis is to gauge whether or not nitrogen discharges to the watershed have reached the embayment. This involves a temporal review of land use changes and the time of groundwater travel provided by the USGS watershed model. As mentioned above, all of the watershed to Rushy Marsh is within 10 years worth of groundwater flow (Figure IV-1). After reviewing land use development records, and water quality modeling, it was determined that the present watershed nitrogen load appears to accurately reflect the present nitrogen sources to the estuaries.

In order to determine nitrogen loads from the watershed detailed individual lot-by-lot data is used for some portion of the loads, while information developed from other detailed studies is applied to other portions of the watershed. The Linked Watershed-Embayment Management Model (Howes and Ramsey 2001) uses a land-use Nitrogen Loading Sub-Model based upon subwatershed-specific land-uses and pre-determined nitrogen loading rates. For the Rushy

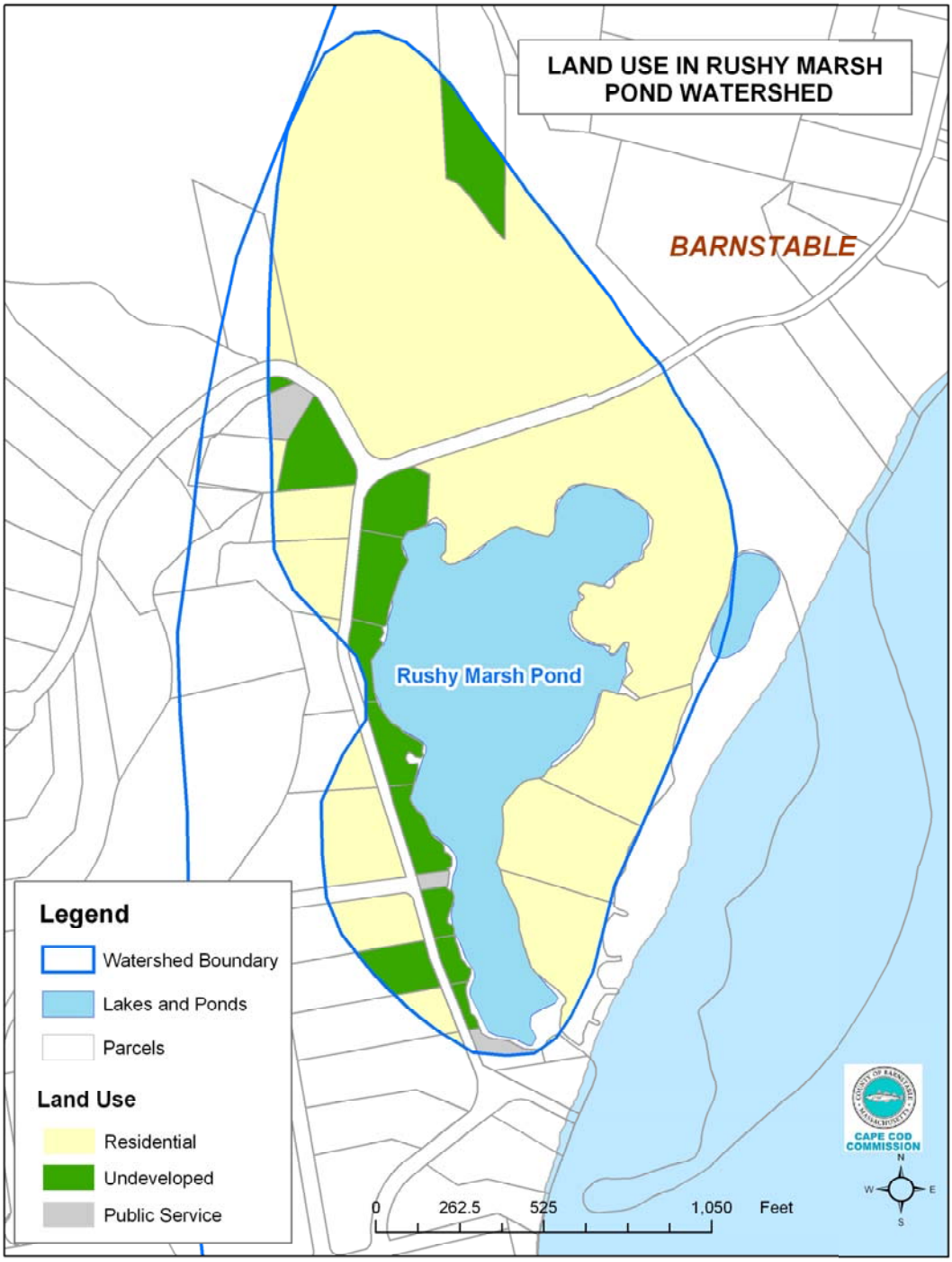


Figure IV-1. Land-use coverage in the Rushy Marsh watershed. Land use classifications are based on assessors' records provided by the Town of Barnstable. Note the shoreline overlaying the water of Nantucket Sound represents the shoreline of 19XX, while the present barrier beach shoreline is shown to the west (white/blue interface). The small pond in the barrier beach is all that remains today of the larger cove created by the spit.

Marsh embayment system, the model used Town of Barnstable specific land-use data transformed to nitrogen loads using both regional nitrogen load factors and local watershed-specific data (such as parcel by parcel water use). Determination of the nitrogen loads required obtaining watershed-specific information regarding wastewater, fertilizers, runoff from impervious surfaces and atmospheric deposition. The primary regional factors were derived for southeastern Massachusetts from direct measurements. The resulting nitrogen loads represent the "potential" nitrogen load to each receiving embayment, since attenuation during transport has not yet been included.

Based upon the lack of streams or great ponds (>10 acres) within the Rushy Marsh Pond watershed, natural attenuation of nitrogen during transport from land-to-sea (Section IV.2) was determined to be negligible. Natural attenuation during stream transport or in passage through fresh ponds of sufficient size to effect groundwater flow patterns (area and depth) is a standard part of the data collection effort of the MEP. However, even if attenuation of nitrogen is occurring during transport, given the distribution of the nitrogen sources and small ponds that do exist within the watershed, nitrogen loading to the estuary would only be slightly (~10%) overestimated. Based upon these considerations, the MEP Technical Team used the conservative estimate of nitrogen loading based upon direct groundwater discharge. Internal nitrogen recycling was also determined throughout the tidal reach of the Rushy Marsh embayment; measurements were made to capture the spatial distribution of sediment nitrogen regeneration from the sediments to the overlying water-column. Nitrogen regeneration focused on summer months, the critical nitrogen management interval and the focal season of the MEP approach and application of the Linked Watershed-Embayment Management Model (Section IV.3).

IV.1.1 Land Use and Water Use Database Preparation

Estuaries Project staff obtained digital parcel and tax assessors data from the Town of Barnstable. Digital parcel and land use data are from 2004 and were obtained from the Town of Barnstable GIS Unit. These land use databases contain traditional information regarding land use classifications (Massachusetts DOR, 2002) plus additional information developed by the Town. The parcel coverages and assessors' database were combined for the MEP analysis by using the Cape Cod Commission Geographic Information System (GIS).

Figure IV-1 shows land uses within the watershed area contributing freshwater and nitrogen to the Rushy Marsh estuarine waters. Land use in the Rushy Marsh Pond watershed is one of four land use types: 1) residential, 2) undeveloped, 3) agricultural, and 4) public service/government, including road rights-of-way. "Public service" is the land classification assigned by the Massachusetts Department of Revenue to tax exempt properties, including lands owned by government (e.g., wellfields, schools, open space, roads) and private groups like churches and colleges. Massachusetts Assessors land uses classifications (MADOR, 2002), which are common to all towns were are aggregated into these four land use categories.

In the Rushy Marsh watershed, the predominant land use based on area is residential, which accounts for 79% (70.1 acres) of the watershed area; undeveloped land is the second highest percentage of the watershed (11%). In addition, 38% of the parcels in the system watershed are classified as single family residences (MADOR land use code 101) and single family residences account for 97% of the residential land area. There are no properties classified as commercial or industrial in the Rushy Marsh watershed, and there are no municipal well areas. The remaining 9% of the land-use is divided between public service (roads, rights-of-way) and agriculture, 5% and 4%, respectively (Figure IV-2).

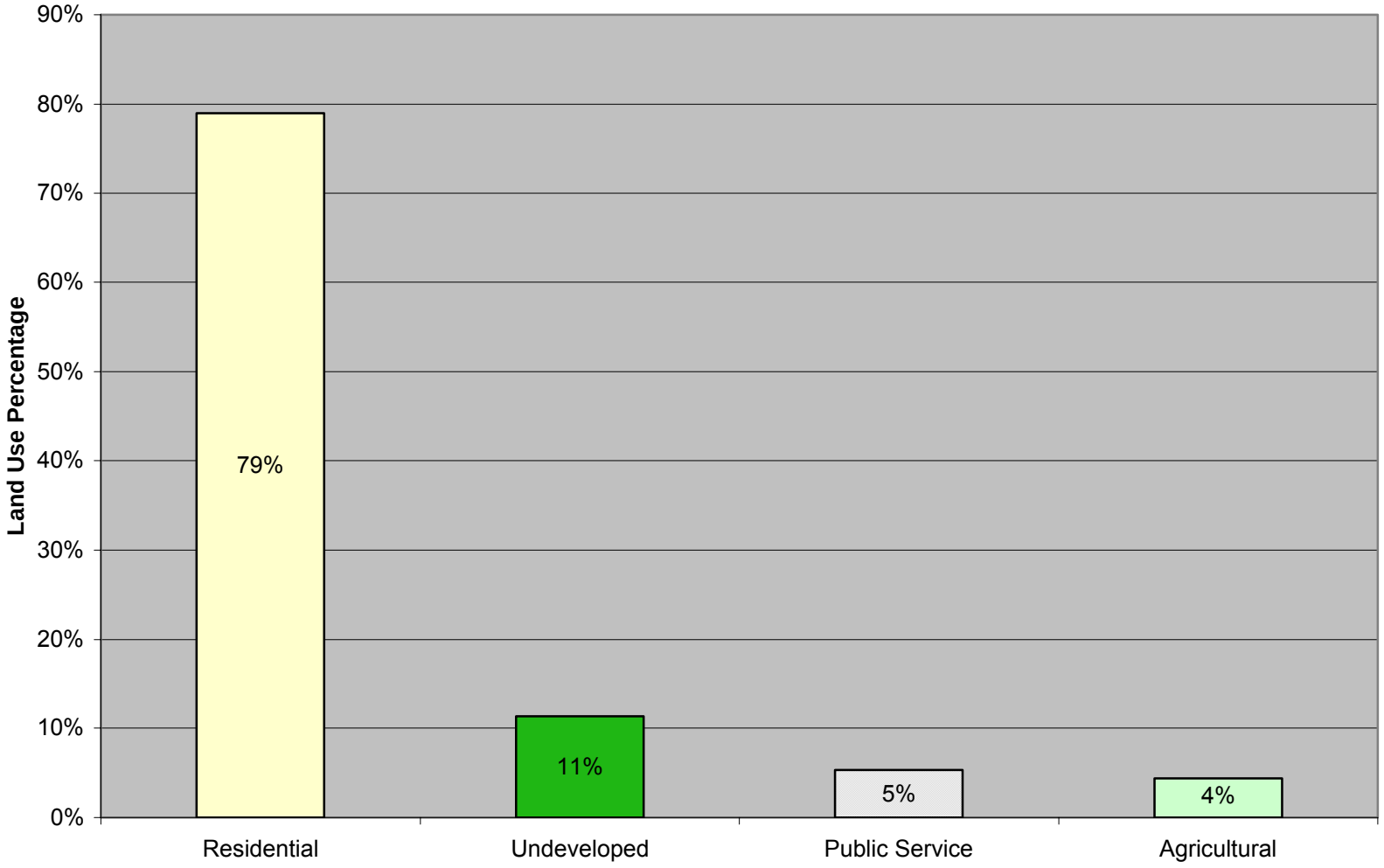


Figure IV-2. Distribution of land-uses within the Rushy Marsh watershed. Single family residential parcels make up 97% of the residential land-use.

In order to estimate wastewater flows within the Rushy Marsh Pond watershed, MEP staff also obtained parcel by parcel water use information for the Cotuit Water District from the Town of Barnstable GIS Unit. The Cotuit water use data is for one year (October 2002 through October 2003). Water use information was linked to the parcel and assessors data using GIS techniques. Water use for each parcel was converted to an annual volume for purposes of the nitrogen loading calculations. All parcels use on-site septic treatment and disposal of wastewater as there are no municipal wastewater treatment facilities (WWTFs) in the Rushy Marsh watershed.

As noted previously, all wastewater within the Rushy Marsh Pond watershed is returned to the aquifer through individual on-site septic systems. Wastewater-based nitrogen loading from the individual parcels using on-site septic systems is based upon the measured water-use, nitrogen concentration, and an assumed consumptive loss of water before the remainder is treated in a septic system. All wastewater in the Rushy Marsh watershed is returned to the aquifer through septic systems.

IV.1.2 Nitrogen Loading Input Factors

Wastewater/Water Use

Similar to many other watershed nitrogen loading analyses, the Massachusetts Estuaries Project septic system nitrogen loading rate is fundamentally based upon a per Capita Nitrogen load to the receiving aquatic system. Specifically, the MEP septic system wastewater nitrogen loading is based upon directly measured septic system and per capita loads determined on Cape Cod or in similar geologic settings (Nelson et al. 1990, Weiskel & Howes 1991, 1992, Koppelman 1978, Frimpter et al. 1990, Brawley et al. 2000, Howes and Ramsey 2001, Costa et al. 2002). Variation in per capita nitrogen load has been found to be relatively small, with average annual per capita nitrogen loads generally between 1.9 to 2.3 kg person-yr^{-1}. However, given the seasonal shifts in occupancy in many of the watersheds throughout southeastern Massachusetts, census data yields accurate estimates of total population only in specific watersheds (see below). To correct for this uncertainty, the MEP employs a water-use approach. The water-use approach (Weiskel and Howes 1992) is applied on a parcel-by-parcel basis within a watershed, where usually an average of multiple years annual water meter data is linked to assessors parcel information using GIS techniques. The parcel specific water use data is converted to septic system nitrogen discharges (to the receiving aquatic systems) by adjusting for consumptive use (e.g. irrigation) and applying a wastewater nitrogen concentration. The water use approach focuses on the nitrogen load, which reaches the aquatic receptors down-gradient in the aquifer. All losses within the septic system are incorporated. For example, information developed at the DEP Alternative Septic System Test Center at the Massachusetts Military Reservation on Title 5 septic systems have shown nitrogen removals between 21% and 25%. Multi-year monitoring from the Test Center has revealed that nitrogen removal within the septic tank was small (1% to 3%), with most (20 to 22%) of the removal occurring within five feet of the soil adsorption system (Costa et al. 2002). Aquifer studies indicate that further nitrogen loss during aquifer transport is negligible (Robertson et al. 1991, DeSimone and Howes 1996).

In its application of the water-use approach to septic system nitrogen loads, the MEP has ascertained for the Estuaries Project region that while the per capita septic load is well constrained by direct studies, the consumptive use and nitrogen concentration data are less certain. As a result, the MEP has derived a combined term the effective N Loading Coefficient (consumptive use times N concentration) of 23.63, to convert water (per cubic meter) to nitrogen load (N grams). This term uses a per capita nitrogen load of 2.1 kg N person-yr^{-1} and is based

upon direct measurements and corrects for changes in concentration that result from per capita shifts in water-use (e.g. due to installing low plumbing fixtures or high versus low irrigation usage, etc.).

The resulting nitrogen loads, based upon the above approach have been validated in a number of long and short term field studies where integrated measurements of nitrogen discharge from watersheds could be directly measured. For example, Weiskel and Howes (1991, 1992) conducted a detailed watershed/stream tube study that monitored septic systems, leaching fields and the transport of the nitrogen in groundwater to adjacent Buttermilk Bay. This monitoring resulted in estimated annual per capita nitrogen loads of 2.17 kg (as published) to 2.04 kg (if new attenuation information is included). The selected "effective N loading coefficient" also agrees with available watershed nitrogen loading analyses conducted on other Cape Cod estuaries. Aside from the concurrence observed between modeled and observed nitrogen concentrations in the estuary analyses completed under the MEP, analyses of other estuaries completed using this effective septic system nitrogen loading coefficient, the modeled loads also match observed concentrations in streams in the MEP region. Modeled and measured nitrogen loads were determined for a small sub-watershed to West Falmouth Harbor (Smith and Howes 2006) where a small stream drained the aquifer from a residential neighborhood. In this effort, the measured nitrogen discharge from the aquifer was within 5% of the modeled N load. A second evaluation was conducted by surveying nitrogen discharge to the Mashpee River in reaches with swept sand channels and in winter when nitrogen attenuation is minimal. The measured and observed loads showed a difference of less than 8%, easily attributable to the low rate of attenuation expected at that time of year and under the ecological situation (Samimy and Howes unpublished data).

While census based population data has limitations in the highly seasonal MEP region, part of the regular MEP analysis is to compare expected water used based on average residential occupancy to measured average water uses. This is performed as a quality assurance check to increase certainty in the final results. This comparison has shown that the larger the watershed the better the match between average water use and occupancy. For example, in the cases of the combined Great Pond, Green Pond and Bournes Pond watershed in the Town of Falmouth and the Popponesset Bay/Eastern Waquoit Bay watershed, which cover large areas and have significant year-round populations, the septic nitrogen loading based upon the census data is within 5% of that from the water use approach. This comparison matches some of the variability seen in census data itself, census blocks, which are generally smaller areas of the towns, have shown up to a 13% difference in average occupancy from town-wide occupancy rates. These analyses provide additional support for the use of the water use approach in the MEP study region.

Overall, the MEP water use approach for determining septic system nitrogen loads has been both calibrated and validated in a variety of watershed settings. The approach: (a) is consistent with a suite of studies on per capita nitrogen loads from septic systems in sandy outwash aquifers; (b) has been validated in studies of the MEP Watershed "Module", where there has been excellent agreement between the nitrogen load predicted and that observed in direct field measurements corrected to other MEP Coefficients for stormwater, lawn fertilization, etc; (c) the MEP septic nitrogen loading coefficient agrees in specific studies of consumptive water use and N attenuation between the septic tank and the discharge site; and (d) the watershed module provides estimates of nitrogen attenuation by freshwater systems that are consistent with a variety of ecological studies. It should be noted that while points b-d support the use of the MEP Septic N Coefficient, they were not used in its development. The MEP Technical Team has worked out the septic system nitrogen load over many years, and the

general agreement among the number of supporting studies has greatly enhanced the certainty of this critical watershed nitrogen loading term.

The independent validation of the water quality model (Section VI) and the reasonableness of the freshwater attenuation (Section IV.2) add additional weight to the nitrogen loading coefficients used in the MEP analyses and a variety of other MEP embayments. While the MEP septic system nitrogen load is the best estimate possible, it is also conservative in watersheds dominated by residential land-uses. Sensitivity analysis by MEP Technical Team showed that higher septic nitrogen loading factors (up to 33% larger), resulted in only slight changes in the required nitrogen removal (estimated at 1% to 5% lower)), to lower embayment nitrogen levels to a nitrogen target (e.g. nitrogen threshold, cf. Section VIII.

The independent validation of the water quality model (Section VI) and the reasonable assumption regarding the lack of the freshwater attenuation in the Rushy Marsh Pond watershed (Section IV.2) add additional weight to the nitrogen loading coefficients used in the MEP analyses and a variety of other MEP embayments. While the MEP septic system nitrogen load is the best estimate possible, to the extent that it may underestimate the nitrogen load from this source reaching receiving waters provides a safety factor relative to other higher loads that are generally used in regulatory situations.

Water use in the Rushy Marsh watershed is somewhat different than for many of the watersheds in the MEP region because of the comparatively low number of parcels. The average water use among the eight single family residences in the Rushy Marsh watershed is 426 gpd; further evaluation of this number found that the average water use per thousand square feet of building is 110 gpd. When this is multiplied by the average size single family residence determined for Mashpee in a previous MEP study (1,500 sq. ft.), the average flow is 166 gpd; this flow more closely approximates average single family residential flow in most previous MEP watershed analyses and is appropriate for use in determining flow from additional properties determined from the buildout assessment and the one residence without water use information in the Rushy Marsh watershed.

In order to provide an independent validation of the residential water use average within the study areas, MEP staff reviewed US Census population values. The state on-site wastewater regulations (*i.e.*, 310 CMR 15, Title 5) assume that two people occupy each bedroom and each bedroom has a wastewater flow of 110 gallons per day (gpd), so each person generates 55 gpd of wastewater. Average occupancy within the Town of Barnstable during the 2000 US Census was 2.44 people per household. If the Barnstable average of 2.44 is multiplied by 55 gpd, the average residential wastewater flow in the Rushy Marsh watershed would be 134 gpd. The adjusted flow in the Rushy Marsh watershed is a fairly good match with this simple check on the water use data.

Nitrogen Loading Input Factors: Fertilized Areas

The second largest source of estuary watershed nitrogen loading is usually fertilized lawns and golf courses, with lawns being the predominant source within this category. In order to add this source to the nitrogen loading model for the Rushy Marsh system, MEP staff reviewed available information about residential lawn fertilizing practices.

Residential lawn fertilizer use has rarely been directly measured in watershed-based nitrogen loading investigations. Instead, lawn fertilizer nitrogen loads have been estimated based upon a number of assumptions: a) each household applies fertilizer, b) cumulative annual

applications are 3 pounds per 1,000 sq. ft., c) each lawn is 5000 sq. ft., and d) only 25% of the nitrogen applied reaches the groundwater (leaching rate). Because many of these assumptions had not been rigorously reviewed in over a decade, the MEP Technical Staff undertook an assessment of lawn fertilizer application rates and a review of leaching rates for inclusion in the Watershed Nitrogen Loading Sub-Model.

The initial effort was to determine nitrogen fertilization rates for residential lawns in the Towns of Falmouth, Mashpee and Barnstable. The assessment accounted for proximity to fresh ponds and embayments. Based upon ~300 interviews and over 2,000 site surveys, a number of findings emerged: 1) average residential lawn area is ~5000 sq. ft., 2) half of the residences did not apply lawn fertilizer, and 3) the weighted average application rate was 1.44 applications per year, rather than the 4 applications per year recommended on the fertilizer bags. Integrating the average residential fertilizer application rate with a leaching rate of 20% resulted in a fertilizer contribution of N to groundwater of 1.08 lb N per residential lawn for use in the nitrogen loading calculations. It is likely that this still represents a conservative estimate of nitrogen load from residential lawns. It should be noted that professionally maintained lawns were found to have the higher rate of fertilization application and hence higher estimated loss to groundwater of 3 lb/lawn/yr. Only residential fertilizer applications are included in the Rushy Marsh nitrogen loading.

Nitrogen Loading Input Factors: Other

The nitrogen loading factors for atmospheric deposition, impervious surfaces and natural areas are from the MEP Embayment Modeling Evaluation and Sensitivity Report (Howes and Ramsey 2001). The factors are similar to those utilized by the Cape Cod Commission's Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and Massachusetts DEP's Nitrogen Loading Computer Model Guidance (1999). The recharge rate for natural areas and lawn areas is the same as utilized in the MEP-USGS groundwater modeling effort (Section III). Cranberry bog fertilizer application rate and percent nitrogen attenuation in the bogs is based on the only annual study of nutrient cycling and loss from cranberry agriculture (Howes and Teal, 1995). Only the bog loses measurable nitrogen, the forested upland release only very low amounts. For the land-use N loading analysis, the areas of active bog surface are based on 85% of the total property area with cranberry bog land use codes. Factors used in the nitrogen loading analysis for the Rushy Marsh Pond watershed are summarized in Table IV-1.

Table IV-1. Primary Nitrogen Loading Factors used in the Rushy Marsh MEP analysis. General factors are from MEP modeling evaluation (Howes and Ramsey 2001). Site-specific factors are derived from Town of Barnstable data. *Data from MEP lawn study in Falmouth, Mashpee & Barnstable 2001.

Nitrogen Concentrations:	mg/l
Road Run-off	1.5
Roof Run-off	0.75
Direct Precipitation on Embayments and Ponds	1.09
Natural Area Recharge	0.072
Wastewater Coefficient	23.63
Fertilizer:	
Average Residential Lawn Size (ft^2)*	5,000
Residential Watershed Nitrogen Rate (lbs/lawn)*	1.08
Nitrogen Fertilizer Rate for golf courses, cemeteries, and public parks determined by site-specific information	

Recharge Rates:	in/yr
Impervious Surfaces	40
Natural and Lawn Areas	27.25

Water Use/Wastewater:	
Rushy Marsh Residential Parcels Wo/water accounts and Buildout additions	166 gpd
For Commercial Properties wo/water accounts and Buildout additions:	18 gpd/1,000 ft^2 of building
For Parcels w/water accounts:	Measured annual water use
Average percentage of lot occupied by commercial dwelling = 28 percent	

IV.1.3 Calculating Nitrogen Loads

Once all the land and water use information was linked to the parcel coverages, parcels were assigned to various watersheds based initially on whether at least 50% or more of the land area of each parcel was located within a respective watershed. Following the assigning of boundary parcels, all large parcels were examined individually and were split (as appropriate) in order to obtain less than a 2% difference between the total land area of each subwatershed and the sum of the area of the parcels within each subwatershed. The resulting "parcelized" watersheds to Rushy Marsh are shown in Figure IV-3.

The review of individual parcels straddling watershed boundaries included corresponding reviews and individualized assignment of nitrogen loads associated with lawn areas, septic systems, and impervious surfaces. Individualized information for parcels with atypical nitrogen loading (condominiums, WWTFs, etc.) were also assigned at this stage. It should be noted that small shifts in nitrogen loading due to the above assignment procedure generally have a negligible effect on the total nitrogen loading to an overall estuary. However, in the case of Rushy Marsh, the limited number of parcels suggests that individual parcel assignment could have a significant impact on the total nitrogen loading. In order to ensure accurate assignment, MEP staff reviewed aerial photography to assess cleared locations close to houses likely to be the location of septic system leach fields. The assignment effort was undertaken to better define the sub-embayment loads and enhance the use of the Linked Watershed-Embayment Model for the analysis of management alternatives. As mentioned previously, the Rushy Marsh study area contains only one watershed (Figure IV-3).

For management purposes, the aggregated embayment watershed nitrogen loads are partitioned by the major types of nitrogen sources in order to focus development of nitrogen management alternatives. Within the Rushy Marsh System, the major types of nitrogen loads are: wastewater, fertilizer, impervious surfaces, direct atmospheric deposition to water surfaces, and recharge within natural areas (Table IV-2). The output of the watershed nitrogen loading model is the annual mass (kilograms) of nitrogen added to the contributing area of component sub-embayments, by each source category (Figure IV-4). In general, the annual watershed nitrogen input to the watershed of an estuary is then adjusted for natural nitrogen attenuation during transport to the estuarine system before use in the embayment water quality sub-model. However, as noted above, the Rushy Marsh watershed nitrogen input is not subject to attenuation within the watershed, as there are no associated streams or great fresh ponds.

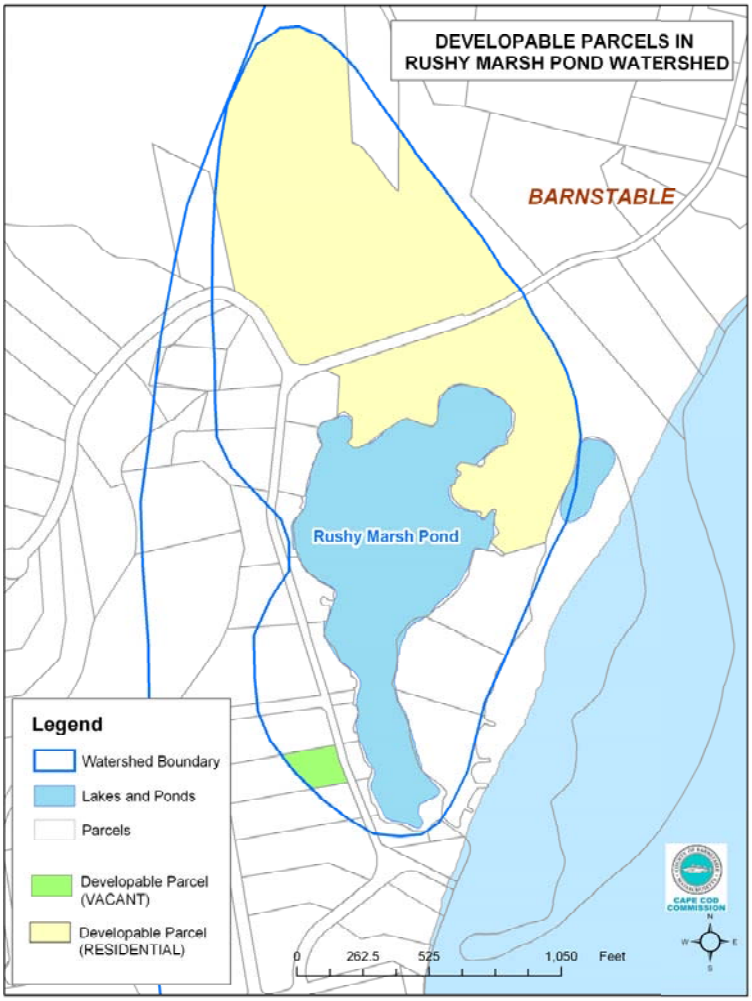


Figure IV-3. Parcels, Parcelized Watersheds, and Developable Parcels in the Rushy Marsh watershed.

Table IV-2. Nitrogen Loads to the Rushy Marsh Pond Estuary. There is negligible attenuation during transport to Rushy Marsh Pond and groundwater travel times are less than 10 years throughout the watershed. Wastewater represents on-site septic treatment and disposal from residential dwellings.

Values: kg N/yr	*Rushy Marsh Watershed N Loads by Input:*						*Present N Loads Without Atmos N to Estuary*			*Buildout N Loads Without Atmos N to Estuary*			*Atmos N to Estuary*
Name	Wastewater	Lawn Fertilizers	Impervious Surfaces	Water Body Surface Area	"Natural" Surfaces	Buildout	UnAtten N Load	Atten %	Atten N Load	UnAtten N Load	Atten %	Atten N Load	UnAtten N Load
Rushy Marsh Pond	129	6	11	0	17	168	163	**0%**	163	331	**0%**	331	74

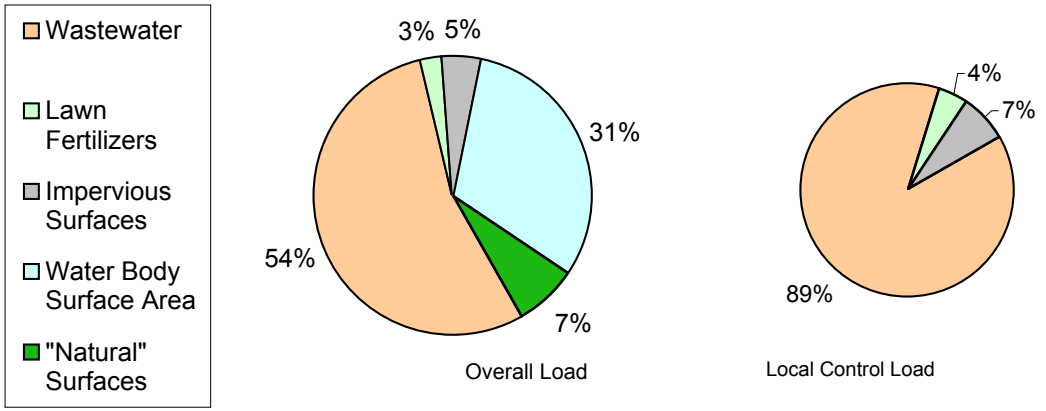


Figure IV-4. Land use-specific unattenuated nitrogen load (by percent) to the Rushy Marsh watershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control (e.g. excludes atmospheric deposition to estuarine surface).

Freshwater Pond Nitrogen Loads

Freshwater ponds on Cape Cod are generally kettle hole depressions that intercept the surrounding groundwater table revealing what some call "windows on the aquifer." Groundwater typically flows into the pond along the upgradient shoreline, then lake water flows back into the groundwater system along the downgradient shoreline. Occasionally a Cape Cod pond will have a stream outlet or herring run too. Since the nitrogen loads flow into the pond with the groundwater, the relatively more productive ecosystems in the ponds incorporate some of the nitrogen, retain some of it in the sediments, and change it among its various oxidized and reduced forms. As result of these interactions, some of the nitrogen is removed from the watershed system, mostly through burial in the sediments and denitrification that returns it to the atmosphere. Following these reductions, the remaining, reduced loads flow back into the groundwater system along the downgradient side of the pond or through a stream outlet and eventual discharge into the downgradient embayment. The nitrogen load summary in Table IV-2 includes both the unattenuated (nitrogen load to each subwatershed) and attenuated nitrogen loads. However, for Rushy Marsh Pond there are no great fresh ponds within the watershed and all watershed derived nitrogen enters the estuary through direct groundwater seepage, without attenuation.

Buildout

Part of the regular MEP watershed nitrogen loading modeling is to prepare a buildout assessment of potential development within the study area watershed. For the Rushy Marsh modeling, MEP staff consulted with town planners to determine the parameters that would be used in the assessment.. The standard buildout assessment is to evaluate town zoning to determine minimum lot sizes in each of the zoning districts, including overlay districts (*e.g.*, water resource protection districts). Larger lots are subdivided by the minimum lot size to determine the total number of new lots. Staff also review developed properties with additional development potential; for example, residential lots that are twice the minimum lot size, but only have one residence. Parcels that are classified as developable residential (state class land use codes 130 and 131) but are less than the minimum lot size and are greater than 5,000 square feet are assigned an additional residence in the buildout; 5,000 square feet is a minimum lot size in some Cape Cod town zoning regulations. Commercial properties are not subdivided; the area of each parcel and the factors in Table IV-1 were used to determine a wastewater flow for these properties. Parcels included in the buildout assessment for the Rushy Marsh watershed are shown in Figure IV-3. A nitrogen load for each additional parcel included in the buildout analysis was determined for addition to the load determined for the existing development by using the factors presented in Table IV-1 and discussed above. A summary of total potential additional nitrogen loading from build-out is presented as unattenuated and attenuated loads in Table IV-2.

IV.2 ATTENUATION OF NITROGEN IN SURFACE WATER TRANSPORT

IV.2.1 Background and Purpose

Modeling and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land or watershed. This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out or sewering analysis) to changes in water quality and habitat health. Therefore, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems. Rates of nitrogen loading to the watershed of the Rushy

Marsh System were based upon the delineated watersheds (Section III) and their land-use coverages (Section IV.1). If all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters. This condition exists in watersheds where nitrogen transport is through groundwater in sandy outwash aquifers. The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. This is the case for the Rushy Marsh watershed. Unlike most watersheds in southeastern Massachusetts, nitrogen does not pass through a surface water ecosystem on its path to the adjacent embayment. It is in these surface water systems that the needed conditions for nitrogen retention and denitrification exist. As there were no streams or great fresh ponds within the Rushy Marsh watershed, the watershed loading approach considered that nitrogen reaching the water table was transported without attenuation in the groundwater system until discharge to the estuary.

IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS

The overall objective of the Benthic Nutrient Flux Task was to quantify the summertime exchange of nitrogen, between the sediments and overlying waters within the Rushy Marsh Pond basin. The mass exchange of nitrogen between watercolumn and sediments is a fundamental factor in controlling nitrogen levels within coastal waters. These fluxes and their associated biogeochemical pools relate directly to carbon, nutrient and oxygen dynamics and the nutrient related ecological health of these shallow marine ecosystems. In addition, these data are required for the proper modeling of nitrogen in shallow aquatic systems, both fresh and salt water.

IV.3.1 Sediment-Watercolumn Exchange of Nitrogen

As stated in above sections, nitrogen loading and resulting levels within coastal embayments are the critical factors controlling the nutrient related ecological health and habitat quality within a system. Nitrogen enters the Rushy Marsh embayment predominantly in highly bioavailable forms from the surrounding upland watershed and more refractory forms in the inflowing tidal waters. If all of the nitrogen remained within the watercolumn (once it entered), predicting watercolumn nitrogen levels would be simply a matter of determining the watershed loads, dispersion, and hydrodynamic flushing. However, as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bioavailable form nitrate. This nitrate and other bioavailable forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved forms into phytoplankton “particles”. Most of these “particles” remain in the watercolumn for sufficient time to be flushed out to a downgradient larger waterbody (like Nantucket Sound). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence), a fraction of the phytoplankton with their associated nitrogen “load” become incorporated into the surficial sediments of the bays.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within small enclosed basins (e.g. Rushy Marsh Pond). To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary.

Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic

(oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter (with its nitrogen content) that bioavailable nitrogen is returned to the embayment watercolumn for another round of uptake by phytoplankton. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that we have investigated, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. Failure to account for this recycled nitrogen generally results in significant errors in determination of threshold nitrogen loadings. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

IV.3.2 Method for Determining Sediment-Watercolumn Nitrogen Exchange

For the Rushy Marsh Pond system, in order to determine the contribution of sediment regeneration to nutrient levels during the most sensitive summer interval (July-August), sediment samples were collected and incubated under *in situ* conditions. Sediment samples were collected in the Rushy Marsh Pond basin from 8 sites (Figure IV-5) in July 2004. Measurements of total dissolved nitrogen, nitrate + nitrite, ammonium were made in time-series on each incubated core sample. As part of a separate research investigation, the rate of oxygen uptake was also determined and measurements were made of sediment bulk density, organic nitrogen, and carbon content. These measurements were made by the Coastal Systems Program at SMAST-UMD.

Rates of nitrogen release were determined using undisturbed sediment cores incubated for 24 hours in temperature-controlled baths. Sediment cores (15 cm inside diameter) were collected by SCUBA divers and cores transported by a small boat to the shoreside field “lab”. Cores were maintained from collection through incubation at *in situ* temperatures. Bottom water was collected and filtered from each core site to replace the headspace water of the flux cores prior to incubation. The number of core samples (see Figure IV-5) within Rushy Marsh central basin and channel were as follows:

Rushy Marsh System

- Station 1 – 1 core (Rushy Marsh – channel)
- Station 2 – 1 core (Rushy Marsh – channel)
- Station 3 – 1 core (Rushy Marsh – central basin)
- Station 4 – 1 core (Rushy Marsh – central basin)
- Station 5 – 1 core (Rushy Marsh – central basin)
- Station 6/7 – 2 cores (Rushy Marsh – central basin)
- Station 8 – 1 cores (Rushy Marsh – central basin)

Sampling was distributed throughout the embayment system and the results for each site combined for calculating the net nitrogen regeneration rates for the water quality modeling effort.

Sediment-watercolumn exchange follow the methods of Jorgensen (1977), Klump and Martens (1983), and Howes *et al.* (1995) for nutrients and metabolism. Upon return to the field laboratory (private residence on the shore of Rushy Marsh) the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with filtered water), filtered into acid leached polyethylene bottles

and held on ice for nutrient analysis. Ammonium (Scheiner 1976) and ortho-phosphate (Murphy and Reilly 1962) assays were conducted within 24 hours and the remaining sample frozen (-20°C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia *et al.* 1977). Rates were determined from linear regression of analyte concentrations through time.

Chemical analyses were performed by the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST) at the University of Massachusetts in New Bedford, MA. The laboratory follows standard methods for saltwater analysis and sediment geochemistry.



Figure IV-5. Rushy Marsh System locations (red diamonds) of sediment sample collection for determination of nitrogen regeneration rates. Numbers are for reference in Table IV-3.

IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments

Watercolumn nitrogen levels are the balance of inputs from direct sources (land, rain etc), losses (denitrification, burial), regeneration (watercolumn and benthic), and uptake (e.g. photosynthesis). As stated above, during the warmer summer months the sediments of shallow embayments typically act as a net source of nitrogen to the overlying waters and help to stimulate eutrophication in organic rich systems. However, some sediments may be net sinks for nitrogen and some may be in "balance" (organic N particle settling = nitrogen release). Sediments may also take up dissolved nitrate directly from the watercolumn and convert it to dinitrogen gas (termed "denitrification"), hence effectively removing it from the ecosystem. This process is typically a small component of sediment denitrification in embayment sediments, since the watercolumn nitrogen pool is typically dominated by organic forms of nitrogen, with very low nitrate concentrations. However, this process can be very effective in removing nitrogen loads in some systems, particularly in salt marshes, where overlying waters support high nitrate levels.

In addition to nitrogen cycling, there are ecological consequences to habitat quality of organic matter settling and mineralization within sediments, which relate primarily to sediment and watercolumn oxygen status. However, for the modeling of nitrogen within an embayment it is the relative balance of nitrogen input from watercolumn to sediment versus regeneration which is critical. Similarly, it is the net balance of nitrogen fluxes between water column and sediments during the modeling period that must be quantified. For example, a net input to the sediments represents an effective lowering of the nitrogen loading to down-gradient systems and net output from the sediments represents an additional load.

The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the organic levels within the sediment (oxic/anoxic) and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake throughout the summer months, even though organic nitrogen is being mineralized and released to the overlying water as well. The rate of nitrate uptake simply dominates the overall sediment nitrogen cycle.

In order to model the nitrogen distribution within an embayment it is important to be able to account for the net nitrogen flux from the sediments within each part of each system. This requires that an estimate of the particulate input and nitrate uptake be obtained for comparison to the rate of nitrogen release. Only sediments with a net release of nitrogen contribute a true additional nitrogen load to the overlying waters, while those with a net input to the sediments serve as an "in embayment" attenuation mechanism for nitrogen.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and

early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure IV-6).

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates.

In order to determine the net nitrogen flux between watercolumn and sediments, all of the above factors were taken into account. The net input or release of nitrogen within a specific embayment was determined based upon the measured ammonium release, measured nitrate uptake or release, and estimate of particulate nitrogen input. Dissolved organic nitrogen fluxes were not used in this analysis, since they were highly variable and generally showed a net balance within the bounds of the method.

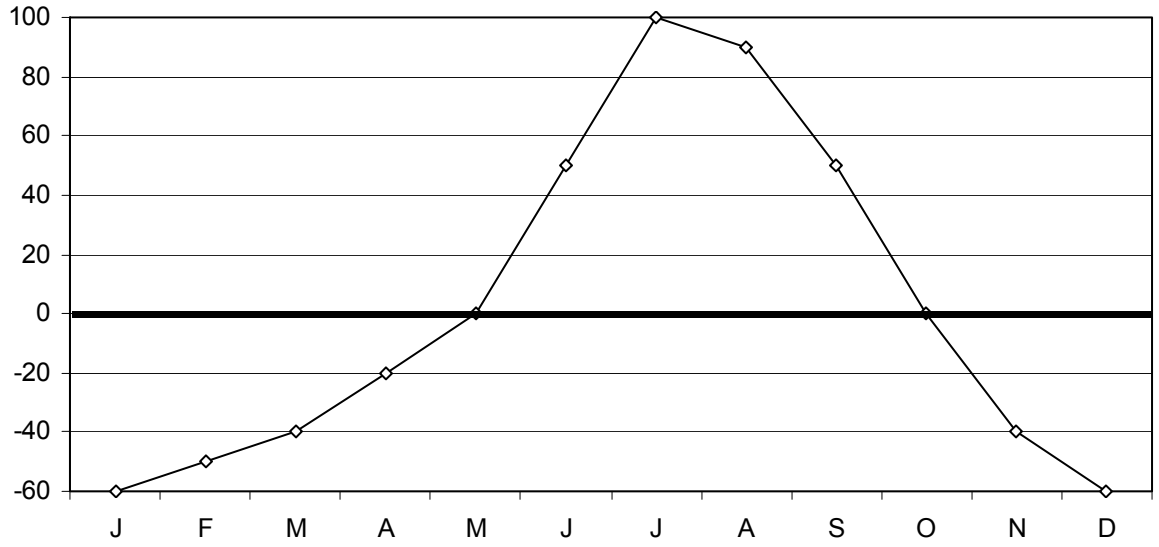


Figure IV-6. Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.

Sediment sampling was conducted throughout Rushy Marsh Pond in order to obtain the nitrogen regeneration rates required for parameterization of the water quality model (Figure IV-5). The distribution of cores was established to cover gradients in sediment type, flow field and phytoplankton density. For each core the nitrogen flux rates (described in the section above) were evaluated relative to measured sediment organic carbon and nitrogen content and bulk density and an analysis of each site's tidal flow velocities. The maximum bottom water flow velocity at each coring site was determined from the hydrodynamic model. These data were then used to determine the nitrogen balance within each sub-embayment.

The magnitude of the settling of particulate organic carbon and nitrogen into the sediments was accomplished by determining the average depth of water within each sediment

site and the average summer particulate carbon and nitrogen concentration within the overlying water. Two levels of settling were used. If the sediments were organic rich and a fine grained and the hydrodynamic data showed low tidal velocities, then a water column particle residence time of 8 days was used (based upon phytoplankton and particulate carbon studies of poorly flushed basins). If the sediments indicated a coarse grained sediments and low organic content and high velocities, then half this settling rate was used. Adjusting the measured sediment releases was essential in order not to over-estimate the sediment nitrogen source and to account for those sediment areas which are net nitrogen sinks for the aquatic system. This approach was validated in outer Cape Cod embayments (Town of Chatham) by examining the relative fraction of the sediment carbon turnover (total sediment metabolism) which would be accounted for by daily particulate carbon settling. This analysis indicated that sediment metabolism in the highly organic rich sediments of the wetlands and depositional basins is driven primarily by stored organic matter (ca. 90%). Also, in the more open lower portions of larger embayments, storage appears to be low and a large proportion of the daily carbon requirement in summer is met by particle settling (approximately 33% to 67%). This range of values and their distribution is consistent with ecological theory and field data from shallow embayments.

Net nitrogen release or uptake from the sediments within Rushy Marsh Pond for use in the water quality modeling effort (Chapter VI) are presented in Table IV-3. The Rushy Marsh Pond sediments are a slight sink for nitrogen in the central basin and a moderate strength source of recycled nitrogen within the shallow channel. The system is highly eutrophic with enriched total nitrogen concentrations, phytoplankton blooms and periodic oxygen depletion of bottom waters. As a result the sediments are generally very soft to fluid organic muds. Within the channel and deeper basin these organic muds generally had a clear oxidized surface layer, although, within the deeper basin, the surface oxidized layer was not uniform. There was also evidence of a sparse amphipod mat and previous colonization by a submerged aquatic macrophytes, presumably *Ruppia,* although no live plants were observed (see Chapter 7). Nitrogen enrichment of this system stems primarily from the lack of tidal flushing out of Pond waters to Nantucket Sound, rather than a heavy watershed nitrogen input.

Typically, embayments show relative small positive or negative net nitrogen fluxes (e.g. throughout adjacent Popponesset Bay). The pattern in Rushy Marsh Pond appears to result from the relatively high mass of particulate nitrogen settling within this system, due to the high phytoplankton production in the nitrogen rich embayment waters. A similar pattern was found in Oyster Pond (Town of Falmouth), also a highly tidally restricted embayment. However, Rushy Marsh Pond is only periodically oxygen depleted in its bottom waters, whereas the deep basins of Oyster Pond tend to be seasonally anoxic. However, in sediments above the deep basins (<3m depth) in Oyster Pond, the average net nitrogen flux was similar to that for Rushy Marsh. This consistency in sediment nitrogen cycling between embayments of similar hydrodynamics and configuration, serves as additional quality assurance for this parameter.

Table IV-3. Rates of net nitrogen return from sediments to the overlying waters of the Rushy Marsh Embayment System. These values are combined with the basin areas to determine total nitrogen mass in the water quality model (see Chapter VI). Measurements represent Summer rates. Note that the net nitrogen uptake by the central basin (drown kettle)

			Sediment Nitrogen Release		
Basin Region	Depth (m)	Stations	Mean mg N m^{-2} d^{-1}	S.E. mg N m^{-2} d^{-1}	N
Central Basin	1.2-1.7	3-8	-19.1	2.6	6
Channel	1.0	1,2	48.7	1.8	2

V. HYDRODYNAMIC MODELING

V.1 INTRODUCTION

This section summarizes field data collection effort and the development of a hydrodynamic model for the Rushy Marsh Pond estuary system (Figure V-1). For this system, the final calibrated model offers an understanding of water movement through the estuary, and provides the first step towards evaluating water quality, as well as a tool for later determining nitrogen loading "thresholds". Nutrient loading data combined with measured environmental parameters within the system become the basis for an advanced water quality model based on total nitrogen concentrations. This type of model provides a tool for evaluating existing estuarine water quality parameters, as well as determining the likely positive impacts of various alternatives for improving overall estuarine health, facilitating the understanding how pollutant loadings into the estuary will affect the biochemical environment and its ability to sustain a healthy marine habitat.

In general, water quality studies of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. For example, the spread of pollutants may be analyzed from tidal current information developed by the numerical models.

Coastal embayments like Rushy Marsh Pond are the initial recipients of freshwater flows (i.e., groundwater and surfacewater) and the nutrients they carry. An embayment's shape influences the time that nutrients are retained in them before being flushed out to adjacent open waters, and their shallow depths both decrease their ability to dilute nutrient (and pollutant) inputs and increase the secondary impacts of nutrients recycled from the sediments. Degradation of coastal waters and development are tied together through inputs of pollutants in runoff and groundwater flows, and to some extent through direct disturbance, i.e. boating, oil and chemical spills, and direct discharges from land and boats. Excess nutrients, especially nitrogen, promote phytoplankton blooms and the growth of epiphytes on eelgrass and attached algae, with adverse consequences including low oxygen, shading of submerged aquatic vegetation, and aesthetic problems.

Rushy Marsh Pond is set in the southern shoreline of Barnstable. The layout of the Rushy Marsh Pond system is shown in Figure V-1. The central basin of the pond has a surface area of approximately 18 acres including areas of marsh fringing the main body of the pond. The pond is open to Nantucket Sound via a 12-inch culvert that is often blocked by littoral sediments. In the 1800s, a natural inlet connected Rushy Marsh to Nantucket Sound north of the existing culvert. Between the early 1950s and 1970s, a wooden flume near the southern end of the pond provided an ephemeral connection to Nantucket Sound.

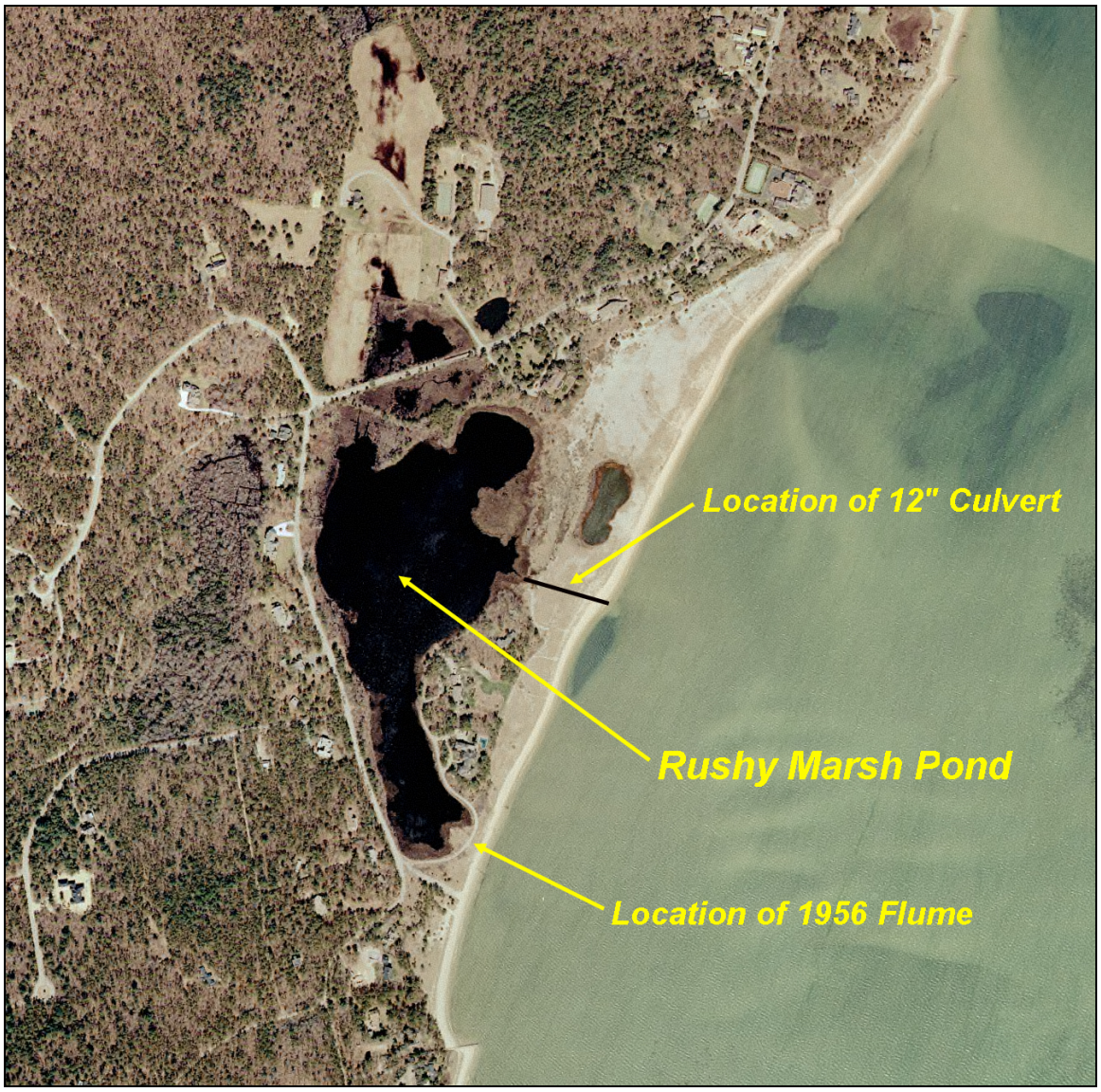


Figure V-1. Aerial photograph of Rushy Marsh in 2001, showing the location of the existing 12-inch culvert, as well as the 1956 flume location. Culvert is in location of natural inlet that existed prior to 1896.

V.2 GEOMORPHIC AND ANTHROPOGENIC EFFECTS TO THE ESTUARINE SYSTEM

A general understanding of the hydrodynamic controls and coastal processes influencing estuarine dynamics provides the initial framework for the hydrodynamic analysis. In addition, both natural and anthropogenic changes to the estuarine system can guide the evaluation of effective alternatives to enhance tidal circulation and improve water quality.

The southern coast of Cape Cod in the vicinity of Rushy Marsh can be considered a moderately dynamic region, where natural wave and tidal forces continue to reshape the shoreline. Due to the protection afforded by the islands of Martha's Vineyard and Nantucket, the south shore of Cape Cod is protected from the influence of long period open ocean wave conditions. Similar to many portions of the Massachusetts coast, the available sediment supply influences the migration and/or stability of tidal inlets. Tidal inlets can become overwhelmed by

the gradual wave-driven migration of a barrier beach separating the estuaries from the ocean. To balance the effect of gradual longshore sediment transport, episodic breaching of a barrier beach system creates new inlets that alter the pathways of water entering the estuary. Storm-driven inlet formation often leads to hydraulically efficient estuarine systems, where seawater exchanges more rapidly with water inside the estuary. As beaches elongate, the inlet channels to the estuaries often become long, sinuous, and hydraulically inefficient. Periodically, overwash from storm events will erode the barrier beach enough at a point to allow again the formation of a new inlet. It is then possible that the new inlet will stabilize and become the main inlet for the system, while the old inlet eventually fills in. Several examples of this process along the Massachusetts coast include Allen's Pond (Westport), New Inlet/Chatham Harbor (Chatham), and Nauset Inlet (Orleans). In addition to these natural coastal processes, man-made structures often can influence the stability of a shoreline/tidal inlet system.

V.2.1 Natural Coastal Processes

For the Rushy Marsh estuarine system, the process of barrier spit elongation and breaching has had a significant influence on tidal exchange. Over the past 100 years, the Popponesset Beach barrier elongation and breaching processes have governed the stability of the Rushy Marsh inlet. The USGS map from 1893 (Figure V-2) illustrates shows the Popponesset Beach spit in a condition where the barrier is elongated slightly beyond present day conditions and the flood shoal is emergent (Thatch Island). Between the late 1800s and 1950, the Popponesset barrier elongated past the Rushy Marsh tidal inlet. Due to the influx of sediment associated with this barrier elongation, the natural tidal inlet to Rushy Marsh closed. The 1943 USGS map (Figure V-3) of the area shows the condition of the system prior to the Popponesset Beach breach. As described in Aubrey and Goud (1983), the loss of nearly one-half of the Popponesset Beach barrier between 1954 and the early 1980s led to concerns regarding future barrier spit migration. Figures V-4 and V-5 illustrate changes to the barrier spit over the 30 year period between 1951 and 1981. According to Aubrey and Gaines (1982), the present spit length has been historically the stable configuration. It wasn't until after about 1860 that the spit began to grow past its present location.

As the barrier spit elongated between the early 1900s and the mid-1950s due to regional littoral drift, the inlet channel to Popponesset Bay become less efficient, where the tide height within Popponesset Bay decreased and the lag time between high tide in the estuary and Nantucket Sound increased. This increase in tidal attenuation was remedied in 1954, when a hurricane breached the barrier spit, creating an efficient inlet in the vicinity of the present inlet. Once the spit had breached, the remnants of the spit east of the inlet gradually overwashed and rejoined the shoreline (primarily in the vicinity of Rushy Marsh). This inlet spit growth and breaching process has been documented extensively for the southeastern coast of Massachusetts (e.g. Fitzgerald, 1993).

The specific influence of barrier elongation and breaching upon the Rushy Marsh system was described in a report to the Town of Barnstable prepared by the Coast & Harbor Institute and Robert L. Fultz Associates (2002). A schematic representation of barrier beach processes and their influence on Rushy Marsh is shown in Figure V-6. Although the inlet to Rushy Marsh had naturally closed in the early 1900s, the influx of littoral sediment caused by the 1954 breach of the Popponesset barrier further widened the barrier beach system fronting Rushy Marsh. Efforts to maintain an effective inlet near the southern end of the Pond have been complicated by the unstable nature of the shoreline, the relatively weak littoral drift that continues to supply sediment to this region, and the small potential tidal prism exiting Rushy Marsh.

Figure V-7 shows the historic shoreline change fronting Rushy Marsh and the Three Bays region between 1938 and 2005. Much of the accretion along the barrier beach separating Rushy Marsh from Nantucket Sound is a result of the Popponesset spit remnants joining the barrier beach fronting Rushy Marsh. After this spit welded onto the existing shoreline, the net west-to-east directed littoral drift has "straightened" the shoreline in this region, where slight erosion has been observed along the beach fronting the southwest end of the pond and significant accretion has been observed along the beach fronting the remainder of the pond. In general, the shoreline region between Rushy Marsh Pond and the Popponesset Bay entrance has been relatively stable since the 1950s.

Recent monitoring of beach profiles at Oregon Beach fronting Rushy Marsh Pond has been performed by volunteers overseen by Jim O'Connell of the Woods Hole Oceanographic Institution's Sea Grant Program. Locations of transects at Oregon Beach are shown in Figure V-8. Initial monitoring results indicate a relatively stable shoreline and dune system. Elevation of the natural dunes varies from about 6.5 to 8 feet NGVD. The beach slope varies from about 1:10 to 1:20 (v:h) and levels off at about -1 ft NGVD to a tidal flat. Figures V-9 and V-10 show the inter-annual variation of transects OB#1 and OB#3, respectively.

V.2.2 Anthropogenic Changes Influencing Rushy Marsh Pond

Manmade coastal structures along the shoreline immediately west of Rushy Marsh Pond consist primarily of groins along this updrift shoreline. Based on site observations, most of these structures are not effective barriers to natural littoral drift; therefore, beach compatible material continues to supply the barrier fronting Rushy Marsh Pond. The volume of material transported along this shoreline stretch is relatively small, due primarily to the quiescent wave conditions within the protected waters of Nantucket Sound. The conclusion that the longshore sediment transport rate is relatively low is further supported by the stable shoreline northeast of Rushy Marsh Pond and the small maintenance dredging volumes required to maintain the entrance to Cotuit Bay (which receives littoral sediments from both the east and the west).

Although man has modified much of the coastline between the Popponesset Bay and Cotuit Bay entrances, most of the large-scale changes to the estuarine systems have been caused by nature. For example, the 1954 breach of Popponesset Beach created a much more efficient inlet channel to this system; however, the influx of littoral sediments associated with this breach caused a substantial increase in the barrier beach width fronting Rushy Marsh Pond. Relatively large-scale natural changes to the shoreline over the approximate 20-year period following the breach of the Popponesset spit hampered efforts to establish a stable inlet to Rushy Marsh Pond. The only existing connection between Rush Marsh Pond and Nantucket Sound is a 12 inch culvert that often is clogged at the seaward end.

The 1943 USGS map (Figure V-3) shows that no inlet existed to Rushy Marsh Pond prior to the 1954 breach of the Popponesset spit; therefore, release of freshwater from the pond has been performed mechanically for the past 60+ years. Following the breach, the influx of littoral sediments to the barrier beach system made it more difficult to establish and/or maintain manmade structures to enhance water exchange between Rushy Marsh Pond and Nantucket Sound.

Following the 1954 breach of Popponesset spit, in 1956 a wooden flume was constructed across Oregon Beach to link Rushy Marsh Pond to Nantucket Sound to provide emergency drainage from the pond (Coast & Harbor Institute and Robert L. Fultz Associates, 2002). This flume was approximately 8 feet wide, 2 feet deep, and 72 feet in length. Based on the 2002

analysis by Coast & Harbor Institute and Robert L. Fultz Associates, the base of the structure was at approximately the existing elevation of the pond, where only the highest tides could enter the pond. Before 1974, the flume became ineffective and was replaced by 24-inch culver near the location of the existing 12-inch culvert. Shortly after abandonment, the flume became buried by the beach and dune system. Hurricane Bob in 1991 uncovered the flume for a short period of time (Figure V-11).

Over the past 30 years, a variety of culverts have been utilized to provide freshwater drainage for Rushy Marsh Pond. Due to the relatively small watershed associated with the pond, freshwater flow through the culvert is not sufficient to keep the seaward end of the culvert open.

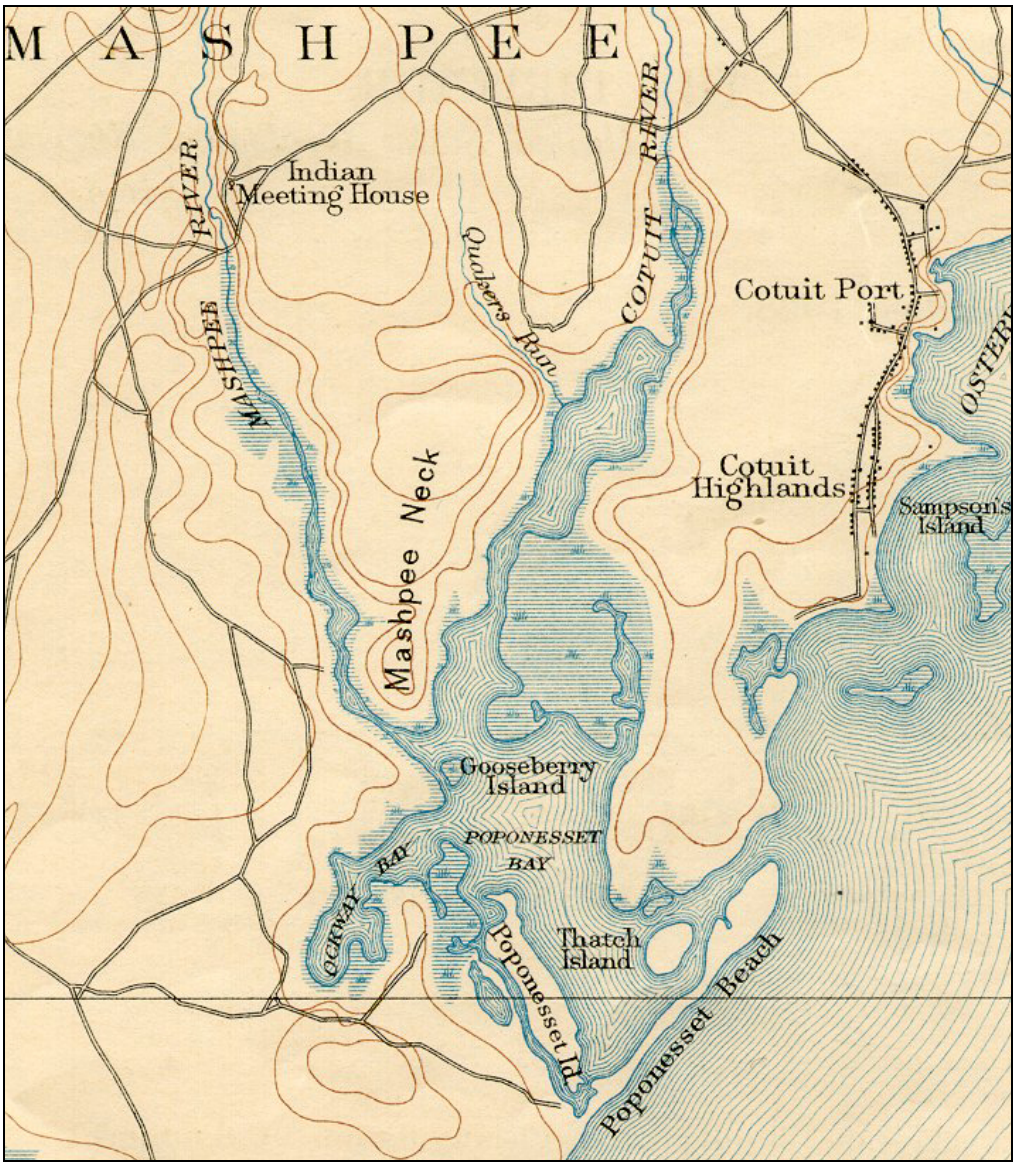


Figure V-2. Portion of the 1893 USGS topographic map (Cotuit Quadrangle) showing the position of the inlet at a similar location as the present inlet.



Figure V-3. Portion of the 1943 USGS topographic map (Cotuit Quadrangle) showing the elongation of Popponesset Beach and closed inlet conditions at Rushy Marsh.

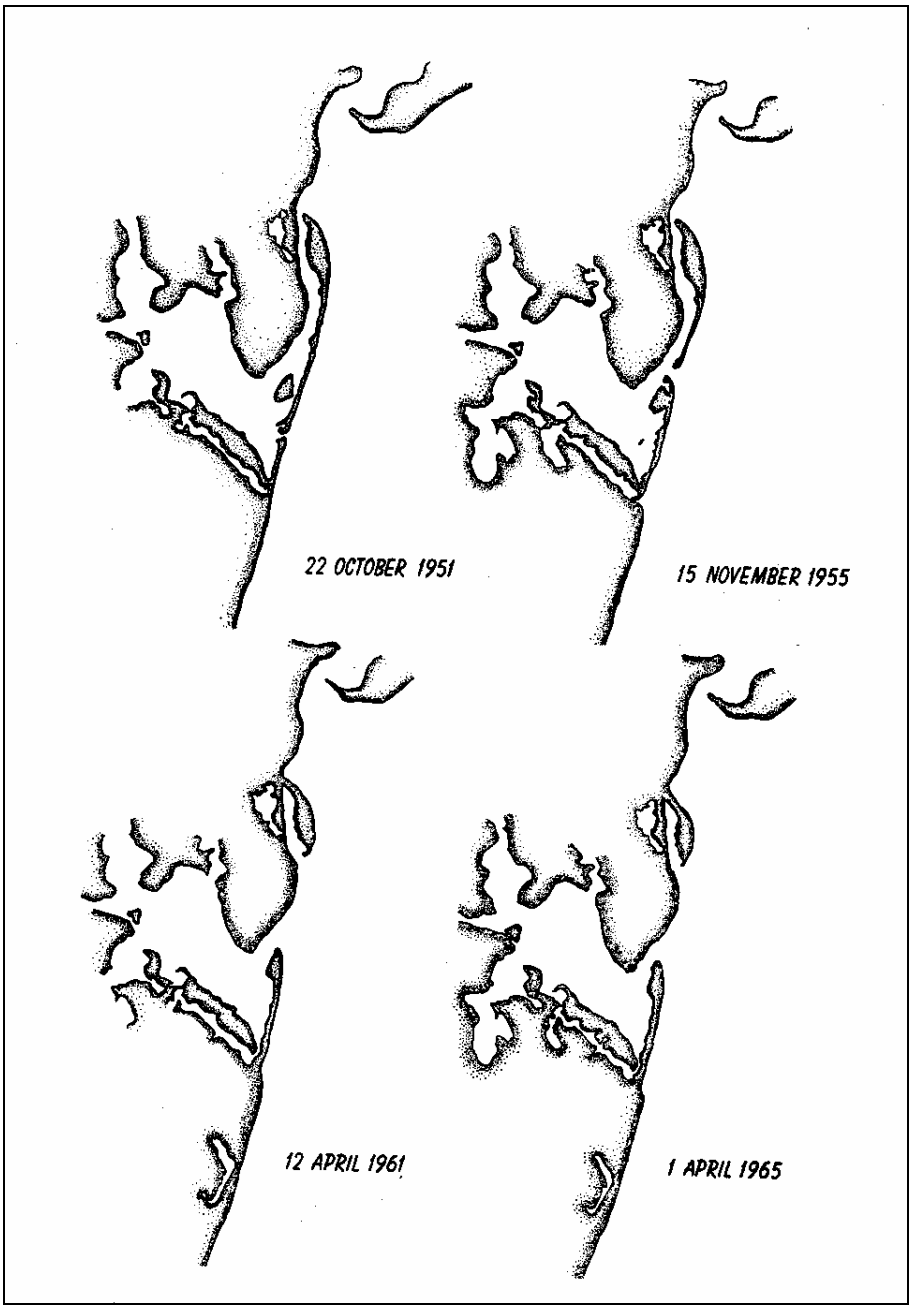


Figure V-4. Outlines of vertical aerial photographs illustrating stages of shoreline evolution in the Popponesset Spit region between 1951 and 1965 (from Aubrey and Goud, 1983).

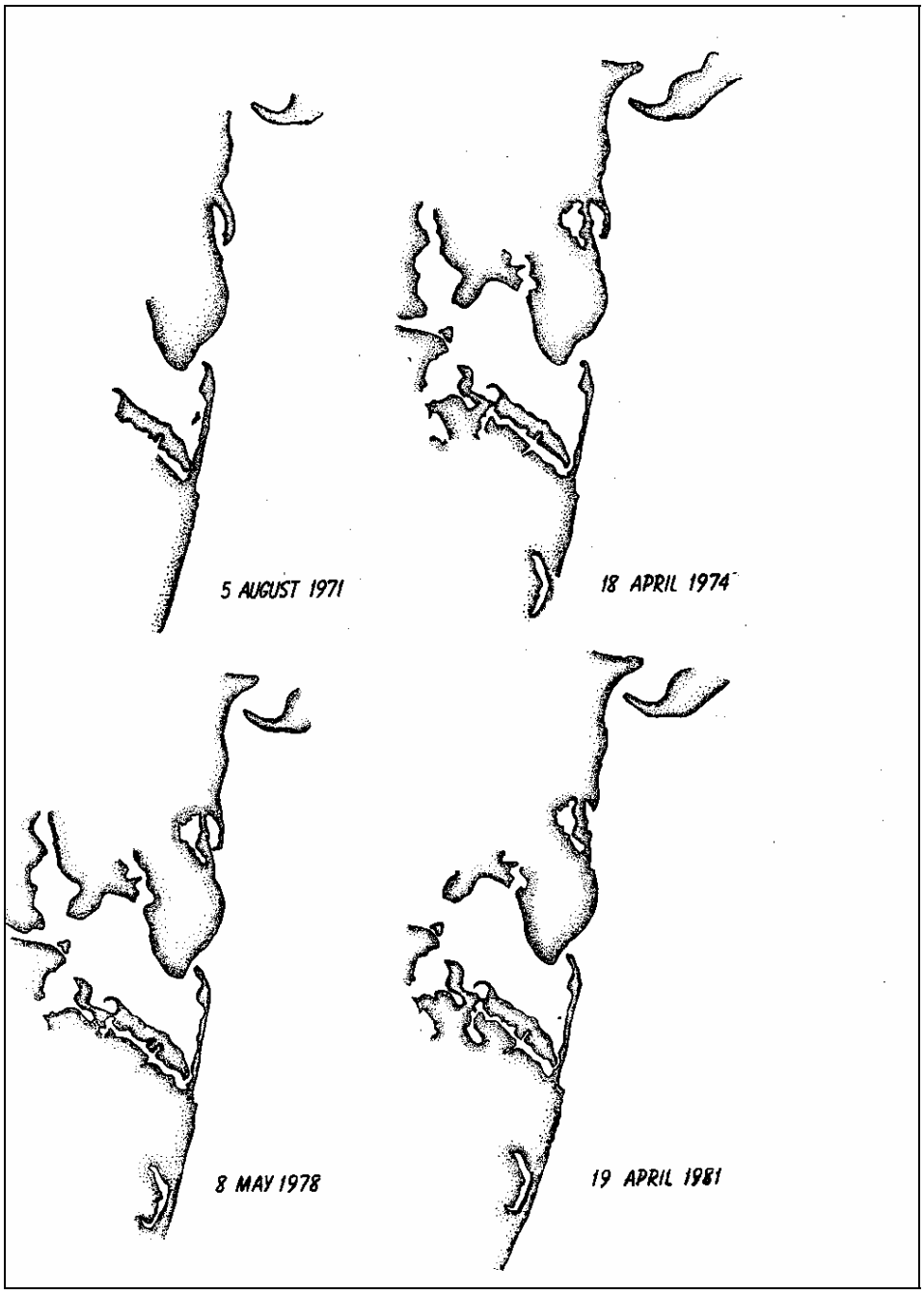


Figure V-5. Outlines of vertical aerial photographs illustrating stages of shoreline evolution in the Popponesset Spit region between 1971 and 1981 (from Aubrey and Goud, 1983).

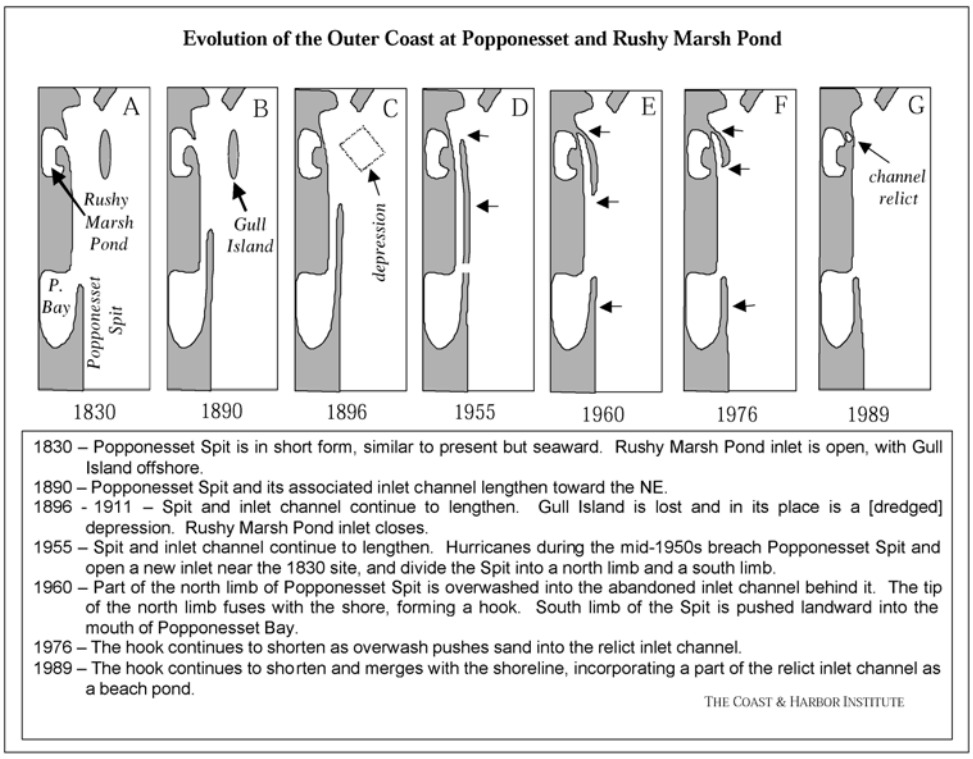


Figure V-6. A schematic description of barrier spit evolution in the vicinity of Popponesset Bay and Rushy Marsh Pond (Coast & Harbor Institute and Robert L. Fultz Associates, 2002).



Figure V-7. Observed shoreline change from 1938 to 2001/2005 for the shoreline area in the vicinity of Rushy Marsh Pond and Three Bays in Barnstable.



Figure V-8. Locations of beach transect monitoring stations along Oregon Beach.

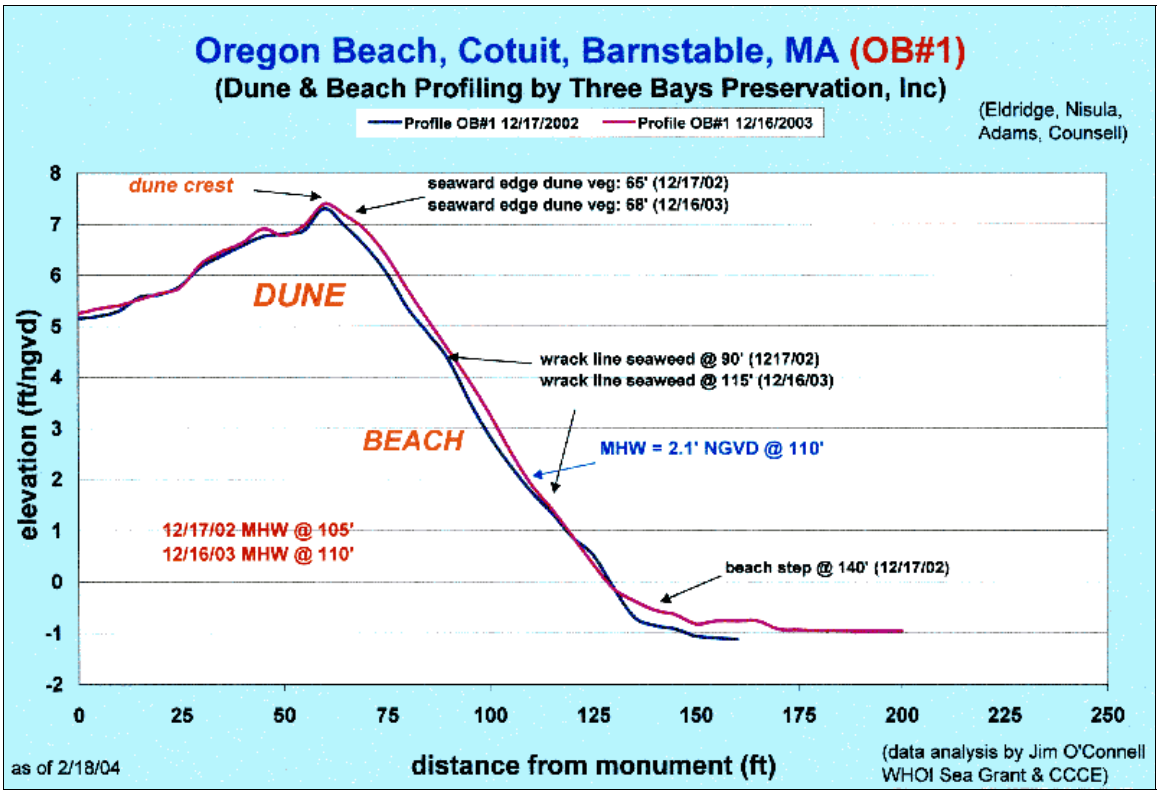


Figure V-9. Inter-annual changes to beach profile at Station OB#1 shown in Figure V-7.

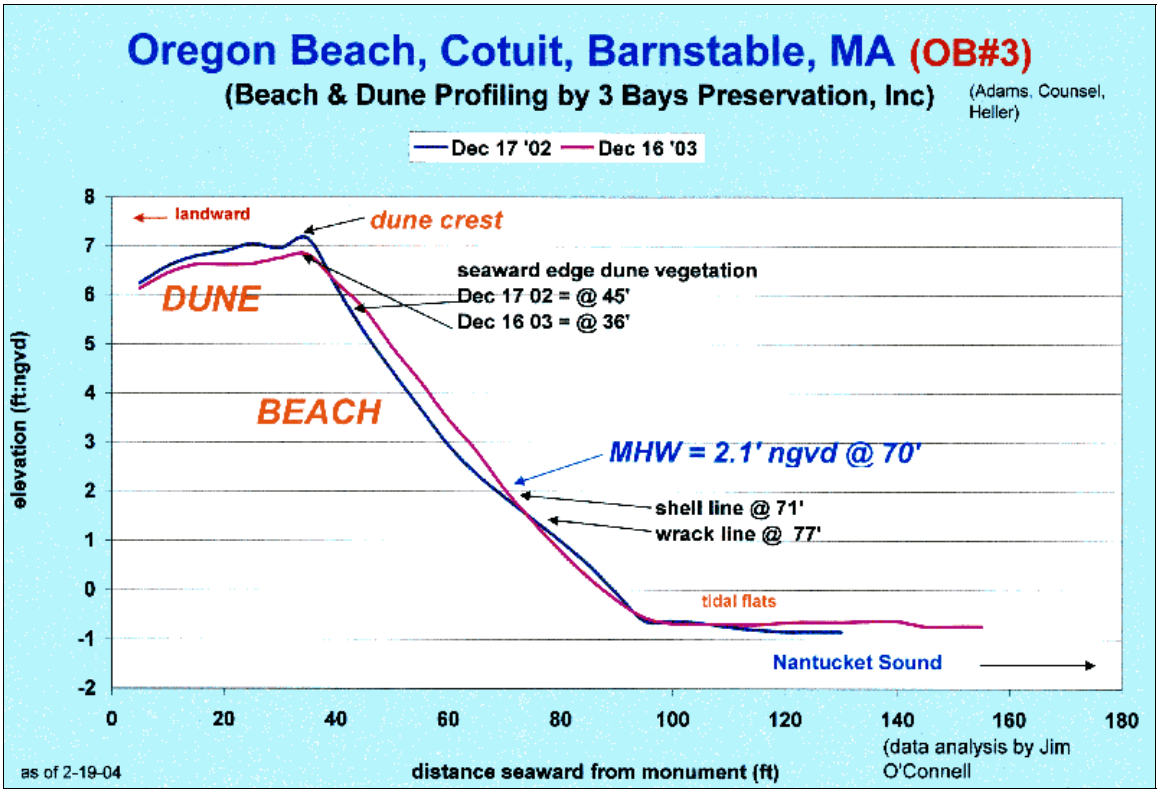
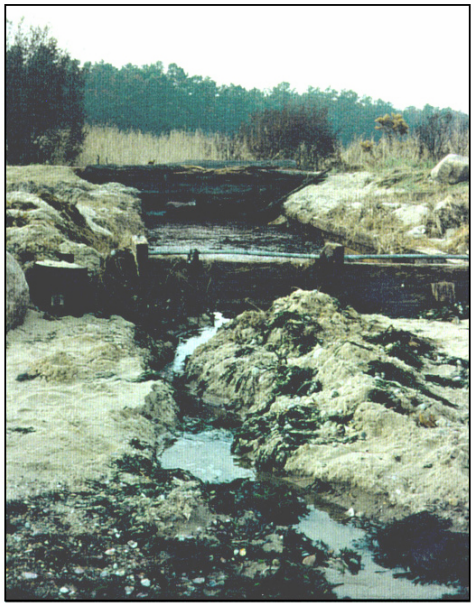


Figure V-10. Inter-annual changes to beach profile at Station OB#3 shown in Figure V-7.



The old wooden sluiceway (ca. 1956) exhumed in 1991 by hurricane Bob. View from Nantucket Sound toward Rushy Marsh Pond. The bulkhead in the foreground is a horizontally hinged gate. The bridge over the sluiceway is seen in the background (photo by E. Bragdon).

The old wooden sluiceway exhumed in 1991 by hurricane Bob. View from the bridge crossing the structure toward Nantucket Sound. The bulkhead in the background is a hinged gate (photo by R. Gatewood).



Figure V-11. The 1956 wood flume built to hydraulically connect Rushy Marsh Pond to Nantucket Sound (Coast & Harbor Institute and Robert L. Fultz Associates, 2002).

V.3 FIELD DATA COLLECTION AND ANALYSIS

A precise description of embayment geometries and hydrodynamic forcing processes is required for the development of numerical models. To support the MEP hydrodynamic and water quality modeling effort in Rushy Marsh, the embayment bathymetry and water elevation variations were measured.

Bathymetry data was collected throughout the main basin of Rushy Marsh estuary. Survey data was not collected above of the roadway embankment on the north side of Rushy Marsh, since the area was not be directly incorporated in the hydrodynamic model. Tidal elevation measurements were used for both forcing conditions and to evaluate tidal attenuation through the culvert into the system. Figure V-12 shows the location of the tide gauges.



Figure V-12. Rushy Marsh with tide gauge locations labeled as W1 (forcing tide) and W2 (Rushy Marsh tide)

V.3.1 Bathymetry

Bathymetry, or depth, of Rushy Marsh was measured during field a survey in May 2004. The survey was completed using a small vessel equipped with a precision fathometer interfaced to a differential GPS receiver. The fathometer has a depth resolution of approximately 0.1 foot

and the differential GPS provides x-y position measurements accurate to approximately 1-3 feet. Digital data output from both the echo sounder and GPS were logged to a data recorder.

GPS positions and echo sounder measurements were merged to produce data sets consisting of water depth as a function of x-y horizontal position (in Massachusetts Mainland State Plane, 1983). These data were combined with water surface elevations to obtain the vertical elevation of the bottom (z) relative to the NGVD 1929 vertical datum (NGVD29). The resulting xyz files were input to mapping software to calculate depth contours for the system shown in Figure V-13. The bathymetry was supplemented by existing data from NOAA collected in 1942 to define the offshore region.

V.3.2 Water Elevation Measurements and Analysis

Changes in water surface elevation were measured using internal recording tide gauges. These tide gauges were installed on fixed platforms (screw anchors) to record changes in water pressure over time. Variations in the water surface can be due to tides, wind set-up, or other low frequency oscillations of the sea surface. The tide gauges were installed in 2 locations for Rushy Marsh (Figure V-12) on April 10, 2004 and recovered on May 21, 2004. Data records span at least 29 days to yield an adequate time period for resolving the primary tidal constituents.

The tide gauges used for the study were Brancker XR-420 TG. Data recording was set for 10-minute intervals, with each observation resulting from an average of 60 1-second pressure measurements on 10-minute intervals. These instruments use strain gauge transducers to sense variations in pressure, with resolution on the order of 1 cm (0.39 inches) head of water. Each gauge was calibrated prior to installation to assure accuracy.

Once the data were downloaded from each instrument, the water pressure readings were corrected for variations in atmospheric pressure. Hourly atmospheric readings were obtained from the NOAA buoy in Buzzards Bay (site BUZM3), interpolated to 10-minute intervals, and subtracted from the pressure readings, resulting in water pressure above the instrument. Further, a (constant) water density value of 1025 kg/m^3 was applied to the readings to convert from pressure units (psi) to head units (for example, feet of water above the tide gauge). Sensors were surveyed into local benchmarks to provide vertical rectification of the water level; these survey values were used to adjust the water surface to a known vertical datum. The result from each gauge is a time series representing the variations in water surface elevation relative to NGVD29. Figure V-14 present the water levels at each gauge location.

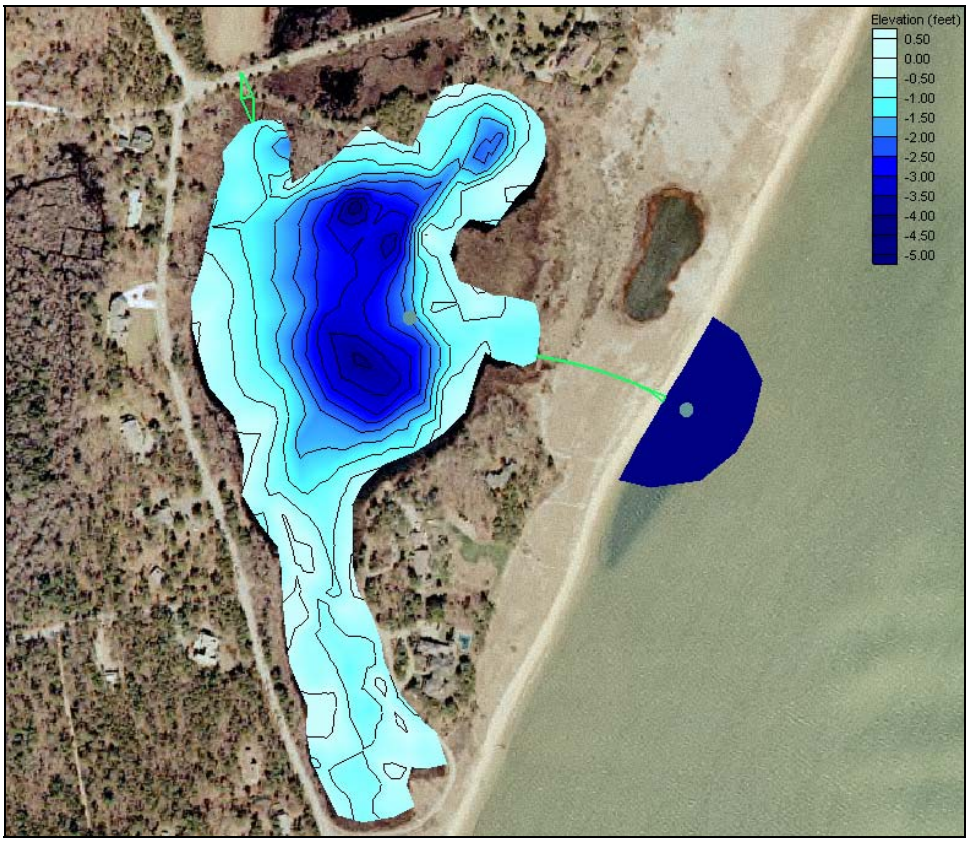


Figure V-13. Bathymetry showing depth contours of the numerical grid for the Rushy Marsh embayment at 0.5-foot contour intervals relative to NGVD29.

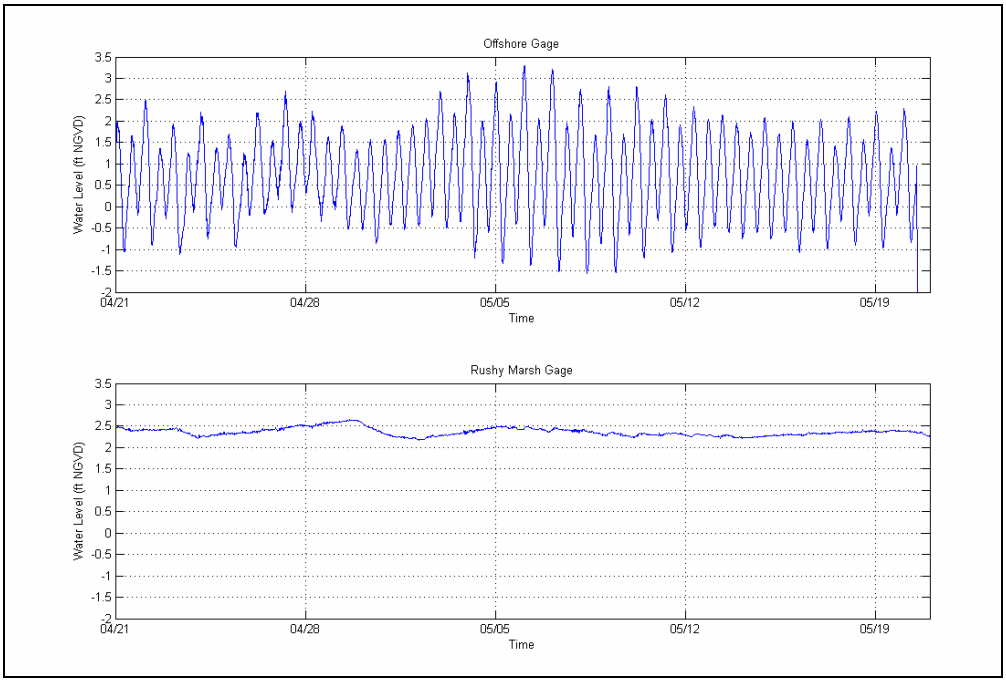


Figure V-14. Tidal elevation observations offshore Rushy Marsh relative to the Rushy Marsh embayment. (Upper) location W1 and (Lower) location W2 within Rushy Marsh. Locations are shown in Figure V-12.

Figure V-14 shows the tidal elevation for the period April 21 through May 20, 2004 at offshore gauge and in Rushy Marsh. The offshore curve has a predominant 12.42-hour variation around the lunar semi-diurnal (twice-a-day), or M_2, tidal constituent. Modulation of the lunar and solar tides, results in the spring-neap fortnightly cycle, typically evidence by a gradual increase and decrease in tide range. Offshore of Rushy Marsh the neap (or minimum) tide range was approximately 2.0 feet, occurring April 30. The spring (maximum) tide range was approximately 4.7 feet, and occurred on May 8. Inside Rushy Marsh the tidal signal very minimal due to the frictional damping caused by the culvert and sediment obstructing the inlet to the culvert. Figure V-14 illustrates that the fluctuations in water surface elevation resulting from non-tidal processes are greater than the tidal component. The tidal signal is less than 0.1 foot within Rushy Marsh.

Analyses of the tide data provided insight into the hydrodynamic characteristics of the system. Harmonic analysis of the tidal time series produced tidal amplitude and phase of the major tidal constituents, and provided assessments of hydrodynamic 'efficiency' of the system in terms of tidal attenuation. This analysis also yielded an assessment of the relative influence of non-tidal, or residual, processes (such as wind forcing) on the hydrodynamic characteristics of the offshore waters and the Rushy Marsh embayment.

Harmonic analyses were performed on the time series for each gauge location. Harmonic analysis is a mathematical procedure that fits sinusoidal functions of known frequency to the measured signal. The amplitudes and phase of 23 known tidal constituents result from this procedure. Table V-1 presents the amplitudes of the eight largest tidal constituents. The M_2, or the familiar twice-a-day lunar semi-diurnal, tide is the strongest contributor to the signal with an amplitude of 1.18 feet at the offshore gauge. The range of the M_2 tide is twice the amplitude, or 2.36 feet. The diurnal tides, K_1 and O_1, possess amplitudes of approximately 0.30 feet. The N_2 (12.66-hour period) semi-diurnal tide, also contributes significantly to the total tide signal with an amplitude of 0.32 feet. The M_4 and M_6 tides are higher frequency harmonics of the M_2 lunar tide (exactly half the period of the M_2 for the M_4, and one third of the M_2 for the M_6), results from frictional attenuation of the M_2 tide in shallow water. The M_4 is approximately 14% of the amplitude of the M_2 in the offshore gauge (about 0.16 feet). The M_6 amplitude is relatively small throughout the system (less than 0.06 feet). The M_{sf} is a lunarsolar fortnightly constituent with a period of approximately 14 days, and is the result of the periodic conjunction of the sun and moon. The observed astronomical tide is therefore the sum of several individual tidal constituents, with a particular amplitude and frequency.

Table V-1. Tidal Constituents, Rushy Marsh, April-May 2004

AMPLITUDE (feet)								
Period (hours)	M2 12.42	M4 6.21	M6 4.14	S2 12.00	N2 12.66	K1 23.93	O1 25.82	Msf 354.61
Offshore	1.18	0.16	0.06	0.14	0.32	0.35	0.30	0.01
Rushy Marsh	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02

Table V-1 also shows that the constituents within the marsh are very minimal due to the culvert restrictions. Generally, the constituents would vary as the tide propagates through the inlet into the marsh, however the frictional damping and restrictions are large enough to remove a majority of the tidal energy before it propagates into the system.

In addition to the tidal analysis, the data were further evaluated to determine the importance of tidal versus non-tidal processes to changes in water surface elevation. These other processes include wind forcing (set-up or set-down) within the estuary, as well as sub-tidal oscillations of the sea surface. Nantucket Sound is a relatively shallow semi-enclosed basin, therefore the water surface responds readily to wind-forcing. Variations in water surface elevation can also be affected by freshwater discharge into the system, if these volumes are relatively large. This analysis calculated the energy (or variance) of the original water elevation time series, and compared these energy values to that of the purely tidal signal (re-created by summing the contributions from the 23 known harmonic constituents). Subtracting the tidal signal from the original elevation time series resulted with the non-tidal, or residual, portion of the water elevation changes. The energy of this non-tidal signal is compared to the tidal signal, and yields a quantitative measure of how important these non-tidal physical processes can be to hydrodynamic circulation within the estuary. The results of this analysis for are presented in Table V-2.

Table V-2. Percentages of Tidal versus Non-Tidal Energy, Rushy Marsh, 2004.

	Total Variance ($ft^2 \cdot sec$)	Total (%)	Tidal (%)	Non-tidal (%)
Offshore	0.922	100	94.3	5.7
Rushy Marsh	0.010	100	4.1	95.9

The variability analysis shows that a majority of the change in water surface elevation in Nantucket Sound was due to tidal processes. However, in Rushy Marsh more than 90-percent of the energy was the result of non-tidal processes. The significant increase in non-tidal energy is due to tidal damping and frictional losses through the culvert.

In addition to the in-depth harmonic analysis of the offshore data records, a simpler analysis of the offshore tide record was undertaken to determine the elevation of standard tide datums. These computed datums are presented in Table V-3. The Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) levels represent the mean of the daily highest and lowest water levels. The Mean High Water (MHW) and Mean Low Water (MLW) levels represent the mean of all the high and low tides of a record, respectively. The Mean Tide Level (MTL) is simply the mean of MHW and MLW. The tides in Nantucket Sound are semi-diurnal, meaning that there are typically two tide cycles in a day. There is usually a small variation in the level of the two daily tides. This variation can be seen in the differences between the MHHW and MHW, as well as the MLLW and MLW levels.

Table V-3. Tide datums computed from tide record collected in Nantucket Sound. Datum elevations are given relative to NGVD 27.

Tide Datum	Offshore (feet)
Maximum Tide	3.29
MHHW	2.49
MHW	2.13
MTL	0.68
MLW	-0.76
MLLW	-1.01
Minimum Tide	-1.56

V.4 HYDRODYNAMIC MODELING

For the modeling of Rushy Marsh, Applied Coastal utilized a state-of-the-art computer model to evaluate tidal circulation and flushing in these systems. The particular model employed was the RMA-2 model developed by Resource Management Associates (King, 1990). It is a two-dimensional, depth-averaged finite element model, capable of simulating transient hydrodynamics. The model is widely accepted and tested for analyses of estuaries or rivers.

V.4.1 Model Theory

In its original form, RMA-2 was developed by William Norton and Ian King under contract with the U.S. Army Corps of Engineers (Norton et al., 1973). Further development included the introduction of one-dimensional elements, state-of-the-art pre- and post-processing data programs, and the use of elements with curved borders. Recently, the graphic pre- and post-processing routines were updated by a Brigham Young University through a package called the Surfacewater Modeling System or SMS (BYU, 1998). Graphics generated in support of this report primarily were generated within the SMS modeling package.

RMA-2 is a finite element model designed for simulating one- and two-dimensional depth-averaged hydrodynamic systems. The dependent variables are velocity and water depth, and the equations solved are the depth-averaged Navier Stokes equations. Reynolds assumptions are incorporated as an eddy viscosity effect to represent turbulent energy losses. Other terms in the governing equations permit friction losses (approximated either by a Chezy or Manning formulation), Coriolis effects, and surface wind stresses. All the coefficients associated with these terms may vary from element to element. The model utilizes quadrilaterals and triangles to represent the prototype system. Element boundaries may either be curved or straight.

The time dependence of the governing equations is incorporated within the solution technique needed to solve the set of simultaneous equations. This technique is implicit; therefore, unconditionally stable. Once the equations are solved, corrections to the initial estimate of velocity and water elevation are employed, and the equations are re-solved until the convergence criteria is met.

V.4.2 Model Setup

There are three main steps required to implement RMA-2:

- Grid generation
- Boundary condition specification
- Calibration

The extent of each finite element grid was generated using the shorelines within Rushy Marsh from 1994 digital aerial photographs from the MassGIS online orthophoto database. A time-varying water surface elevation boundary condition (measured tide) was specified along the offshore boundary to Rushy Marsh based on the tide gauge data collected near the entrance to Rushy Marsh in Nantucket Sound. Once the grid and boundary conditions were set, the model was calibrated to ensure accurate predictions of tidal flushing. Various friction and eddy viscosity coefficients were adjusted, through several model calibration simulations for the system, to obtain agreement between measured and modeled tides. The calibrated model provides the requisite information for future detailed water quality modeling.

V.4.2.1 Grid Generation

The grid generation process was aided by the use of the SMS package. A 1994 digital aerial orthophoto and the bathymetry survey data were imported to SMS, and a finite element grid was generated to represent the embayment and inlet. The aerial photograph was used to determine the land boundary of the system, as well as determine the surface coverage of adjoining salt marshes. The bathymetry data was interpolated to the developed finite element mesh of the system. The completed grid consists of 934 nodes, which describes 307 2-dimensional (depth averaged) quadratic elements. The maximum nodal depth is -6.0 ft (NGVD 29), along the offshore boundary to Nantucket Sound. The completed grid mesh of Rushy Marsh is shown in Figure V-15.

The finite element grid for the system provided the detail necessary to evaluate accurately the variation in hydrodynamic properties in Rushy Marsh. Fine grid resolution and one dimension elements were required to simulate the inlet culvert which has a significant impact the estuarine hydrodynamics. The SMS grid generation program was used to develop quadrilateral and triangular two-dimensional elements throughout the estuary.

Grid resolution was governed by two factors: 1) expected flow patterns, and 2) the bathymetric variability of the system. Relatively fine grid resolution was employed where complex flow patterns were expected. For example, smaller node spacing around the culvert were designed to provide a more detailed analysis in these regions of rapidly varying flow. Widely spaced nodes were often employed in areas where flow patterns are not likely to change dramatically. Appropriate implementation of wider spacing of nodes and larger elements reduced computer run time with no sacrifice of accuracy.

V.4.2.2 Boundary Condition Specification

Two types of boundary conditions were employed for the RMA-2 model of the Rushy Marsh system: 1) "slip" boundaries, and 2) tidal elevation boundaries. All of the elements with land borders have "slip" boundary conditions, where the direction of flow was constrained shore-parallel. The model generated all internal boundary conditions from the governing conservation equations. A tidal boundary condition was specified at the inlet. Tide gauge (TDR) measurements provided the required data. The rise and fall of the tide in Nantucket Sound is the primary driving force for estuarine circulation in this system. For the boundary a dynamic (time-varying) water surface elevation condition was specified every model time step (10 minutes) to represent the tidal forcing.



Figure V-15. Hydrodynamic model grid mesh for Rushy Marsh.

V.4.2.3 Calibration

After developing the finite element grid, and specifying boundary conditions, the model for the Rushy Marsh was calibrated. The calibration procedure ensures that the model predicts accurately what was observed in nature during the field measurement program. Numerous model simulations are required for an estuary model, specifying a range of friction and eddy viscosity coefficients, to calibrate the model.

Calibration of the hydrodynamic model requires a close match between the modeled and measured water surface elevations in the sub-embayments where tides were measured (i.e., from the TDR deployments). Initially, the model was calibrated to obtain visual agreement between modeled and measured water surface elevations. Once visual agreement is obtained, the normal procedure is to calibrate the model based on dominant tidal constituents. However, since the tidal fluctuations within Rushy Marsh are minimal due to tidal dampening through the culvert, a RMS error analysis was used to assess the agreement between modeled and measured water surface elevations.

The calibration was performed for a seven-day period beginning April 30, 2004 at 0000 EDT. This representative time period included the spring tide range of conditions in Nantucket Sound.

The calibrated model was used to analyze existing detailed flow patterns and compute residence times. The ability to model a range of flow conditions is a primary advantage of a

numerical tidal flushing model. For instance, average residence times were computed over the entire seven-day simulation. Other methods, such as dye and salinity studies, evaluate tidal flushing over relatively short time periods (less than one day). These short-term measurement techniques may not be representative of average conditions due to the influence of unique, short-lived atmospheric events.

V.4.2.3.1 Friction Coefficients

Friction inhibits flow along the bottom of estuary channels or other flow regions where velocities are relatively high. Friction is a measure of the channel roughness, and can cause both significant amplitude damping and phase delay of the tidal signal. Friction is approximated in RMA-2 as a Manning coefficient, and is applied to grid areas by user specified material types. Initially, Manning's friction coefficients between 0.020 and 0.07 were specified for all element material types. These values correspond to typical Manning's coefficients determined experimentally in smooth earth-lined channels with no weeds (low friction) to winding channels and marsh plains with higher friction (Henderson, 1966).

To improve model accuracy, friction coefficients were varied throughout the model domain. First, the Manning's coefficients were matched to bottom type. For example, lower friction coefficients were specified for the smooth sandy/silty bottom found in Rushy Marsh, versus the inlet culvert, which provides greater flow resistance. Final model calibration runs incorporated various specific values for Manning's friction coefficients, depending upon flow damping characteristics of separate regions within each estuary. Manning's values for different bottom types were initially selected based ranges provided by the Civil Engineering Reference Manual (Lindeburg, 1992), and values were incrementally changed when necessary to obtain a close match between measured and modeled tides. Final calibrated friction coefficients are summarized in the Table V-4. The extents of each material type are shown in Figure V-16.

Table V-4. Manning's Roughness coefficients used in simulations of modeled embayments. These embayment delineations correspond to the material type areas shown in Figure V-16.

System Embayment	Bottom Friction
Offshore	0.040
Culvert	0.065
Rushy Marsh	0.025
Ground Water	0.025

V.4.2.3.2 Turbulent Exchange Coefficients

Turbulent exchange coefficients approximate energy losses due to internal friction between fluid particles. The significance of turbulent energy losses increases where flow is swifter, such as inlets and bridge constrictions. According to King (1990), these values are proportional to element dimensions (numerical effects) and flow velocities (physics). In most cases, the modeled systems were relatively insensitive to turbulent exchange coefficients because there were no regions of strong turbulent flow. Typically, model turbulence coefficients were set between 50 and 80 lb-sec/ft^2.



Figure V-16. Hydrodynamic model grid material properties. Color patterns designate the different model material types used to vary model calibration parameters and compute flushing rates.

V.4.2.3.3 Comparison of Modeled Tides and Measured Tide Data

A best-fit of model predictions for the first tide gauge (TDR) deployment was achieved using the aforementioned values for friction and turbulent exchange. Figure V-17 illustrates the seven-day calibration simulation for Rushy Marsh. Modeled (solid line) and measured (dotted line) tides are illustrate the tide record. For this 200-hour simulation, the RMA analysis confirms that the model has very good correlation with the measured marsh elevation data, with a computed R^2 correlation coefficient of 0.63, and an rms error of 0.05 ft.

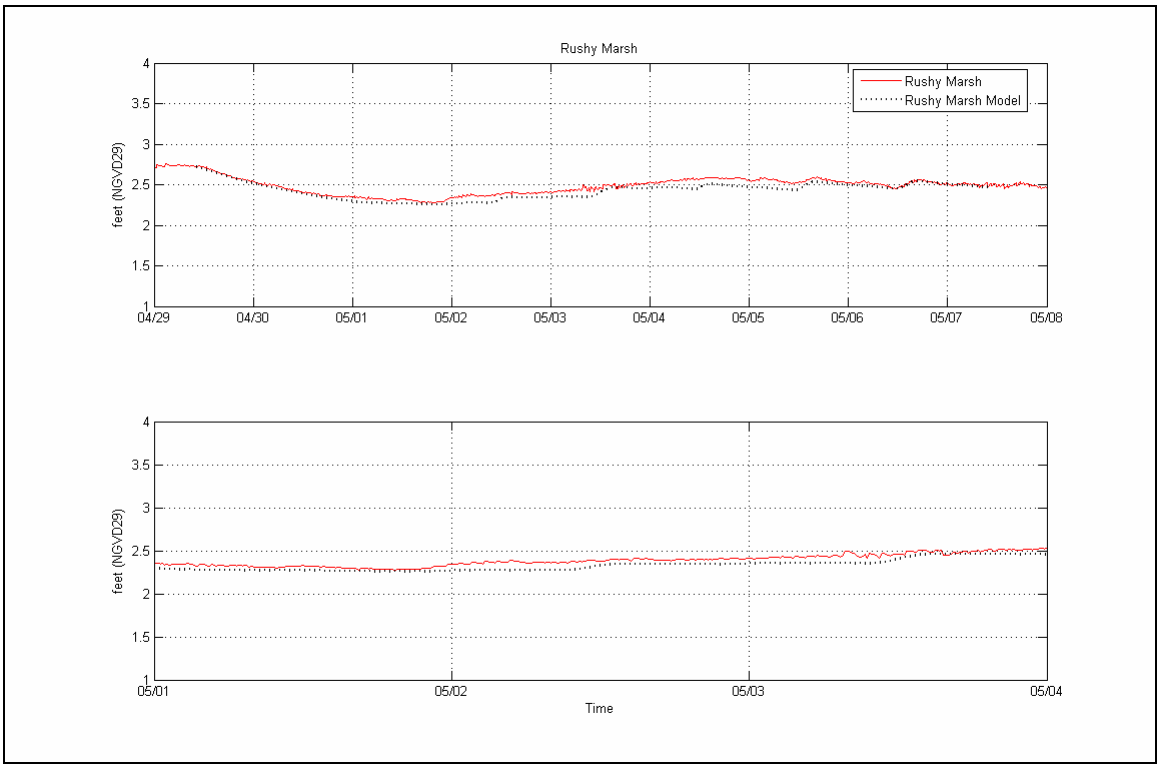


Figure V-17. Comparison of model output and measured tides for the gauge site in Rush Marsh. Differences between the observed (solid line) and modeled (dashed line) tidal elevation are generally imperceptible.

V.4.2.4 Model Circulation Characteristics

The final calibrated model serves as a useful tool in investigating the circulation characteristics of the system. Using model inputs of bathymetry and tide data, current velocities and flow rates can be determined at throughout the model domain. This is a very useful feature of a hydrodynamic model, where a limited amount of collected data can be expanded to determine the physical attributes of the system in areas where no physical data record exists.

Examining the results from the model run of Rushy Marsh shows the pond is minimally tidal and operates more as a salt water pond, with little to no current velocities within the main basin. The variation of flow as the tide floods and ebbs is seen in the plot of system flow rates in Figure V-18. The total flow rate of water flowing through a culvert was computed with the hydrodynamic model. Maximum flow rates occur during flood tides in this system, an indication that this estuary system is flood dominant, and likely a sediment sink (a system that accumulates sediment).

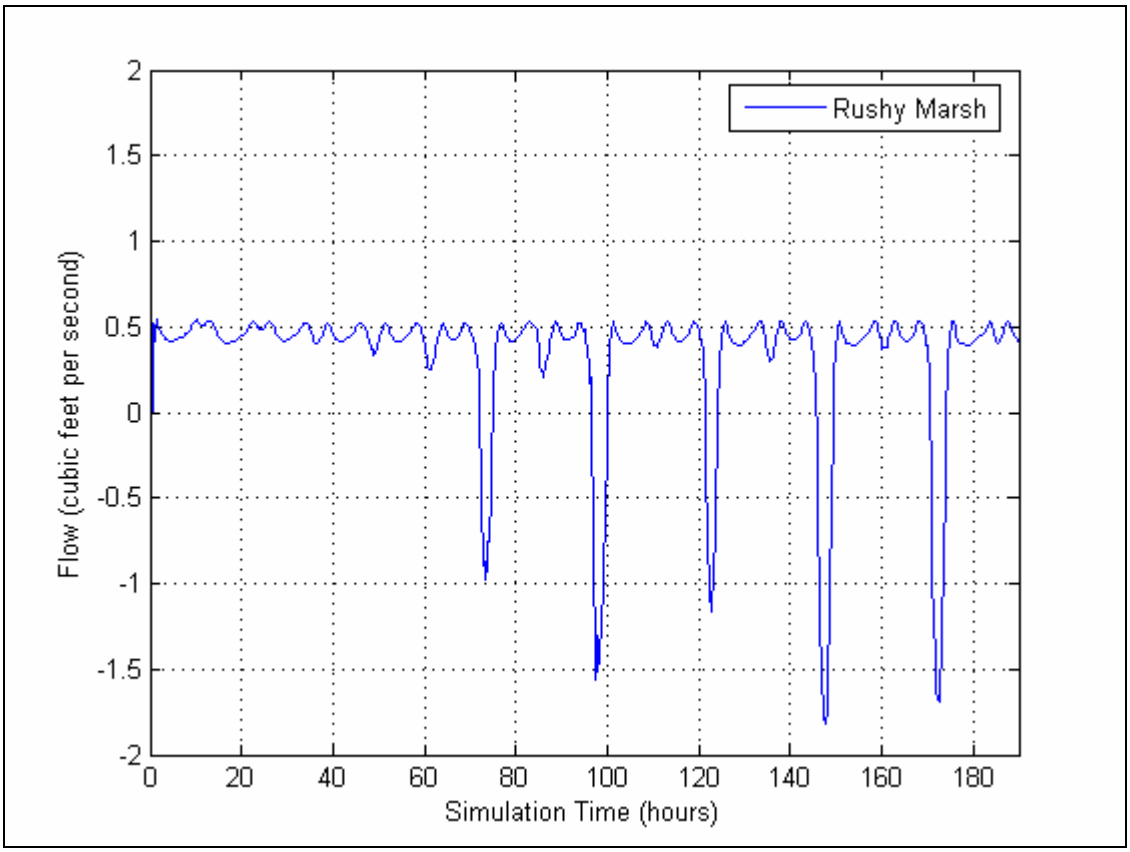


Figure V-18. Time variation of computed flow rate for inlet to Rushy Marsh. Model period shown corresponds to spring tide conditions, where the tide range is the largest. Positive flow indicated ebbing tide, while negative flow indicates flooding tide.

V.5 FLUSHING CHARACTERISTICS

Even with the highly restricted inlet, tidal exchange is much larger than the magnitude of freshwater inflow. The result is that the primary mechanism controlling estuarine water quality within the modeled Rushy Marsh system is tidal exchange. A rising tide offshore in Nantucket Sound creates a slope in water surface from the ocean into the modeled systems. Consequently, water flows into (floods) the system. Similarly, the estuary drains into the open waters of Nantucket Sound on an ebbing tide. This exchange of water between each system and the ocean is defined as tidal flushing. The calibrated hydrodynamic model is a tool to evaluate quantitatively tidal flushing of each system, and was used to compute flushing rates (residence times) and tidal circulation patterns.

Flushing rate, or residence time, is defined as the average time required for a parcel of water to migrate out of an estuary from points within the system. For this study, system residence times were computed as the average time required for a water parcel to migrate from a point within the each embayment to the entrance of the system. System residence times are computed as follows:

$$T_{system} = \frac{V_{system}}{P} t_{cycle}$$

where T_{system} denotes the residence time for the system, V_{system} represents volume of the (entire) system at mean tide level, P equals the tidal prism (or volume entering the system through a single tidal cycle), and t_{cycle} the period of the tidal cycle, typically 12.42 hours (or 0.52 days).

Residence times are provided as a first order evaluation of estuarine water quality. Lower residence times generally correspond to higher water quality; however, residence times may be misleading depending upon pollutant/nutrient loading rates and the overall quality of the receiving waters. As a qualitative guide, system residence times are applicable for systems where the water quality within the entire estuary is degraded and higher quality waters offshore provide the only means of reducing the high nutrient levels. This is a valid approach in the case of Rushy Marsh, since Nantucket Sound has relatively higher quality water then the Rushy Marsh.

The rate of pollutant/nutrient loading and the quality of adjacent offshore waters both must be evaluated in conjunction with residence times to obtain a clear picture of water quality. Efficient tidal flushing (low residence time) is not an indication of high water quality if pollutants and nutrients are loaded into the estuary faster than the tidal circulation can flush the system. Neither are low residence times an indicator of high water quality if the water flushed into the estuary is of poor quality. Advanced understanding of water quality will be obtained from the calibrated hydrodynamic model by extending the model to include pollutant/nutrient dispersion. The water quality model will provide a valuable tool to evaluate the complex mechanisms governing estuarine water quality in the system (see Section VI).

Since the calibrated RMA-2 model simulated accurate two-dimensional hydrodynamics in the system, model results were used to compute residence times. Residence times were calculated as the volume of water (based on the mean volumes computed for the simulation period) in the entire system divided by the average volume of water exchanged with each sub-embayment over a flood tidal cycle (tidal prism). Units then were converted to days. The volume of the entire estuary was computed as cubic feet.

The residence time was averaged for the tidal cycles comprising a representative 7.25 day period (14 tide cycles), and is listed in Table V-6. The modeled time period used to compute the flushing rate was the modeled calibration period, and included the transition from spring to neap tide conditions. The model calculated flow crossing specified grid lines along the inlet to compute the tidal prism volume. Since the 7.25-day period used to compute the flushing rates of the system represent average tidal conditions, the measurements provide the most appropriate method for determining mean flushing rates for the system embayment.

Table V-6. Embayment mean volume and average tidal prism during simulation period.

Embayment	Mean Volume (ft^3)	Tide Prism Volume (ft^3)
Rushy Marsh	2,848,800	30,936

Table V-7. Computed residence times for Rushy Marsh system.

Embayment	System Residence Time (days)
Rushy Marsh	47.7

The computed flushing rate for the Rushy Marsh shows that system takes approximately 48 days for the volume of the system to be exchanged. This suggests that the system has inadequate tidal flushing. This method assumes all the water in the system is exchanged, while in reality the water around the outlet of the culvert is most likely to be exchanged. Meaning that water quality continues to decrease in the remaining portions of the marsh.

Generally, possible errors in computed residence times can be linked to two sources: the bathymetry information and simplifications employed to calculate residence time. In this study, the most significant errors associated with the bathymetry data result from the process of interpolating the data to the finite element mesh, which was the basis for all the flushing volumes used in the analysis. In addition, limited topographic measurements were available on the marsh plains. Minor errors may be introduced in residence time calculations by simplifying assumptions. Flushing rate calculations assume that water exiting the estuary does not return on the following tidal cycle. For regions where a strong littoral drift exists, this assumption is valid. However, water exiting a small sub-embayment on a relatively calm day may not completely mix with estuarine waters. In this case, the “strong littoral drift” assumption would lead to an under-prediction of residence time. Since littoral drift along the coast of Nantucket Sound typically is strong because of the local winds induce tidal mixing within the regional estuarine systems, the “strong littoral drift” assumption only will cause minor errors in residence time calculations. Based on our knowledge of estuarine processes, we estimate that the combined errors due to bathymetric inaccuracies represented in the model grid and the “strong littoral drift” assumption are within 10% to 15% of “true” residence times.

VI. WATER QUALITY MODELING

VI.1 DATA SOURCES FOR THE MODEL

Several different data types and calculations are required to support the water quality modeling effort for the Rushy Marsh estuary system. These include the output from the hydrodynamics model, calculations of external nitrogen loads from the watersheds, measurements of internal nitrogen loads from the sediment (benthic flux), and measurements of nitrogen in the water column.

VI.1.1 Hydrodynamics and Tidal Flushing in the Embayment

Extensive field measurements and hydrodynamic modeling of the embayment were an essential preparatory step to the development of the water quality model. The result of this work, among other things, was a calibrated model output representing the transport of water within the system embayment. Files of node locations and node connectivity for the RMA-2V model grid were transferred to the RMA-4 water quality model; therefore, the computational grid for the hydrodynamic model also was the computational grid for the water quality model. The period of hydrodynamic output for the water quality model calibration was a 10-tidal cycle period in late April early May 2004. Each modeled scenario (e.g., present conditions, build-out) required the model be run for a 28-day spin-up period, to allow the model had reached a dynamic “steady state”, and ensure that model spin-up would not affect the final model output.

VI.1.2 Nitrogen Loading to the Embayment

Three primary nitrogen loads to embayment are recognized in this modeling study: external loads from the watersheds, nitrogen load from direct rainfall on the embayment surface, and internal loads from the sediments. Additionally, there is a fourth load to Rushy Marsh, consisting of the background concentrations of total nitrogen in the waters entering from Nantucket Sound. This load is represented as a constant concentration along the seaward boundary of the model grid.

VI.1.3 Measured Nitrogen Concentrations in the Embayment

In order to create a model that realistically simulates the total nitrogen concentrations in a system in response to the existing flushing conditions and loadings, it is necessary to calibrate the model to actual measurements of water column nitrogen concentrations. The refined and approved data for each monitoring station used in the water quality modeling effort are presented in Table VI-1. Station locations are indicated in Figure VI-1. The multi-year averages present the “best” comparison to the water quality model output, since factors of tide, temperature and rainfall may exert short-term influences on the individual sampling dates and even cause inter-annual differences. Three years of baseline field data is the minimum required to provide a baseline for MEP analysis. Four years of data (collected between 2002 and 2005) were available for stations monitored within Rushy Marsh by Three Bays Preservation in partnership with the Town of Barnstable, with technical assistance from the Coastal Systems Program, SMAST.

VI.2 MODEL DESCRIPTION AND APPLICATION

A two-dimensional finite element water quality model, RMA-4 (King, 1990), was employed to study the effects of nitrogen loading in the Rushy Marsh estuary system. The RMA-4 model has the capability for the simulation of advection-diffusion processes in aquatic environments. It is the constituent transport model counterpart of the RMA-2 hydrodynamic model used to

Table VI-1. Water Quality Monitoring Pond-Watcher measured data, and modeled Nitrogen concentrations for the Rushy Marsh system used in the model calibration plots of Figure VI-2. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means.

Sub-Embayment	monitoring station	2002 mean	2003 mean	2004 mean	2005 mean	data mean	s.d. all data	N	model min	model max	Model average
Rushy Marsh - north	RM1	1.174	1.411	0.991	0.898	1.111	0.271	28	1.098	1.106	1.102
Rushy Marsh - east	RM2	1.195	1.407	1.004	0.875	1.117	0.248	28	1.099	1.112	1.107
Rushy Marsh - west	RM3	1.317	1.447	0.974	0.812	1.123	0.306	22	1.103	1.112	1.108
Rushy Marsh - south	RM4	1.267	1.415	1.011	1.052	1.170	0.353	22	1.154	1.159	1.156

simulate the fluid dynamics of the Rushy Marsh. Like RMA-2 numerical code, RMA-4 is a two-dimensional, depth averaged finite element model capable of simulating time-dependent constituent transport. The RMA-4 model was developed with support from the US Army Corps of Engineers (USACE) Waterways Experiment Station (WES), and is widely accepted and tested. Applied Coastal staff have utilized this model in water quality studies of other Cape Cod embayments, including systems in Falmouth (Ramsey *et al*., 2000); Mashpee, MA (Howes *et al*., 2004) and Chatham, MA (Howes *et al*., 2003).

The overall approach involves modeling total nitrogen as a non-conservative constituent, where bottom sediments act as a source or sink of nitrogen, based on local biochemical characteristics. This modeling represents summertime conditions, when algal growth is at its maximum. Total nitrogen modeling is based upon various data collection efforts and analyses presented in previous sections of this report. Nitrogen loading information was derived from the Cape Cod Commission watershed loading analysis, Section IV.1 (based on the USGS watersheds, Chapter III), as well as the measured bottom sediment nitrogen fluxes (Section IV.3). Water column nitrogen measurements were utilized as model boundaries and as calibration data. Hydrodynamic model output (discussed in Section V) provided the remaining information (tides, currents, and bathymetry) needed to parameterize the water quality model of the system.



Figure VI-1. Estuarine water quality monitoring station locations in the Rushy Marsh system. Station labels correspond to those provided in Table VI-1.

VI.2.1 Model Formulation

The formulation of the model is for two-dimensional depth-averaged systems in which concentration in the vertical direction is assumed uniform. The depth-averaged assumption is justified since vertical mixing by wind and tidal processes prevent significant stratification in the modeled sub-embayments. The governing equation of the RMA-4 constituent model can be most simply expressed as a form of the transport equation, in two dimensions:

$$\left(\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y}\right) = \left(\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x} + \frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y} + \sigma\right)$$

where c in the water quality constituent concentration; t is time; u and v are the velocities in the x and y directions, respectively; D_x and D_y are the model dispersion coefficients in the x and y directions; and σ is the constituent source/sink term. Since the model utilizes input from the RMA-2 model, a similar implicit solution technique is employed for the RMA-4 model.

The model is therefore used to compute spatially and temporally varying concentrations c of the modeled constituent (i.e., total nitrogen), based on model inputs of 1) water depth and velocity computed using the RMA-2 hydrodynamic model; 2) mass loading input of the modeled constituent; and 3) user selected values of the model dispersion coefficients. Dispersion coefficients used for each system sub-embayment were developed during the calibration process. During the calibration procedure, the dispersion coefficients were incrementally changed until model concentration outputs matched measured data.

The RMA-4 model can be utilized to predict both spatial and temporal variations in total for a given embayment system. At each time step, the model computes constituent concentrations over the entire finite element grid and utilizes a continuity of mass equation to check these results. Similar to the hydrodynamic model, the water quality model evaluates model parameters at every element at 10-minute time intervals throughout the grid system. For this application, the RMA-4 model was used to predict tidally averaged total nitrogen concentrations throughout Rushy Marsh.

VI.2.2 Water Quality Model Setup

Required inputs to the RMA-4 model include a computational mesh, computed water elevations and velocities at all nodes of the mesh, constituent mass loading, and spatially varying values of the dispersion coefficient. Because the RMA-4 model is part of a suite of integrated computer models, the finite-element meshes and the resulting hydrodynamic simulations previously developed for the Rushy Marsh system was used for the water quality constituent modeling portion of this study.

Based on groundwater recharge rates from the USGS, the hydrodynamic model was set-up to include the latest estimate of surface water flow into Rushy Marsh. The groundwater recharge has a measure flow rate of 0.28 ft^3/sec (682 m^3/day).

For the model, an initial total N concentration equal to the concentration at the open boundary was applied to the entire model domain. The model was then run for a simulated month-long (28 day) spin-up period. At the end of the spin-up period, the model was run for an additional 5 tidal-day (125 hour) period. Model results were recorded only after the initial spin-up period. The time step used for the water quality computations was 10 minutes, which corresponds to the time step of the hydrodynamics input for the Rushy Marsh system.

VI.2.3 Boundary Condition Specification

Mass loading of nitrogen into each model included 1) sources developed from the results of the watershed analysis, 2) estimates of direct atmospheric deposition, 3) summer benthic regeneration. Nitrogen loads from each separate sub-embayment watershed were distributed across the sub-embayment. For example, the combined watershed direct atmospheric deposition load for Rushy Marsh was evenly distributed at grid cells that formed the perimeter of the embayment. Benthic regeneration load was distributed among another sub-set of grid cells which are in the interior portion of each basin.

The loadings used to model present conditions in Rushy Marsh estuary systems are given in Table VI-2. Watershed and depositional loads were taken from the results of the analysis of Section IV.1. Summertime benthic flux loads were computed based on the analysis of sediment cores in Section IV.3. The area rate (g/sec/m^2) of nitrogen flux from that analysis was applied to the surface area coverage computed for each sub-embayment (excluding marsh coverages, when present), resulting in a total flux for each embayment (as listed in Table VI-2). Due to the highly variable nature of bottom sediments and other estuarine characteristics of coastal embayments in general, the measured benthic flux for existing conditions also is variable. For present conditions, some sub-embayments have almost twice the loading rate from benthic regeneration as from watershed loads. For other sub-embayments, the benthic flux is relatively low or negative indicating a net uptake of nitrogen in the bottom sediments.

In addition to mass loading boundary conditions set within the model domain, concentrations along the model open boundary were specified. The model uses concentrations at the open boundary during the flooding tide periods of the model simulations. TN concentrations of the incoming water are set at the value designated for the open boundary. The boundary concentration in Vineyard Sound was set at 0.280 mg/L, based on SMAST data from the Sound. The open boundary total nitrogen concentration represents long-term average summer concentrations found within Nantucket Sound.

Table VI-2. Sub-embayment and surface water loads used for total nitrogen modeling of the Rushy Marsh, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent **present loading conditions.**

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Rushy Marsh	0.447	0.203	-0.197

VI.2.4 Model Calibration

Calibration of the total nitrogen model proceeded by changing model dispersion coefficients so that model output of nitrogen concentrations matched measured data. Generally, several model runs of each system were required to match the water column measurements. Dispersion coefficient (*E*) values were varied through the modeled system by setting different values of *E* for each grid material type, as designated in Section V. Observed values of *E* (Fischer, *et al.*, 1979) vary between order 10 and order 1000 m^2/sec for riverine estuary systems characterized by relatively wide channels (compared to channel depth) with moderate currents (from tides or atmospheric forcing). Generally, the relatively quiescent Rushy Marsh embayment system require values of *E* that are lower compared to the riverine

estuary systems evaluated by Fischer, et al., (1979). Observed values of *E* in these calmer areas typically range between order 10 and order 0.001 m^2/sec (USACE, 2001). Final values of *E* used in each sub-embayment of the modeled systems are presented in Table VI-3. These values were used to develop the "best-fit" total nitrogen model calibration. For the case of TN modeling, "best fit" can be defined as minimizing error between the model and data at all sampling locations, utilizing reasonable ranges of dispersion coefficients within each sub-embayment.

Table VI-3. Values of longitudinal dispersion coefficient, E, used in calibrated RMA4 model runs of salinity and nitrogen concentration for Rushy Marsh estuary system.

Embayment Division	E m^2/sec
Main Basin Rushy Marsh	1.0
Southern Arm Rushy Marsh	1.0
Culvert	0.7
Nantucket Sound	8.0

Comparisons between model output and measured nitrogen concentrations are shown in plots presented in Figure VI-2. In these plots, means of the water column data and a range of two standard deviations of the annual means at each individual station are plotted against the modeled maximum, mean, and minimum concentrations output from the model at locations which corresponds to the SMAST monitoring stations.

For model calibration, the mid-point between maximum modeled TN and average modeled TN was compared to mean measured TN data values, at each water-quality monitoring station. The calibration target would fall between the modeled mean and maximum TN because the monitoring data are collected, as a rule, during mid ebb tide.

Also presented in this figure are unity plot comparisons of measured data verses modeled target values for the system. The model fit is exceptional for the Rushy Marsh model, with rms error of 0.01 mg/L and an R^2 correlation coefficient of 0.72.

A contour plot of calibrated model output is shown in Figure VI-3 for Rushy Marsh. In the figure, color contours indicate nitrogen concentrations throughout the model domain. The output in the figure show average total nitrogen concentrations, computed using the full 5-tidal-day model simulation output period.

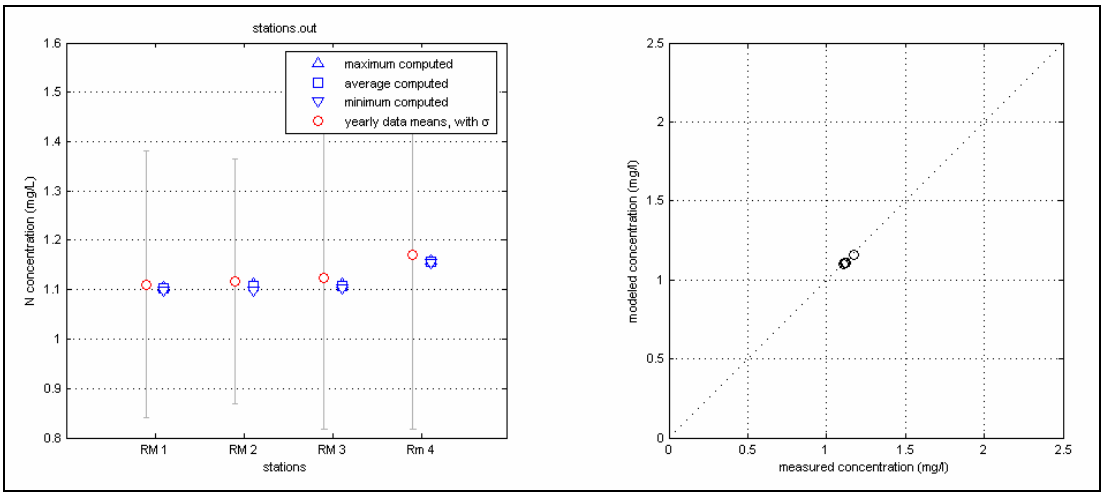


Figure VI-2. Comparison of measured total nitrogen concentrations and calibrated model output at stations in Rushy Marsh. For the left plot, station labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed concentration for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset. For the plots to the right, model calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for each model are also presented.

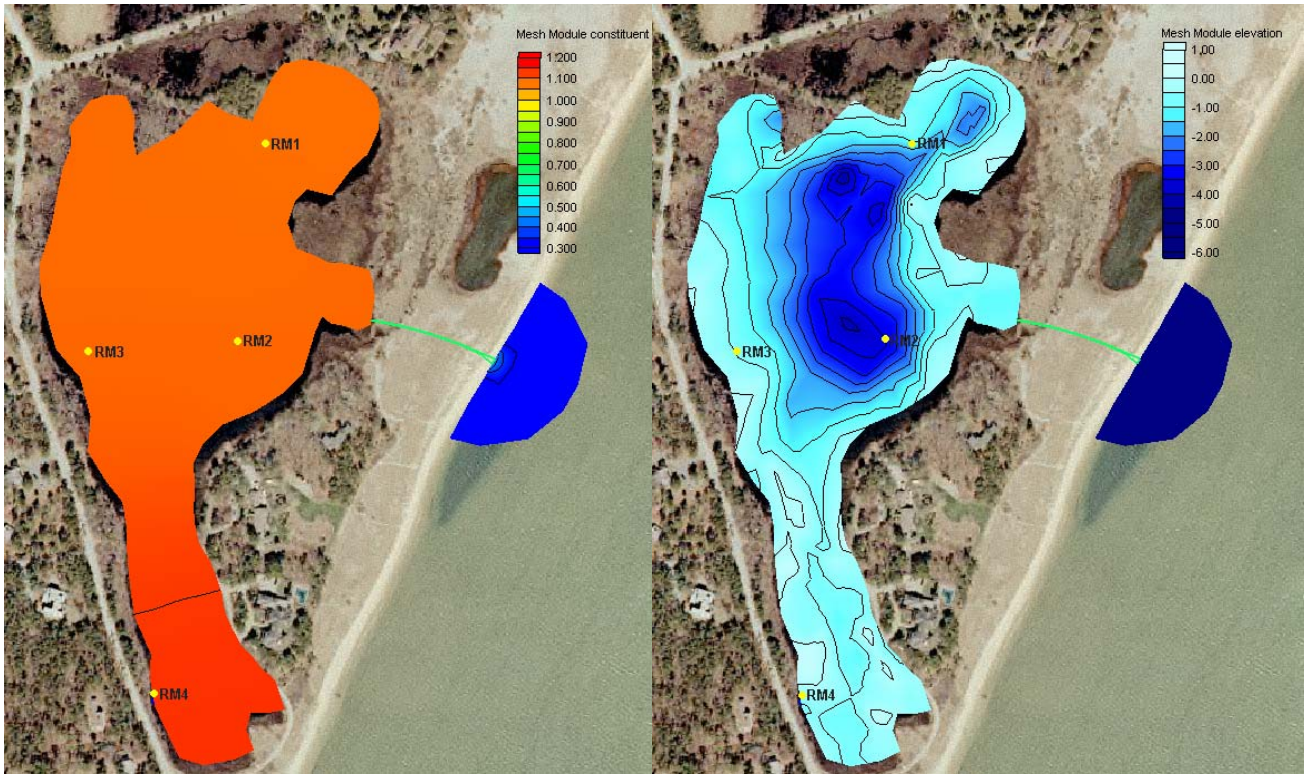


Figure VI-3. Contour plots of average total nitrogen concentrations from results of the present conditions loading scenario and the bathymetry, for Rushy Marsh. The approximate location of the sentinel threshold station for Rushy Marsh (RM2) is shown.

VI.2.5 Model Salinity Verification

In addition to the model calibration based on nitrogen loading and water column measurements, numerical water quality model performance is typically verified by modeling salinity. This step was performed for the Rushy Marsh system using salinity data collected at the same stations as the nitrogen data. The only required inputs into the RMA4 salinity model of each system, in addition to the RMA2 hydrodynamic model output, were salinities at the model open boundary and groundwater inputs. The open boundary salinity was set at 29.6 ppt. For groundwater inputs salinities were set at 0 ppt. Groundwater input used for the model was 0.28 ft^3/sec (682 m^3/day). Groundwater flows were distributed evenly in each model through the use of several 1-D element input points positioned along each model's land boundary.

Comparisons of modeled and measured salinities are presented in Figure VI-4, with contour plots of model output shown in Figure VI-5. Though model dispersion coefficients were not changed from those values selected through the nitrogen model calibration process, the model skillfully represents salinity gradients in Rushy Marsh. The rms error of the models was 1.3 ppt, and correlation coefficient was 0.95. The salinity verification provides a further independent confirmation that model dispersion coefficients and represented freshwater inputs to the model correctly simulate the real physical systems.

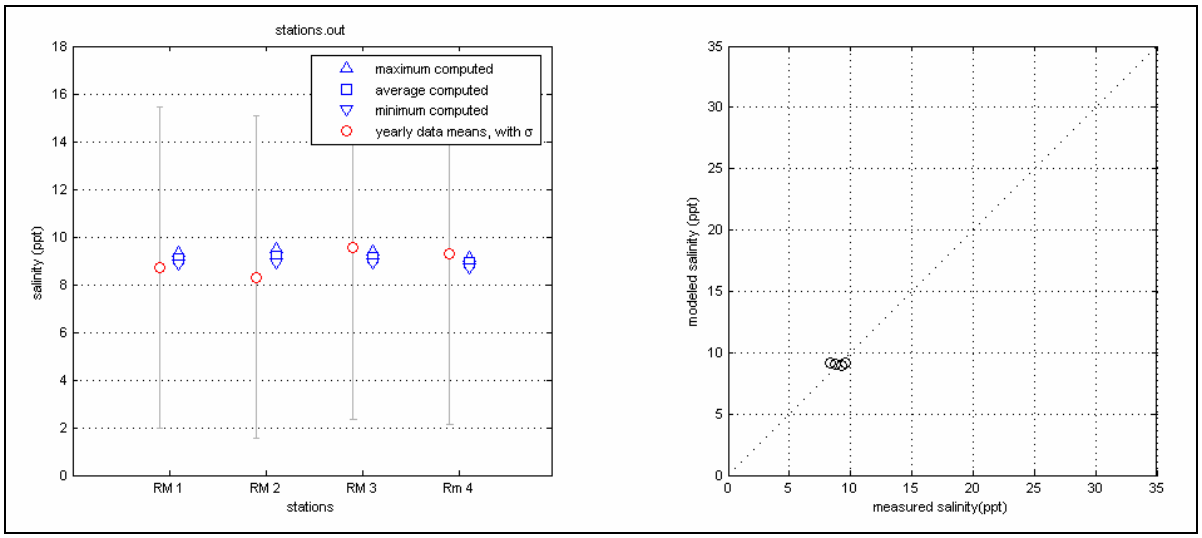


Figure VI-4. Comparison of measured and calibrated model output at stations in Rushy Marsh. For the left plots, stations labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed salinity for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset. For the plots to the right, model calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for each model are also presented.

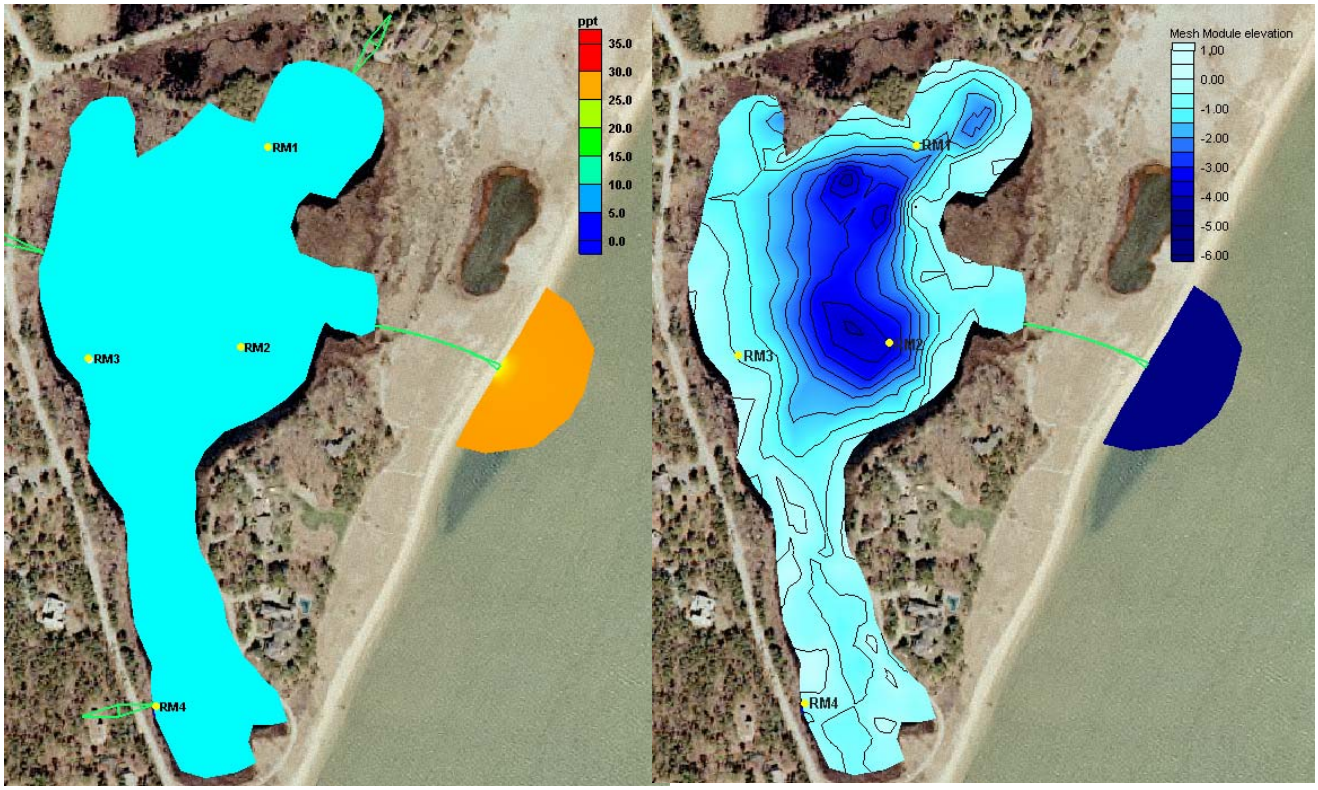


Figure VI-5. Contour plots of modeled salinity (ppt) and bathymetry in Rushy Marsh.

VI.2.6 Build-Out and No Anthropogenic Load Scenarios

To assess the influence of nitrogen loading on total nitrogen concentrations within the embayment system, two standard water quality modeling scenarios were run: a "build-out" scenario based on potential development (described in more detail in Section IV) and a "no anthropogenic load" or "no load" scenario assuming only atmospheric deposition on the watershed and sub-embayment, as well as a natural forest within each watershed. Comparisons of the alternate watershed loading analyses are shown in Table VI-4. Loads are presented in kilograms per day (kg/day) in this Section, since it is inappropriate to show benthic flux loads in kilograms per year due to seasonal variability.

Table VI-4. Comparison of sub-embayment watershed loads used for modeling of present, build-out, and no-anthropogenic ("no-load") loading scenarios of the Rushy Marsh system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	build out (kg/day)	build-out % change	no load (kg/day)	no load % change
Rushy Marsh Pond	0.447	0.907	+103.1%	0.077	-82.8%

VI.2.6.1 Build-Out

In general, certain sub-embayments would be impacted more than others. The build-out scenario indicates that there would be more than a 100% increase in watershed nitrogen load to Rushy Marsh as a result of potential future development. For the no load scenarios, almost all

of the load entering the watershed is removed; therefore, the load is generally lower than existing conditions by over 80%.

For the build-out scenario, a breakdown of the total nitrogen load entering the Rushy Marsh embayment is shown in Table VI-5. The benthic flux for the build-out scenarios is assumed to vary proportional to the watershed load, where an increase in watershed load will result in an increase in benthic flux (i.e., a positive change in the absolute value of the flux), and *vise versa*.

Projected benthic fluxes (for both the build-out and no load scenarios) are based upon projected PON concentrations and watershed loads, determined as:

$$(Projected\ N\ flux) = (Present\ N\ flux) * [PON_{projected}]/[PON_{present}]$$

where the projected PON concentration is calculated by,

$$[PON_{projected}] = R_{load} * \Delta PON + [PON_{(present\ offshore)}],$$

using the watershed load ratio,

$$R_{load} = (Projected\ N\ load) / (Present\ N\ load),$$

and the present PON concentration above background,

$$\Delta PON = [PON_{(present\ flux\ core)}] - [PON_{(present\ offshore)}].$$

Table VI-5. Build-out sub-embayment and surface water loads used for total nitrogen modeling of the Rushy Marsh, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Rushy Marsh	0.907	0.203	-0.310

Following development of the nitrogen loading estimates for the build-out scenario, the water quality model of Rushy Marsh was run to determine nitrogen concentrations at each measurement station (Table VI-6). Total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios. Total N concentrations increased evenly across the system due to the limited marsh circulation. Color contours of model output for the build-out scenario are present in Figure VI-6. The range of nitrogen concentrations shown are the same as for the plot of present conditions in Figure VI-3, which allows direct comparison of nitrogen concentrations between loading scenarios.

Table VI-6. Comparison of model average total N concentrations from present loading and the build-out scenario, with percent change, for the Rushy Marsh system. Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	build-out (mg/L)	% change
Rushy Marsh - north	RM1	1.102	1.237	+12.2%
Rushy Marsh - east	**RM2**	**1.107**	**1.245**	**+12.5%**
Rushy Marsh - west	RM3	1.108	1.246	+12.5%
Rushy Marsh - south	RM4	1.156	1.320	+14.2%

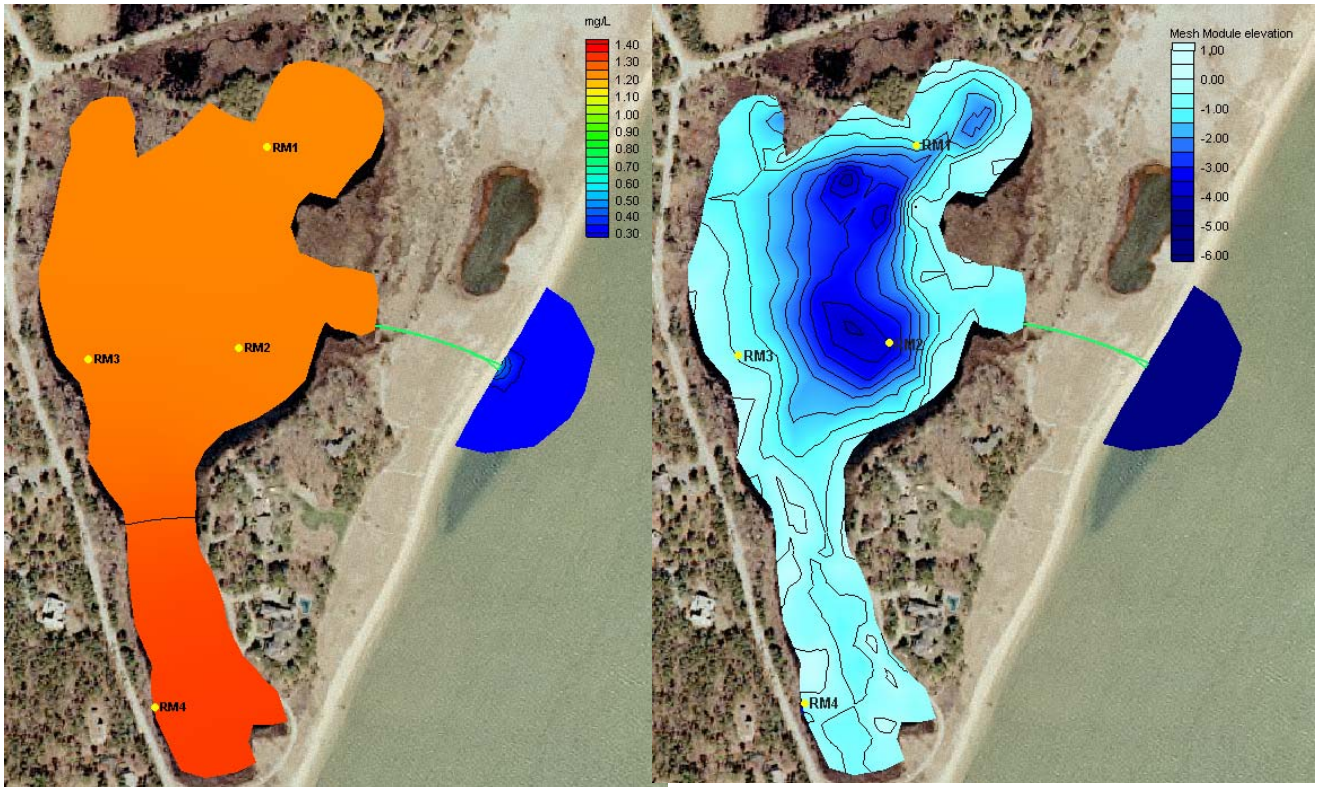


Figure VI-6. Contour plots of modeled total nitrogen concentrations (mg/L) in Rushy Marsh, for projected build-out loading conditions, and bathymetry. The approximate location of the sentinel threshold station for Rushy Marsh (RM2) is shown.

VI.2.6.2 No Anthropogenic Load

A breakdown of the total nitrogen load entering each sub-embayment for the no anthropogenic load ("no load") scenario is shown in Table VI-7. The benthic flux input to each embayment was reduced (toward zero) based on the reduction in the watershed load (as discussed in §VI.2.6.1). Compared to the modeled present conditions and build-out scenario, atmospheric deposition directly to each sub-embayment becomes a greater percentage of the total nitrogen load as the watershed load and related benthic flux decrease.

Table VI-7. "No anthropogenic loading" ("no load") sub-embayment and surface water loads used for total nitrogen modeling of Rushy Marsh, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Rushy Marsh	0.077	0.203	-0.110

Following development of the nitrogen loading estimates for the no load scenario, the water quality model was run to determine nitrogen concentrations at each recording station. Again, total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios. The relative change in total nitrogen concentrations resulting from "no load" was significant as shown in Table VI-8, with reductions

greater than 12% occurring the all portions of the systems. Results for each system are shown pictorially in Figure VI-7.

Table VI-8. Comparison of model average total N concentrations from present loading and the no anthropogenic ("no load") scenario, with percent change, for the Rushy Marsh system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	no-load (mg/L)	% change
Rushy Marsh - north	RM1	1.102	0.968	-12.2%
Rushy Marsh - east	**RM2**	**1.107**	**0.970**	**-12.4%**
Rushy Marsh - west	RM3	1.108	0.971	-12.4%
Rushy Marsh - south	RM4	1.156	0.996	-13.8%

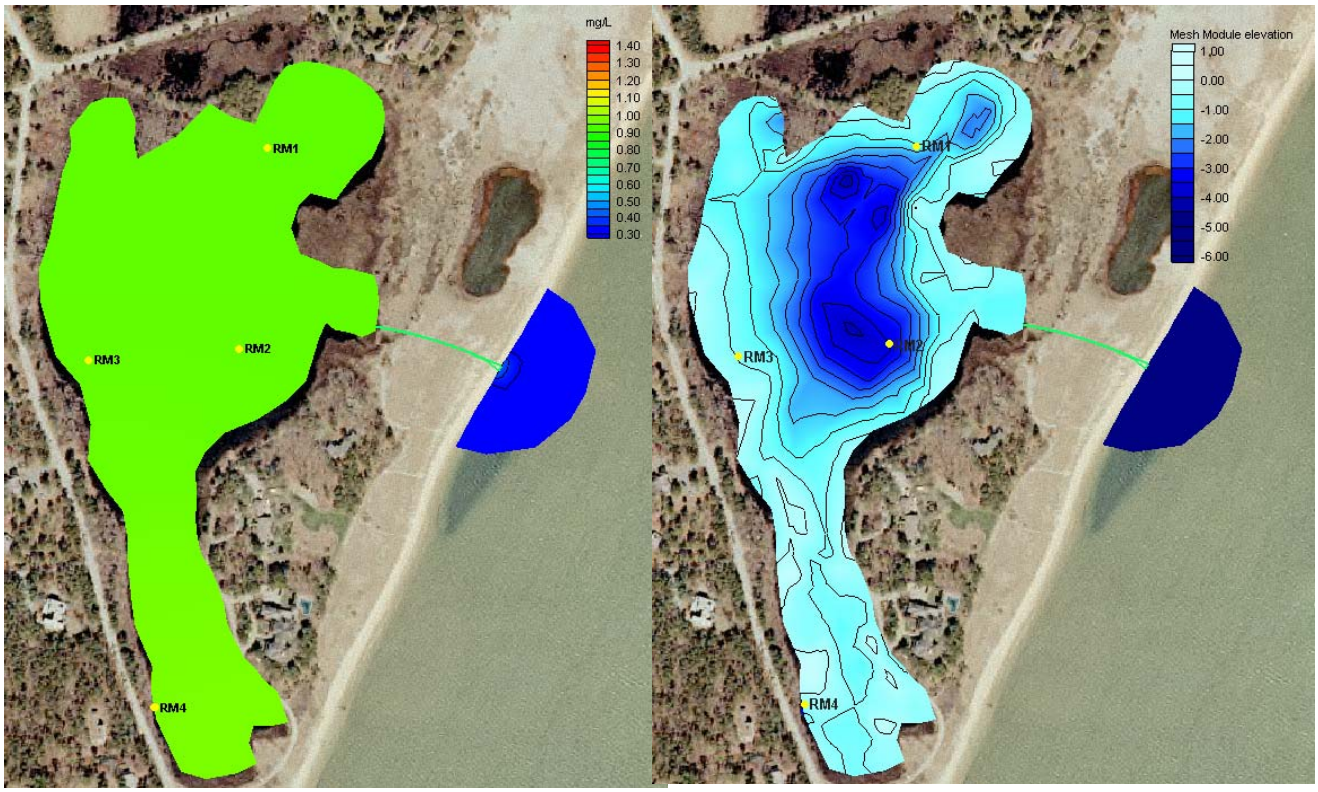


Figure VI-7. Contour plots of modeled total nitrogen concentrations (mg/L) in Rushy Marsh, for no anthropogenic loading conditions, and bathymetry. The approximate location of the sentinel threshold station for Rushy Marsh (RM2) is shown.

VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll, and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (fish, shellfish, infauna) which it supports. For the Rushy Marsh embayment system, our assessment is based upon data from the water quality monitoring database and our surveys of eelgrass distribution, benthic animal communities and sediment characteristics, and dissolved oxygen records conducted during the summer of 2004. These data form the basis of an assessment of this system's present health, and when coupled with a full water quality synthesis and projections of future conditions based upon the water quality modeling effort, will support complete nitrogen threshold development for these systems (Chapter VIII).

VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS

There are a variety of indicators that can be used in concert with water quality monitoring data for evaluating the ecological health of embayment systems. The best biological indicators are those species which are non-mobile and which persist over relatively long periods, if environmental conditions remain constant. The concept is to use species which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

As a basis for a nitrogen thresholds determination, MEP focused on major habitat quality indicators: (1) bottom water dissolved oxygen and chlorophyll a (Section VII.2), (2) eelgrass distribution over time (Section VII.3) and (3) benthic animal communities (Section VII.4). Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate cause being nitrogen loading). However, oxygen conditions can change rapidly and frequently show strong tidal and diurnal patterns. Even severe levels of oxygen depletion may occur only infrequently, yet have important effects on system health. To capture this variation, the MEP Technical Team deployed dissolved oxygen sensors within Rushy Marsh Pond (2004) to record the frequency and duration of low oxygen conditions during the critical summer period, July-September.

The MEP habitat analysis uses eelgrass as a sentinel species for indicating nitrogen over-loading to coastal embayments. Eelgrass is a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. Assessment of eelgrass beds, past and present, within the Rushy Marsh System was conducted for comparison to historic records (DEP Eelgrass Mapping Program, C. Costello). Temporal trends in the distribution of eelgrass beds are used by the MEP to assess the stability of the habitat and to determine trends potentially related to water quality. Eelgrass beds can decrease within embayments in response to a variety of causes, but throughout almost all of the embayments within southeastern Massachusetts, the primary cause appears to be related to increases in embayment nitrogen levels. Within Rushy Marsh Pond present and/or historic eelgrass distribution provides guidance for setting habitat restoration goals and associated nitrogen thresholds.

In areas that do not support eelgrass beds, benthic animal indicators were used to assess the level of habitat health from "healthy" (low organic matter loading, high D.O.) to "highly stressed" (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment

samples were identified and the environments ranked based upon the fraction of healthy, transitional, and stressed indicator species. The analysis is based upon life-history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes *et al.* 1997). These data are coupled with the level of diversity (H') and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

VII.2 BOTTOM WATER DISSOLVED OXYGEN

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 3.8 mg L^{-1}. Massachusetts State Water Quality Classification indicates that SA (high quality) waters maintain oxygen levels above 6 mg L^{-1}. The tidal waters of the Rushy Marsh Pond System, as marine waters, are listed under this Classification as SA. It should be noted that the Classification system represents the water quality that the embayment should support, not the existing level of water quality. It is through the MEP and TMDL processes that management actions are developed and implemented to keep or bring the existing conditions in line with the Classification.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates in summer than winter (Figure VII-1). It is not surprising that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute levels (mg L^{-1}) are found during the summer in southeastern Massachusetts embayments when water column respiration rates are greatest. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen conditions within shallow embayments (Taylor and Howes, 1994). To more accurately capture the degree of bottom water dissolved oxygen depletion during the critical summer period, autonomously recording oxygen sensors were moored 30 cm above the embayment bottom within the central basin of the Rushy Marsh basin (Figure VII-2). The sensors (YSI 6600) were first calibrated in the laboratory and then checked with standard oxygen mixtures at the time of initial instrument mooring deployment. In addition periodic calibration samples were collected at the sensor depth and assayed by Winkler titration (potentiometric analysis, Radiometer) during each deployment. Each instrument mooring was serviced and calibration samples collected at least biweekly and sometimes weekly during the 3 month deployment, July – September.

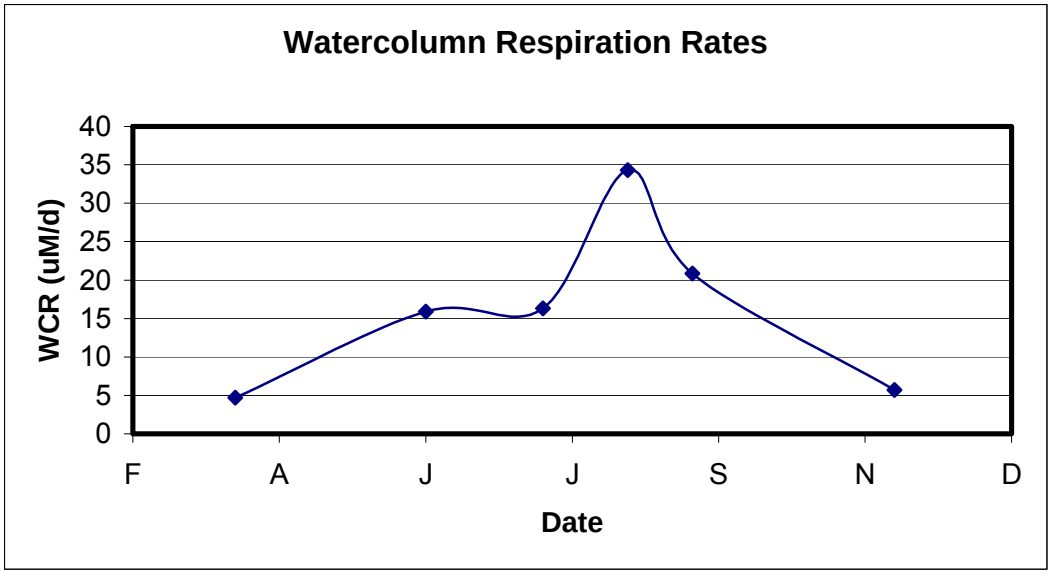


Figure VII-1. Average watercolumn respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System (Schlezinger and Howes, unpublished data). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Similar to other embayments in southeastern Massachusetts, the Rushy Marsh system evaluated in this assessment showed high frequency variation, apparently related to diurnal and sometimes tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration the each mooring site, underscores the need for continuous monitoring within these systems.

Dissolved oxygen and chlorophyll a records were examined both for temporal trends and to determine the percent of the deployment period that these parameters were below/above various benchmark concentrations (Tables VII-1, VII-2). These data indicate both the temporal pattern of minimum or maximum levels of these critical nutrient related constituents, as well as the intensity of the oxygen depletion events and phytoplankton blooms. However, it should be noted that the frequency of oxygen depletion needs to be integrated with the actual temporal pattern of oxygen levels, specifically as it relates to daily oxygen excursions.
The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality within the estuary (Figures VII-3 through VII-4). Oxygen depletion was frequently to levels <4 mg/L (29 days) and periodically to < 3 mg/L (8 days). The oxygen data is consistent with high organic matter loads from phytoplankton production (chlorophyll a levels) indicative of nitrogen enrichment and eutrophication of this estuarine system, although the nitrogen enrichment stems primarily from the restriction of tidal exchange. The frequent significant level of oxygen depletion coupled to the frequent phytoplankton blooms is clear evidence of that Rushy Marsh Pond is presently nitrogen over-loaded eutrophic embayment.



Figure VII-2. Aerial Photograph of the Rushy Marsh embayment system in the Town of Barnstable showing locations of the Dissolved Oxygen mooring deployment conducted in the Summer of 2004.

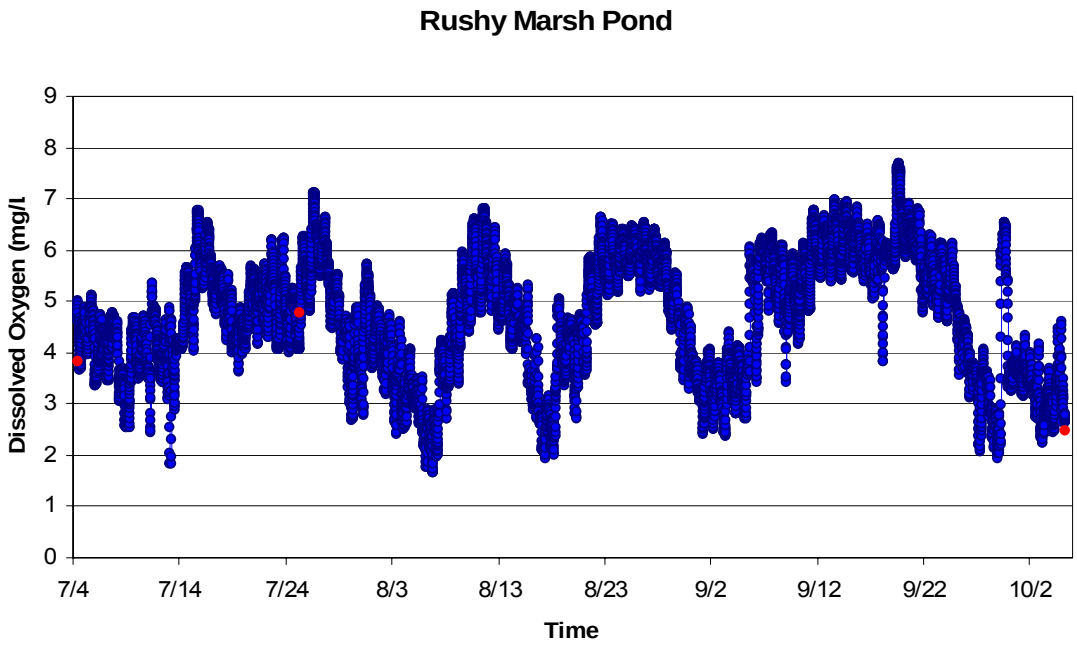


Figure VII-3. Bottom water record of dissolved oxygen in the Rushy Marsh Pond station, Summer 2004. Calibration samples represented as red dots

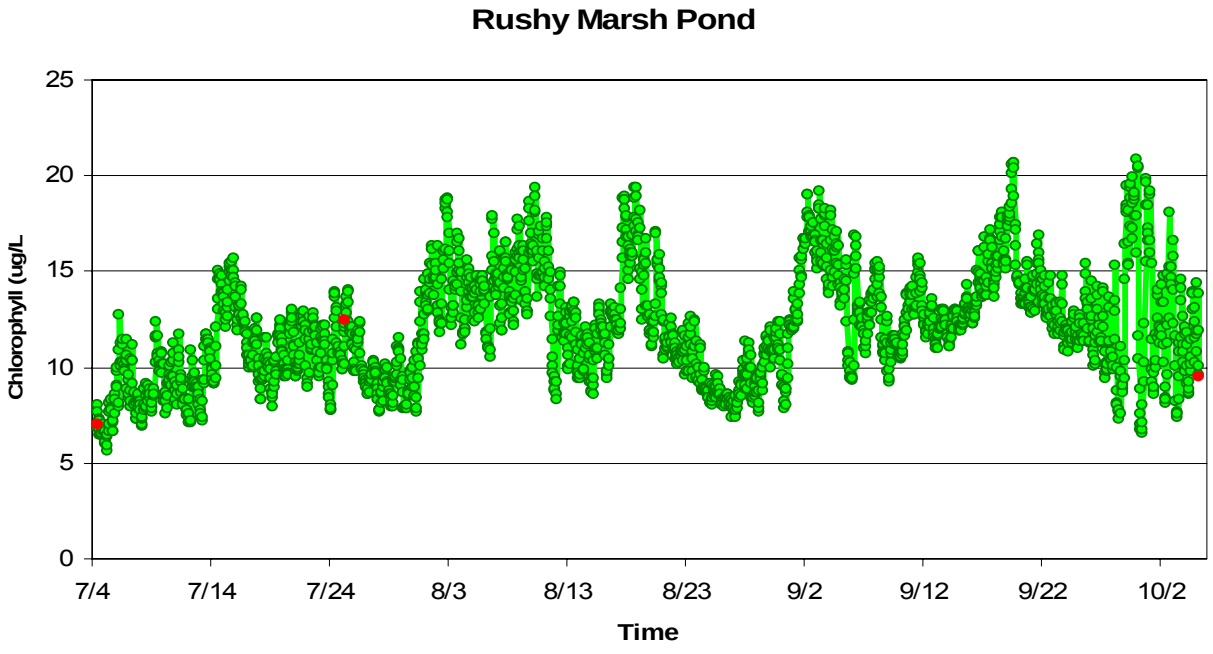


Figure VII-4. Bottom water record of Chlorophyll-*a* in the Rushy Marsh Pond station, Summer 2004. Calibration samples represented as red dots

Table VII-1. Bottom water dissolved oxygen levels within the principal sub-embayments to the Rushy Marsh Estuary. Percent of time during deployment of in situ sensors that bottom water oxygen levels were below various benchmark oxygen levels during July – September 2004.

Sub-Embayment	Dissolved Oxygen: Continuous Record, Summer 2000- 2002				
	Deployment Days	< 6 mg/L (% of days)	< 5 mg/L (% of days)	< 4 mg/L (% of days)	< 3 mg/L (% of days)
Rushy Marsh	93.0	80%	53%	31%	9%

Table VII-2. Duration (% of deployment time) that chlorophyll a levels exceed various benchmark levels within the embayment system. "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST. The mean in the final column is the average level over the deployment.

Sub-Embayment	Start Date	End Date	Total Deployment (Days)	> 5 ug/L Duration (Days)	> 10 ug/L Duration (Days)	> 15 ug/L Duration (Days)	> 20 ug/L Duration (Days)	> 25 ug/L Duration (Days)	Mean Chl a Level (ug/L)
Rushy Marsh Pond	7/4/2004	10/5/2004	93.0	**99.9%**	**99.1%**	**73.3%**	**52.7%**	**15.6%**	
		Mean		23.3	1.4	1.03	1.02	0.30	12.0
		S.D.		24.4	0.8	2.67	0.58	0.41	

VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS

Eelgrass surveys and analysis of historical data was conducted for the Rushy Marsh Estuary by the DEP Eelgrass Mapping Program as part of the MEP Technical Team by other members of the Team. Field survey data Surveys was conducted in 2004, in concert with the MEP benthic recycling and infaunal animal sampling. Additional analysis of available aerial photos from 1951 were examined to determine eelgrass distribution under conditions of lower watershed nitrogen loading. The 1951 data were only anecdotally validated, while the 2004 information was by direct observation. The primary use of the data is to indicate (a) if eelgrass once or currently colonizes a basin and (b) if large-scale system-wide shifts have occurred. Integration of the data sets can provide a view of temporal trends in eelgrass distribution from 1951 to 2004; the period in which watershed nitrogen loading increased (although present level is only moderate to low). This temporal information can be used to determine the stability of the eelgrass community.

At present, eelgrass is not present within Rushy Marsh Pond. Rushy Marsh Pond is functionally a basin with fringing wetland, and the sediments are currently soft muds rich in organic matter, which in some locations overlay medium to fine sands. The current lack of eelgrass beds is expected given the high chlorophyll a and low dissolved oxygen levels and watercolumn nitrogen concentrations within this system. In addition, it does not appear that eelgrass beds were present in the system in 1951, as well. It appears that the restriction of the tidal exchange starting circa 1900, resulted in an absence of eelgrass sometime prior to 1951 (Chapter V). The restriction of tidal exchange has resulted in an enrichment of estuarine waters in nitrogen to the extent that the system is currently eutrophic. Restoration of tidal exchange will be needed for habitat restoration of this system, as watershed nitrogen inputs are relatively low.

Other factors which influence eelgrass bed loss in embayments are not at play in Rushy Marsh Pond. However, a brief listing of non-nitrogen related factors is useful. Eelgrass bed loss does not seem to be directly related to mooring density, as the Bay supports no boat moorings. Similarly, pier construction and boating pressure may be adding additional stress in nutrient enriched areas, but are not a factor in Rushy Marsh as there are no docks. Similarly, there is no present effect of shellfishing on benthic habitat, as there is no shellfishing harvesting.

Given that eelgrass has not been documented for this system, it is not clear that even when the system was much better flushed, it supported eelgrass beds. However, observations of brackish water submerged aquatic vegetation in the shallow region of the western channel suggest that eelgrass habitat might be sustainable under lower effective nitrogen loading rates (i.e. higher flushing). To the extent that conditions could be improved to the level of eelgrass colonization in this system, the acreage would likely range from 4-12 acres, most likely in the southern channel and the margins of the main basin.

The eelgrass information is consistent with the results of the benthic infauna analysis and the observed eelgrass loss is typical of nutrient enriched shallow embayments (see below).

VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling was conducted at 7 locations throughout the Rushy Marsh Pond Estuary (Figure VII-5). In some cases multiple assays were conducted. In all areas and particularly those that do not support eelgrass beds, benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain

species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity and evenness of the community. It should be noted that, given the loss of eelgrass beds, portions of the Three Bays System are clearly impaired by nutrient overloading. However, to the extent that it can still support healthy infaunal communities, the benthic infauna analysis is important for determining the level of impairment (moderately impaired→significantly impaired→severely degraded). This assessment is also important for the establishment of site-specific nitrogen thresholds (Chapter VIII).

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas, as shown by the oxygen and chlorophyll records and eelgrass coverage, have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5.

The Infauna Study indicated that presently, habitat capable of supporting benthic infaunal communities is virtually absent in Rushy Marsh Pond (Table VII-3). The infaunal survey found that summer conditions apparently are sufficient to prevent a community from developing in the central basin. In the shallower southern channel region, again only very few individuals and species were found. The low numbers of species and individuals indicates that benthic infaunal habitat has been severely degraded throughout Rushy Marsh Pond. The conditions proximately result from the high level of nitrogen and organic matter enrichment and associated oxygen depletion of bottom waters. Ultimately, the cause is the highly restricted tidal exchange and very low flushing rate of Pond waters (system residence time ~48 d). However, restoration of infaunal animal communities should occur at the point that habitat can be restored.



Figure VII-5. Aerial photograph of the Rushy Marsh embayment system showing location of benthic infaunal sampling stations (green symbol).

Table VII-3. Benthic infaunal community data for the Rushy Marsh embayment system. Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations (Samples represent surface area of 0.0625 m2).

Location	ID	Total Actual Species	Total Actual Individuals	Species Calculated @75 Indiv.	Weiner Diversity (H')	Evenness (E)	Infaunal Indicators
Rushy Marsh Pond							
Channel	RMP-1	5	9	N/A	1.94	0.83	
	RMP-1a	1	1	N/A	0	N/A	
	RMP-2	3	10	N/A	1.33	0.84	
	RMP-2a	1	2	N/A	0.50	N/A	
	Average	2.5	6	N/A	0.94	N/A	***SD***[1]
Main Basin	RMP-3	0	0	N/A	N/A	N/A	
	RMP-4	0	0	N/A	N/A	N/A	
	RMP-5	0	0	N/A	N/A	N/A	
	RNP-6	0	0	N/A	N/A	N/A	
	RMP-8/9	0	0	N/A	N/A	N/A	
	Average	0	0	N/A	N/A	N/A	***SD***

H – Healthy, MI – Moderately Impaired, SI – Significantly Impaired, SD – Severely Degraded. A system is severely degraded if the infaunal community shows both low numbers of individuals and species or is dominated by stress indicator species.

VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS

VIII.1 ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires integration of key habitat parameters (infauna and eelgrass), sediment characteristics, and nutrient related water quality information (particularly dissolved oxygen and chlorophyll a). Additional information on temporal changes within each sub-embayment and its watershed further strengthen the analysis. These data were collected to support threshold development for the Rushy Marsh Pond System by MEP Team and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels from the long-term baseline Water Quality Monitoring Program conducted by Three Bays Preservation in partnership with the Town of Barnstable, with technical guidance from the Coastal Systems Program at SMAST. At present, Rushy Marsh Pond is showing significantly impaired to severely degraded habitat quality. All of the habitat indicators are consistent with this evaluation of the whole of system (Chapter VII).

Eelgrass: At present, eelgrass is not found within Rushy Marsh Pond. The current lack of eelgrass beds is expected given the high chlorophyll a and low dissolved oxygen levels and watercolumn nitrogen concentrations within this system. In addition, it does not appear that eelgrass beds were present in the system in 1951. It appears that the restriction of the tidal exchange starting circa 1900, resulted in an absence of eelgrass sometime prior to 1951. The restriction of tidal exchange has resulted in an enrichment of estuarine waters in nitrogen to the extent that the system is currently eutrophic. Restoration of tidal exchange will be needed for habitat restoration of this system, as watershed nitrogen inputs are relatively low.

Given that eelgrass has not been documented for this system, it is not clear that even when the system was much better flushed, it supported eelgrass beds. However, observations of brackish water submerged aquatic vegetation in the shallow region of the western channel suggest that eelgrass habitat might be sustainable under lower effective nitrogen loading rates (i.e. higher flushing). To the extent that conditions could be improved to the level of eelgrass colonization in this system, the acreage would likely range from 4-12 acres, most likely in the southern channel and the margins of the main basin.

The eelgrass information is consistent with the results of the benthic infauna analysis and the observed eelgrass loss is typical of nutrient enriched shallow embayments (see below).

Water Quality: Rushy Marsh Pond currently exhibits seasonal oxygen stress, consistent with nitrogen enrichment (Tables VII-1, VII-2). That the cause is eutrophication is supported by the high levels of chlorophyll a, 15 ug/L to >20 ug/L (Table VII-2). Oxygen conditions and chlorophyll a levels indicated nutrient related stress throughout the Pond

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality within the estuary (Figures VII-3, VII-4). Oxygen depletion was frequently to levels <4 mg/L (29 days) and periodically to < 3 mg/L (8 days). The oxygen data is consistent with high organic matter loads from phytoplankton production (chlorophyll a levels) indicative of nitrogen enrichment and eutrophication of this estuarine system, although the nitrogen enrichment stems primarily from the restriction of tidal exchange. The frequent significant level of oxygen depletion coupled to the frequent phytoplankton blooms is clear evidence of that Rushy Marsh Pond is presently

nitrogen over-loaded eutrophic embayment. The chlorophyll a, dissolved oxygen and total nitrogen within Rushy Marsh Pond are consistent with the observed eelgrass losses (above) and the significantly impaired infaunal animal communities (below).

Infaunal Communities: The Infauna Study indicated that all areas are presently severely degraded and that habitat capable of sustaining benthic infaunal animals is virtually absent in Rushy Marsh Pond (Table VII-3). The infaunal survey found that summer conditions apparently are sufficient to prevent a community from developing in the central basin. In the shallower southern channel region, again only very few individuals and species were found. The low numbers of species and individuals indicates that benthic infaunal habitat has been severely degraded throughout Rushy Marsh Pond. The conditions proximately result from the high level of nitrogen and organic matter enrichment and associated oxygen depletion of bottom waters. Ultimately, the cause is the highly restricted tidal exchange and very low flushing rate of Pond waters (system residence time ~48 d). However, restoration of infaunal animal communities should occur at the point that habitat can be restored.

The infaunal community based classification throughout Rushy Marsh Pond is fully supported by the water quality and eelgrass data discussed in the text above.

Table VIII-1. Summary of Nutrient Related Habitat Health within the Rushy Marsh Pond Estuary on the south shore of Barnstable, MA., based upon assessment data presented in Chapter VII.

Health Indicator	Estuary	
	Rushy Marsh	
	Main Basin	Channel
Dissolved Oxygen	SI/SD[1]	--
Chlorophyll	SI	SI
Macroalgae	SI/SD[2]	SI
Eelgrass	SI/SD[3]	SI[4]
Infaunal Animals	SD[5]	SD
Overall:	**SD**	**SD**

1 – periodic oxygen depletions to <3 mg/L and frequently <4 mg/L.
2 – macroalgal accumulations on bottom.
3 – no eelgrass in pond presently and likely for over 60 years.
4 – no eelgrass, but strands of brackish submerged aquatic vegetation, possibly *Ruppia*.
5 – virtual absence of infaunal animal community in 2004 survey.
H = healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment; SD = Severe Degradation
-- = not applicable to this estuarine reach

VIII.2 THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout and embayment system, is to first identify a sentinel location within the embayment and second to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality. The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level are

determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

Within the Rushy Marsh Estuary the most appropriate sentinel station was about in the center of the basin at Station RM2 in Figure VIII-1. This location was selected because restoration of nitrogen conditions supportive of eelgrass or infauna at this location will necessarily result in similar quality conditions throughout the basin. As is shown below and in Chapter IX, concentrations at the Sentinel Station (RM2) approximate concentrations throughout the pond waters (i.e. it is representative or higher than the other pond locations).

Following the MEP protocol, since eelgrass has not been documented in Rushy Marsh Pond, restoration of infaunal habitat is the restoration goal. Infaunal animal habitat is a critical resource to the Rushy Marsh System and estuaries in general. Since there are virtually no infaunal animals remaining in the sub-tidal Rushy Marsh Pond sediments, comparisons to the muddy basins of other nearby estuarine systems were relied upon for setting the nitrogen threshold for healthy infaunal habitat at a nitrogen level of TN <0.5 mg TN L^{-1}. This level was found for Popponesset Bay where based upon the infaunal analysis coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN L-1 were found supportive of high infaunal habitat quality in this system. Similarly, in the Three Bays System, healthy infaunal areas are found at nitrogen levels of TN <0.42 mg TN L^{-1} (Cotuit Bay and West Bay), with impairment in areas where nitrogen levels of TN >0.5 mg TN L^{-1} (North Bay), and severe degradation at nitrogen levels of TN >0.6 mg TN L^{-1}.

Given the low watershed nitrogen load to Rushy Marsh Pond, reconstruction of the tidal inlet will be required to meet the nitrogen threshold level and achieve restoration of this system. In addition, restoration of tidal exchange (i.e. tide range) will allow the restoration of fringing salt marsh in this system, which has lost its salt water wetlands.

VIII.3 DEVELOPMENT OF TARGET NITROGEN LOADS

The nitrogen thresholds developed in the previous section were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Rushy Marsh. Tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel stations chosen for Rushy Marsh. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

As shown in Table VIII-2, the nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations were not attainable with 100% removal of septic load (associated with direct groundwater discharge to the embayment) for the systems watershed. The limited circulation within the system prevents the threshold goals from be achieved. In order to meet the threshold concentrations in the system, alternative approaches beyond load reductions are required to increase circulation and water exchange with Nantucket Sound. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Rushy Marsh system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Rushy Marsh	0.353	0.000	-100.0%

Tables VIII-3 and VIII-4 provide additional loading information associated with the thresholds analysis. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. Removal of 100% of the septic load from the watershed of Rushy Marsh results in an 79% reduction in total nitrogen load. Table VIII-4 shows the breakdown of threshold sub-embayment loads used for total nitrogen modeling. In Table VIII-4, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound.

Table VIII-3. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Rushy Marsh system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Rushy Marsh	0.447	0.093	-79.1%

Table VIII-4. Threshold sub-embayment loads and attenuated surface water loads used for total nitrogen modeling of the Rushy Marsh system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Rushy Marsh	0.093	0.203	-0.113

Comparison of model results between existing loading conditions and the selected loading scenario attempting to achieve the target TN concentrations at the sentinel station is shown in

Table VIII-5. To achieve the threshold nitrogen concentrations at the sentinel station, a different structural approach to increase circulation in the system is required for Rushy Marsh.

Table VIII-5. Comparison of model average total N concentrations from present loading and the modeled potential threshold scenario, with percent change, for the Rushy Marsh system. This threshold scenario (100% of septic, Table VIII-2) failed to meet the infaunal threshold (<0.5 mg N/L) at the sentinel station (bold print)

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Rushy Marsh - north	RM1	1.102	0.988	-10.4%
Rushy Marsh - east	**RM2**	**1.107**	**0.990**	**-10.6%**
Rushy Marsh - west	RM3	1.108	0.991	-10.6%
Rushy Marsh - south	RM4	1.156	1.018	-11.9%

IX. ALTERNATIVES TO IMPROVE TIDAL FLUSHING AND WATER QUALITY

IX.1 FLUSHING IMPROVEMENTS TO RUSHY MARSH BY RECONSTRUCTION OF THE INLET

Water quality improvements may be possible by improving tidal exchange in an estuary. It is clear from the nitrogen loading (Chapter IV), tidal flushing (Chapter V) and habitat assessment (Chapter VII) that Rushy Marsh Pond supports only significantly impaired to severely degraded sub-tidal habitats as a result of highly restricted tidal exchange with Nantucket Sound waters. In addition, the brackish nature of the Pond waters, the minimal tidal range and prolonged elevation of water levels in previous years during periods of inlet blockage have resulted in the virtual absence of salt marsh within this estuarine system. It is clear from the MEP analysis that Rushy Marsh could benefit from flushing improvements.

At present, tidal attenuation is through the existing culvert is very high, resulting in an average tide range within Rushy Marsh Pond less than 1% that of the offshore range. Attenuation in this system is primarily caused by an undersized inlet and sedimentation. In contrast, for the adjacent estuaries, Three Bays and Popponesset Bay, tide attenuation is near zero, respectively, compared to the range offshore in Nantucket Sound.

Historically, Rushy Marsh was connected to Nantucket Sound through a jettied inlet. The inlet was located at the southern end of the marsh situated between the existing stone groins. Once the inlet closed, rather than reopening the inlet, a culvert was constructed to connect the marsh with the sound. Reconstruction of an inlet and channel provide the most appropriate approach for improving the tidal flushing in Rushy Marsh to achieve habitat restoration. The tidal restriction is the predominant source of the nutrient related habitat degradation in Rushy Marsh Pond. Removal of all of the watershed nitrogen load, would still result in an estuarine system that is significantly impaired. The reason stems from the relatively low present watershed load and the very restricted tidal flushing, which allows the build-up of eutrophying constituents within the pond. A more detailed analysis of inlet stability, maintenance requirements, and potential environmental impacts is required to fully assess inlet reconstruction. To quantitatively assess inlet improvements, two model simulations were executed to simulate Rushy Marsh hydrodynamics with a new 4-ft wide inlet and a new 10-ft wide inlet, each located at the southern end of the marsh.

Hydrodynamic model results for existing and improved inlet conditions are presented in Figure IX-1. In the top plot, tide attenuation is apparent by the lack of a tidal signature in the water surface elevations in the marsh. The middle plot shows a clear tidal signature in the marsh, tidal attenuation is still present with higher elevation of the low tides, and also by the time delay of the tide signal inside the marsh. In the bottom plot of this figure, tidal attenuation is reduced for the proposed 10 ft-wide inlet.

Based on model output, the average tidal prism increases by 6 fold with the improved 4-foot inlet and 20 fold with the 10-foot inlet. Average volumes of Rushy Marsh Pond for existing conditions and for a 20ft-wide inlet scenario are presented in Table IX-1. As a result of the increased tidal prism volume and the reduced mean tide volume of the system, the computed system residence time decreases from 47.6 days for existing conditions, to 4.9 days and 1.6 days for the 4-foot and 10-foot inlets, respectively. The restoration of tidal conditions should also encourage the re-establishment of fringing salt marsh habitat, an important additional benefit of estuarine restoration in this system.

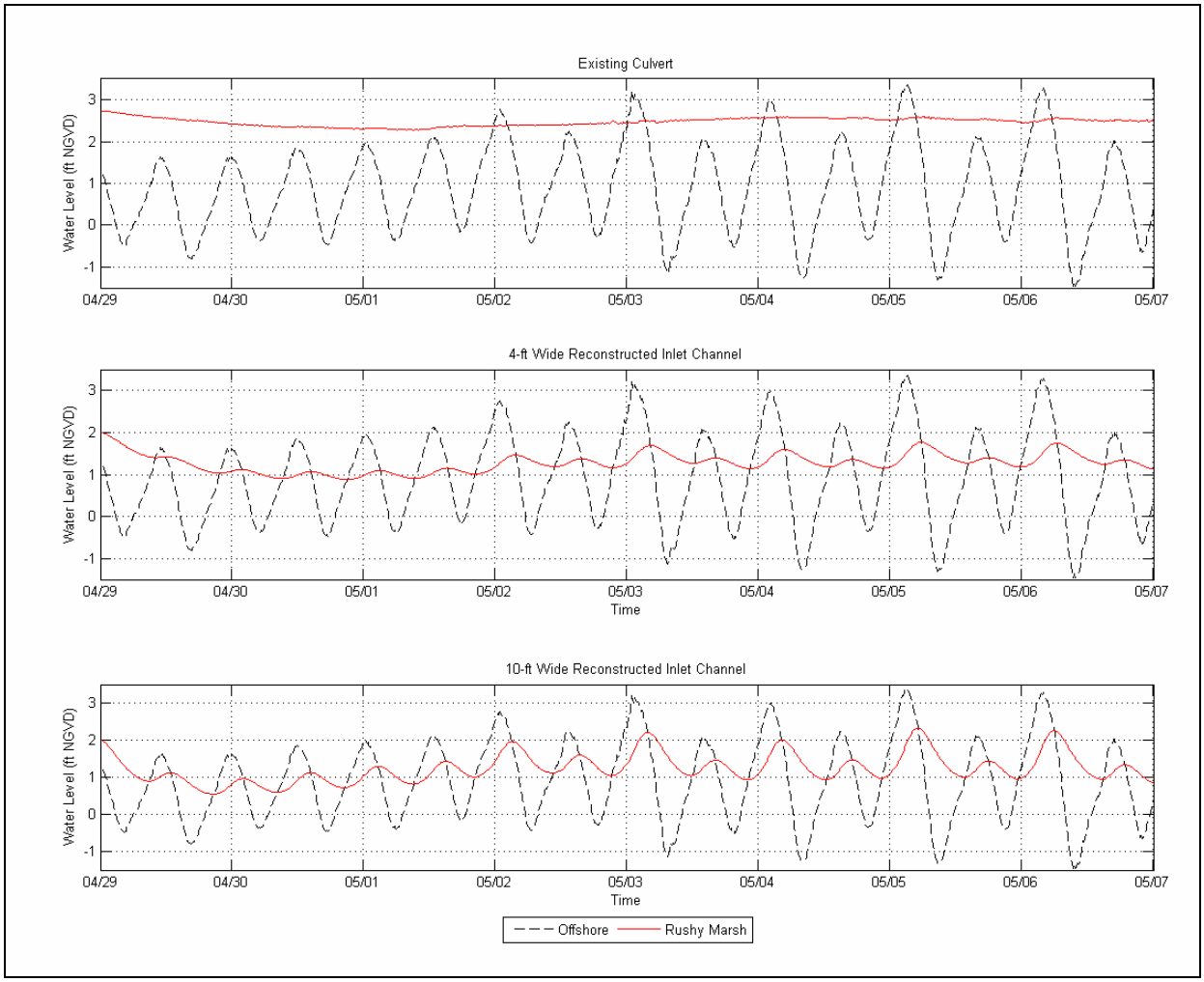


Figure IX-1. Plots showing a comparison of typical tides for modeled existing conditions (top plot), proposed reconstructed 4 ft-wide inlet (middle plot), and proposed reconstructed 10 ft-wide inlet (bottom plot) to Rushy Marsh.

Table IX-1. Average mean tide volumes, mean tide prism, and residence times for Rushy Marsh, for existing inlet conditions, and for the proposed inlet configurations.

	existing inlet	4 ft-wide inlet	10 ft-wide inlet
Mean Volume (ft^3)	2,848,800	1,950,600	1,882,400
Mean Prism Volume (ft^3)	30,936	204,625	629,120
Residence Time (days)	47.65	4.93	1.55

Water quality model runs were performed using the hydrodynamic model output of the proposed reconstructed 4-foot and 10-foot wide inlets. First, present loading conditions were modeled with the reconstructed inlets. Results from the existing loading conditions with the improved hydrodynamics of the reconstructed inlets are presented in Tables IX-2 and IX-3, and plotted in Figures IX-2 and IX-3. The TN concentrations are significantly reduced with the new

inlets (i.e., up to an 62% reduction in the northern portion of the marsh), the reduction is large enough to meet the threshold limits set for Rushy Marsh (TN of 0.50 mg/L at water quality monitoring station RM2). Potential environmental and regulatory implications exist for reconfiguration of the inlet; therefore, a complete analysis of the costs, benefits, and impacts of this strategy would be required prior to further consideration of this option. From an engineering cost perspective alone, it likely is cheaper to modify the inlet than to sewer a large portion of the upper watershed, especially as sewering alone will not achieve the nitrogen threshold levels in Rushy Marsh Pond. In contrast, given the low watershed nitrogen load, reconstruction of the tidal inlet alone, will achieve the nitrogen threshold level and restoration of this system. In addition, restoration of tidal exchange (i.e. tide range) will allow the restoration of fringing salt marsh in this system, which has lost its salt water wetlands.

Table IX-2. Comparison of model average total N concentrations from present loading and the reconstructed 4 ft-wide inlet scenario with present loading, with percent change.

Sub-Embayment	monitoring station	present (mg/L)	Channel mod, present (mg/L)	% change
Rushy Marsh - north	RM1	1.102	0.417	-62.2%
Rushy Marsh - east	**RM2**	**1.107**	**0.414**	**-62.6%**
Rushy Marsh - west	RM3	1.108	0.414	-62.6%
Rushy Marsh - south	RM4	1.156	0.374	-67.7%

Table IX-3. Comparison of model average total N concentrations from present loading and the reconstructed 10 ft-wide inlet scenario with present loading, with percent change.

Sub-Embayment	monitoring station	present (mg/L)	Channel mod, present (mg/L)	% change
Rushy Marsh - north	RM1	1.102	0.336	-69.5%
Rushy Marsh - east	**RM2**	**1.107**	**0.333**	**-69.9%**
Rushy Marsh - west	RM3	1.108	0.333	-69.9%
Rushy Marsh - south	RM4	1.156	0.315	-72.7%

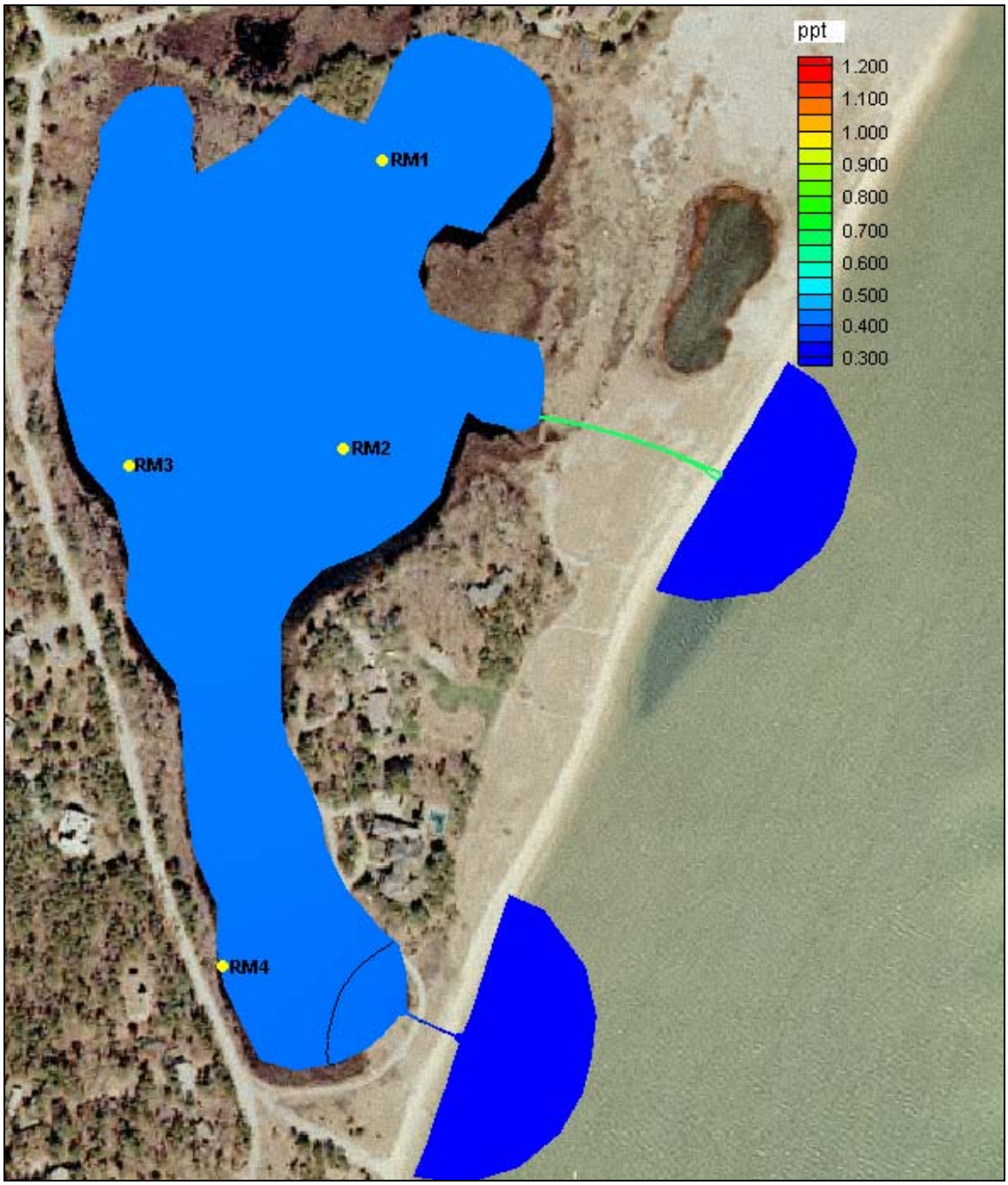


Figure IX-2. Contour Plot of modeled total nitrogen concentrations (mg/L) in Rushy Marsh, for present loading conditions, and reconstructed inlet channel (4 ft), with existing culvert. The approximate location of the sentinel threshold station for Rushy Marsh (RM2) is shown.



Figure IX-3. Contour Plot of modeled total nitrogen concentrations (mg/L) in Rushy Marsh, for present loading conditions, and reconstructed inlet channel (10 ft), with existing culvert. The approximate location of the sentinel threshold station for Rushy Marsh (RM2) is shown.

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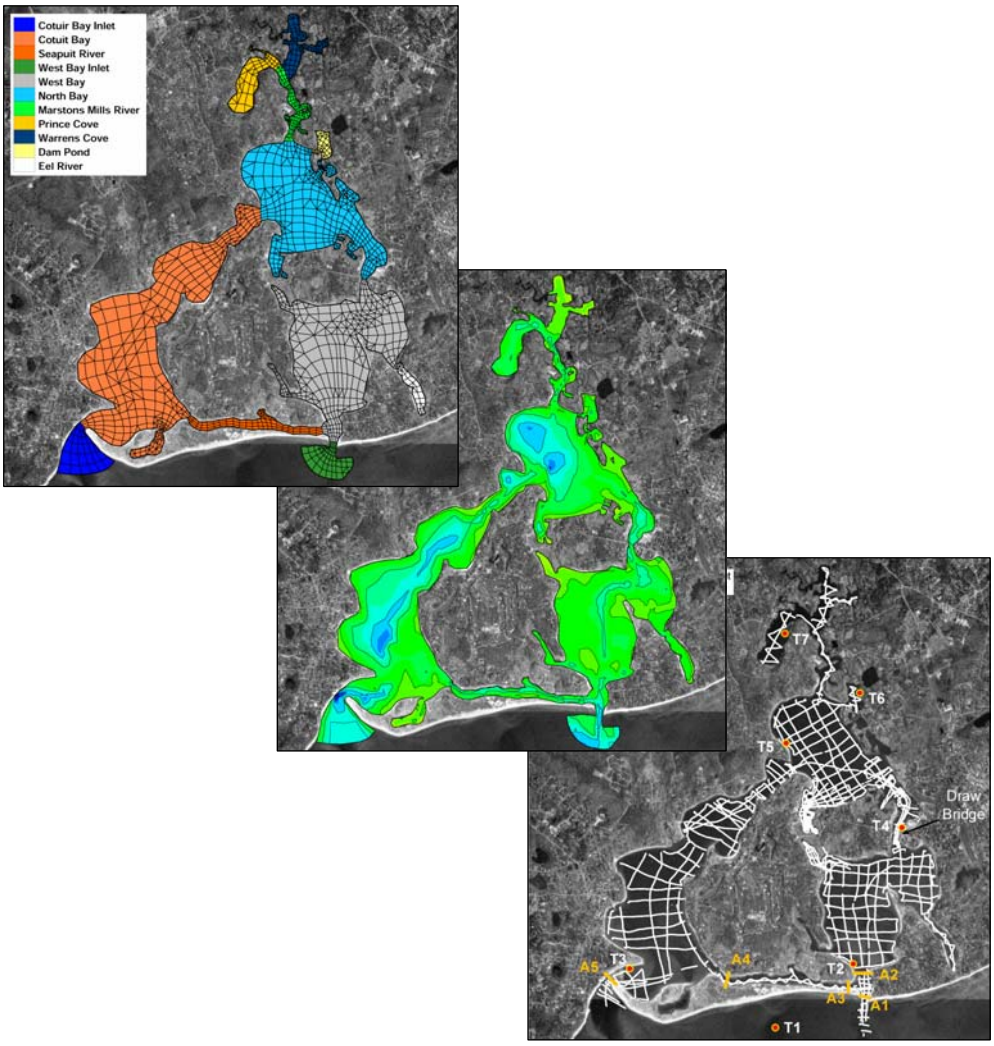
Appendix W

MEP Technical Report for Three Bay System; MEP, April 2006

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts



University of Massachusetts Dartmouth
School of Marine Science and Technology

Massachusetts Department of Environmental Protection

FINAL REPORT –APRIL 2006

Massachusetts Estuaries Project

LINKED WATERSHED-EMBAYMENT MODEL TO DETERMINE CRITICAL NITROGEN LOADING THRESHOLDS FOR THREE BAYS IN THE TOWN OF BARNSTABLE, MA

FINAL REPORT – APRIL 2006

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I. INTRODUCTION

The Three Bays Embayment System is a complex estuary located entirely within the Town of Barnstable on Cape Cod, Massachusetts with a southern shore bounded by water from Nantucket Sound (Figure I -1). The Bay's watershed is distributed primarily among the Towns of Barnstable and Sandwich, with a small region adjacent Santuit Pond (<1% of the watershed) within the Town of Mashpee and comprised primarily "protected" forest land. The Town of Sandwich has jurisdiction over land and associated land uses in the uppermost portions of the overall watershed to The Three Bays system. Specifically, portions of the Three Bays watershed that exist within the Town of Sandwich are generally situated above the Spectacle Pond, Lawrence Pond and Triangle Pond system and within the contributing area to the upper and mid reaches of the Marstons Mills River. However, the majority of the watershed falls within the Town of Barnstable, which includes the watershed contributing direct groundwater discharge to the estuary and contributing to the lower Marstons Mills River and to the Little River. Although land-uses closest to an embayment generally have greater impact than those in the upper portions of the watershed, which are subject to nitrogen attenuation during transport through natural aquatic systems (e.g. ponds, rivers, wetlands etc.) prior to discharge to the embayment, effective restoration of the Three Bays System, will require both the Towns of Barnstable and Sandwich to be active in nutrient management and restoration discussions and planning.

The large number of sub-embayments to the Three Bays System greatly increases the shoreline and decreases the travel time of groundwater (and its pollutants) from the watershed recharge areas to bay regions of discharge. The nature of enclosed embayments in populous regions brings two opposing elements to bear: as protected marine shoreline they are popular regions for boating, recreation, and land development; as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the Three Bays system and its sub-embayments along the Barnstable shores are at risk of eutrophication (over enrichment) from high nitrogen loads in the groundwater and runoff from their watersheds.

The Three Bays Embayment System is a complex estuary, with multiple inlets and sub-embayments (Cotuit Bay, West Bay, North Bay, Prince's's/Warren's Cove). The estuary receives tidal waters from Nantucket Sound into its two large lower basins, Cotuit Bay to the west of Osterville Grand Island, and West Bay to the east of Grand Island. Floodwaters from Nantucket Sound enter the two large lower basins of the Three Bays system through 2 tidal inlets and flow through the Seapuit River (Figure I-1). Both Cotuit Bay and West Bay exchange tidal waters with upgradient North Bay through "natural" channels. A third tidal passage apparently once existed through the salt marsh between Little Island and Grand Island, but this no longer exists, due to the causeway supporting the roadway from the mainland to Grand Island. Further upgradient of North Bay are two smaller sub-embayments (Prince's's Cove and Warren's Cove). These smaller sub-embayments (including Tim's Cove adjacent to Cotuit Bay, Eel River adjacent to West Bay and Seapuit River connecting Cotuit Bay to West Bay) constitute important components of the Town's natural and cultural resources.

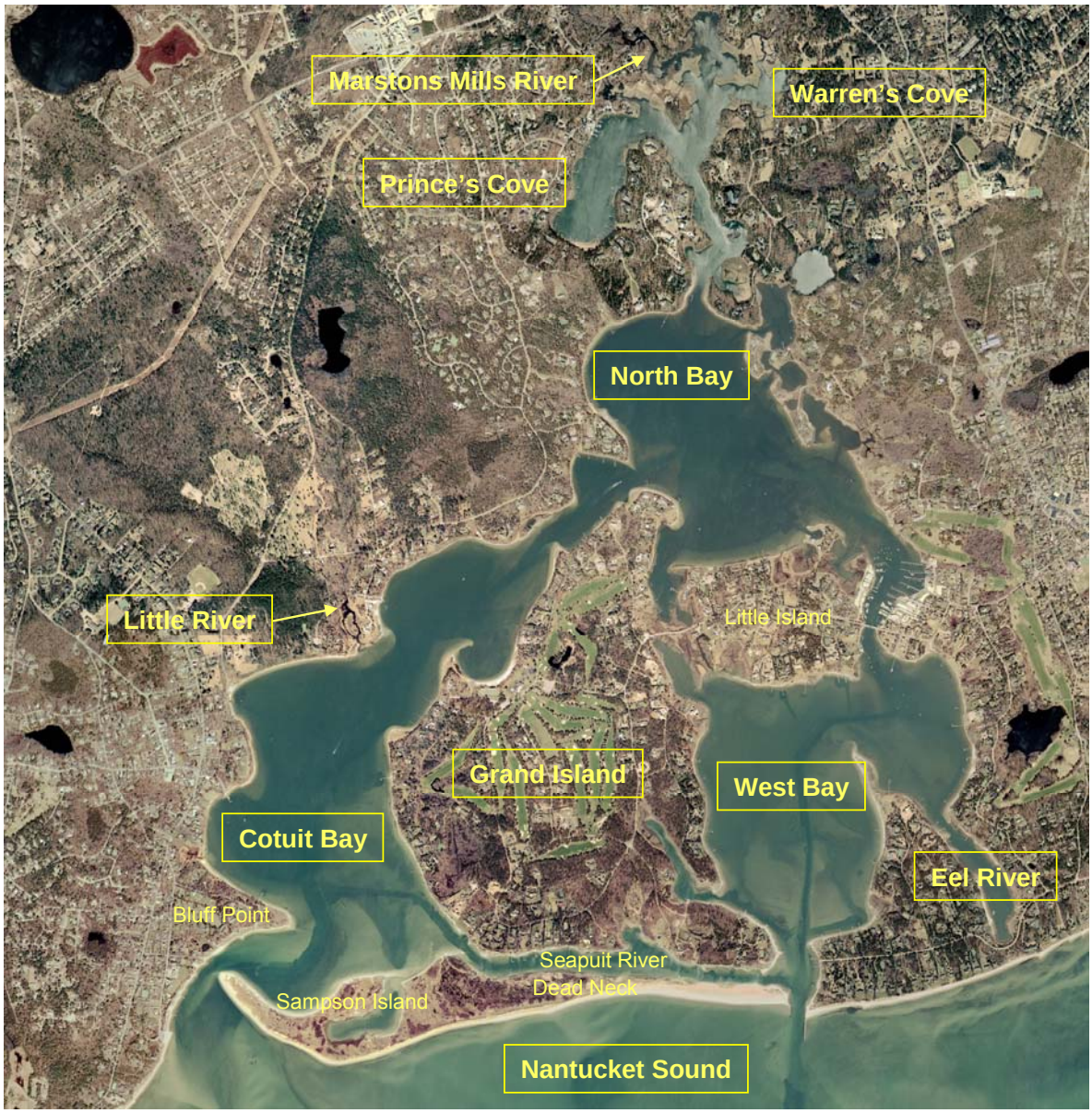


Figure I-1. Study region for the Massachusetts Estuaries Project analysis of the Three Bays Embayment System. Tidal waters enter the Bay through two inlets from Nantucket Sound. Freshwaters enter from the watershed primarily through 2 surface water discharges (Marstons Mills River and Little River) and direct groundwater discharge.

The present Three Bays system results from tidal flooding of drowned river valleys formed primarily by the Marstons Mills River discharging to the Prince'ss Cove/Warren's Cove sub-embayment upgradient of North Bay as well as incorporated ancient kettle ponds. Little River may also have contributed slightly to the formation, discharging to the head of Cotuit Bay, although the upper reach of Little River is primarily man-made for herring production. Drowning of the river valleys occurred gradually as a result of rising sea level following the last glaciation approximately 18,000 years before present (BP). It appears that the Three Bays system has had multiple inlet positions as an estuary. Coastal processes, including the formation of a barrier spit (beach and dune deposits) have altered the positions of the tidal inlet(s) to the Three

Bays system, affected tidal exchange and are responsible for enclosing Cotuit Bay and West Bay from Nantucket Sound as sea level rose. The Bay is presently separated from Nantucket Sound by a barrier spit (Dead Neck/Sampson Island), which grew from the southeastern shore, and is a very dynamic geomorphic feature. The Bay presently exchanges tidal water with Nantucket Sound through two maintained inlets. The smaller man-made eastern inlet has been stabilized with riprap where as the larger western inlet flowing into Cotuit Bay remains unarmored and is maintained by infrequent dredging.

The primary ecological threat to the Three Bays embayment system as a coastal resource is degradation resulting from nutrient enrichment. Although the watershed and the Bay have some organic contamination and bacterial contamination issues, these do not appear to be having large system-wide impacts (Howes et al. MEP Bacterial Tech Report 2004). Bacterial contamination causes closures of shellfish harvest areas regularly within the Prince's's Cove and Warren's Cove sub-embayments as well as portions of North Bay. In contrast, loading of the critical eutrophying nutrient, nitrogen, to the Three Bays System has been greatly increased over the past few decades with further increases certain unless nitrogen management is implemented. The nitrogen loading to the Bay, like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater.

The Town of Barnstable has been among the fastest growing towns in the Commonwealth over the past two decades and does have a centralized wastewater treatment system located in Hyannis, however, the vast majority of the Three Bays watershed is not connected to any municipal sewerage system, but rather, rely on privately maintained septic systems for treatment and disposal of wastewater. As existing and probable increasing levels of nutrients impact Barnstable's coastal embayments, water quality degradation will accelerate, with further harm to invaluable environmental resources.

As the primary stakeholder to the Three Bays System, the Town of Barnstable was among the first communities to become concerned over perceived degradation of Bay waters. The concern over declining habitat quality followed significant on-going efforts to preserve open space within the Marstons Mills River and Little River sub-watersheds. This local concern also led to the conduct of several studies (see Chapter II) of nitrogen loading to the system (Cape Cod Commission 1998) and the formation of a citizens organization, Three Bays Preservation Inc., to provide local stewardship of the Three Bays system and to assist in advancing restoration of the System within the Town. One of the initial projects of Three Bays Preservation was to establish, in 1999, a nitrogen related water quality monitoring program throughout the Three Bays system to support restoration efforts. The Three Bays Water Quality Monitoring Program was provided technical assistance by the Coastal Systems Program at SMAST-UMD and over the past several years have been incorporated into Barnstable's Town-wide embayment monitoring program. This effort provides the quantitative watercolumn nitrogen data (1999-2004) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study.

Since the initial results of the Water Quality Monitoring Program and the land-use studies indicated that parts of the Three Bays system were presently impaired by land-derived nitrogen inputs, the Town of Barnstable and Three Bays Preservation undertook additional site-specific data collection to support MEP's ecological assessment and modeling project. The effort was part of the Town's Wastewater Facilities Planning effort and was aimed at restoration of the resources within the Three Bays system. Under the direction of the Town of Barnstable DPW, the Three Bays System was included in the second tier of the Massachusetts Estuaries Project (rank #15).

The common focus of the Barnstable effort has been to gather site-specific data on the current nitrogen related water quality throughout the Three Bays System and determine its relationship to watershed nitrogen loads. This multi-year effort has provided the baseline information required for determining the link between upland loading, tidal flushing, and estuarine water quality. The MEP effort builds upon the Water Quality Monitoring Program, and previous hydrodynamic and water quality analyses, and includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for each major sub-embayment. These critical nitrogen targets and the link to specific ecological criteria form the basis for the nitrogen threshold limits necessary to complete wastewater planning and nitrogen management alternatives development needed by the Town of Barnstable. While the completion of this complex multi-step process of rigorous scientific investigation to support watershed based nitrogen management has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, the results stem directly from the efforts of large number of Town staff and volunteers over many years, most notably from members of the local non-governmental organization (NGO) Three Bays Preservation. The modeling tools developed as part of this program provide the quantitative information necessary for the Town of Barnstable to develop and evaluate the most cost effective nitrogen management alternatives to restore this valuable coastal resource which is currently being degraded by nitrogen overloading. It is important to note that the Three Bays System has been significantly altered by human activities over the past ~400 years (see Section I.2, below). As a result, the present nitrogen "overloading" appears to result partly from alterations to the geomorphology and ecological systems. These alterations subsequently affect nitrogen loading within the watershed and influence the degree to which nitrogen loads impact the estuary. Therefore, restoration of this system should focus on managing nitrogen through both management of nitrogen loading within the watershed and restoration/management of processes which serve to lessen the amount or impact of nitrogen entering the estuary.

I.1 THE MASSACHUSETTS ESTUARIES PROJECT APPROACH

Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The nutrients are primarily related to changes in watershed land-use associated with increasing population within the coastal zone over the past half century. Many of Massachusetts' embayments have nutrient levels that are approaching or are currently over this assimilative capacity, which begins to cause declines in their ecological health. The result is the loss of fisheries habitat, eelgrass beds, and a general disruption of benthic communities and the food chain which they support. At higher levels, nitrogen loading from surrounding watersheds causes aesthetic degradation and inhibits even recreational uses of coastal waters. In addition to nutrient related ecological declines, an increasing number of embayments are being closed to swimming, shellfishing and other activities as a result of bacterial contamination. While bacterial contamination does not generally degrade the habitat, it restricts human uses. However like nutrients, bacterial contamination is frequently related to changes in land-use as watersheds become more developed. The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities.

The primary nutrient causing the increasing impairment of the Commonwealth's coastal embayments is nitrogen and the primary sources of this nitrogen are wastewater disposal, fertilizers, and changes in the freshwater hydrology associated with development. At present there is a critical need for state-of-the-art approaches for evaluating and restoring nitrogen

sensitive and impaired embayments. Within Southeastern Massachusetts alone, almost all of the municipalities (as is the case with the Town of Barnstable) are grappling with Comprehensive Wastewater Planning and/or environmental management issues related to the declining health of their estuaries.

Municipalities are seeking guidance on the assessment of nitrogen sensitive embayments, as well as available options for meeting nitrogen goals and approaches for restoring impaired systems. Many of the communities have encountered problems with "first generation" watershed based approaches, which do not incorporate estuarine processes. The appropriate method must be quantitative and directly link watershed and embayment nitrogen conditions. This "Linked" Modeling approach must also be readily calibrated, validated, and implemented to support planning. Although it may be technically complex to implement, results must be understandable to the regulatory community, town officials, and the general public.

The Massachusetts Estuaries Project represents the next generation of watershed based nitrogen management approaches. The Massachusetts Department of Environmental Protection (MASSDEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool for watershed-embayment management for communities throughout Southeastern Massachusetts.

The Massachusetts Estuary Project is founded upon science-based management. The Project is using a consistent, state-of-the-art approach throughout the region's coastal waters and providing technical expertise and guidance to the municipalities and regulatory agencies tasked with their management, protection, and restoration. The overall goal of the Massachusetts Estuaries Project is to provide the DEP and municipalities with technical guidance to support policies on nitrogen loading to embayments. In addition, the technical reports prepared for each embayment system will serve as the basis for the development of Total Maximum Daily Loads (TMDLs). Development of TMDLs is required pursuant to Section 303(d) of the Federal Clean Water Act. TMDLs must identify sources of the pollutant of concern (in this case nitrogen) from both point and non-point sources, the allowable load to meet the state water quality standards and then allocate that load to all sources taking into consideration a margin of safety, seasonal variations, and several other factors. In addition, each TMDL must contain an outline of an implementation plan. For this project, the DEP recognizes that there are likely to be multiple ways to achieve the desired goals, some of which are more cost effective than others and therefore, it is extremely important for each Town to further evaluate potential options suitable to their community. As such, DEP will likely be recommending that specific activities and timelines be further evaluated and developed by the Towns (sometimes jointly) through the Comprehensive Wastewater Management Planning process.

In appropriate estuaries, bacterial technical reports will be developed in support of a Cape Cod wide TMDL for bacterial contamination. As possible, these analyses of bacterial contamination will be conducted in concert with the nutrient effort (particularly if there is a 303d listing), as was the case for the Prince's's Cove sub-embayment to the Three Bays system. The MEP (through SMAST) has already completed the Technical Analysis and Report to support the inclusion of this system in the Cape Cod wide bacterial TMDL that the MASSDEP is in the process of producing. The goal of the bacterial program is to provide information to guide targeted sampling for specific source identification and remediation.

The MEP nitrogen threshold analysis includes site-specific habitat assessments and watershed/embayment modeling approaches to develop and assess various nitrogen

management alternatives for meeting selected nitrogen goals supportive of restoration/protection of embayment health.

The major MEP nitrogen management goals are to:

- provide technical analysis and supporting documentation to Towns as a basis for sound nutrient management decision making towards embayment restoration
- develop a coastal TMDL working group for coordination and rapid transfer of results,
- determine the nutrient sensitivity of each of the 89 embayments in Southeastern MA
- provide necessary data collection and analysis required for quantitative modeling,
- conduct quantitative TMDL analysis, outreach, and planning,
- keep each embayment's model "alive" to address future municipal needs.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. This approach represents the "next generation" of nitrogen management strategies. It fully links watershed inputs with embayment circulation and nitrogen characteristics. The Linked Model builds on and refines well accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied for watershed nitrogen management in approximately 15 embayments throughout Southeastern Massachusetts. In these applications it has become clear that the Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options.

The Linked Watershed-Embayment Model when properly parameterized, calibrated and validated for a given embayment becomes a nitrogen management planning tool, which fully supports TMDL analysis. The Model facilitates the evaluation of nitrogen management alternatives relative to meeting water quality targets within a specific embayment. The Linked Watershed-Embayment Model also enables Towns to evaluate improvements in water quality relative to the associated cost. In addition, once a model is fully functional it can be "kept alive" and updated for continuing changes in land-use or embayment characteristics (at minimal cost). In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

Linked Watershed-Embayment Model Overview: The Model provides a quantitative approach for determining an embayment's: (1) nitrogen sensitivity, (2) nitrogen threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is both calibrated and fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2). This methodology integrates a variety of field data and models, specifically:

- Watercolumn Monitoring - multi-year embayment nutrient sampling
- Hydrodynamics -
  - embayment bathymetry
  - site specific tidal record
  - current records (in complex systems only)
  - hydrodynamic model
- Watershed Nitrogen Loading
  - watershed delineation
  - stream flow (Q) and nitrogen load
  - land-use analysis (GIS)
  - watershed N model
- Embayment TMDL - Synthesis
  - linked Watershed-Embayment N Model
  - salinity surveys (for linked model validation)
  - rate of N recycling within embayment
  - D.O record
  - Macrophyte survey
  - Infaunal survey

I.2 SITE DESCRIPTION

The Three Bays embayment system exchanges tidal water with Nantucket Sound through two inlets at the east and west ends of a barrier beach referred to as Dead Neck/Sampson Island. The eastern most inlet connecting Nantucket Sound to West Bay was opened by dredging in 1900 and is armored on both the Oyster Harbors Beach/Dead Neck side as well as the Wianno Beach side. For the MEP analysis, the Three Bays estuarine system has been partitioned into five general sub-embayment groups: the 1) Cotuit Bay, 2) West Bay/Eel River, 3) North Bay, 4) Prince's's Cove and 5) Warren's Cove (see Figure I-1). The estuarine reach of the Marstons Mills River was considered as part of the Prince's's Cove / Warren's Cove sub-embayment system flowing into the head of North Bay in the modeling and thresholds analysis.

Within the Three Bays System, the tidal portion of the Prince's's Cove and Warren's Cove sub-embayment system (Marstons Mills River) including the upper portion of North Bay show the greatest diversity of estuarine habitats, with most of the System's salt marsh area, shallow tidal flats and large salinity fluctuations being present in this area. In contrast, Cotuit Bay and West Bay show more typical embayment characteristics dominated by open water areas, small fringing salt marshes, relatively stable salinity gradients and relatively large basin volumes relative to tidal prism. Although the upper two sub-embayment systems up-gradient of North Bay and the open water portions of Cotuit Bay and West Bay exhibit different hydrologic characteristics (river dominated versus tidally dominated), the tidal forcing for these systems is generated from Nantucket Sound. Nantucket Sound, adjacent Dead Neck (Oyster Harbors Beach), exhibits a moderate to low tide range, with a mean range of about 2.5 ft. Since the water elevation difference between Nantucket Sound and the Three Bays system is the primary driving force for tidal exchange, the local tide range naturally limits the volume of water flushed

during a tidal cycle (note the tide range off Stage Harbor Chatham is ~4.5 ft, Wellfleet Harbor is ~10 ft).

Tidal damping (reduction in tidal amplitude) through an embayment can range from negligible, indicating "well-flushed" conditions, or show tidal attenuation caused by constricted channels and marsh plains, indicating a "restrictive" system, where tidal flow and the associated flushing are inhibited. Tidal data indicate only minimal tidal damping through the two inlets into the Three Bays system. It appears that both the tidal inlets are operating efficiently, possibly due to the active inlet maintenance program. Similarly, within the Three Bays System, the tide propagates to the sub-embayments with negligible attenuation, consistent with generally well-flushed conditions throughout.

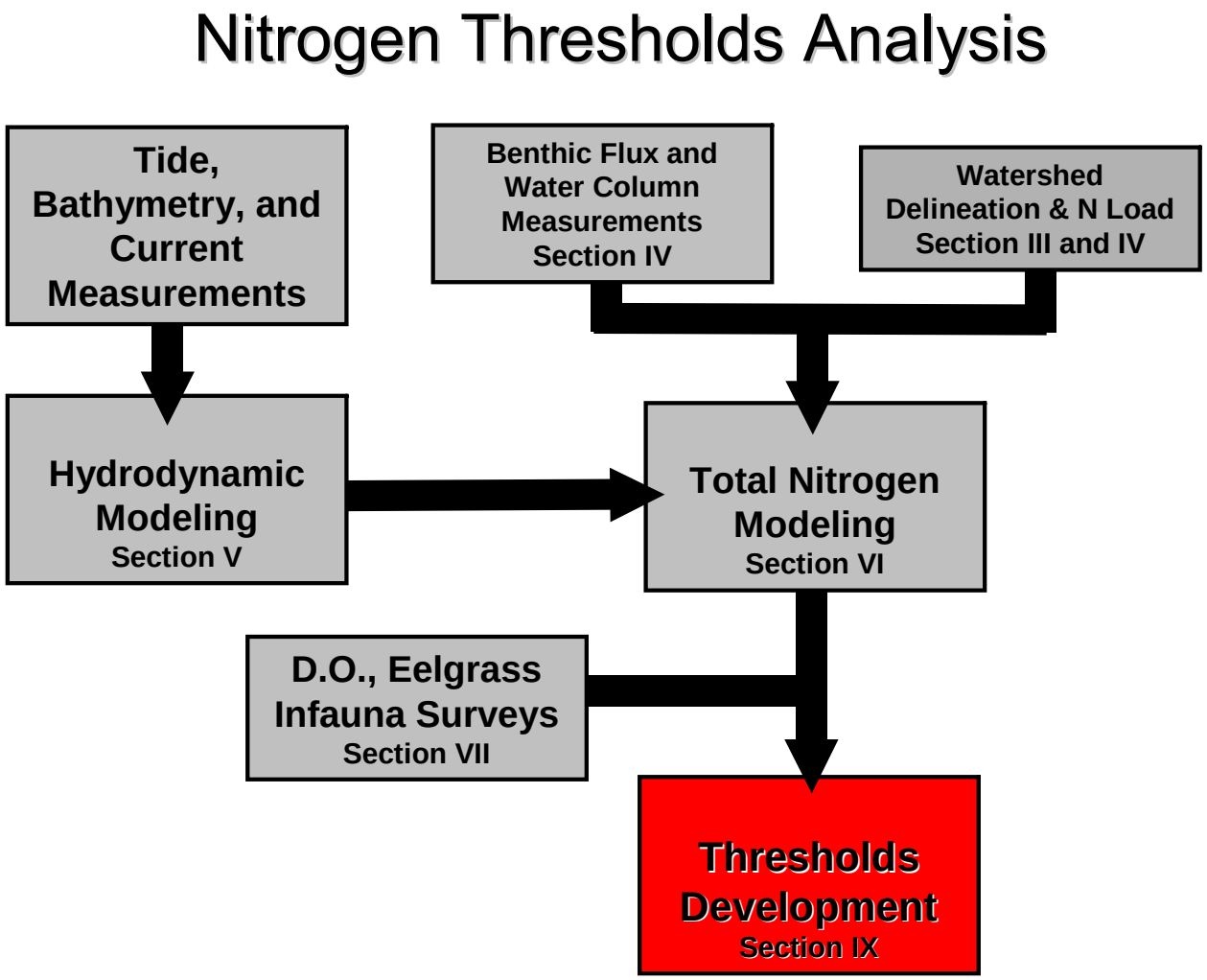


Figure I-2. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

History of Change

As management alternatives are being developed and evaluated, it is important to note that the Three Bays System is naturally a relatively dynamic system. Equally important is the recognition that it has been significantly altered by man's activities over the past ~300 years and particularly over the past century.

Management of coastal systems requires not only an understanding of both present conditions, but also of the history of physical and environmental alteration. In addition, within degraded or partially degraded systems, an evaluation of the system's "maximum level of sustainable environmental health" is also needed. It is clear that there has been significant alteration of the Three Bays hydrologic and biological systems over the past several centuries since the early days of the mills along Goodspeeds River. What follows is a brief description of the Three Bays system focusing on major upland or embayment alterations relating to present system health (Howes and Hampson 2000).

While the nutrient related health of the Three Bays System as it exists today is very much linked to changes wrought by human activities, it is the physical structure of the system laid down by the retreat of the Laurentide Ice Sheet that still controls much of the Bays' tolerance to nutrient inputs. The physical structure, shape and depth of a coastal embayment plays a major role in its susceptibility to ecological impacts from nutrient loading. Physical structure (geomorphology), which includes embayment bathymetry, inlet configuration and saltwater reaches, when coupled with the tidal range of the adjacent open waters, determines the system's rate of flushing. System flushing rate is generally the primary factor for removing nutrients from active cycling within coastal bays and harbors like the Three Bays system. As a result maximizing system flushing is one of the standard approaches for controlling the nutrient related health of coastal embayments.

As the Cape Cod Bay and Buzzards Bay Lobes of the Ice Sheet retreated, the sandy outwash plain that now holds the Three Bays watershed was formed. This sandy outwash produced the highly permeable soils found throughout upper Cape Cod. It is the permeability of the soils which has resulted in the importance of groundwater flow as a major pathway for nutrient transfers from sub-watersheds to adjacent coastal waters in this region. The presence of both groundwater and surface water pathways for input of nutrients into the present estuary has significant impact on its response to changing nutrient loadings with the surrounding watershed from changing land-uses.

As sea level rose and flooded the present basins of the Three Bays system, salt marshes began to form and an estuarine ecosystem began to function. At present it is not clear to what extent the basins of the embayment were formed from flooding kettle ponds versus merely flooding erosional valleys. However, given the shape and depth of the basins compared to other non-kettle systems on the southern shore of the upper Cape, it seems likely that kettle ponds with freshwater stream inflows and outflow were incorporated. With further sea-level rise the present marine beach deposits of Dead Neck, Sampson's Island, Bluff Point, northern tip of Grand Island and near the bridge to Little Island began to develop. The result was a complex estuarine system with a single inlet to Nantucket Sound through Cotuit Bay and major freshwater inputs through the Marstons Mills River and to a lesser extent, Little River.

Based upon studies from other regions of Cape Cod, it is likely that Native Americans utilized the resources of the Three Bays System for several thousand years before ceding the region to Captain Miles Standish in 1648. Native Americans likely used both the upland and

estuarine resources. The marine food sources of the system would provide both shellfish (scallops, oysters and quahogs) and fish, particularly herring. According to James Otis, the name Mystic was the Native American term for small streams and ponds, particularly where herring and trout abounded. The largest lake within the watershed is still called Mystic Lake reputedly from this early term.

In 1653 when Roger Goodspeed, the first European to settle within the Three Bay watershed, settled by the Marstons Mills River (for a while named Goodspeeds River), the Three Bays system was different from the present system in both its circulation and water quality. The upland was largely forested with some open lands, the Marstons Mills River was free flowing (no dams) and had more extensive freshwater marshes within its lower reaches and the embayment was connected to Nantucket Sound via a single inlet. While this single inlet almost certainly reduced the tidal exchange with high quality Nantucket Sound waters, the much lower terrestrial input of nutrients suggests a high quality estuarine system. However, it is also likely that, similar to today, within the region of the estuarine reach of the Marstons Mills River and associated salt marshes the sediments and bay waters were among the most nutrient and organic matter rich within the Three Bays System. However, the aquatic and upland components of this System began to change rapidly. By 1689 a fulling mill was constructed on the Marstons Mills River. In 1704-5 the dam was constructed thus altering the pathway of surface water transport and associated nutrients to the estuary. Town records indicating the leasing of herring rights and the requirement that all mills maintain fishways is testament to the magnitude of the herring population supported by this system. An active herring run within the Marstons Mills River continues to this day.

During the 1800's utilization of the estuary and its watershed continued to increase. Regions of the watershed were cleared for agricultural land and the Grist Mill at Marstons Mills continued operations past 1842. Within the watershed were changes to the freshwater systems which attenuate nitrogen during transport to bay waters. Most notable were the modification of riparian zones either through channelization, restriction, or filling of freshwater wetlands and, in some cases, transformation to cranberry agriculture. Most of the alterations reduced the nutrient buffering capacity of these systems, magnifying the nitrogen loading to the bay which greatly increased in the next century. Land clearing was accelerated by the development of salt works on the shores of the Bay which used fire to fuel evaporation for salt production. This activity peaked in 1812 and then declined.

Direct use of marine resources focused on oyster production, where oysters were initially pickled and shipped in barrels to market. In these earlier centuries, as today, oysters were cultured on the Bays' bottom. One of the first growers, Captain George Fisher who was granted a large section of Cotuit Bay shipped oysters to widespread U.S. markets. With the demand for oysters, the natural beds surrounding Grand Island became depleted and spat were imported from Long Island for grow out. However, at least for awhile, seed could be collected at the mouth of nearby Popponesset Bay on deployed scallop shells to supply the grow out needs. During this period, scallops were harvested within the Three Bays system in quantity and even at the turn of the century scallops represented a major economic resource. This record of substantial scallop harvest indicates that eelgrass beds were likely prevalent throughout the Bays. This suggests that the water was clearer (greater transparency due to less phytoplankton), hence less nutrient loading from the watershed was occurring. During this period the population was still small, for example there were only 36 homes in Santuit, Little River and Cotuit combined. Throughout the 1800's the residents relied heavily on coastal resources as salt making, oyster production, fishing, farming, ship-building and coastal trading.

By far the greatest changes to the Three Bays watershed and estuary have occurred during the last 100 years. The most obvious change has been the dramatic shift in land-use to residential housing during the last half of the 1900's. With this shift and the advent of fertilized lawns, has come a dramatic increase in the amount of nitrogen, which enters the Three Bays system. The previous large shifts in land-use, primarily from forest to agriculture did not have the same resultant increase in nitrogen loading, as the historic population was <10% of today. The present year-round population per square mile is greater than the entire town population of 50 years ago (total population based on 2000 census for Towns of Mashpee, Sandwich, and Barnstable are 12,946, 20,136 and 47,821 respectively). Unfortunately previous reductions in the capacity of the freshwater systems to attenuate nitrogen prior to its entry into the Three Bays system has accelerated the rate of nitrogen impairment as land-use changed. While this may be a partial cause of the present estuarine decline, it may also represent a potential opportunity for restoration of bay systems.

It is the recent increase in nitrogen load which is responsible for the observed declines in estuarine habitat quality throughout most of the Three Bays Estuary. In addition to this multi-decadal shift in watershed nitrogen loading, there were likely pulses of nutrients to the system during the 1940's associated with the military training areas within the Bays. The associated barracks, warehouses and storage tanks installed during WWII would result in a “new” source of nitrogen loading and the paving of the beach from Baxters Neck to Point Isabella (western shore of North Bay) may have also increased bacterial contamination in the adjacent waters.

In the late 1800's there was another major change to the Three Bays Estuarine System. Until this time, tidal exchange with Nantucket Sound was restricted to a single inlet to Cotuit Bay. However, a second inlet was opened which likely increased the flushing of West Bay, which previously had exchanged estuarine waters via the Seapuit River and through North Bay. Regardless of the extent to which this second inlet increased the flushing out of nutrient rich estuarine waters, it will have helped to buffer the Bays against the coming nutrient increases in the latter part of the century. Recent efforts to maintain the Bays for navigation may have also helped to maintain tidal exchanges, but the extent that this may have helped lessen the effects of increased watershed loadings has not been determined. Dredging of the Marstons Mills River from Prince’s Cove to North Bay in 1957 and the inlet to Cotuit Bay (most recently in the late 1990's) are two of the more notable examples of recent efforts.

Unfortunately while nutrient related decline in environmental health of the Three Bays System will be reduced by maximizing tidal exchange with the high quality waters of Nantucket Sound, the growing watershed nutrient loading and the structure of the system will require watershed management to restore the estuarine habitats within the Three Bays system to meet the high level of quality designated by the State Water Quality Standards. Watershed management will likely involve reduction of nitrogen inputs from various sources and possibly the removal of large loads (eg. wastewater) from the watershed. Watershed management targeted at embayment restoration will usher in a new phase in the ever changing Three Bays System to the benefit of both present and future generations.

I.3 NUTRIENT LOADING

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the Three Bays System, phosphorus is highly retained during groundwater transport as a result of sorption to

aquifer minerals (Weiskel and Howes 1992). Since even Cape Cod "rivers" are primarily groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1998, Weiskel and Howes 1992, Smith *et al.* 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within the Three Bays Estuary follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. This point can be termed the "nutrient threshold" and in estuarine management this threshold sets the target nutrient level for restoration or protection. Because nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 and in press, Ramsey et al., 1995, Howes and Taylor, 1990, and the Falmouth Coastal Overlay Bylaw). While each approach may be different, they all focus on changes in nitrogen loading from watershed to embayment, and aim at projecting the level of increase in nitrogen concentration within the receiving waters. Each approach depends upon estimates of circulation within the embayment; however, few directly link the watershed and hydrodynamic models, and virtually none include internal recycling of nitrogen (as was done in the present effort). However, determination of the "allowable N concentration increase" or "threshold nitrogen concentration" used in previous studies had a significant uncertainty due to the need for direct linkage of watershed and embayment models and site-specific data. In the present effort we have integrated site-specific data on nitrogen levels and the gradient in N concentration throughout the Three Bays System monitored by the Town of Barnstable/Three Bays Preservation. The Water Quality Monitoring Program with site-specific habitat quality data (D.O., eelgrass, phytoplankton blooms, benthic animals) was utilized to "tune" general nitrogen thresholds typically used by the Cape Cod Commission, Buzzards Bay Project, and Massachusetts State Regulatory Agencies.

Unfortunately, almost all of the estuarine reaches within the Three Bays System are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout the Systems and eelgrass beds have not been

observed within the Three Bays system for over a decade, although some plants were observed within the shallows of the upper estuary until 1995. Nitrogen related habitat impairment within the Three Bays Estuary shows a gradient of high to low moving from the inland reaches to the tidal inlet. The result is that nitrogen management of the primary sub-embayments to the Three Bays system is aimed at restoration, not protection or maintenance of existing conditions. In general, nutrient over-fertilization is termed "eutrophication" and in certain instances can occur naturally over long periods of time. When the nutrient loading is rapid and primarily from human activities leading to changes in a coastal watershed, nutrient enrichment of coastal waters is termed "cultural eutrophication". Although the influence of human-induced changes has increased nitrogen loading to the systems and contributed to the degradation in ecological health, it is sometimes possible that eutrophication within the Three Bays sub-embayments could potentially occur without human influence and must be considered in the nutrient threshold analysis. While this finding would not change the need for restoration, it would change the approach and potential targets for management. As part of future restoration efforts, it is important to understand that it may not be possible to turn each embayment into a "pristine" system.

I.4 WATER QUALITY MODELING

Evaluation of upland nitrogen loading provides important "boundary conditions" (e.g. watershed derived and offshore nutrient inputs) for water quality modeling of the Three Bays System; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within each system. Therefore, water quality modeling of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. The spread of pollutants may be analyzed from tidal current information developed by the numerical models.

The MEP water quality evaluation examined the potential impacts of nitrogen loading into the Three Bays System, including the tributary sub-embayments of Prince's's Cove, Warren's Cove, North Bay, Cotuit Bay and West Bay. A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for each of the systems. Once the hydrodynamic properties of each estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates.

Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic models were then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis, based upon watershed delineations by USGS using a modification of the West Cape model for sub-watershed areas designated by MEP. Almost all nitrogen entering the Three Bays System is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Nantucket Sound source waters and throughout the Three Bays system were taken from the Three Bays Water Quality Monitoring Program (a coordinated effort between the Town of Barnstable, Three Bays Preservation and the Coastal Systems Program at SMAST).

Measurements of current salinity and nitrogen and salinity distributions throughout estuarine waters of the Systems (1999-2004) were used to calibrate and validate the water quality model (under existing loading conditions).

I.5 REPORT DESCRIPTION

This report presents the results generated from the implementation of the Massachusetts Estuaries Project linked watershed-embayment approach to the Three Bays System for the Town of Barnstable. A review of existing water quality studies is provided (Section II). The development of the watershed delineations and associated detailed land use analysis for watershed based nitrogen loading to the coastal system is described in Sections III and IV. In addition, nitrogen input parameters to the water quality model are described. Since benthic flux of nitrogen from bottom sediments is a critical (but often overlooked) component of nitrogen loading to shallow estuarine systems, determination of the site-specific magnitude of this component also was performed (Section IV). Nitrogen loads from the watershed and sub-watersheds surrounding the estuary were derived from Cape Cod Commission data and offshore water column nitrogen values were derived from an analysis of monitoring stations in Nantucket Sound (Section IV). Intrinsic to the calibration and validation of the linked-watershed embayment modeling approach is the collection of background water quality monitoring data (conducted by municipalities) as discussed in Section IV. Results of hydrodynamic modeling of embayment circulation are discussed in Section V and nitrogen (water quality) modeling, as well as an analysis of how the measured nitrogen levels correlate to observed estuarine water quality are described in Section VI. This analysis includes modeling of current conditions, conditions at watershed build-out, and with removal of anthropogenic nitrogen sources. In addition, an ecological assessment of the component sub-embayments was performed that included a review of existing water quality information and the results of a benthic analysis (Section VII). The modeling and assessment information is synthesized and nitrogen threshold levels developed for restoration of the Bay in Section VIII. Additional modeling is conducted to produce an example of the type of watershed nitrogen reduction required to meet the determined threshold for restoration of the Bay. This latter assessment represents only one of many solutions and is produced to assist the Town in developing a variety of alternative nitrogen management options for this system. Finally, analyses of the Three Bays System were undertaken relative to potential alterations of circulation and flushing, including an analysis to identify hydrodynamic restrictions and an examination of dredging options to improve nitrogen related water quality. The results of the nitrogen modeling for each scenario have been presented in Section IX.

II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

Nutrient additions to aquatic systems cause shifts in a series of biological processes that can result in impaired nutrient related habitat quality. Effects include excessive plankton and macrophyte growth, which in turn lead to reduced water clarity, organic matter enrichment of waters and sediments with the concomitant increased rates of oxygen consumption and periodic depletion of dissolved oxygen, especially in bottom waters, and the limitation of the growth of desirable species such as eelgrass. Even without changes to water clarity and bottom water dissolved oxygen, the increased organic matter deposition to the sediments generally results in a decline in habitat quality for benthic infaunal communities (animals living in the sediments). This habitat change causes a shift in infaunal communities from high diversity deep burrowing forms (which include economically important species), to low diversity shallow dwelling organisms. This shift alone causes significant degradation of the resource and a loss of productivity to both the local shellfisherman and to the sport-fishery and offshore finfishery, which are dependant upon these highly productive estuarine systems as a habitat and food resource during migration or during different phases of their life cycles. This process is generally termed “eutrophication” and in embayment systems, unlike in shallow lakes and pond, it is not a necessarily a part of the natural evolution of a system.

In most marine and estuarine systems, such as the Three Bays system, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if nitrogen addition is controlled, then eutrophication is controlled. This approach has been formalized through the development of tools for predicting nitrogen loads from watersheds and the concentrations of water column nitrogen that may result. Additional development of the approach generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2002).

These tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specifics for any given water body. The present Massachusetts Estuaries Project (MEP) study focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species. The linked watershed-embayment model is built using embayment specific measurements, thus enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including the Three Bays System. As the MEP approach requires substantial amounts of site specific data collection, part of the program is to review previous data collection and modeling efforts. These reviews are both for purposes of “data mining” and to gather additional information on an estuary’s habitat quality or unique features.

Numerous studies relating to nitrogen loading, hydrodynamics and habitat health have been conducted within the Three Bays System over the past 10 years. In the late 1980’s and early 1990’s local concern over the health of the sub-embayments to the Three Bays system, particularly in the upper reaches, focused upon closures of shellfish beds. Field measurements by the Town of Barnstable in the mid/late 1990’s indicted that the greater issue of habitat degradation from nitrogen enrichment was occurring particularly in the region of Prince’s Cove. This concern about nutrient related habitat declines resulted in a nitrogen loading and flushing analysis by the Cape Cod Commission under the Cape Cod Coastal Embayment Project (Eichner et al. 1998). In that study the major sub-watersheds to the Three Bays system were delineated based upon available water table measurements, a land-use nitrogen loading model

was implemented to determine nitrogen inputs to bay waters and a box model was used to evaluate flushing rates of the estuary's sub-basins. The box model incorporated both August and October salinity data and the results of a dye study in Prince's Cove. Although the approach yields only approximations, the results clearly supported the concept that nitrogen inputs to the Three Bays system were impacting the water quality system-wide, with greatest degradation in the upper regions of Prince's Cove and Warren's Cove. Further, the landuse analysis indicated that on-site septic disposal of wastewater was the major single source of watershed nitrogen to bay waters. While the overall results of this study have held true, the box model is insufficient to simulate changes in nitrogen within the estuary under different management alternatives. In addition, as quantitative surveys of embayment nitrogen levels were not yet available, the model could not be validated. In addition, as the landuse model did not account for nitrogen attenuation by the surface freshwater ecosystems within the watershed (no data available), it over estimated the role of nitrogen sources in upper (inland most) sub-watersheds compared to the direct groundwater watersheds to the estuary. While base data from this earlier study was incorporated by the MEP, direct use of the modeling results was problematic. Since the landuse model was based upon the 1996 watershed delineations from well data, rather than the MEP's USGS West Cape Model (see Chapter III), the contributing areas are slightly different. Due to the difference in watershed areas and the MEP's update and refinements to the watershed nitrogen loading model (eg. to incorporate attenuation and new nitrogen source information), the results from the MEP are different and supercede those of this earlier study.

At this same time (1996) a group of private citizens formed a non-profit NGO, Three Bays Preservation, to address environmental problems within the Three Bays System. Three Bays Preservation initially focused upon dredging the tidal inlet between Cotuit Bay and Nantucket Sound, with a small amount of dredging in West Bay. As part of this process a 2-D hydrodynamic model was used to evaluate the effects of dredging on water circulation and flushing of the Three Bays system. The model is similar to that used by MEP, but it appears that the model did not calibrate and therefore the effort was revisited by MEP. In addition, as the earlier model focused on the effects of dredging on circulation, the model needed to be redeveloped with appropriate grid spacing to support the MEP water quality modeling effort. After permitting, the dredging effort was carried out with the Town of Barnstable in the winters of 1998-99 (187,000 cu yd), 1999-00 (24,700 cu yd), 2001 (15,000 cu yd) and 2002 (9,000 cu yd). The dredged sand was used to nourish Dead Neck for barrier beach stabilization.

Despite these dredging activities, it was clear that inlet maintenance was not sufficient to redress the nitrogen related declines observed throughout large portions of the Three Bays System. In 1999 Three Bays Preservation established a nitrogen related water quality monitoring program throughout the Three Bays system to support restoration efforts. The Three Bays Water Quality Monitoring Program was provided technical assistance by the Coastal Systems Program at SMAST-UMD and over the past several years the program has been incorporated into Barnstable's Town-wide embayment monitoring program. To date water column sampling has been conducted throughout the system on 6-8 dates per summer, June-August. Initial results of the Three Bays Water Quality Monitoring Program (Howes and Hampson 2000) indicated that:

(a) "some areas within the Estuary are presently showing nutrient related water quality declines and there is a wide variation in habitat quality within the Three Bays System. In general the quality of habitat in the Three Bays system shifts from high quality near the inlets to Nantucket Sound to poor quality (eutrophic) in the inner reaches. Prince's's Cove, and the region of the mouth of the Marstons Mill River through the narrows to

North Bay are showing poor nutrient related environmental health. However, the loss of eel grass beds from most of the Three Bays system proper indicates that the system has undergone nutrient loading related shifts";

(b) "the effects of watershed nutrient inputs can be seen in diminished water transparency, increased chlorophyll and nitrogen levels in the upper system and North Bay.

(c) "the Three Bays Estuary appears to be nitrogen limited, i.e. additions of nitrogen will increase algal production";

(d) "the organic matter within the Three Bays Estuary appears to be produced by phytoplankton supported by inputs of watershed nitrogen and recycled nitrogen within the Bays, as opposed to entering the system in surface water flows";

This effort provides the quantitative watercolumn nitrogen data (1999-2004) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study. In addition, there have been a variety of smaller studies relating to bacterial contamination (see MEP Bacterial Technical Report for Prince'ss Cove 2005) and macroalgal management conducted by Three Bays Preservation.

The MEP has incorporated all appropriate data from all previous studies to enhance the determination of nitrogen thresholds for the Three Bays System and to reduce costs to the Town of Barnstable.

III. DELINEATION OF WATERSHEDS

III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. The USGS has a long history of developing regional models for the six-groundwater flow cells on Cape Cod. Through the years, advances in computing, lithologic information from well installations, water level monitoring, stream flow measurements, and reconstruction of glacial history have allowed the USGS to update and refine the groundwater models. The MODFLOW and MODPATH models utilized by to the USGS to organize and analyze the available data utilize up-to-date mathematical codes and create better tools to answer the wide variety of questions related to watershed delineation, surface water/groundwater interaction, groundwater travel time, and drinking water well impacts that have arisen during the MEP analysis of southeastern Massachusetts estuaries, including the Three Bays embayment system located in the Town of Barnstable, Massachusetts.

In the present investigation, the USGS was responsible for the application of its groundwater modeling approach to define the watershed or contributing area to the Three Bays system under evaluation by the Project Team. The Three Bays estuarine system is a complex estuary, with two tidal inlets, large central islands, and a significant intrusion into the Sagamore groundwater lens. Further watershed modeling was undertaken to sub-divide the overall watershed to the Three Bays system into functional sub-units based upon: (a) defining inputs from contributing areas to each major portion within the embayment system, (b) defining contributing areas to major freshwater aquatic systems which generally attenuate nitrogen passing through them on the way to the estuary (lakes, streams, wetlands), and (c) defining 10 year time-of-travel distributions within each sub-watershed as a procedural check to gauge the potential mass of nitrogen from “new” development, which has not yet reached the receiving estuarine waters. The three-dimensional numerical model employed is also being used to evaluate the contributing areas to public water supply wells in the Three Bays watershed. Model assumptions for calibration were matched to surface water inputs and flows from current (2002 to 2003) stream gage information.

The relatively transmissive sand and gravel deposits that comprise most of Cape Cod create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by the land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994a,b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the sources of nitrogen that they carry requires determination of the portion of the watershed that contributes directly to the stream and the portion of the groundwater system that discharges directly into the estuary as groundwater seepage.

III.2 MODEL DESCRIPTION

Contributing areas to the Three Bays system and local freshwater bodies were delineated using a regional model of the Sagamore Lens (Walter and Whealan, 2005). The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh, *et al.*, 2000) was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program MODPATH4 (Pollock, 2000), which uses output files from MODFLOW-2000 to track the

simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. This approach was used to determine the contributing areas to the main basins of the Three Bays embayment system and also to determine portions of recharged water that may flow through freshwater ponds and streams prior to discharging into the tidal waters of the Three Bays system.

The Sagamore Flow Model grid consists of 246 rows, 365 columns and 20 layers. The horizontal model discretization, or grid spacing, is 400 by 400 feet. The top 17 layers of the model extend to a depth of 100 feet below NGVD 29 and have a uniform thickness of 10 ft. Layers 1-7 are stacked above NGVD 29 and layers 8 to 20 extend below. Layer 18 has a thickness of 40 feet and layer 19 extends to 240 feet below sea level. The bottom layer, layer 20, extends to the bedrock surface and has a variable thickness depending upon site characteristics. The rewetting capabilities of MODFLOW-2000, which allows drying and rewetting of model cells, was used to simulate the top of the water table, which varies in elevation depending on the location in the Lens. Since the Three Bays watershed extends to the top portion of the Sagamore Lens, most of the uppermost layers of the groundwater model are active in its delineation

The glacial sediments that comprise the aquifer of the Sagamore Lens consist of gravel, sand, silt, and clay that were deposited in a variety of depositional environments. The sediments generally show a fining downward with sand and gravel deposits deposited in glaciofluvial (river) and near-shore glaciolacustrine (lake) environments underlain by fine sand, silt and clay deposited in deeper, lower-energy glaciolacustrine environments. Most groundwater flow in the aquifer occurs in shallower portions of the aquifer dominated by coarser-grained sand and gravel deposits. The Three Bays watershed is situated in the midst of the very-coarse grained Mashpee Pitted Plain deposits (Masterson, et al., 1996). Lithologic data used to determine hydraulic conductivities used in the groundwater model were obtained from a variety of sources including well logs from USGS, local Town records and data from previous investigations. Final aquifer parameters were determined through calibration to observed water levels and stream flows. Hydrologic data used for model calibration included historic water-level data obtained from USGS records and local Towns and water level and streamflow data collected in May 2002.

The model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Large withdrawals of groundwater from pumping wells may have a significant influence on water tables and watershed boundaries and therefore the flow and distribution of nitrogen within the aquifer. After accounting for the 15% consumptive loss and measured discharge at municipal treatment facilities, water withdrawn from the modeled aquifer by public drinking water supply wells is evenly returned within designated residential areas utilizing on-site septic systems. Since the watershed to the Three Bays system lacks municipal sewers, these areas are part of the Barnstable, Mashpee, and Sandwich residential areas in the groundwater model.

III.3 THREE BAYS CONTRIBUTORY AREAS

Newly revised watershed and sub-watershed boundaries to the Three Bays embayment system were determined by the United States Geological Survey (USGS) (Figure III-1). Model outputs of MEP watershed boundaries were “smoothed” to (a) correct for the grid spacing, (b) to enhance the accuracy of the characterization of the pond and coastal shorelines, and (c) to

more closely match the sub-embayment segmentation of the tidal hydrodynamic model. The smoothing refinement was a collaborative effort between the USGS and the rest of the MEP Technical Team. Overall, 59 sub-watershed areas, including thirteen freshwater ponds and six public water supply wellfields, were delineated within the watershed to the Three Bay embayment system.

Table III-1 provides the daily freshwater discharge volumes for each of the subwatersheds as calculated by the groundwater model and these volumes were used to assist in the salinity calibration of the tidal hydrodynamic models in order to determine hydrologic turnover in the lakes/ponds, as well as for comparison to measured surface water discharges. The MEP delineation includes 10 yr time of travel boundaries. The overall estimated freshwater inflow to the estuarine waters of the Three Bays system from the MEP watershed is 95,608 m3/d.

The delineations completed by the MEP are the second watershed delineation completed in recent years for the Three Bays estuary. Figure III-2 compares the delineation completed under the current effort with the delineation completed by the Cape Cod Commission in 1995 as part of the Cape Cod Embayment Project (Eichner, et al., 1998). The delineation completed in 1995 was defined based on regional water table measurements collected from available wells over a number of years and normalized to average conditions; delineations based on this previous effort were incorporated into the Commission's regulations through the Regional Policy Plan (CCC, 1996 & 2001).

Overall, the MEP contributing area to the Three Bays system based upon the groundwater modeling effort is similar to the previous delineation based upon available well data, the MEP area being only 2.5% or 324 acres smaller. However, the specific land areas enclosed by the 2 delineation efforts are slightly different. The primary spatial difference is a slight thinning of the portion of the watershed close to the Cape Cod Bay/Vineyard Sound groundwater divide, a slightly more northern location for the top of the Sagamore Lens, and a more eastern location for the western boundary of the system watershed. The change in the western boundary is largely due to a better consideration of Santuit Pond and its relationship to Popponesset Bay than was possible in the earlier effort (see Figure III-2). There was insufficient data to support the development of the subwatersheds to the individual great fresh ponds in the earlier delineation effort.

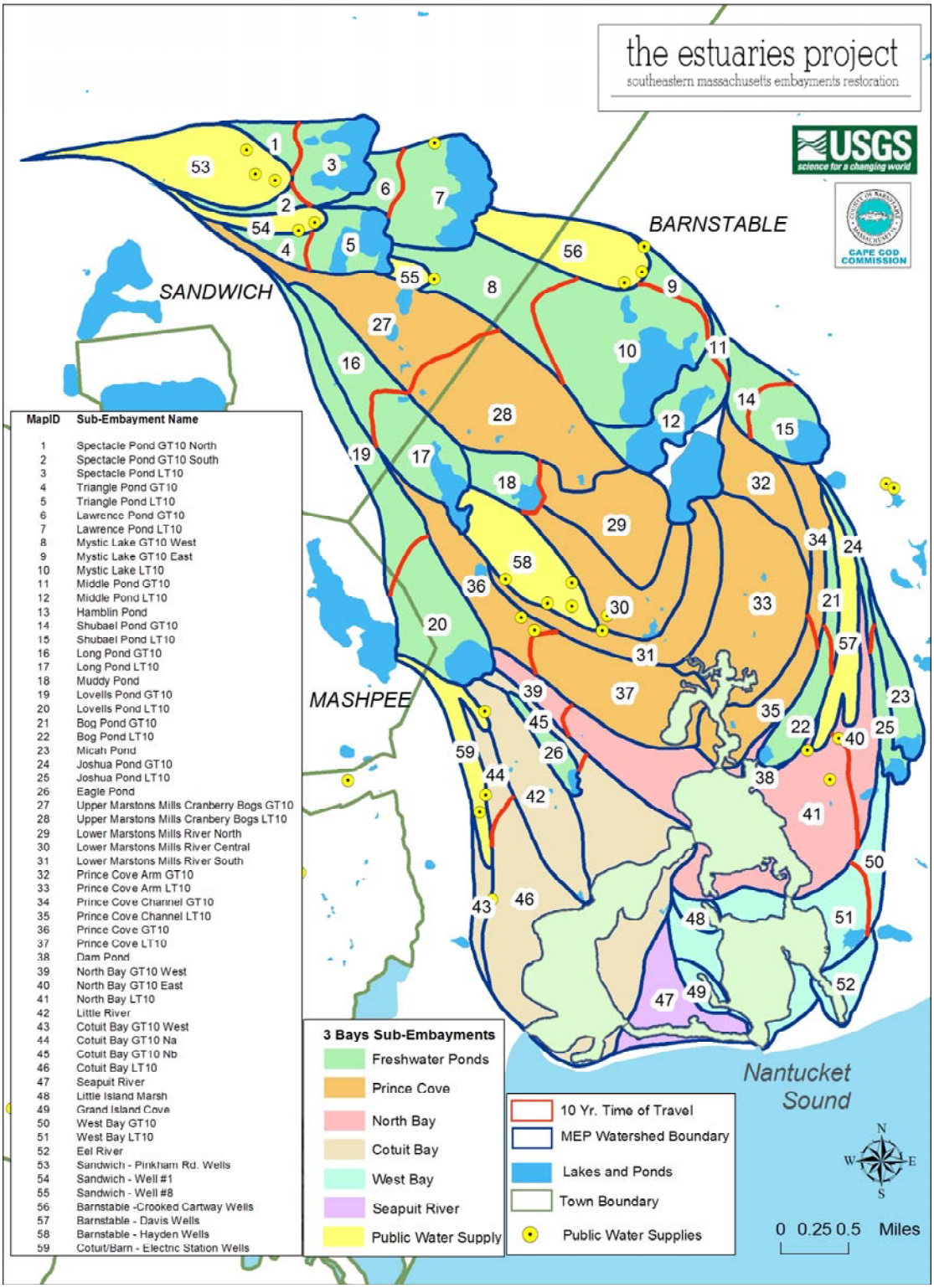


Figure III-1. Watershed and sub-watershed delineations for the Three Bays estuary system. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a "10" in the watershed names (above). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

Table III-1. Daily groundwater discharge to each of the sub-embayments in the Three Bays system, as determined from the USGS groundwater model.

Watershed	Watershed #	Discharge	
		m^3/day	ft^3/day
Spectacle Pond GT10N	1	463	16357
Spectacle Pond GT10S	2	329	11632
Spectacle Pond LT10	3	1572	55508
Triangle Pond GT10	4	423	14924
Triangle Pond LT10	5	1305	46087
Lawrence Pond GT10	6	601	21234
Lawrence Pond LT10	7	2491	87948
Mystic Lake GT10W	8	2540	89690
Mystic Lake GT10E	9	469	16545
Mystic Lake LT10	10	4795	169309
Middle Pond GT10	11	190	6726
Middle Pond LT10	12	1722	60794
Hamblin Pond	13	1235	43606
Shubael Pond GT10	14	699	24699
Shubael Pond LT10	15	1275	45025
Long Pond GT10	16	1378	48651
Long Pond LT10	17	1992	70320
Muddy Pond	18	961	33930
Lovells Pond GT10	19	2065	72910
Lovells Pond LT10	20	2506	88485
Bog Pond GT10	21	387	13671
Bog Pond LT10	22	965	34065
Micah Pond	23	897	31682
Joshua Pond GT10	24	345	12171
Joshua Pond LT10	25	613	21657
Eagle Pond	26	528	18632
Upper MM River GT10	27	3314	117010
Upper MM River LT10	28	4735	167195
Lower MM River N	29	2403	84843
Lower MM River Mid	30	2415	85272
Lower MM River S	31	2258	79727
Prince's Cove Arm GT10	32	1496	52834
Prince's Cove Arm LT10	33	4236	149562
Prince's Cove Channel GT10	34	919	32441
Prince's Cove Channel LT10	35	1395	49265
Prince's Cove GT10	36	1869	65989
Prince's Cove LT10	37	2926	103319
Dam Pond	38	183	6466
North Bay GT10 W	39	548	19347
North Bay GT10 E	40	1205	42562
North Bay LT10	41	5332	188282

Table III-1 (continued). Daily groundwater discharge to each of the sub-embayments in the Three Bay system, as determined from the USGS groundwater model.

Watershed	Watershed #	Discharge	
		m^3/day	ft^3/day
Little River	42	2487	87805
Cotuit Bay GT10W	43	495	17485
Cotuit Bay GT10Na	44	550	19438
Cotuit Bay GT10Nb	45	354	12488
Cotuit Bay LT10	46	6720	237270
Seapuit River	47	1593	56233
Little Island Marsh	48	290	10232
Grand Island Cove	49	369	13037
West Bay GT10	50	738	26048
West Bay LT10	51	2679	94601
Eel River	52	675	23843
Sandwich - Pinkham Rd. Wells	53	2879	101651
Sandwich - Well #1	54	670	23657
Sandwich - Well #8	55	238	8418
Barnstable - Crooked Cartway Wells	56	2156	76125
Barnstable - Davis Wells	57	1383	48831
Barnstable - Hayden Wells	58	2225	78565
Cotuit/Barnstable - Electric Station Wells	59	1128	39818

Note: Discharge rates are based on 27.25 inches per year of recharge (Walter and Whealan, 2005)

The evolution of the watershed delineations for the Three Bays system has allowed increasing accuracy as each new version adds new hydrologic data to that previously collected; the model allows all this data to be organized and to be brought into congruence with data from adjacent watersheds. The evaluation of older data and incorporation of new data during the development of the model is important as it decreases the level of uncertainty in the final calibrated and validated linked watershed-embayment model used for the evaluation of nitrogen management alternatives. Errors in watershed delineations do not necessarily result in proportional errors in nitrogen loading as errors in loading depend upon the land-uses that are included/excluded within the contributing areas. Small errors in watershed area can result in large errors in loading if a large source is counted in or out. Conversely, large errors in watershed area that involve only natural woodlands have little effect on nitrogen inputs to the down gradient estuary.

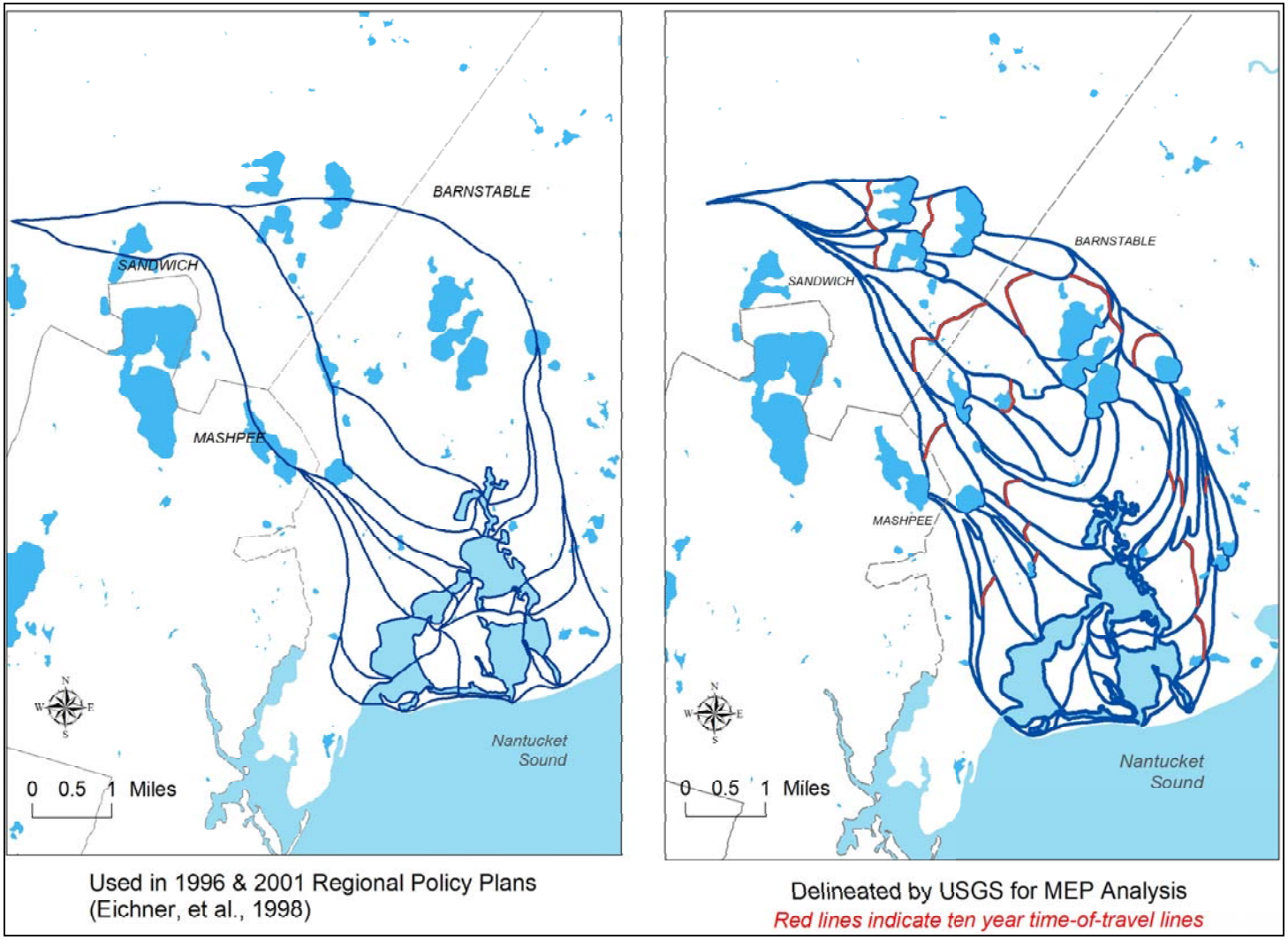


Figure III-2. Comparison of previous CCC (left) and MEP (right) Three Bay watershed and subwatershed delineations. The MEP watershed area is only 2.5% or 324 acres smaller than the 1996 delineation, but encloses slightly different land areas. The difference is primarily in the region close to the Cape Cod Bay/Vineyard Sound groundwater divide and stems from a better consideration of Santuit Pond and its relationship to Popponesset Bay than was possible in the earlier effort.

IV. WATERSHED NITROGEN LOADING TO EMBAYMENT: LAND USE, STREAM INPUTS, AND SEDIMENT NITROGEN RECYCLING

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS

Management of nutrient related water quality and habitat health in coastal waters requires determination of the amount of nitrogen transported by freshwaters (surface water flow, groundwater flow) from the surrounding watershed to the receiving embayment of interest. In southeastern Massachusetts, the nutrient of management concern for estuarine systems is nitrogen and this is true for the Three Bays system. Determination of watershed nitrogen inputs to these embayment systems requires the (a) identification and quantification of the nutrient sources and their loading rates to the land or aquifer, (b) confirmation that a groundwater transported load has reached the embayment at the time of analysis, and (c) quantification of nitrogen attenuation that can occur during travel through lakes, ponds, streams and marshes. This latter natural attenuation process results from biological processes that naturally occur within ecosystems. Failure to account for attenuation of nitrogen during transport results in an over-estimate of nitrogen inputs to an estuary and an underestimate of the sensitivity of a system to new inputs (or removals). In addition to the nitrogen transport from land to sea, the amount of direct atmospheric deposition on each embayment surface must be determined as well as the amount of nitrogen recycling within the embayment, specifically nitrogen regeneration from sediments. Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms, which may be released to the overlying waters or lost to denitrification within the sediments. Burial of nitrogen is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters and leads to errors in predicting water quality if it is not included in determination of summertime nitrogen load.

The MEP Technical Team includes technical staff from the Cape Cod Commission (CCC). In coordination with other MEP technical team staff, CCC staff developed nitrogen loading rates (Section IV.1) to the Three Bays embayment system (Section III). The Three Bays watershed was sub-divided to define contributing areas for each of the major inland freshwater systems and each major sub-embayment to the Three Bays system. The overall watershed to the system was further sub-divided into regions greater and less than 10 year groundwater travel time from the receiving estuary yielding a total of 59 sub-watersheds in all. The nitrogen loading effort also involved further refinement of watershed delineations to accurately reflect shoreline areas to freshwater ponds for Three Bays and to each sub-embayment.

The initial task in the MEP land use analysis is to gauge whether or not nitrogen discharges to the watershed have reached the embayment. This involves a temporal review of land use changes and the time of groundwater travel provided by the USGS watershed model. After reviewing the percentage of nitrogen loading in the less than 10 year time of travel (LT10) and greater than 10 year time of travel (GT10) watersheds (Table IV-1), previous nitrogen loading assessments (Eichner, et al., 1998), land use development records, and water quality modeling, it was determined that Three Bays is currently in balance with its watershed load. At present, the bulk (75%) of the watershed nitrogen load is less than 10 years travel time to the estuarine waters of Three Bays. Therefore, the distinction of less than 10 year and greater than 10 year time of travel regions within a subwatershed (Figure III-1) was eliminated and the number of subwatersheds was reduced to 37 (Figure IV-1). Potential errors resulting from long

Table IV-1. Percentage of unattenuated nitrogen loads in less than 10 time of travel subwatersheds to Three Bays. Note that not all of the "outflow" from these ponds is to the Three Bays Estuary. The load to the estuary is presented below in Table IV-5.

WATERSHED		LT10	GT10	TOTAL	%LT10
Name	#	kg/yr	kg/yr	kg/yr	
Spectacle Pond	1	662	395	1056	63%
Triangle Pond	2	629	315	944	67%
Lawrence Pond	3	727	26	753	96%
Mystic Lake	4	3429	2460	5890	58%
Middle Pond	5	857	67	924	93%
Hamblin Pond	6	693	0	693	100%
Shubael Pond	7	1520	711	2231	68%
Long Pond	8	2270	1396	3666	62%
Muddy Pond	9	525	0	525	100%
Lovells Pond	10	1734	1752	3486	50%
Bog Pond	11	1097	294	1391	79%
Micah Pond	12	869	0	869	100%
Joshua Pond	13	763	411	1174	65%
Eagle Pond	14	567	0	567	100%
Upper Marstons Mills River	15	4583	2819	7402	62%
Lower MM River N	16	2162	0	2162	100%
Lower MM River Mid	17	1929	0	1929	100%
Lower MM River S	18	1157	0	1157	100%
Prince's Cove Arm	19	2521	1490	4011	63%
Prince's Cove Channel	20	1327	506	1833	72%
Prince's Cove	21	3204	1033	4236	76%
Dam Pond	22	118	0	118	100%
North Bay	23	5821	2404	8225	71%
Little River	24	1617	0	1617	100%
Cotuit Bay	25	4796	1304	6100	79%
Seapuit River	26	1375	0	1375	100%
Little Island Marsh	27	338	0	338	100%
Grand Island Cove	28	204	0	204	100%
West Bay	29	3619	1719	5338	68%
Eel River	30	915	0	915	100%
Sandwich - Pinkham Rd. Wells	31	1500	0	1500	100%
Sandwich - Well #1	32	590	0	590	100%
Sandwich - Well #8	33	19	0	19	100%
Barnstable - Crooked Cartway Wells	34	1012	0	1012	100%
Barnstable - Davis Wells	35	1479	0	1479	100%
Barnstable - Hayden Wells	36	1231	0	1231	100%
Cotuit/Barnstable - Electric Station Wells	37	711	0	711	100%
TOTAL		58569	19102	77671	75%

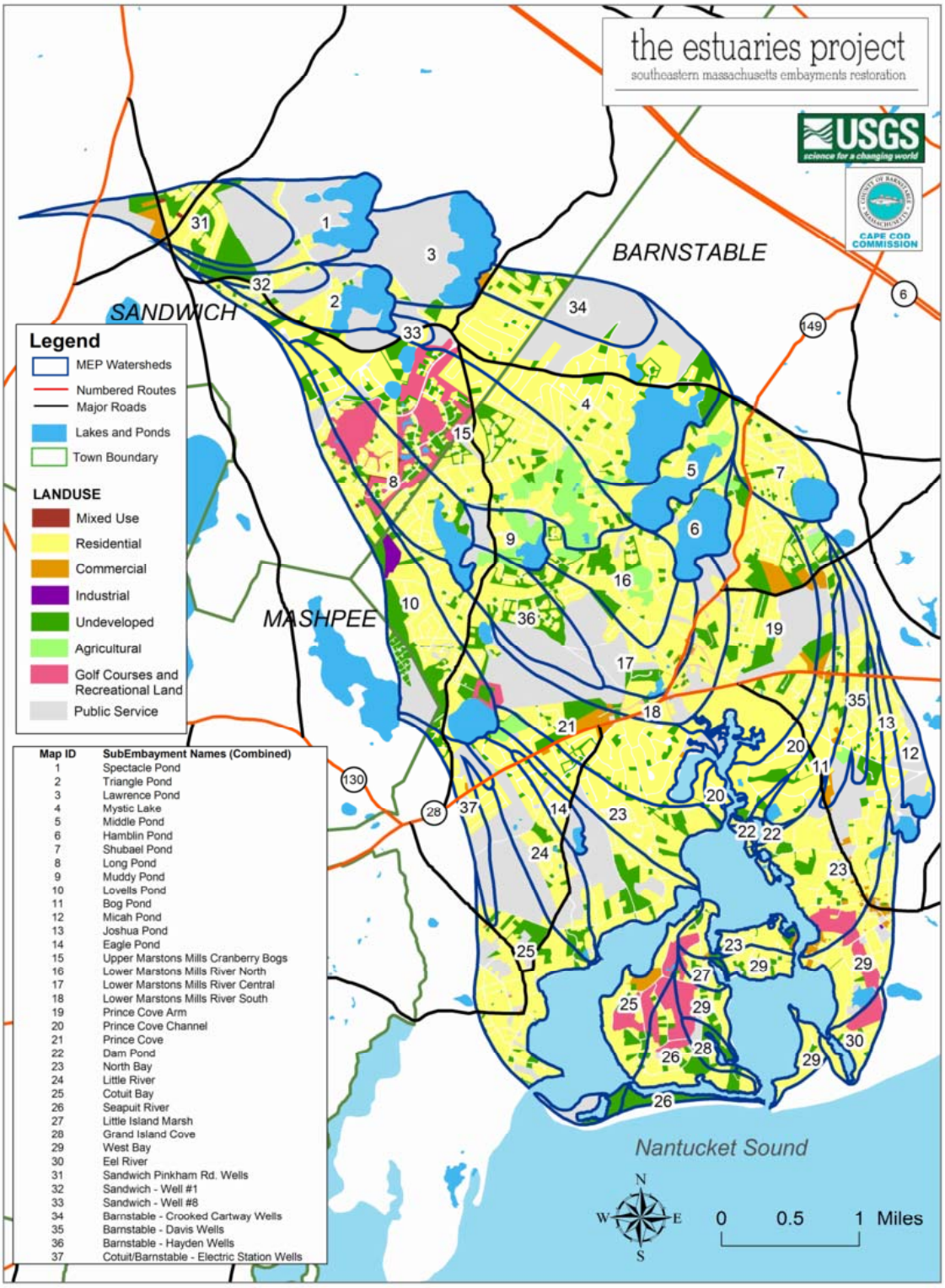


Figure IV-1. Land-use coverage in the watershed to the Three Bays Embayment System. The watershed encompasses portions of the Towns of Barnstable, Sandwich, and Mashpee and land use classifications are based on assessors' records provided by each of the towns.

travel times appear to be relatively small in the Three Bays System, since development in the watershed nearest the estuary (lower Marstons Mill River and groundwatersheds to the bays) indicate that 82% of the nitrogen sources are within 10 years travel times. Longer travel times in the watersheds to the fresh ponds does not create a proportional error, as these sources are generally significantly attenuated (i.e. nitrogen is lost) during transport. In addition, the watersheds nearest the embayment have been relatively stable over recent years. The overall result of the timing of development relative to groundwater travel times is that the present watershed nitrogen load appears to accurately reflect the present nitrogen sources to the estuaries (after accounting for natural attenuation, see below).

In order to determine nitrogen loads from the watersheds, detailed individual lot-by-lot data is used for some portion of the loads, while information developed from other detailed studies is applied to other portions. The Linked Watershed-Embayment Management Model (Howes & Ramsey, 2001) uses a land-use Nitrogen Loading Sub-Model based upon subwatershed-specific land-uses and pre-determined nitrogen loading rates. For the Three Bays embayment system, the model used Barnstable, Sandwich, and Mashpee-specific land-use data transformed to nitrogen loads using both regional nitrogen load factors and local watershed-specific data (such as parcel by parcel water use). Note that the small portion of the watershed in Mashpee (<1%) is predominantly open space adjacent Santuit Pond. Determination of the nitrogen loads required obtaining watershed-specific information regarding wastewater, fertilizers, runoff from impervious surfaces and atmospheric deposition. The primary regional factors were derived for southeastern Massachusetts from direct measurements. The resulting nitrogen loads represent the “potential” nitrogen load to each receiving embayment, since attenuation during transport has not yet been included.

Natural attenuation within the Three Bays watershed of nitrogen during transport from land-to-sea (Section IV.2) was determined based upon site-specific studies within the freshwater portion of the Marstons Mills River and Little River and through the freshwater ponds within the watershed. Attenuation during transport through each of the major fresh ponds was determined through (a) comparison with other Cape Cod lake studies and (b) data collected on each pond. Attenuation during transport through each of the major fresh ponds was assumed to equal 50% based on available monitoring of selected Cape Cod lakes. Available historic data collected from individual fresh ponds in the Three Bays watershed confirmed the appropriateness of this general assumption. Attenuation factors based upon site-specific studies were developed to three ponds (Mystic, Middle, and Hamblin) based on an extensive dataset collected during 2004 (Eichner, et al., in preparation). Internal nitrogen recycling was also determined throughout the tidal reaches of the Three Bays embayment; measurements were made to capture the spatial distribution of sediment nitrogen regeneration from the sediments to the overlying water-column. Nitrogen regeneration focused on summer months, the critical nitrogen management interval and the focal season of the MEP approach and application of the Linked Watershed-Embayment Management Model (Section IV.3).

IV.1.1 Land Use and Water Use Database Preparation

Estuaries Project staff obtained digital parcel and tax assessors data from the Towns of Barnstable, Sandwich, and Mashpee. Digital parcels and land use data are from 2004 for Barnstable, 2000 for Sandwich, and 2001 for Mashpee and were obtained from the Town of Barnstable GIS Unit, the Town of Sandwich Planning Department, and the Town of Mashpee Planning Department, respectively. These land use databases contain traditional information regarding land use classifications (MADOR, 2002) plus additional information developed by each of the towns; different information is available depending on the town (e.g., Mashpee has

developed information about impervious surfaces (building area, driveways, and parking area) on individual lots). The parcel coverages and assessors' database were combined for the MEP analysis by using the Cape Cod Commission Geographic Information System (GIS).

Figure IV-1 shows the land uses within the Three Bays study area. Land use in the Three Bays study area can be apportioned into one of eight land use types: 1) residential, 2) commercial, 3) industrial, 4) undeveloped, 5) agricultural, 6) mixed use, 7) golf course and recreational land, and 8) public service/government, including road rights-of-way. "Public service" is the land classification assigned by the Massachusetts Department of Revenue to tax exempt properties, including lands owned by government (e.g., wellfields, schools, open space, roads) and private groups like churches and colleges. Massachusetts Assessors land uses classifications (MADOR, 2002), which are common to each town in the watershed, are aggregated into these eight land use categories.

In the Three Bays watershed, the predominant land use based on area is residential, which accounts for slightly less than half (46%) of the watershed area; public service (government owned lands including open space, roads, and rights-of-way) is the second highest percentage of the watershed (28%). In addition, 76% of the parcels in the system watershed are classified as single family residences (MADOR land use code 101) and single family residences account for 88% of the residential land area. In addition, residential land uses are the predominant land use in all the major Three Bays subwatersheds with a range of 39% to 63% of the subwatershed areas. Public service land uses are the second highest percentage in all of the major subwatersheds except for the Seapuit River subwatershed where undeveloped land uses are the second highest. Overall, undeveloped land uses account for 11% of the whole Three Bays watershed and are shown in Figure IV-2. Commercial properties account for only about 1% of the Three Bays watershed area.

In order to estimate wastewater flows within the Three Bays watershed, MEP staff also obtained parcel by parcel water use information from the Cotuit Water District and Centerville, Osterville, Marstons Mills (COMM) Water District from the Town of Barnstable GIS Unit, the Sandwich Water District, and the Mashpee Water District. The COMM water use data is three years (2001-2003) of biannual readings, while the Cotuit water use data is only for one year (October 2002 through October 2003). Sandwich water use data is two and a half years (January 2002 through June 2004), while Mashpee water use data is three years (1997 through 1999). Water use information was linked to the parcel and assessors data using GIS techniques. Water use for each parcel was converted to an annual volume for purposes of the nitrogen loading calculations. Two wastewater treatment facilities (WWTFs) currently exist in the Three Bays watershed: one at the Cotuit Landing shopping area (21,600 gallon per day design capacity) in the Prince's Cove subwatershed and another at the Barnstable Horace Mann Charter School (32,000 gallon per day design capacity) in the Joshua Pond subwatershed.

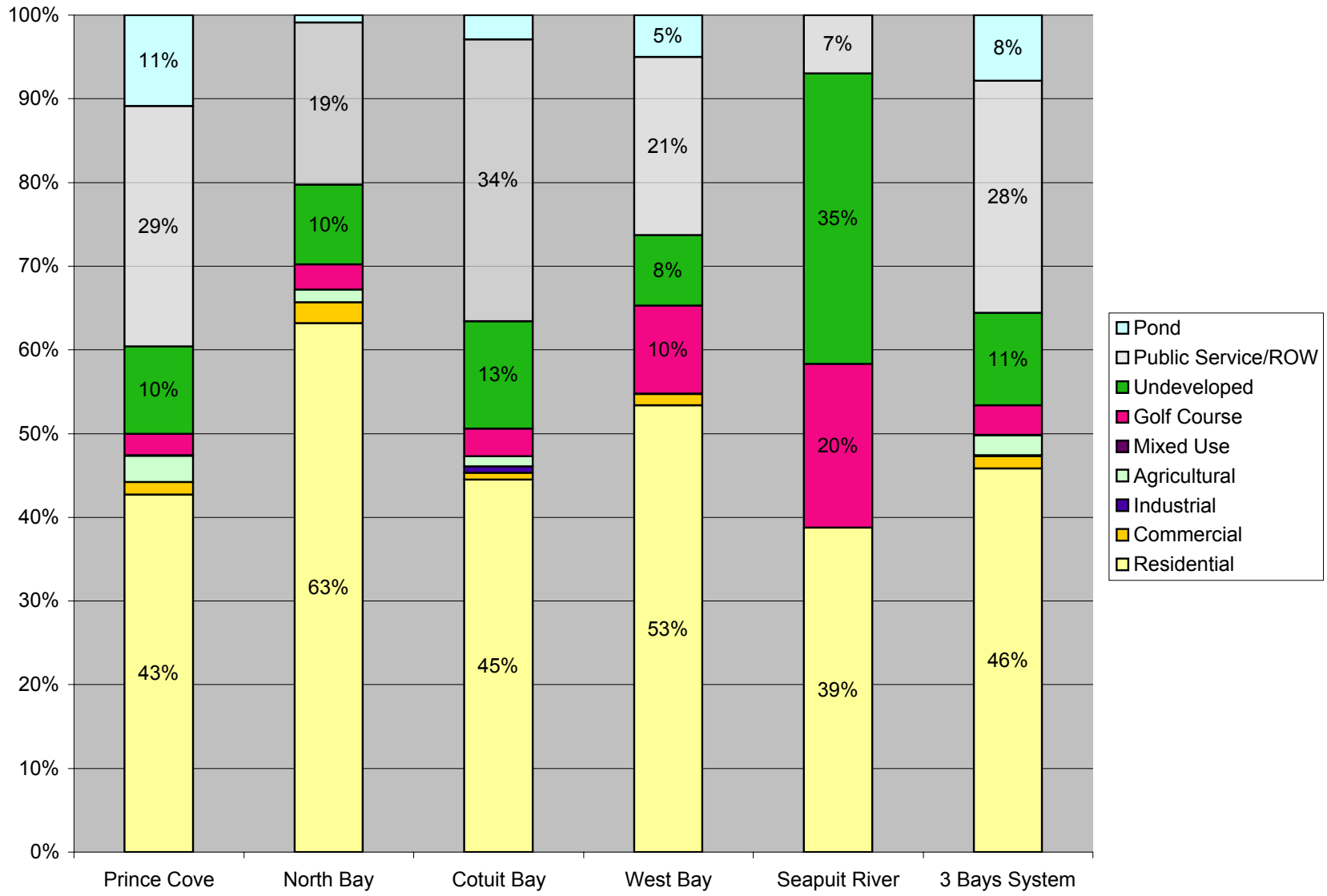


Figure IV-2. Distribution of land-uses within the major subwatersheds and whole watershed to Three Bays. Only percentages greater than or equal to 5% are shown.

IV.1.2 Nitrogen Loading Input Factors

Wastewater/Water Use

Except for the small WWTFs, all wastewater within the Three Bays watershed is returned to the aquifer through individual on-site septic systems. Wastewater-based nitrogen loading from the individual parcels using on-site septic systems is based upon the measured water-use, nitrogen concentration, and consumptive loss of water before the remainder is treated in a septic system or WWTF.

Similar to many other watershed nitrogen loading analyses, the Massachusetts Estuaries Project septic system nitrogen loading rate is fundamentally based upon a per capita nitrogen load to the receiving aquatic system. Specifically, the MEP septic system wastewater nitrogen loading is based upon directly measured septic system and per capita loads determined on Cape Cod or in similar geologic settings (Nelson et al. 1990, Weiskel & Howes 1991, 1992, Koppelman 1978, Frimpter et al. 1990, Brawley et al. 2000, Howes and Ramsey 2000, Costa et al. 2001). Variation in per capita nitrogen load has been found to be relatively small, with average annual per capita nitrogen loads generally between 1.9 to 2.3 kg/person-yr^{-1}. However, given the seasonal shifts in occupancy in many of the watersheds throughout southeastern Massachusetts, census data yields accurate estimates of total population only in specific watersheds (see below). To correct for this uncertainty, the MEP employs a water-use approach. The water-use approach (Weiskel and Howes 1991) is applied on a parcel-by-parcel basis within a watershed, where usually an average of multiple years annual water meter data is linked to assessors parcel information using GIS techniques. The parcel specific water use data is converted to septic system nitrogen discharges (to the receiving aquatic systems) by adjusting for consumptive use (e.g. irrigation) and applying a wastewater nitrogen concentration. The water use approach focuses on the nitrogen load, which reaches the aquatic receptors down-gradient in the aquifer. All losses within the septic system are incorporated. For example, information developed at the DEP Alternative Septic System Test Center at the Massachusetts Military Reservation on Title 5 septic systems have shown nitrogen removals between 21% and 25%. Multi-year monitoring from the Test Center has revealed that nitrogen removal within the septic tank was small (1% to 3%), with most (20 to 22%) of the removal occurring within five feet of the soil adsorption system (Costa et al. 2001). Aquifer studies indicate that further nitrogen loss during aquifer transport is negligible (Robertson et al. 1991, DeSimone and Howes 1996).

In its application of the water-use approach to septic system nitrogen loads, the MEP has ascertained for the Estuaries Project region that while the per capita septic load is well constrained by direct studies, the consumptive use and nitrogen concentration data are less certain. As a result, the MEP has derived a combined term for the effective N Loading Coefficient (consumptive use times N concentration) of 23.63, to convert water (per cubic meter) to nitrogen load (N grams). This term uses a per capita nitrogen load of 2.1 kg N person-yr^{-1} and is based upon direct measurements and corrects for changes in concentration that result from per capita shifts in water-use (e.g. due to installing low plumbing fixtures or high versus low irrigation usage, etc.).

The resulting nitrogen loads, based upon the above approach have been validated in a number of long and short term field studies where integrated measurements of nitrogen discharge from watersheds could be directly measured. For example, Weiskel and Howes (1991, 1992) conducted a detailed watershed/stream tube study that monitored septic systems, leaching fields and the transport of the nitrogen in groundwater to adjacent Buttermilk Bay. This

monitoring resulted in estimated annual per capita nitrogen loads of 2.17 kg (as published) to 2.04 kg (if new attenuation information is included). The selected "effective N loading coefficient" also agrees with available watershed nitrogen loading analyses conducted on other Cape Cod estuaries. Aside from the concurrence observed between modeled and observed nitrogen concentrations in the estuary analyses completed under the MEP, analyses of other estuaries completed using this effective septic system nitrogen loading coefficient, the modeled loads also match observed concentrations in streams in the MEP region. Modeled and measured nitrogen loads were determined for a small sub-watershed to West Falmouth Harbor (Smith and Howes 2006, in review) where a small stream drained the aquifer from a residential neighborhood. In this effort, the measured nitrogen discharge from the aquifer was within 5% of the modeled N load. A second evaluation was conducted by surveying nitrogen discharge to the Mashpee River in reaches with swept sand channels and in winter when nitrogen attenuation is minimal. The measured and observed loads showed a difference of less than 8%, easily attributable to the low rate of attenuation expected at that time of year and under the ecological situation (Samimy and Howes unpublished data).

While census based population data has limitations in the highly seasonal MEP region, part of the regular MEP analysis is to compare expected water used based on average residential occupancy to measured average water uses. This is performed as a quality assurance check to increase certainty in the final results. This comparison has shown that the larger the watershed the better the match between average water use and occupancy. For example, in the cases of the combined Great Pond, Green Pond and Bournes Pond watershed in the Town of Falmouth and the Popponesset Bay/Eastern Waquoit Bay watershed, which cover large areas and have significant year-round populations, the septic nitrogen loading based upon the census data is within 5% of that from the water use approach. This comparison matches some of the variability seen in census data itself, census blocks, which are generally smaller areas of the towns have shown up to a 13% difference in average occupancy from town-wide occupancy rates. These analyses provide additional support for the use of the water use approach in the MEP study region.

Overall, the MEP water use approach for determining septic system nitrogen loads has been both calibrated and validated in a variety of watershed settings. The approach: (a) is consistent with a suite of studies on per capita nitrogen loads from septic systems in sandy outwash aquifers; (b) has been validated in studies of the MEP Watershed "Module", where there is been excellent agreement between the nitrogen load predicted and that observed in direct field measurements corrected to other MEP coefficients for stormwater, lawn fertilization, etc; (c) the MEP septic nitrogen loading coefficient agrees in specific studies of consumptive water use and N attenuation between the septic tank and the discharge site; and (d) the watershed module provides estimates of nitrogen attenuation by freshwater systems that are consistent with a variety of ecological studies. It should be noted that while points b-d support the use of the MEP Septic N Coefficient, they were not used in its development. The MEP Technical Team has worked out the septic system nitrogen load over many years, and the general agreement among the number of supporting studies has greatly enhanced the certainty of this critical watershed nitrogen loading term.

The independent validation of the water quality model (Section VI) and the reasonableness of the freshwater attenuation (Section IV.2) add additional weight to the nitrogen loading coefficients used in the MEP analyses and a variety of other MEP embayments. While the MEP septic system nitrogen load is the best estimate possible, to the extent that it may underestimate the nitrogen load from this source reaching receiving waters provides a safety factor relative to other higher loads that are generally used in regulatory

situations. The lower concentration results in slightly higher amounts of nitrogen mitigation (estimated at 1% to 5%)) needed to lower embayment nitrogen levels to a nitrogen target (e.g. nitrogen threshold, cf. Section VIII). The additional nitrogen removal is not proportional to the septic system nitrogen level, but is related to the how the septic system nitrogen mass compares to the nitrogen loads from all other sources that reach the estuary (i.e. attenuated loads).

For the purposes of the Three Bays nitrogen loading modeling, performance data for the two WWTFs in the watershed were obtained from a review of WWTF effluent monitoring data associated with the DEP permit. Measurement and reporting of average monthly flows and effluent discharge N concentrations are required of both the Barnstable Horace Mann Charter School and Cotuit Landing WWTF. Averages of effluent flow and total nitrogen concentrations were incorporated into the model based on monitoring data collected between 2002 and 2004 (Table IV-2).

Table IV-2. Wastewater Treatment Facilities in the Three Bays Watershed

System Name	Average Effluent Characteristics		
Facility Name	Flow (gallons per day)	Total Nitrogen Concentration (mg/liter)	Annual Nitrogen Load (kg N/yr)
Barnstable Horace Mann Charter School	3,907[a]	4.64[b]	25
Cotuit Landing	5,206[c]	4.69[d]	34

Notes: [a] average flow (April 2002-September 2004); [b] average discharge concentration (April 2002-September 2004); [c] average flow (September 2002-December 2004); [d] average discharge concentration (September 2002-December 2004); all data from DEP records (personal communication, B. Dudley SERO)

Water use information exists for 85% of the 9,153 parcels in the Three Bays watershed. Only 1,411 parcels appear to utilize private wells for drinking water. These are properties that are classified with land use codes that should be developed (e.g., 101 or 325), have been confirmed as having buildings on them through a review of aerial photographs, and do not have a listed account in the water use databases. Of the 1,411 parcels, almost all, (92%, 1,295) are classified as single family residences (land use code 101), 12 are classified as commercial land uses (codes between 300 to 389), one is a plant nursery, and the remainder is other residential land uses (i.e., multiple houses on one lot, two family residences, condominiums, etc).

Water use and wastewater flows from the parcels on private wells were extrapolated from the other parcels in the watershed. To develop nitrogen loads from these developed parcels in the nitrogen loading modeling. MEP staff developed water use estimates based on average water uses of similar land uses in the Three Bays watershed (Table IV-3). For the residential land uses, the average water use of single family residences (227 gallons per day) was assigned to all residential parcels assumed to have private wells, as well as all new residences estimated through the buildout analysis. Estimates for commercial properties were treated differently. For most of the commercial properties, the area of the buildings occupying a given site and the percentage of the property occupied by the buildings are available. This information was combined with water use information to develop a flow per 1,000 square feet of building for existing properties (18 gpd/ 1,000 ft2) and an average building coverage (28% of the lot) for use in buildout projections. It is recognized that a variety of commercial land uses and a wide range of water use (e.g., small offices with one or two employees to large water users, like restaurants) are contained in the average, but the developed average has been selected as the

most appropriate estimate for these land uses. The ranges in Table IV-3 are very similar to those observed in the MEP analysis of water use in other watersheds.

Table IV-3. Average Water Use in Three Bays Watershed based upon multi-year water meter data.

Land Use	State Class Codes	# of Parcels in Study Area	Water Use (gallons per day)	
			Study Area Average	Study Area Range
Residential	101	5,668	227	0 to 3,203
Commercial	300 to 389	103	379	0 to 2,910
Industrial	400 to 439	2	49	--

Note: All data for analysis supplied by towns or water districts. Only one industrial property has water use within the study area

In order to provide an independent validation of the residential water use average within the study areas, MEP staff reviewed US Census population values. In non-seasonal watersheds, estimates of census data can provide a good estimate of total population for comparison to total population estimates derived from water meter data. The state on-site wastewater regulations (*i.e.*, 310 CMR 15, Title 5) assume that two people occupy each bedroom and each bedroom has a wastewater flow of 110 gallons per day (gpd), so each person generates 55 gpd of wastewater. Average occupancy within the Town of Barnstable during the 2000 US Census was 2.44 people per household, 2.46 in Mashpee, and 2.30 in Sandwich; using a weighted average based on the percent area of each town within the watershed, the Three Bays watershed 2000 Census occupancy is 2.41. If 2.41 were multiplied by 55 gpd, 132 gpd would be calculated as the average residential wastewater flow in the Three Bays watershed. However, the measured average residential water use in the Three Bays watershed is 227 gpd, which would equate to 204 gpd of wastewater flow (0.9 X 227 gpd).

In most previously completed MEP studies, average population and average water use have generally agreed fairly well, although the Oyster Pond analysis also did not show good agreement. As a result of the relatively poor agreement between census and water use population estimates in the Three Bays watershed, MEP staff reviewed more refined US Census information and water use information for each parcel within the watershed. Besides reviewing data on town and state levels, the US Census also develops information for smaller areas (i.e., tracts and blocks). Average occupancy in the Census tracts within the Three Bays watershed range between 2.18 and 3.05, which would produce a water use range of 120 to 168 gpd if 55 gpd is assumed for each person. The top end of this range is still lower than the measured water use in the Three Bays watershed, but this range does suggest a higher potential population in the watershed than a review of town-wide data and supports the need for the MEP parcel-by-parcel water use approach, rather than use of census data alone. The overall review of Census data suggests that the Three Bay watershed is an area where water use should be increasing.

MEP staff then reviewed the average water uses measured in the subwatersheds of the Three Bay system. While the overall average for single family residences (SFRs) is 227 gpd, averages in the subwatersheds varied widely with a range between 78.5 and 1,072 gpd. The range for water uses in watersheds with 100 SFRs or greater is 152 to 374 gpd. The standard

deviation among all the watershed averages is 161 gpd; the 132 gpd population estimated average fits within one standard deviation of the 227 gpd measured water use mean.

The purpose of the wateruse approach is to provide direct measurements which relate to wastewater generation, rather than to make approximations using census data in highly seasonal watersheds or in areas where occupancy rates are not reflected in straight census data. Given all the above analysis and the absence of information suggesting errors in the water use data, MEP staff decided to continue to use the Three Bays watershed-specific average water use for residential parcels without water use and for the 1,530 additional residential parcels included in the buildout analysis.

Nitrogen Loading Input Factors: Fertilized Areas

The second largest source of estuary watershed nitrogen loading is usually fertilized lawns and golf courses, with lawns being the predominant source within this category. In order to add this source to the nitrogen loading model for the Three Bays system, MEP staff reviewed available information about residential lawn fertilizing practices and, for the Three Bays watershed, attempted to contact managers of large tracts of turf, such as golf courses, to incorporate site-specific fertilizer application rates.

Residential lawn fertilizer use has rarely been directly measured in watershed-based nitrogen loading investigations. Instead, lawn fertilizer nitrogen loads have been estimated based upon a number of assumptions: a) each household applies fertilizer, b) cumulative annual applications are 3 pounds per 1,000 sq. ft., c) each lawn is 5000 sq. ft., and d) only 25% of the nitrogen applied reaches the groundwater (leaching rate). Because many of these assumptions had not been rigorously reviewed in over a decade, the MEP Technical Staff undertook an assessment of lawn fertilizer application rates and a review of leaching rates for inclusion in the Watershed Nitrogen Loading Sub-Model.

The initial effort was to determine nitrogen fertilization rates for residential lawns in the Towns of Falmouth, Mashpee and Barnstable. The assessment accounted for proximity to fresh ponds and embayments. Based upon ~300 interviews and over 2,000 site surveys, a number of findings emerged: 1) average residential lawn area is ~5000 sq. ft., 2) half of the residences did not apply lawn fertilizer, and 3) the weighted average application rate was 1.44 applications per year, rather than the 4 applications per year recommended on the fertilizer bags. Integrating the average residential fertilizer application rate with a leaching rate of 20% resulted in a fertilizer contribution of N to groundwater of 1.08 lb N per residential lawn for use in the nitrogen loading calculations. It is likely that this still represents a conservative estimate of nitrogen load from residential lawns. It should be noted that professionally maintained lawns were found to have the higher rate of fertilization application and hence higher estimated loss to groundwater of 3 lb/lawn/yr.

There are four golf courses in the Three Bays watershed: Wianno Golf Club, Oyster Harbors Club, Ridge Club, and Holly Ridge. Golf courses usually have different fertilizer application rates for different turf areas, usually higher annual application rates for tees and greens (~3-4 pounds per 1,000 square feet) and lower rates for fairways and roughs (~2-3.5 pounds per 1,000 square feet). Fertilizer application rates were available from Wianno Golf Club and Oyster Harbors Club; the application rates at the other two courses were assumed to be an average of application rates from the two watershed courses within application information and four other Cape Cod golf courses outside the watershed.

Fertilizer application information was also requested for ball fields and cemeteries within the Three Bays watershed, as well as the Marstons Mills Airport. Contacts for this information stated that none of these had active fertilizer applications. Only residential fertilizer applications are included in the nitrogen loading for the Three Bays system.

Nitrogen Loading Input Factors: Other

The nitrogen loading factors for atmospheric deposition, impervious surfaces and natural areas are from the MEP Embayment Modeling Evaluation and Sensitivity Report (Howes and Ramsey 2001). The factors are similar to those utilized by the Cape Cod Commission's Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and Massachusetts DEP's Nitrogen Loading Computer Model Guidance (1999). The recharge rate for natural areas and lawn areas is the same as utilized in the MEP-USGS groundwater modeling effort (Section III). Cranberry bog fertilizer application rate and percent nitrogen attenuation in the bogs is based on the only annual study of nutrient cycling and loss from cranberry agriculture (Howes and Teal, 1995). Only the bog loses measurable nitrogen, the forested upland areas release only very low amounts. For the land-use N loading analysis, the areas of active bog surface are based on 85% of the total property area with cranberry bog land use codes. Factors used in the nitrogen loading analysis for the Three Bays watershed are summarized in Table IV-4.

IV.1.3 Calculating Nitrogen Loads

Once all the land and water use information was linked to the parcel coverages, parcels were assigned to various watersheds based initially on whether at least 50% or more of the land area of each parcel was located within a respective watershed. Following the assigning of boundary parcels, all large parcels were examined individually and were split (as appropriate) in order to obtain less than a 2% difference between the total land area of each subwatershed and the sum of the area of the parcels within each subwatershed. The resulting "parcelized" watersheds to Three Bays are shown in Figure IV-3.

This review of individual parcels straddling watershed boundaries included corresponding reviews and individualized assignment of nitrogen loads associated with lawn areas, septic systems, and impervious surfaces. Individualized information for parcels with atypical nitrogen loading (condominiums, WWTFs, etc.) were also assigned at this stage. It should be noted that small shifts in nitrogen loading due to the above assignment procedure, has a negligible effect on the total nitrogen loading to the Three Bays estuary. The assignment effort was undertaken to better define the sub-embayment loads and enhance the use of the Linked Watershed-Embayment Model for the analysis of management alternatives.

Table IV-4. Primary Nitrogen Loading Factors used in the Three Bays MEP analyses. General factors are from MEP modeling evaluation (Howes & Ramsey 2001). Site-specific factors are derived from Barnstable, Sandwich, and Mashpee watershed-specific data for Three Bays. *Data from MEP lawn study in Falmouth, Mashpee & Barnstable 2001. **Commercial assumptions also utilized for existing developed properties without water use.

Nitrogen Concentrations:	mg/l
Road Run-off	1.5
Roof Run-off	0.75
Direct Precipitation on Embayments and Ponds	1.09
Natural Area Recharge	0.072
Wastewater Coefficient	23.63
Fertilizers:	
Average Residential Lawn Size (ft^2)*	5,000
Residential Watershed Nitrogen Rate (lbs/lawn)*	1.08
Cranberry Bogs nitrogen application (lbs/ac)	31
Cranberry Bogs nitrogen attenuation	34%
Nitrogen Fertilizer Rate for golf courses, cemeteries, and public parks determined from site-specific information	

Recharge Rates:	in/yr
Impervious Surfaces	40
Natural and Lawn Areas	27.25
Water Use/Wastewater:	
Existing residential developed parcels wo/water accounts	227 gpd
Existing developed parcels w/water accounts	Measured annual water use
Buildout Parcels Assumptions:	
Residential parcels:	227 gpd
Commercial and industrial parcels**	18 gpd/1,000 ft2 of building
Commercial and industrial building coverage**	28%

Following the assignment of all parcels to individual subwatersheds in the Three Bays watershed, spreadsheets were generated for each of the 59 sub-watersheds summarizing water use, parcel area, frequency, sewer connections, private wells, and road area. As mentioned above, these results were then condensed to 37 subwatersheds based upon the time of travel analysis (<10 yr vs. > 10 yr) discussed above.

The results from the 37 individual sub-watershed assessments in the Three Bays study area were then integrated to generate nitrogen loading tables relating to each of the individual estuaries and their major components: Prince's Cove, Cotuit Bay, West Bay, North Bay, and the Seapuit River. The sub-embayments represent the functional embayment units for the Linked Watershed-Embayment Model's water quality component.

For management purposes, the aggregated sub-embayment watershed nitrogen loads are partitioned by the major types of nitrogen sources in order to focus development of nitrogen management alternatives. Within the Three Bays system, the major types of nitrogen loads are:

wastewater, fertilizer, impervious surfaces, direct atmospheric deposition to water surfaces, and recharge within natural areas (Table IV-5). The output of the watershed nitrogen loading model is the annual mass (kilograms) of nitrogen added to the contributing area of component sub-embayments, by each source category (Figures IV-4 a-f for Three Bays). The Three Bays annual watershed nitrogen input is then adjusted for natural nitrogen attenuation during transport to the estuarine system before use in the embayment water quality sub-model. Natural attenuation within Marstons Mills River and Little River is also directly measured (Section IV.2) and compared to the attenuated annual watershed nitrogen load from the land-use sub-model

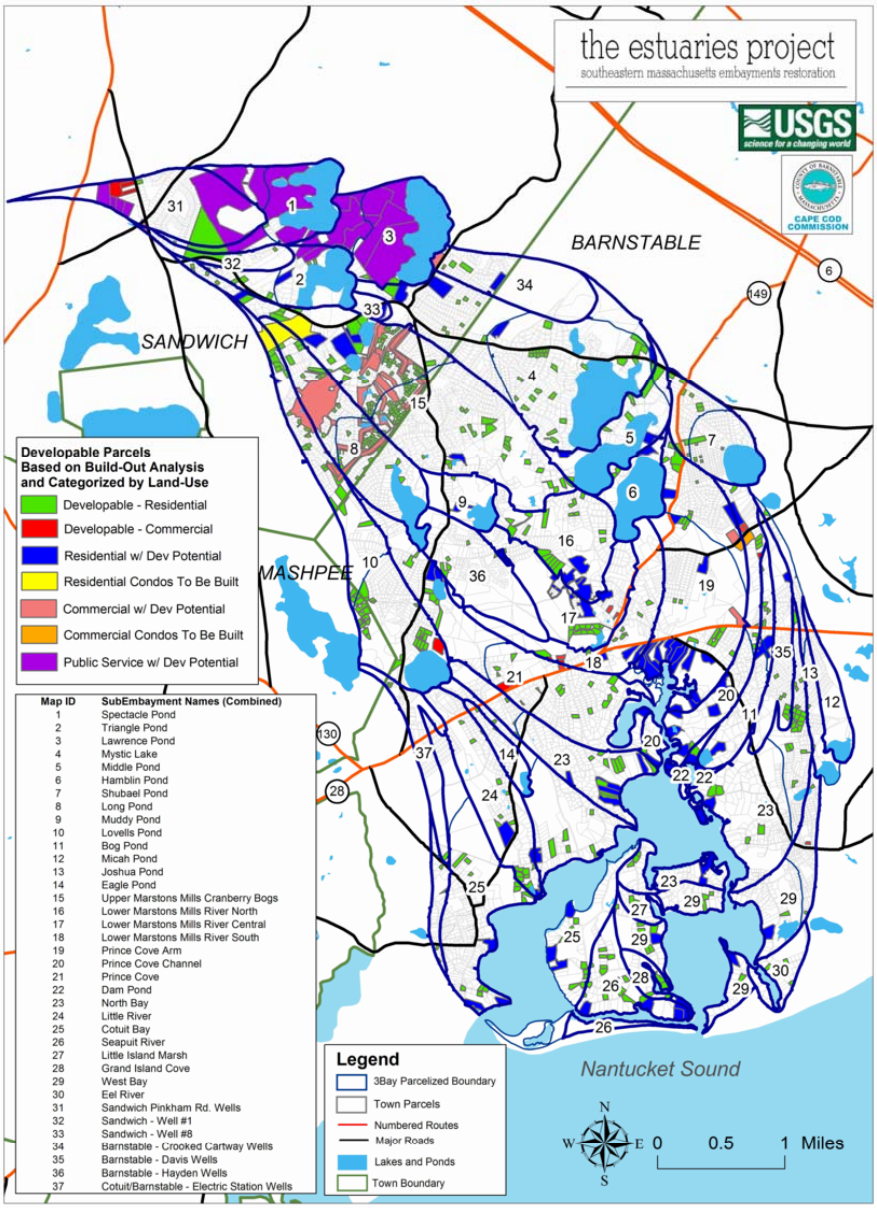
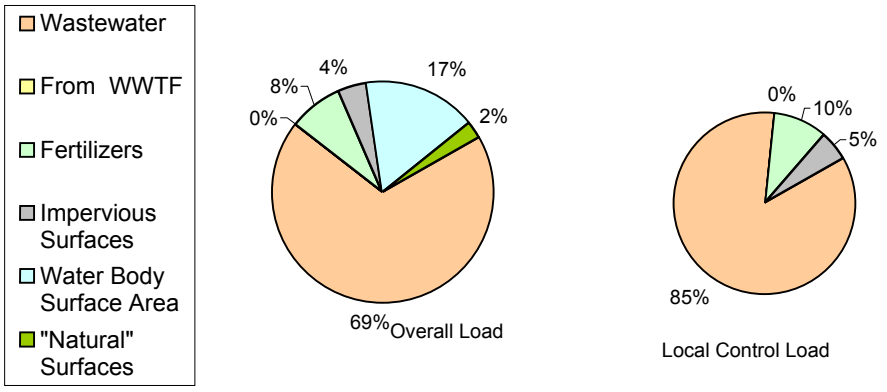


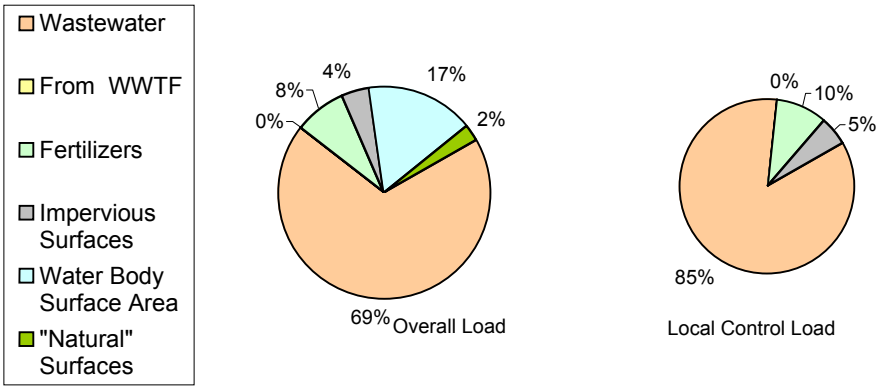
Figure IV-3. Parcels, Parcelized Watersheds, and Developable Parcels in the sub-watersheds to the Three Bays Estuary.

Table IV-5. Nitrogen Loads to the tidal waters of the Three Bays Estuary. Attenuation of the Three Bays system nitrogen loads occurs as nitrogen moves through up-gradient ponds, the Marstons Mills River, and Little River during transport to the estuary.

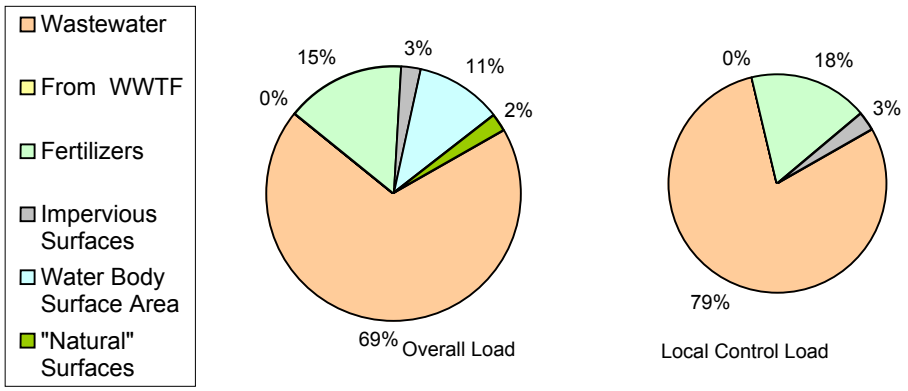
		Three Bay N Loads by Input:							% of Pond Outflow	*Present N Loads*			*Buildout N Loads*		
Watershed Name	**Watershed ID#**	**Wastewater**	**From WWTF**	**Fertilizers**	**Impervious Surfaces**	**Water Body Surface**	**"Natural" Surfaces**	**Buildout**		**UnAtten N Load**	**Atten %**	**Atten N Load**	**UnAtten N Load**	**Atten %**	**Atten N Load**
Three Bay Estuary		53584	39	7920	2828	8555	1641	10372		74567		54657	84939		61296
Cotuit Bay Estuary	42,43,44,45, 46,59 + EP	9739	0	1086	589	2366	352	1915		14132		11653	16047		12929
Cotuit Bay Estuary surface deposition						2112				2112		2112	2112		2112
Little River Total	42 + LVP	2370	0	222	155	93	91	642		2932	30%	1592	3575	30%	1888
Seapuit River	47	1066	0	235	39	165	35	270		1540		1540	1810		1810
Seapuit River Estuary surface deposition						165				165		165	165		165
West Bay Estuary	48,49,50,51 + JP, MIP	5832	6	913	260	1623	97	372		8730		8505	9102		8873
West Bay Estuary surface deposition						1545				1545		1545	1545		1545
North Bay Estuary	21,22,38,39, 40,41,57 + LVP	9898	0	994	477	1527	221	1210		13117		12191	14327		13259
North Bay Estuary surface deposition						1443				1443		1443	1443		1443
Prince Cove Estuary	27,28,29,30, 31,32,33,34, 35,36,37 + TP,MDP,MP,HP	27050	34	4692	1463	2874	935	6605		37048		20768	43652		24425
Prince Cove Estuary surface deposition						449				449		449	449		449
Prince Cove Channel	34,35 + SP	1882	0	111	118	40	58	392		2208		2021	2600		2396
Prince Cove Arm	32,33 + HP	5666	0	458	323	842	221	1793		7510		4390	9303		5581
Prince Cove Subwatershed	36,37 + LP	4514	34	498	227	120	125	806		5519		4877	6324		5547
Lower MM River South	31,58 + LP,HP	4902	0	782	296	653	192	1121		6825	30%	2662	7946	30%	3023
Mill Pond	Lower MM River N & C	10086	0	2842	500	771	339	2493		14537	30%	6369	17030	30%	7431
Lower MM River Central	30 + MDP	2192	0	238	122	248	79	376		2880		2114	3256		2359
Lower MM River N (streamgauge)	27,28,29 + TP,MDP,MP,HP	7893	0	2604	378	523	260	2118		11657	30%	6984	13775	30%	8256



a. Three Bays System Overall

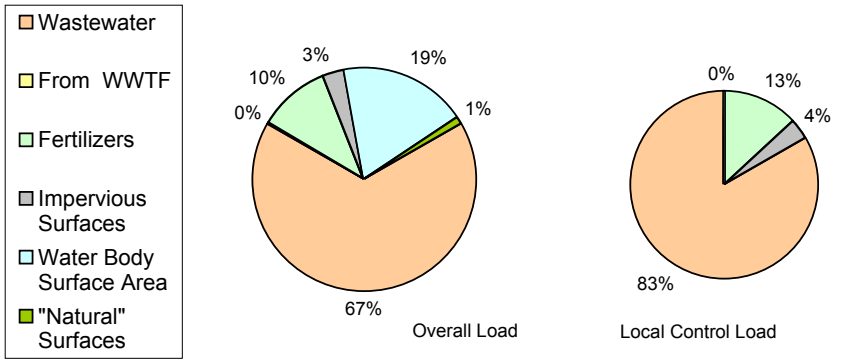


b. Cotuit Bay

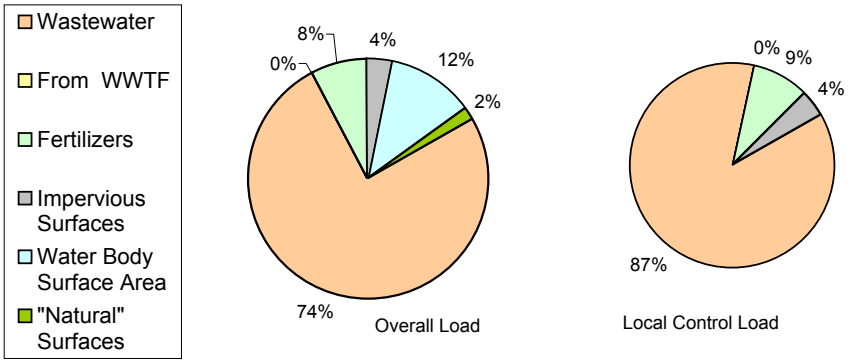


c. Seapuit River

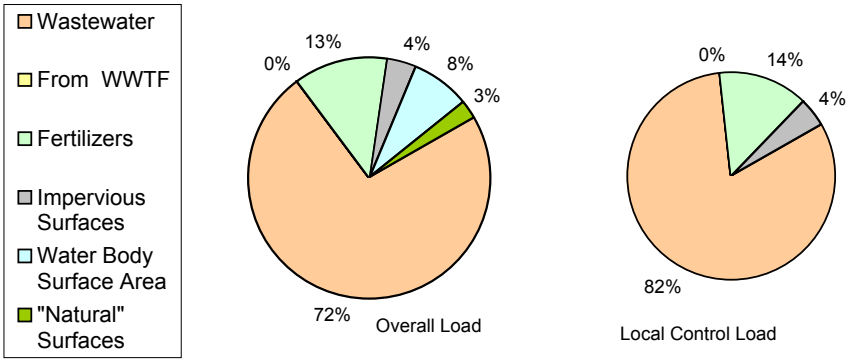
Figure IV-4 (a-c). Land use-specific unattenuated nitrogen load (by percent) to the (a) overall Three Bays System watershed, (b) Cotuit Bay subwatershed, and (c) Seapuit River subwatershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control.



d. West Bay



e. North Bay



f. Prince Cove

Figure IV-4 (d-f). Land use-specific unattenuated nitrogen load (by percent) to the (d) West Bay subwatershed, (e) North Bay subwatershed, and (f) Prince's Cove subwatershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control.

Since groundwater outflow from a pond can enter more than one downgradient sub-watershed, the length of shoreline on the downgradient side of the pond was used to apportion the pond-attenuated nitrogen load to respective downgradient watersheds. The apportionment was based on the percentage of discharging shoreline bordering each downgradient sub-watershed. So for example, Lawrence Pond has a downgradient shoreline of 7,020 feet; 54% of that shoreline discharges out of the Three Bays watershed, 26% discharges to the Crooked Cartway wellfield subwatershed (watershed 34 in Figure IV-1), and 19% discharges to the Mystic Lake subwatershed (watershed 34 in Figure IV-1). The nitrogen load discharging from Lawrence Pond is divided among these subwatershed based on these percentages of the downgradient shoreline.

Freshwater Pond Nitrogen Loads

Freshwater ponds on Cape Cod are generally kettle hole depressions that intercept the surrounding groundwater table revealing what some call "windows on the aquifer." Groundwater typically flows into the pond along the upgradient shoreline, then lake water flows back into the groundwater system along the downgradient shoreline. Occasionally a Cape Cod pond will have a stream outlet or herring run. Since the nitrogen loads flow into the pond with the groundwater, the relatively more productive ecosystems in the ponds incorporate some to the nitrogen, retain some of it in the sediments, and change it among its various oxidized and reduced forms. As result of these interactions, some of the nitrogen is removed from the watershed system, mostly through burial in the sediments and denitrification that returns it to the atmosphere. Following these reductions, the remaining, reduced loads flow back into the groundwater system along the downgradient side of the pond or through a stream outlet and eventually discharge into the downgradient embayment. The nitrogen load summary in Table IV-5 includes both the unattenuated (nitrogen load to each subwatershed) and attenuated nitrogen loads reaching the estuary.

Pond nitrogen attenuation in freshwater ponds is generally set at 50% in MEP analyses based upon investigations within the MEP region. Detailed studies of other southeastern Massachusetts freshwater systems including Ashumet Pond (AFCEE, 2000) and Agawam/Wankinco River Nitrogen Discharges (CDM, 2001) have supported a 50% attenuation factor. However, if sufficient monitoring information is available for a specific fresh pond, an alternative attenuation rate is incorporated into the watershed nitrogen load modeling. In order to estimate nitrogen attenuation in the ponds physical and chemical data for each pond is reviewed. Available bathymetric information is reviewed relative to measured pond temperature profiles to determine whether an epilimnion (*i.e.*, well mixed, homothermic, upper portion of the water column) exists in each pond. Of the ponds in the Three Bays study area, bathymetric information is available for all the ponds with delineated watersheds except Bog Pond, Muddy Pond, and Triangle Pond. Of the ponds with bathymetric information, Hamblin, Mystic, Shubael, and Spectacle are deep enough to develop strong temperature stratification and a separate epilimnion. Generally, if a strong epilimnion develops, the epilimnion is the active area of nitrogen uptake and transport to the shallow sediments and to the isolated hypolimnion. During stratification lower thermal layers are impacted by sediment regeneration of nitrogen.

In MEP analyses, freshwater recharging the downgradient shoreline, the available nitrogen concentrations and vertical structure of individual ponds are reviewed to determine the amount of nitrogen passing through. Analysis of the vertical structure (stratification) is made to determine whether the entire volume of the pond or the epilimnion is used in the hydraulic turnover calculations. Turnover time is how long it takes the recharge from the upgradient watershed to completely exchange the water in the pond or, in the case of a thermally stratified

pond, just the epilimnion. The total mass of nitrogen in the pond or epilimnion is adjusted using the pond turnover time to determine the annual nitrogen load returned to the aquifer through the downgradient shoreline. This mass is then compared to the nitrogen load coming from the pond watershed to determine the nitrogen attenuation factor for the pond. However, the effort is undertaken as validation that overall a 50% attenuation factor is reasonable (i.e. the calculated values are $\geq$50%). In almost all cases that the MEP has examined to date, monitoring data has supported the use of a 50% attenuation as a conservative estimate.

The standard attenuation assumption for the other ponds in the Three Bays watershed was checked through the use of pond water quality information collected from the annual Cape Cod Pond and Lake Stewardship (PALS) water quality snapshot. The PALS Snapshot is a collaborative Cape Cod Commission/SMAST Program that allows trained, citizen volunteers of each of the 15 Cape Cod towns to collect pond samples in August and September using a standard protocol. Snapshot samples have been collected every year between 2001 and 2005. The standard protocol for the Snapshot includes field collection of dissolved oxygen and temperature profiles, Secchi disk depth readings and water samples at various depths depending on the total depth of the pond. PALS Snapshot data is available in the Three Bays watershed for the following ponds: Bog, Eagle, Hamblin, Joshua, Lawrence, Long, Lovells, Micah, Mill, Muddy, Mystic, Shubael, Spectacle, and Triangle. Water samples were analyzed at the SMAST laboratory for total nitrogen, total phosphorus, chlorophyll *a*, alkalinity, and pH.

In the Three Bays watershed there are 3 ponds with sufficient data to support a pond-specific attenuation factor: Mystic Lake, Middle Pond, and Hamblin Pond. These ponds form the Indian Ponds Complex and have been the subject of detailed nutrient related water quality monitoring between May and November 2004 and long-term monitoring (1999-2004).. The detailed 2004 water quality sampling effort was by Indian Ponds Association (IPA) volunteers and the longer term data from Three Bays Preservation. All samples were analyzed by the SMAST Coastal Systems Analytical Facility Laboratory with support from the University of Massachusetts-Dartmouth. Interpretation of the results is part of a current project that is being completed by the Cape Cod Commission for the Town of Barnstable and the IPA (Eichner, et al, in preparation).

The Indian Ponds analysis allowed the comparison of nitrogen, phosphorus, and water budgets for the three ponds. Water budget development began with the USGS watersheds (Figure III-1) and volume estimates based on Massachusetts Division of Fisheries and Wildlife bathymetric maps. Using the USGS recharge rate (27.25 inches per year), residence times were developed for each of the ponds. These residence times were checked against observed phosphorus concentrations and estimates of phosphorus loading. This analysis suggested that pumping of the public water supply wells (watersheds 31, 32, 33, and 34 on Figure IV-1) upgradient of the ponds was removing recharge and thereby altering the pond water budgets (e.g. lowering turnover). Nitrogen loads from the MEP analysis were then compared with measured total nitrogen concentrations and total mass within the ponds. Average total mass in the ponds over the entire sampling season were then compared with the watershed loading estimates and corrected to account for residence times. Based on this analysis, the nitrogen attenuation rates for the Indian Ponds are: 87%, Mystic Lake; 40%, Middle Pond; and 52%, Hamblin Pond.

Table IV-6 summarizes the pond attenuation estimates calculated from land-use modeled nitrogen inflow loads and nitrogen loads recharged to the downgradient aquifer or to outflow streams from each pond based on pond characteristics and measured nitrogen levels. Nitrogen attenuation within these ponds averaged 73% (20% s.d), with a range of 40% to 97%.

However, a caveat to these attenuation estimates, except for the Indian Ponds, is that they are based upon nitrogen outflow loads from water column samples collected during summer and are not necessarily representative of the annual nitrogen loads transferred downgradient. Sampling at least comparable to that available for Mystic Lake, Middle Pond, and Hamblin Pond would be recommended for use of an attenuation rate different than 50%.

Table IV-6. Nitrogen attenuation by Freshwater Ponds in the Three Bays watershed based upon 2001 through 2004 Cape Cod Pond and Lakes Stewardship (PALS) program sampling and 2004 IPA/Barnstable sampling of Mystic Lake, Middle Pond, and Hamblin Pond. *Site specific nitrogen attenuation by these systems. Overall, estimates support the use of a 50% pond N attenuation rate within the Three Bays watershed for the MEP Linked N Model approach.

Pond	PALS ID	Area acres	Maximum Depth m	Overall turnover time Yrs	N Load Attenuation %
Bog Pond	BA-802	7.2	0.8	0.03	59%
Eagle Pond	BA-815	8.5	4.2	0.51	86%
Hamblin Pond*	BA-668	115.4	17.6	1.00	52%
Joshua Pond	BA-807	14.7	7.1	0.74	97%
Lawrence Pond	SA-431	133.8	8.2	2.40	91%
Long Pond	BA-675	54.8	5.5	0.48	81%
Lovells Pond	BA-759	55.5	10.3	0.78	46%
Micah Pond	BA-797	16.0	10.5	0.97	95%
Middle Pond*	BA-640	104.6	9.3	0.56	40%
Muddy Pond	BA-694	24.6	4	0.71	65%
Mystic Lake*	BA-584	148.4	13.5	1.10	87%
Shubael Pond	BA-664	55.1	11.2	1.92	91%
Spectacle Pond	SA-409	97.1	12.2	1.20	48%
Triangle Pond	SA-504	83.1	9.1	2.35	85%
				Mean	73%
				std dev	20%

Data sources: all areas from CCC GIS; Max Depth from MADFW or Cape Cod PALS monitoring; Volume for turnover time calculations from MADFW bathymetric maps (www.mass.gov/dfwele/dfw/dfw_pond.htm) and estimates based on max depth (max depth estimated for Bog, Muddy, and Triangle) ; TN concentrations for attenuation calculation from PALS monitoring and IPA study (Eichner, et al., in preparation)

Buildout

Part of the regular MEP watershed nitrogen loading modeling is to prepare a buildout assessment of potential development within the study area watershed. For the Three Bays modeling, MEP staff consulted with town planners to determine the parameters that would be used in the assessment and, in the case of Sandwich in the Three Bays watershed, reviewed the development potential of each property in the watershed. The standard buildout

assessment is to evaluate town zoning to determine minimum lot sizes in each of the zoning districts, including overlay districts (*e.g.*, water resource protection districts). Larger lots are subdivided by the minimum lot size to determine the total number of new lots. Staff also review developed properties with additional development potential; for example, residential lots that are twice the minimum lot size, but only have one residence. Parcels that are classified as developable residential (state class land use codes 130 and 131) but are less than the minimum lot size and are greater than 5,000 square feet are assigned an additional residence in the buildout; 5,000 square feet is a minimum lot size in some Cape Cod town zoning regulations. Commercial properties are not subdivided; the area of each parcel and the factors in Table IV-4 were used to determine a wastewater flow for these properties. The Sandwich Town Planner also requested that the Three Bays buildout include additional development potential for selected public service properties (state class land use codes in the 900s). All the parcels included in the buildout assessment of the Three Bays watershed are shown in Figure IV-3. A nitrogen load for each additional parcel included in the buildout and these was determined for the existing development using the factors presented in Table IV-4 and discussed above. A summary of total potential additional nitrogen loading from build-out is presented as unattenuated and attenuated loads in Table IV-5.

IV.2 ATTENUATION OF NITROGEN IN SURFACE WATER TRANSPORT

IV.2.1 Background and Purpose

Modeling and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land or watershed. This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out or sewering analysis) to changes in water quality and habitat health. Therefore, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems. Rates of nitrogen loading to the sub-watersheds of each sub-embayment of the overall Three Bays embayment system under study were based upon the delineated watersheds (Section III) and their land-use coverages (Section IV.1). If all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters. This condition exists in watersheds where nitrogen transport is through groundwater in sandy outwash aquifers with direct discharge to estuarine waters. The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. However, in most watersheds in southeastern Massachusetts, nitrogen passes through a surface water ecosystem on its path to the adjacent embayment. Surface water systems, unlike sandy aquifers, do support the needed conditions for nitrogen retention and removal (e.g. burial and denitrification). The result is that the mass of nitrogen passing through lakes, ponds, streams and marshes (fresh and salt) is diminished by natural biological processes which represent removal (not just temporary storage). However, this natural attenuation of nitrogen load is not uniformly distributed within the watershed, but is associated with ponds, streams and marshes. Typical of other large embayment systems in the MEP region, most of the freshwater flow and transported nitrogen entering Three Bays, first passes through a surface water system, and frequently multiple systems, producing the opportunity for significant nitrogen attenuation.

Failure to determine the attenuation of watershed derived nitrogen overestimates the nitrogen load to receiving waters. If nitrogen attenuation is significant in one portion of a watershed and insignificant in another the result is that nitrogen management would likely be more effective in achieving water quality improvements if focused on the watershed region

having unattenuated nitrogen transport (other factors being equal). In addition to attenuation by freshwater ponds (see Section IV.1.3, above), attenuation in surface water flows is also important. An example of the significance of surface water nitrogen attenuation relating to embayment nitrogen management was seen in the Agawam River, where >50% of nitrogen originating within the upper watershed was attenuated prior to discharge to the Wareham River Estuary (CDM 2001). Similarly, in a preliminary study of Great, Green and Bournes Ponds in Falmouth, measurements indicated a 30% attenuation of nitrogen during stream transport (Howes and Ramsey 2001). An example where natural attenuation played a significant role in nitrogen management can be seen relative to West Falmouth Harbor (Falmouth, MA), where ~40% of the nitrogen discharge to the Harbor originating from the groundwater discharge from the WWTF was attenuated by a small salt marsh prior to reaching Harbor waters. Similarly, the small tidal basin of Frost Fish Creek in the Town of Chatham showed ~20% nitrogen attenuation or watershed nitrogen load prior to discharge to Ryders Cove. Clearly, proper development and evaluation of nitrogen management options requires determination of the nitrogen loads reaching an embayment, not just loaded to the watershed.

Given the importance of determining accurate nitrogen loads to embayments for developing effective management alternatives, and the potentially large errors associated with ignoring natural attenuation, direct integrated measurements were undertaken as part of the MEP Approach. MEP conducted multiple studies on natural attenuation relating to sub-embayments of the Three Bays system in addition to the natural attenuation measures by fresh kettle ponds, addressed above. These additional site-specific studies were conducted in each of the 2 major surface water flow systems (i.e. the Marstons Mills River discharging to the tidal portion of the Prince's Cove/Warren's Cove sub-embayment and Little River discharging to Cotuit Bay).

Quantification of watershed based nitrogen attenuation is contingent upon being able to compare nitrogen load to the embayment system directly measured in freshwater stream flow (or in tidal marshes, net tidal outflow) to nitrogen load as derived from the detailed land use analysis (Section IV.1). Measurement of the Marstons Mills River (immediately upgradient of Mill Pond just above Route 28) and Little River (immediately down gradient of Old Post Road) provide a direct integrated measure of all of the processes presently attenuating nitrogen in the sub-watersheds upgradient from the gauging sites. In the Marstons Mills River, a separate study was conducted where paired flow and nutrient measurements were made at the gauge site and at the outflows from Mill Pond. These data were used to determine the level of nitrogen attenuation resulting from passage through Mill Pond itself (based upon the N load entering the pond from the river and the watershed load discharging to the Pond through groundwater inflows).

The upper watershed regions to the Rivers account for more than half of the entire watershed area to the Three Bays System. Flow and nitrogen load were measured at the Marstons Mills site for 22 months of record and at the Little River site for 23 months of record (Figure IV-5). During the study period, velocity profiles were completed on each river every month to two months, with an effort to capture the range of flows experienced at each site. Periodic measurement of flows over the entire stream gauge deployment period allowed for the development of a stage-discharge relationship (rating curve) that could be used to obtain flow volumes from the detailed record of stage measured by the continuously recording stream gauges. A complete annual record of stream flow (365 days) was generated for both the Marstons Mills River and the Little River. The annual flow records for both rivers were merged with the nutrient data sets generated through the weekly water quality sampling to determine nitrogen loading rates to the tidally influenced portion of the Marstons Mills River and to Cotuit

Bay in the case of the Little River. Comparing these measured nitrogen loads based on stream flow and water quality sampling to predicted loads based on the land use analysis allowed for the determination of the degree to which natural biological processes within the watersheds to each river currently reduce (percent attenuation) nitrogen loading to the Three Bays embayment system.



Figure IV-5. Location of Stream gauges (red diamonds) on the Marstons Mills River discharging to Warren's Cove and Little River discharging to Cotuit Bay in the Three Bays Embayment System. The red triangle represents the site of periodic measurements coupled to the gauge site to determine attenuation by the associated terminal fresh pond, Mill Pond.

IV.2.2 Surface Water Discharge and Attenuation of Watershed Nitrogen: Marstons Mills River to Warren's Cove/Prince's's Cove (head of North Bay)

The Mystic Lake – Middle Pond – Hamblin Pond group is one of the largest pond complexes on Cape Cod and the complex is referred to as the "Indian Ponds". Unlike many freshwater ponds, this pond system has stream outflow through down gradient cranberry bogs rather than discharging solely to the aquifer along its down-gradient shore. This stream outflow, the Marstons Mills River, may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetlands and stream bed associated with the Marstons Mills River and the terminal man-made pond, Mill Pond. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the Marstons Mills River above the gauge site and the measured annual discharge of nitrogen at the gauge location. Attenuation by Mill Pond was assessed by measurements of nitrogen load entering and exiting the Pond in surface water flows and the nitrogen entering from the Mill Pond sub-watershed determined from the land use model, Figure IV-6. Note that <20% of the Marstons Mills River watershed load is through groundwater discharge to Mill Pond.

At the Marstons Mills River gauge site, a continuously recording vented calibrated water level gauge was installed to yield the level of water in the freshwater portion of the Marstons Mills River (immediately upgradient of Mill Pond) that carries the flows and associated nitrogen load to the Bay. Calibration of the gauge was checked monthly. The gauge on the Marstons Mills River was installed on February 18, 2002 and was set to operate continuously for 22 months such that two summer seasons would be captured in the flow record. Due to an instrument upgrade in July of 2002, stage data collection was extended until December 31, 2003. The 12 month uninterrupted record used in this analysis encompasses the summer 2003 field season.

River flow (volumetric discharge) was measured approximately monthly using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Marstons Mills River site based upon these measurements and measured water levels at the gauge site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. These measurements (Figure IV-6 and Table IV-7) coupled with input/output measurements from Mill Pond allowed for the determination of both total volumetric discharge and nitrogen mass discharge to the estuarine portion of the Marstons Mills River. In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gauge site.

The annual freshwater flow record for the Marstons Mills River (see below), determined from measured stage and the stage – discharge relation developed by the MEP, was compared to the flows determined by the USGS modeling effort (Table IV-8). The measured freshwater discharge from the Marstons Mills River was in good agreement with the long-term average flow from the groundwater model. The gauge on the Marstons Mills River showed an annual average flow 1.16 times the long term average. This is good agreement, especially considering that the rainfall during the deployment period was higher than the long-term average. Intra-annual variation of Marstons Mills flows stems not just from normal stream hydrologic cycles, but from hydrologic management associated with the upgradient cranberry bog system located at the head waters of the Marstons Mills River. Releases of water from the cranberry bog system affect the measured flows observed at the Marstons Mills River gauge. The measured

freshwater flows and associated attenuated total nitrogen loads as obtained using the MEP gauge on the Marstons Mills River (with a slight adjustment for measured freshwater inflow directly from the Mill Pond watershed) were used in the water quality model discussed in Section VI.

Total nitrogen concentrations within the Marstons Mills River outflow to Mill Pond were relatively high, 0.799 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 12,850 g/day (12.85 kg/d) and a measured total annual TN load of 4,690 kg/yr. In the Marstons Mills River, nitrate was the predominant form of nitrogen (60%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the outflowing stream waters also suggests that plant production within the upgradient freshwater ecosystems is not nitrogen limited.

From the measured nitrogen load discharged by the Marstons Mills River to Mill Pond and the nitrogen load determined from the watershed based land use analysis, it appears that there is significant nitrogen attenuation of upper watershed derived nitrogen during transport to the Bay. Based upon lower nitrogen load (12.85 kg N d^{-1}, 4,690 kg yr^{-1}) discharged from the freshwater Marstons Mills River and the nitrogen mass entering from the associated watershed (31.94 kg N d^{-1}, 11,657 kg yr^{-1}) the integrated measure of nitrogen attenuation by the pond/river ecosystem is 60%. Paired measures of water flow and nitrogen load into and out of Mill Pond based using the land use nitrogen load to the gauge site plus that the load directly to Mill Pond indicate an integrated watershed nitrogen attenuation (i.e. nitrogen loading to the estuarine reach of the Marstons Mill River (e.g. below Mill Pond) of ~64%. The added attenuation stems from nitrogen removal within Mill Pond itself. This nitrogen removal by Mill Pond was smaller than the 50% typical of kettle ponds as a result of the shallow nature of the pond (low hydraulic residence time) and that it is a “flow through” pond, i.e. it is dominated by surface water inflows and outflows. The estimate of nitrogen removal by Mill Pond based upon paired measurements in August and September is consistent with the 30% removal typical of rivers and streams. Additional inflow/outflow data is being collected to further refine the Mill Pond specific attenuation rate for assessment of management alternatives (see Table IV-7). The directly measured nitrogen loads from the rivers were used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

Table IV-7. Comparison of water flow and nitrogen discharges from Marstons Mills River to Mill Pond and Little River discharging to Cotuit Bay. The "Stream" data is from the MEP stream gauging effort. Watershed data is based upon the MEP watershed modeling effort by USGS. Note that the total nitrogen load exiting Mill Pond is only ~10% higher than the loading at the gauge site, due to attenuation of River transported nitrogen and nitrogen entering from the Mill Pond sub-watershed.

Stream Discharge Parameter	Stream Discharge to Little River[a]	Stream Discharge to Marstons Mills River[a]	Data Source
Total Days of Record	365[b]	365[b]	(1)
Flow Characteristics			
Stream Average Discharge (m3/day) 2002-2003	3483	16091	(1)
Contributing Area Average Discharge (m3/day) Long Term	4211	13922	(2)
Discharge Stream 2002-03 vs. Long-term Discharge	83%	116%	(5)
Contributing Area, with 40% reduction in Lovell's Pond recharge (m3/d)	3521	--	(7)
Discharge Stream 2002-03 vs. Long-term Discharge without LP recharge	99%	--	
Nitrogen Characteristics			
Stream Average Nitrate + Nitrite Concentration (mg N/L)	0.856	0.481	(1)
Stream Average Total N Concentration (mg N/L)	1.137	0.799	(1)
Nitrate + Nitrite as Percent of Total N (%)	75%	60%	(1)
Total Nitrogen (TN) Average Measured Stream Discharge (kg/day)	3.96	12.85	(1)
TN Average Contributing Area Attenuated Load (kg/day)	4.36	19.13	(2)
TN Average Contributing UN-attenuated Load (kg/day)	8.03	31.94	(3)
Attenuation of Nitrogen in Pond/Stream (%)	51%	60%	(4)
MEP "Best Estimate" of Nitrogen Load in Mill Pond outflow (kg/d)	--	14.52	(6)

(a) Flow and N load to stream discharging to Little River includes Lovell Pond contributing area.
(a) Flow and N load to stream discharging to Marstons Mills RIver includes "Indian Ponds" contributing area.
(b) October 11, 2002 to October 10, 2003.
(1) MEP gage site data
(2) Calculated from MEP watershed delineations to Long Pond and Mares Pond for flow to Little Pond;
the fractional flow path from each sub-watershed which contribute to the flow in the stream to Little Pond;
and the annual recharge rate. Calculated nitrogen exiting Mill Pond using MEP standard attenuation factors.
(3) As in footnote (2), with the addition of pond and stream conservative attentuation rates.
(4) Calculated based upon the measured TN discharge from the rivers vs. the unattenuated watershed load.
(5) Little River measured flows 17% lower than long term average due to hydrologic diversions from Lovell's Pond to nearby cranberry bogs
(6) Nitrogen Load exiting Mill Pond based upon paired measurements of inflow and outflow freshwater and loads, and modeled watershed loading
(7) Modeled discharge in Little River if 40% of the upper watershed flow (above Lovell's Pond) is diverted through management practices.

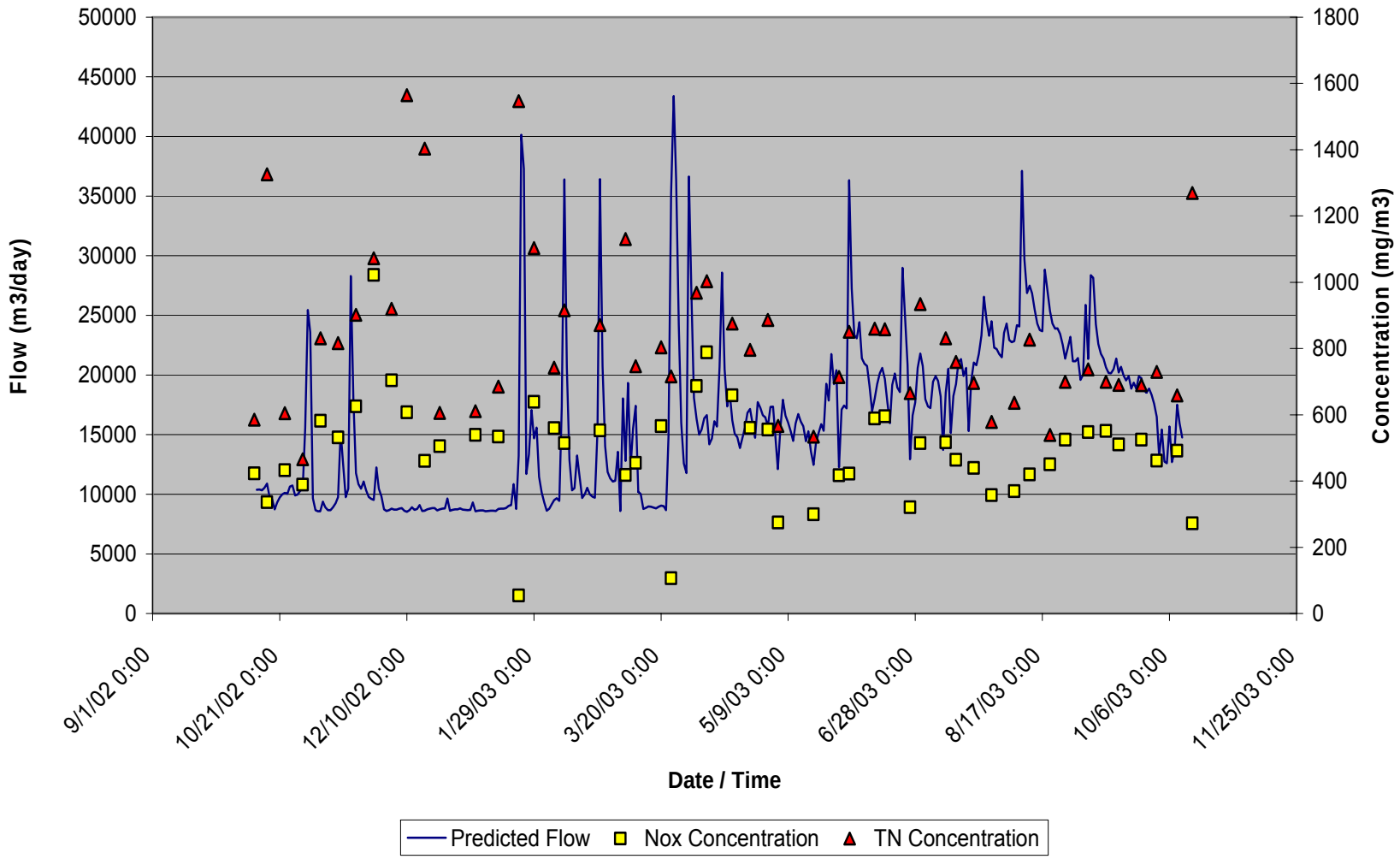


Figure IV-6. Marstons Mills River annual discharge developed from a stream gauge maintained above Mill Pond immediately upgradient of Route 28, Town of Barnstable, October 2002 to October 2003. Nutrient samples (Nox – Nitrate+Nitrite) were collected weekly and analyzed for inorganic and organic nitrogen species. These data were used to determine both annual flow and total nitrogen transport for determining nitrogen attenuation (see Table IV-7).

IV.2.3 Freshwater Discharge and Attenuation of Watershed Nitrogen: Little River to Cotuit Bay

Lovell's Pond is one of the larger ponds within the study area and unlike many of the freshwater ponds, the Lovell's Pond and adjoining cranberry bogs has stream outflow to the Little River, rather than discharging solely to the aquifer on the down-gradient shore. The stream, Little River, has highly manipulated flows into and out of Lovell's Pond. The hydrologic management of this system is such that outflow from Santuit Pond to Lovell's Pond and ultimately to Little River has been significantly altered from year-to-year as part of both cranberry agriculture and as part of fisheries management programs. As in the Marstons Mills River (see IV.2.2 above) the stream outflow from Lovell's Pond may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. Nitrogen attenuation also occurs within the wetlands and stream-bed associated with the Little River. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the Little River above the gauge site and the measured annual discharge of nitrogen.

At the Little River gauge site (Figure IV-5), a continuously recording vented calibrated water level gauge was installed to yield the level of water for the determination of freshwater flow. Calibration of the gauge was checked monthly. The gauge on the Little River was installed on January 14, 2002 and was set to operate continuously for 23 months such that two summer seasons would be captured in the flow record. Due to the desire to have simultaneous measurement of river discharge from the Mashpee and Santuit Rivers, stage data collection was extended until December 5, 2003 (to match the Marstons Mills River). The 12 month uninterrupted record used in this analysis encompasses the summer 2003 field season.

River flow (volumetric discharge) was measured monthly using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Little River site based upon these measurements and measured water levels at the gauge site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. These measurements allowed for the determination of both total volumetric discharge and nitrogen mass discharge to the western shore of Cotuit Bay (Figure IV-7 and Table IV-7). In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gauge site.

The annual freshwater flow record for the Little River (see below), determined from measured stage and the stage – discharge relation developed by the MEP, was compared to the flows determined by the USGS modeling effort (Table IV-8). The measured freshwater discharge from the Little River was approximately 17 percent lower than the long-term average modeled flows. The lower values are attributable to the fact that the functional watershed to Little River is currently smaller than historically. Water management of historic flows related to Santuit Pond appears to have reduced the effective recharge area. An estimate of the amount of reduction in recharge area necessary to account for the observed difference in flows is only ~40% of the uppermost watershed (Table IV-7). The reduction in outflow from Lovell's Pond is supported by observations of the upper most reach of the Little River at its headwaters (Lovell's Pond) going dry during summer. Site reconnaissance identified that Lovell's Pond is connected to the upper most reach of the Little River by a century old ceramic pipe that is greatly compromised along its length prior to discharging to a man made ditch that ultimately becomes the Little River. More importantly, channels transporting water from Santuit Pond have been recently managed for the protection of fisheries to not discharge water associated with

cranberry agriculture or eutrophic Santuit Pond waters to Lovell's Pond. However, as the nitrogen load discharging to Cotuit Bay through the Little River is a direct measurement of the integrated upgradient watershed it represents the current nitrogen loading to the estuary and was used in the water quality modeling for nitrogen threshold determination.

Total nitrogen concentrations within the Little River outflow were relatively high, 1.14 mg N L^{-1}. Average daily total nitrogen discharge from the Little River to the estuary was 3,960 g/day (3.96 kg/d) with a measured total annual TN load of 1,446 kg/yr. As in the Marstons Mills River, nitrate was the predominant form of nitrogen (75%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the outflowing stream waters also suggests that plant production within the upgradient freshwater ecosystems is not nitrogen limited. Nitrate in the Little River is a higher fraction of the total nitrogen pool than in the Marstons Mills River (75% vs. 60%) suggesting that there is less attenuation of inorganic nitrogen in the Little River system. This is partially attributable to the fact that Little River flow passes through fewer ponds and wetlands while also having a shorter river reach prior to discharging to Cotuit Bay.

From the measured nitrogen load discharged by the Little River to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is significant nitrogen attenuation of upper watershed derived nitrogen during transport to Cotuit Bay. Based upon the lower measured nitrogen load (3.96 kg N d^{-1}, 1,440 kg N yr^{-1}) discharged from the Little River and nitrogen mass entering from the associated watershed (8.03 kg N d^{-1}, 2,932 kg yr^{-1}), the integrated measure of nitrogen attenuation by the pond/river ecosystem is 51%. This is consistent with the land-use model which yielded and integrated nitrogen attenuation of 46%, since pond and stream attenuation in the watershed model use conservative attenuation factors (Table IV-6). However, while the directly measured Little River nitrogen load should accurately represent the sub-watershed loading to Cotuit Bay, the issues relating to hydrologic manipulation of upper watershed recharge to Lovell's Pond may result in an overestimate of the unattenuated loading value, hence a slight overestimate of the integrated attenuation rate (i.e. actual current rate may be <51%). Directly measured nitrogen loads from the rivers were used in the Linked Watershed-Embayment Modeling of water quality (Chapter VI).

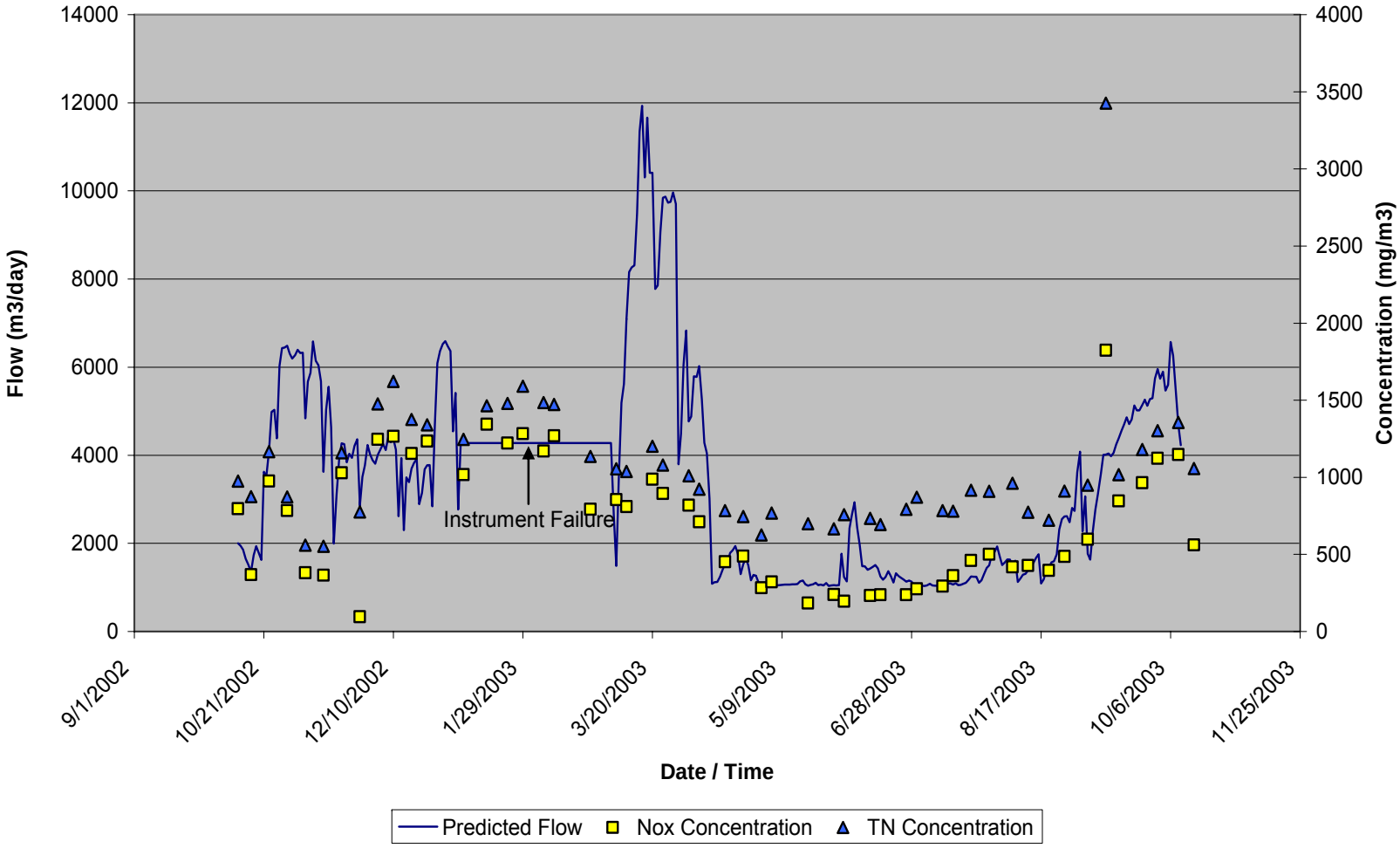


Figure IV-7. Little River annual discharge developed from a stream gauge maintained in the outflow from Lovell's Pond discharging to Cotuit Bay, Town of Barnstable, October 2002 to October 2003. Nutrient samples (Nox – Nitrate+Nitrite) were collected approximately weekly and analyzed for inorganic and organic nitrogen species. These data were used to determine both annual flow and total nitrogen transport for determining nitrogen attenuation (see Table IV-7).

Table IV-8. Summary of Flow and Nutrient loads from both the Marstons Mills River discharging to tidally influenced Warren's Cove (head of North Bay) and the Little River discharging to Cotuit Bay

EMBAYMENT SYSTEM	PERIOD OF RECORD	DISCHARGE (m3/year)	ATTENUATED LOAD (Kg/yr)	
			Nox	TN
Marstons Mills River Marstons Mills River (CCC)	October 11, 2002 to October 10, 2003 Based on Watershed Area and Recharge	5873174 5081596	2824	4690
Little River to Cotuit Little River (CCC)	October 11, 2002 to October 10, 2003 Based on Watershed Area and Recharge	1271311 1536977	1088	1446

IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS

The overall objective of the Benthic Nutrient Flux Task was to quantify the summertime exchange of nitrogen, between the sediments and overlying waters within each major basin area within the Three Bays System. The mass exchange of nitrogen between watercolumn and sediments is a fundamental factor in controlling nitrogen levels within coastal waters. These fluxes and their associated biogeochemical pools relate directly to carbon, nutrient and oxygen dynamics and the nutrient related ecological health of these shallow marine ecosystems. In addition, these data are required for the proper modeling of nitrogen in shallow aquatic systems, both fresh and salt water.

IV.3.1 Sediment-Watercolumn Exchange of Nitrogen

As stated in above sections, nitrogen loading and resulting levels within coastal embayments are the critical factors controlling the nutrient related ecological health and habitat quality within a system. Nitrogen enters the Three Bays embayments predominantly in highly bioavailable forms from the surrounding upland watershed and more refractory forms in the inflowing tidal waters. If all of the nitrogen remained within the watercolumn (once it entered), predicting watercolumn nitrogen levels would be simply a matter of determining the watershed loads, dispersion, and hydrodynamic flushing. However, as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bioavailable form nitrate. This nitrate and other bioavailable forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved forms into phytoplankton "particles". Most of these "particles" remain in the watercolumn for sufficient time to be flushed out to a downgradient larger waterbody (like Nantucket Sound). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence), a fraction of the phytoplankton with their associated nitrogen "load" become incorporated into the surficial sediments of the bays.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within small enclosed basins (e.g. Prince's's Cove, Warren's Cove, etc). To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary.

Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic (oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter with its nitrogen content, that bioavailable nitrogen is returned to the embayment watercolumn for another round of uptake by phytoplankton. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that we have investigated, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. Failure to account for this recycled nitrogen generally results in significant errors in determination of threshold nitrogen loadings. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

IV.3.2 Method for Determining Sediment-Watercolumn Nitrogen Exchange

For the Three Bays System, in order to determine the contribution of sediment regeneration to nutrient levels during the most sensitive summer interval (July-August), sediment samples were collected and incubated under *in situ* conditions. Sediment samples were collected in the Three Bays system from 20 sites (Figure IV-8) in August 2002. Measurements of total dissolved nitrogen, nitrate + nitrite, ammonium were made in time-series on each incubated core sample. As part of a separate research investigation, the rate of oxygen uptake was also determined and measurements were made of sediment bulk density, organic nitrogen, and carbon content. These measurements were made by the Coastal Systems Program at SMAST-UMD.

Rates of nitrogen release were determined using undisturbed sediment cores incubated for 24 hours in temperature-controlled baths. Sediment cores (15 cm inside diameter) were collected by SCUBA divers and cores transported by a small boat. Cores were maintained from collection through incubation at *in situ* temperatures. Bottom water was collected and filtered from each core site to replace the headspace water of the flux cores prior to incubation. The number of core samples from each site (see Figure IV- 8) per incubation were as follows:

Three Bays Embayment System

- Station 1 – 1 core (Prince's's Cove)
- Station 2 – 1 core (Prince's's Cove)
- Station 3 – 1 core (Prince's's Cove)
- Station 4 – 1 core (Warren's Cove)
- Station 5 – 1 core (Marstons Mills River – tidal reach)
- Station 6 – 1 core (North Bay)
- Station 7 – 1 core (North Bay)
- Station 8 – 1 core (North Bay)
- Station 9 – 1 core (North Bay)
- Station 10 – 1 core (West Bay)
- Station 11 – 1 core (West Bay)
- Station 12 – 1 core (West Bay)
- Station 13 – 1 core (West Bay)
- Station 14 – 1 core (Seapuit River)
- Station 15 – 1 core (Cotuit Bay)
- Station 16 – 1 core (Cotuit Bay))
- Station 17/18 – 2 cores (Cotuit Bay)
- Station 19 – 1 core (Cotuit Bay)
- Station 20 – 1 core (Eel River)

Sampling was distributed throughout the embayment system to capture general spatial heterogeneity and the results for each site combined for calculating the net nitrogen regeneration rates for the water quality modeling effort.

Sediment-watercolumn exchange follow the methods of Jorgensen (1977), Klump and Martens (1983), and Howes *et al.* (1995) for nutrients and metabolism. Upon return to the field laboratory (Wianno Yacht Club located on the shores of North Bay, private residence on the shore of Rushy Marsh) the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with

filtered water), filtered into acid leached polyethylene bottles and held on ice for nutrient analysis. Ammonium (Scheiner 1976) and ortho-phosphate (Murphy and Reilly 1962) assays were conducted within 24 hours and the remaining sample frozen (-20°C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia *et al.* 1977). Rates were determined from linear regression of analyte concentrations through time.

Chemical analyses were performed by the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST) at the University of Massachusetts in New Bedford, MA. The laboratory follows standard methods for saltwater analysis and sediment geochemistry.



Figure IV-8. Three Bays System locations (red diamonds) of sediment sample collection for determination of nitrogen regeneration rates. Numbers are for reference in Table IV-9.

IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments

Watercolumn nitrogen levels are the balance of inputs from direct sources (land, rain etc), losses (denitrification, burial), regeneration (watercolumn and benthic), and uptake (e.g. photosynthesis). As stated above, during the warmer summer months the sediments of shallow embayments typically act as a net source of nitrogen to the overlying waters and help to stimulate eutrophication in organic rich systems. However, some sediments may be net sinks for nitrogen and some may be in "balance" (organic N particle settling = nitrogen release). Sediments may also take up dissolved nitrate directly from the watercolumn and convert it to dinitrogen gas (termed "denitrification"), hence effectively removing it from the ecosystem. This process is typically a small component of sediment denitrification in embayment sediments, since the watercolumn nitrogen pool is typically dominated by organic forms of nitrogen, with very low nitrate concentrations. However, this process can be very effective in removing nitrogen loads in some systems, particularly in salt marshes, where overlying waters support high nitrate levels.

In addition to nitrogen cycling, there are ecological consequences to habitat quality of organic matter settling and mineralization within sediments, which relate primarily to sediment and watercolumn oxygen status. However, for the modeling of nitrogen within an embayment it is the relative balance of nitrogen input from watercolumn to sediment versus regeneration which is critical. Similarly, it is the net balance of nitrogen fluxes between water column and sediments during the modeling period that must be quantified. For example, a net input to the sediments represents an effective lowering of the nitrogen loading to down-gradient systems and net output from the sediments represents an additional load.

The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the organic levels within the sediment (oxic/anoxic) and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake throughout the summer months, even though organic nitrogen is being mineralized and released to the overlying water as well. The rate of nitrate uptake simply dominates the overall sediment nitrogen cycle.

In order to model the nitrogen distribution within an embayment it is important to be able to account for the net nitrogen flux from the sediments within each part of each system. This requires that an estimate of the particulate input and nitrate uptake be obtained for comparison to the rate of nitrogen release. Only sediments with a net release of nitrogen contribute a true additional nitrogen load to the overlying waters, while those with a net input to the sediments serve as an "in embayment" attenuation mechanism for nitrogen.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and

early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure IV-9).

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates.

In order to determine the net nitrogen flux between watercolumn and sediments, all of the above factors were taken into account. The net input or release of nitrogen within a specific embayment was determined based upon the measured ammonium release, measured nitrate uptake or release, and estimate of particulate nitrogen input. Dissolved organic nitrogen fluxes were not used in this analysis, since they were highly variable and generally showed a net balance within the bounds of the method.

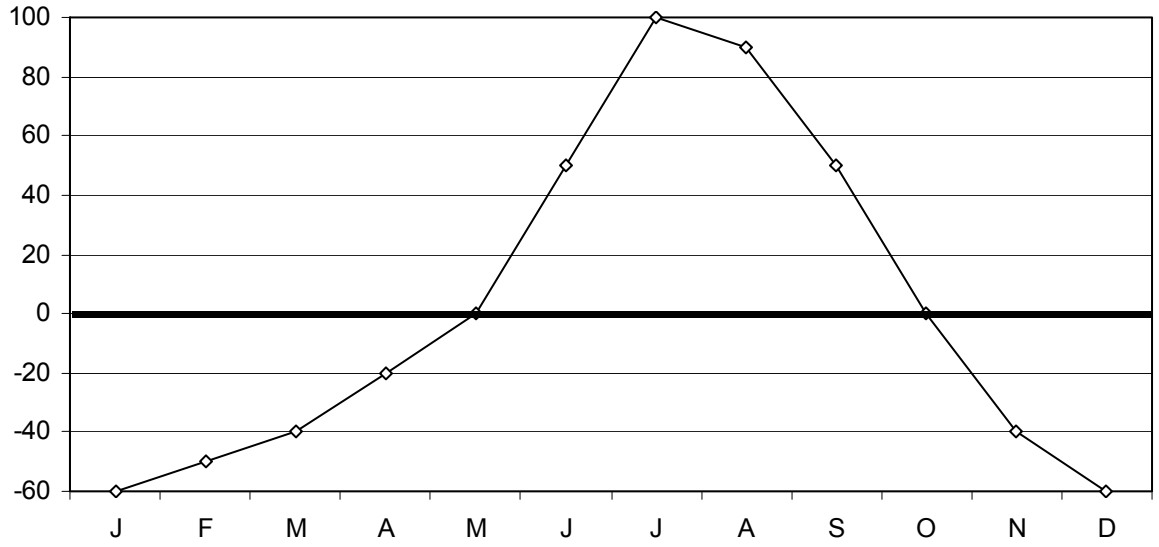


Figure IV-9. Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.

Sediment sampling was conducted within each of the sub-embayments of the Three Bays System in order to obtain the nitrogen regeneration rates required for parameterization of the water quality model (Figure IV-8). The distribution of cores was established to cover gradients in sediment type, flow field and phytoplankton density. For each core the nitrogen flux rates (described in the section above) were evaluated relative to measured sediment organic carbon and nitrogen content and bulk density and an analysis of each site's tidal flow velocities. The maximum bottom water flow velocity at each coring site was determined from the hydrodynamic model. These data were then used to determine the nitrogen balance within each sub-embayment.

The magnitude of the settling of particulate organic carbon and nitrogen into the sediments was accomplished by determining the average depth of water within each sediment site and the average summer particulate carbon and nitrogen concentration within the overlying water. Two levels of settling were used. If the sediments were organic rich and a fine grained and the hydrodynamic data showed low tidal velocities, then a water column particle residence time of 8 days was used (based upon phytoplankton and particulate carbon studies of poorly flushed basins). If the sediments indicated a coarse grained sediments and low organic content and high velocities, then half this settling rate was used. Adjusting the measured sediment releases was essential in order not to over-estimate the sediment nitrogen source and to account for those sediment areas which are net nitrogen sinks for the aquatic system. This approach was validated in outer Cape Cod embayments (Town of Chatham) by examining the relative fraction of the sediment carbon turnover (total sediment metabolism) which would be accounted for by daily particulate carbon settling. This analysis indicated that sediment metabolism in the highly organic rich sediments of the wetlands and depositional basins is driven primarily by stored organic matter (ca. 90%). Also, in the more open lower portions of larger embayments, storage appears to be low and a large proportion of the daily carbon requirement in summer is met by particle settling (approximately 33% to 67%). This range of values and their distribution is consistent with ecological theory and field data from shallow embayments.

Net nitrogen release or uptake from the sediments within the Three Bays embayment for use in the water quality modeling effort (Chapter VI) are presented in Table IV-9. Net nitrogen release from the sediments of the Three Bays sub-embayments shows significant spatial variation, but is typical of other embayments within the MEP region. The general pattern is for higher release from the more heavily nitrogen loaded basins, typically in the inner reaches of the estuary, and lower release or uptake in the basins closer to the tidal inlets. This overall pattern reflects the particle distribution within Three Bays due to phytoplankton production and deposition. This was also the pattern within adjacent Popponesset Bay, which has a similar pattern of loading and multiple large sub-embayments. The high rates of nitrogen release in Warren's Cove reflect both its eutrophic status and its function as a salt marsh basin. Lowering the nitrogen inputs to the inner basins will result in lower net nitrogen release rates over relatively short time scales.

Table IV-9. Rates of net nitrogen return from sediments to the overlying waters of the Three Bays Embayment System. These values are combined with the basin areas to determine total nitrogen mass in the water quality model (see Chapter VI). Measurements represent August rates.

		Sediment Nitrogen Release		
Sub-Embayment	**Station**	**Mean mg N m^{-2} d^{-1}**	**std. dev. mg N m^{-2} d^{-1}**	N
Prince's Cove	1-3	10.3	13.3	3
Warren's Cove	4	108.8	19.2	1
Channel to North Bay	5	24.6	5.1	1
North Bay	6-9	51.4	8.6	4
West Bay	10-13	4.5	8.2	4
Eel River	20	-6.4	11.4	1
Cotuit Bay	15-19	-29.1	3.3	5
Seapuit River	14	-37.7	5.4	1

Higher nitrogen net fluxes from sediments of the upper more nitrogen enriched basins also may result from differences in sediment nitrogen cycling.. There is an indication that the very reducing (anoxic) nature of the Prince'ss Cove and Warren's Cove sediments may be increasing the percentage of nitrogen which is released from the sediments versus the amount of nitrogen being lost to denitrification via the pathway of mineralization→ nitrification → denitrification. The coupled nitrification-denitrification step in the pathway is significantly influenced by the availability of oxygen within the surficial sediments for nitrifying bacteria. That the anoxic/sulfidic nature of the sediment of these basins may be affecting enhancement of nitrogen release is supported by comparisons of measured release with estimates of total nitrogen regeneration (i.e. maximum potentially releasable).. Using this rough approximation, a greater proportion of the potential release rates of nitrogen is achieved in the upper basins than from the other sites. Note that this approach yields general patterns and cannot be used to determine accurate nitrogen removal rates. Lowering nitrogen loading to these upper systems should improve sediment oxidation and improve nitrogen removal rates by these sediments, although quantifying this enhancement is highly site specific. However, based upon this information a linear model for the lowering of nitrogen release with lowered watershed nitrogen loading is conservative.

V. HYDRODYNAMIC MODELING

V.1 INTRODUCTION

This section summarizes the field data collection effort and the development of a hydrodynamic model for the Three Bays estuary system in the Town of Barnstable. For this system, the final calibrated model offers an understanding of water movement through the estuary, and provides the first step towards evaluating water quality, as well as a tool for later determining nitrogen loading "thresholds". Nutrient loading data combined with measured environmental parameters within the system become the basis for an advanced water quality model based on total nitrogen concentrations. This type of model provides a tool for evaluating existing estuarine water quality parameters, as well as determining the likely positive impacts of various alternatives for improving overall estuarine health, facilitating the understanding how pollutant loadings into the estuary will affect the biochemical environment and its ability to sustain a healthy marine habitat.

In general, water quality studies of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. For example, the spread of pollutants may be analyzed from tidal current information developed by the numerical models.

Coastal embayments like the Three Bays system are the initial recipients of freshwater flows (i.e., groundwater and surfacewater) and the nutrients they carry. An embayment's shape influences the time that nutrients are retained in them before being flushed out to adjacent open waters, and their shallow depths both decrease their ability to dilute nutrient (and pollutant) inputs and increase the secondary impacts of nutrients recycled from the sediments. Degradation of coastal waters and development are tied together through inputs of pollutants in runoff and groundwater flows, and to some extent through direct disturbance, i.e. boating, oil and chemical spills, and direct discharges from land and boats. Excess nutrients, especially nitrogen, promote phytoplankton blooms and the growth of epiphytes on eelgrass and attached algae, with adverse consequences including low oxygen, shading of submerged aquatic vegetation, and aesthetic problems.

A hydrodynamic study was performed for the Three Bays system, which is located on the south shore of Cape Cod. A section of a topographic map in Figure V-1 shows the general study area. The three Bays system has four major subdivisions, Cotuit Bay, West Bay, North Bay, and Prince's Cove. Cotuit Bay and West Bay both have there own outlets to Nantucket sound, and are connected though the Seapuit River and also via North Bay. Osterville Grand Island and Little Island lie within the Three Bays system. Dead Neck is the barrier island that describes the southern boundary of this estuarine system, and protects Grand Island from the open waters of Nantucket Sound.



Figure V-1. Topographic map detail of the Three Bays System, in Barnstable, Massachusetts.

The entire Three Bays system has a surface coverage of 1251 acres, including several small sub-embayments attached to the system's main sub-embayments. Cotuit Bay is the largest sub-embayment of the Three Bays system, covering 469 acres. The average depth of the whole embayment is 6.2 ft. West Bay has an area coverage of 343 acres and an average depth of 5.3 ft. North Bay has an area coverage of 309 acres, and an average depth of 5.3 ft. Prince's Cove together with Warren Cove and the Marstons Mills River are the northernmost reaches of the Three Bays system, with a 93-acre coverage. The Marstons Mills River is the largest surface source of fresh water into the estuary.

Circulation in the Three Bays system is dominated by tidal exchange with Nantucket Sound. There is negligible attenuation of the tide range throughout the system, even into its uppermost reaches in Prince's Cove. This indicates that there is little loss of tidal energy

through the system, either due to bottom friction in shallow areas or from channel restrictions, e.g., at the system inlets and the Little Island draw bridge.

This hydrodynamic study proceeded as two component efforts. In the first portion of the study, bathymetry, tide, and circulation velocity data were collected in order to accurately characterize the physical system, and to provide data necessary for the modeling portion of the study. The bathymetry survey of Three Bays was performed to determine the variation of embayment and channel depths throughout the system. This survey addressed the previous lack of available bathymetry data for this system. In addition to the survey, tides were recorded at seven locations within Three Bays for 44 days. These tide data were necessary to run and calibrate the hydrodynamic model of the system. Finally, an Acoustic Doppler Current Profiler (ADCP) survey was completed during a single tide cycle to measure ebb and flood velocities across five channel transects. The ADCP data were used to compute system flow rates and to provide an independent means of verifying the performance of the hydrodynamic model.

A numerical hydrodynamic model of the Three Bays system was developed in he second portion of this study. Using the bathymetry survey data, a model grid mesh was generated for use with the RMA-2 hydrodynamic code. The tide data from offshore Dead Neck were used to define the open boundary conditions that drive the circulation of the model at the two system inlets, and data from the five TDR stations within the system were used to calibrate and verify model performance to ensure that it accurately represents the dynamics of the real, physical system.

The calibrated computer model of Three Bays was used to compute the flushing rates of selected sub-embayments. Though water quality in an embayment cannot be directly inferred by use of computed flushing rates alone, they can serve as useful indicators of embayment flushing performance relative to other areas in the same system. The ultimate utility of this hydrodynamic model is as input into a constituent transport model, where water quality constituents like nitrogen are modeled to determine the real water quality dynamics of a system.

V.2 GEOMORPHIC AND ANTHROPOGENIC EFFECTS TO THE ESTUARINE SYSTEM

A general understanding of the hydrodynamic controls and coastal processes influencing estuarine dynamics provides the initial framework for the hydrodynamic analysis. In addition, both natural and anthropogenic changes to the estuarine system can guide the evaluation of effective alternatives to enhance tidal circulation and improve water quality.

The southern coast of Cape Cod between the Popponesset Bay and West Bay entrances can be considered a moderately dynamic region, where natural wave and tidal forces continue to reshape the shoreline. Due to the protection afforded by the islands of Marthas Vineyard and Nantucket, the south shore of Cape Cod is protected from the influence of long period open ocean wave conditions. Similar to many portions of the Massachusetts coast, the available sediment supply influences the migration and/or stability of tidal inlets. Tidal inlets can become overwhelmed by the gradual wave-driven migration of a barrier beach separating the estuaries from the ocean. In addition to these natural coastal processes, man-made structures often can influence the stability of a shoreline/tidal inlet system.

V.2.1 Natural Coastal Processes

For the Three Bays estuarine system, the process of barrier spit elongation continues to have a significant influence on tidal exchange. Over the past 80 years, the Sampsons Island barrier elongation has influenced tidal exchange through the Cotuit Bay entrance, where the

West Bay inlet has gradually become more vital to tidal exchange within the Three Bays system. Figure V-2 illustrates the gradual narrowing of the Cotuit Bay entrance since 1938. This narrowing has caused migration of the navigation channel to the west. By 2003, some coastal engineering structures along the west side of the inlet became undermined and collapsed into the channel. As the Sampsons Island spit continues to elongate, the Cotuit Bay entrance becomes narrower and the inlet becomes less efficient for tidal exchange.

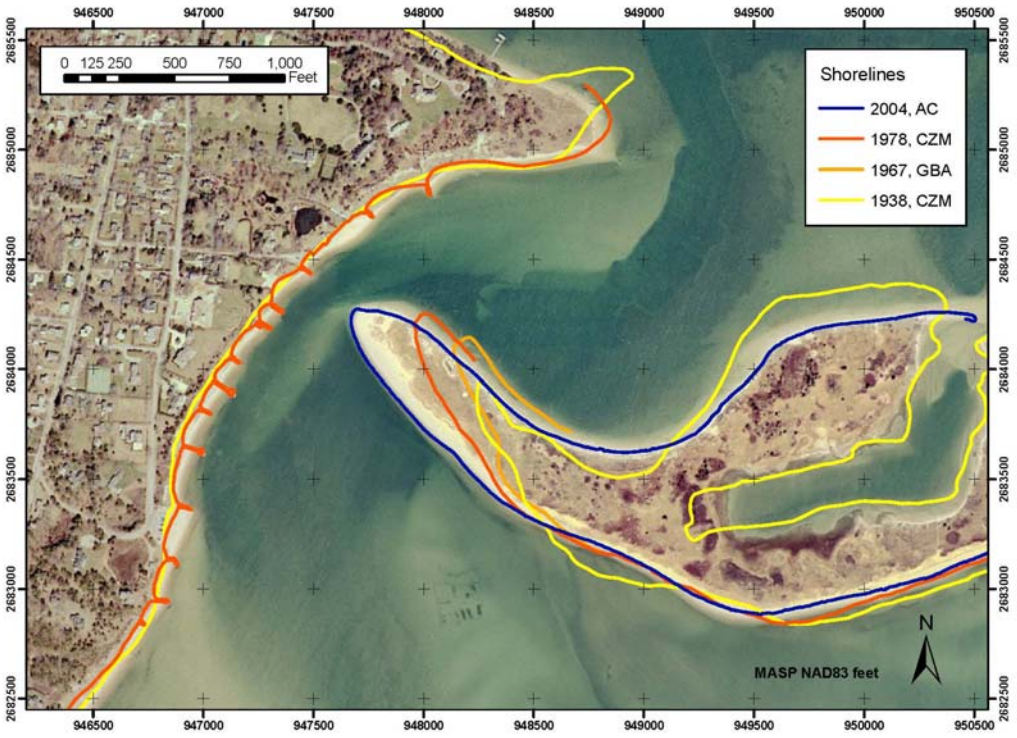


Figure V-2. Historical shoreline positions in the vicinity of the Cotuit Bay entrance between 1938 and 2004.

Figure V-3 shows the historic shoreline change fronting Rushy Marsh and the Three Bays region between 1938 and 2005. Much of the accretion along the barrier beach separating Rushy Marsh from Nantucket Sound is a result of the Popponesset spit remnants joining the barrier beach fronting Rushy Marsh. After this spit welded onto the existing shoreline, the net west-to-east directed littoral drift has "straightened" the shoreline in this region, where slight erosion has been observed along the beach fronting the southwest end of the pond and significant accretion has been observed along the beach fronting the remainder of the pond. To the northeast of Rush Marsh Pond, the shoreline has experienced erosion over the past 60+ years, likely resulting from the westerly migration of Sampsons Island.

Although littoral drift generally moves from west-to-east along the south shore of Cape Cod, due primarily to the prevailing southwest winds, a sediment transport reversal occurs along the shoreline of Dead Neck and Sampsons Islands. This local reversal is due to a slightly different shoreline orientation relative to the incident wave climate. As shown in Figure V-3, the east-to-west littoral drift generally causes erosion along the eastern portion of Dead Neck, with a corresponding accretion/spit elongation at the west end of Sampsons Island. The observed

erosion rates along the eastern portion of Dead Neck are moderated by ongoing beach nourishment efforts (described below).



Figure V-3. Observed shoreline change from 1938 to 2001/2005 for the shoreline area in the vicinity of Rushy Marsh Pond and Three Bays in Barnstable.

V.2.2 Anthropogenic Changes Influencing Rushy Marsh Pond

Manmade coastal structures along the shoreline immediately west of Cotuit Bay entrance consist primarily of groins along this updrift shoreline. Based on site observations, most of these structures are not effective barriers to natural littoral drift; therefore, beach compatible material continues to supply the beach systems along the shoreline of Cotuit Bay. The volume of material transported along this shoreline stretch is relatively small, due primarily to the quiescent wave conditions within the protected waters of Nantucket Sound. The conclusion that the longshore sediment transport rate is relatively low is further supported by the stable shoreline northeast of Rushy Marsh Pond and the small maintenance dredging volumes required to maintain the entrance to Cotuit Bay (which receives littoral sediments from both the east and the west).

The Three Bays estuarine system was significantly modified in 1900 by the construction of the West Bay cut. Prior to this time, only the Cotuit Bay entrance connected the Three Bays system to Nantucket Sound. Figure V-4 illustrates the condition of the system immediately before development of West Bay inlet. Creation of this structured inlet altered the tidal exchange within the Three Bays system, significantly reducing the volume of water flowing through the Cotuit Bay entrance.

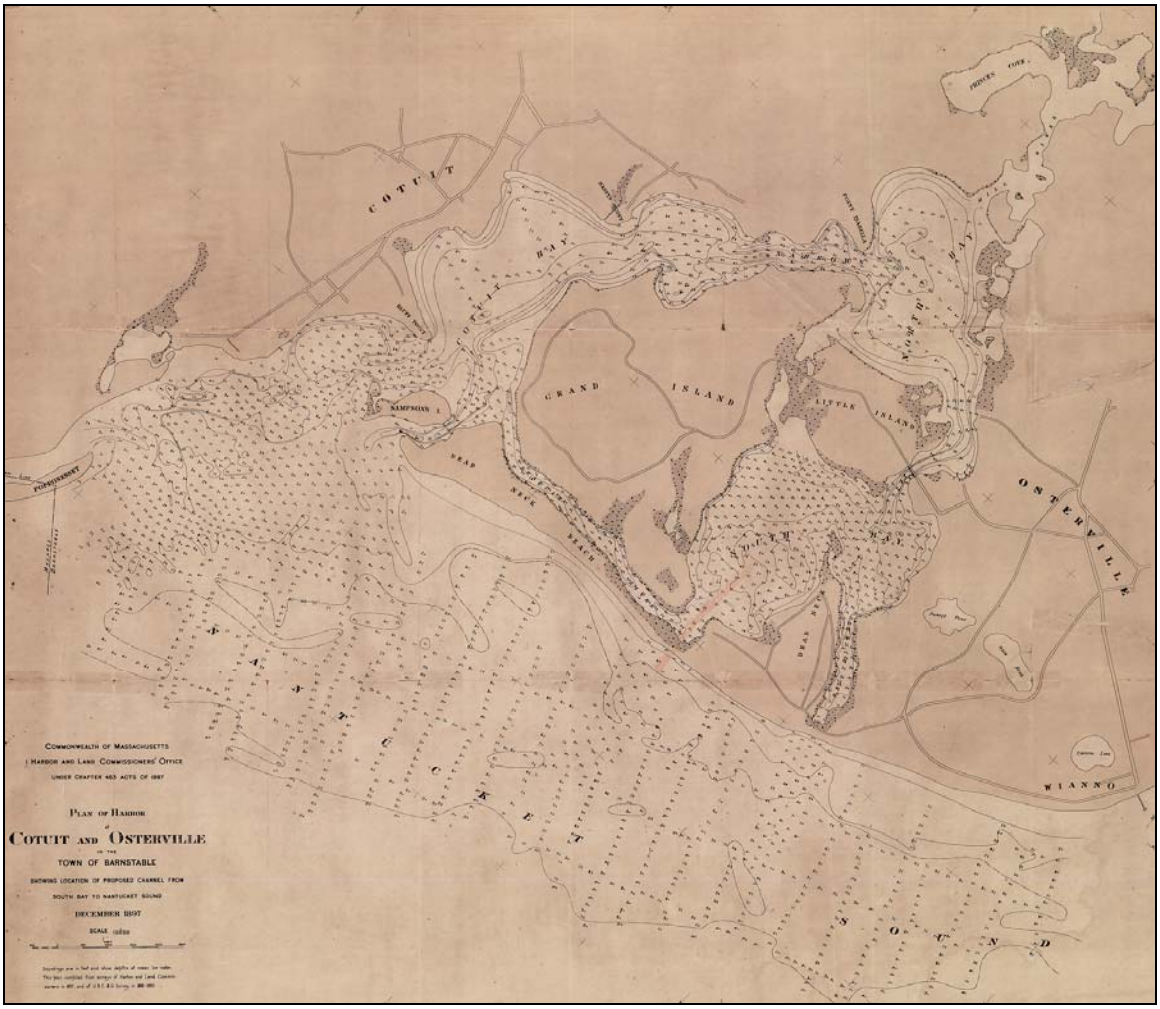


Figure V-4. Bathymetry map of the Three Bays estuarine system in 1897.

Over the past 20 years, significant efforts have been made by homeowners on Grand Island, as well as Three Bays Preservation, Inc. (a non-profit group concerned with the overall environmental conditions of Three Bays), to maintain the integrity of the Dead Neck barrier beach system. This maintenance of the barrier system has been in the form of beach nourishment as described below.

In order to enhance the storm protection capability of the eastern end of Dead Neck, two major beach nourishments have been completed on the island, adjacent to West Bay inlet. This segment of the Dead Neck shoreline has historically been the most erosive area of the island, due to it's proximity to West Bay inlet. The inlet, with its jetties, effectively interrupts littoral transport from updrift beaches. This has been the case since the opening of the inlet in the first half of the 20th century. Net transport along the Dead Neck shoreline is directed toward the Cotuit Bay entrance from the West Bay entrance. Therefore, as it is cut off from the natural source of sediment to the east, the east end of the island continues to erode (apparent as shoreline retreat and lowering of the island), further inhibiting its ability to adequately serve as storm protection for the area directly landward of the island (in the Seapuit River) and in West Bay.

For the first nourishment in 1985, 120,000 cubic yards of sand were placed along the section of beach starting at West Bay inlet and extending 2,400 feet westward (Wood, et al., 1996). Beach compatible material dredged from the West Bay inlet entrance channel was the source of sand used for this project. The design template of the nourishment had a berm elevation of +12.0 ft NGVD and a width of 100 ft. On average, the fill template required 50 to 60 cubic feet of sand per foot length of beach and had a stated design life of 10 years.

The performance of the 1985 nourishment was monitored on a semi-annual basis up to 1993. In 1993 approximately 7% of the nourishment volume remained in the template area. The average volume loss rate for the 7.5-year monitoring period was 14,880 cubic yards per year. Erosion rates along the template were higher than average at the completion of the nourishment as the beach fill profile equilibrated. Toward the end of the monitoring period, erosion rates were again accelerated due to a series of severe storms which impacted this shoreline during this time, including Hurricane Bob (August, 1991), the “no-name” northeast storm of October, 1991 and the Blizzard of 1993.

The second nourishment project commenced in the first half of 1999 and was completed in winter 2000 (Woods Hole Group, 2001). Figures V-5 and V-6 show the condition of the Dead Neck barrier beach in 1999 (immediately preceding nourishment) and 2000 (immediately following nourishment), respectively. The fill template for this nourishment had an elevation of +13 MLW, and a berm crest width of 150 feet. The sand used for the fill was available from channel maintenance dredging at Cotuit and West Bay Inlets. For this nourishment, 187,300 cubic yards were initially placed along a 2,000 foot-length of the Dead Neck shoreline, starting at the West Bay inlet. This resulted in an average fill volume of 95 cubic yards per foot of shoreline. In 2000, the fill was supplemented with an additional 25,100 cubic yards of sand, placed over the easternmost 1,000 feet of the island. The total volume of sand for the 1999-2000 nourishment project was therefore 212,400 cubic yards.

Since the completion of the nourishment in the first quarter of 2000, the movement of the Dead Neck shoreline has been monitored annually through the use of Differential GPS (DGPS) shoreline surveys and cross-shore profile measurements. These two data sets were used to determine shoreline change rates and volume loss in the 1999-2000 nourishment area, as well as shoreline change rates for the entire seaward shoreline of the island. In Figure V-7, measured shoreline change rates are indicated by color bars along the Dead Neck shoreline. For the whole seaward facing shoreline the maximum erosion rate was computed to be -23.4 feet per year (ft/yr). This maximum rate occurred about 1100 feet west of the West Bay Inlet. The average change rate over the 2,000 foot length of the 1999 nourishment was -17.0 feet during this period. At the western end of Dead Neck, the westernmost 1,000 feet of shoreline from Cotuit Inlet was accretional, with an average change rate of +4.9 ft/yr. Based on volume calculations, 36% of the fill volume has been lost from the nourishment area over the last five years. At the time of the September 2004 survey, there were 137,000 yd^3 of sand remaining. Over the approximate five-year period since the bulk of the 1999 nourishment was completed, the average rate of volume loss has been -13,700 yd^3/yr.



Figure V-5. The eastern portion of Dead Neck in 1999, showing at least two locations where the beach had significant storm overwash areas.



Figure V-6. Dead Neck Beach immediately following the beach nourishment in 2000, where the beach width had been increased significantly to prevent breaching of the barrier.

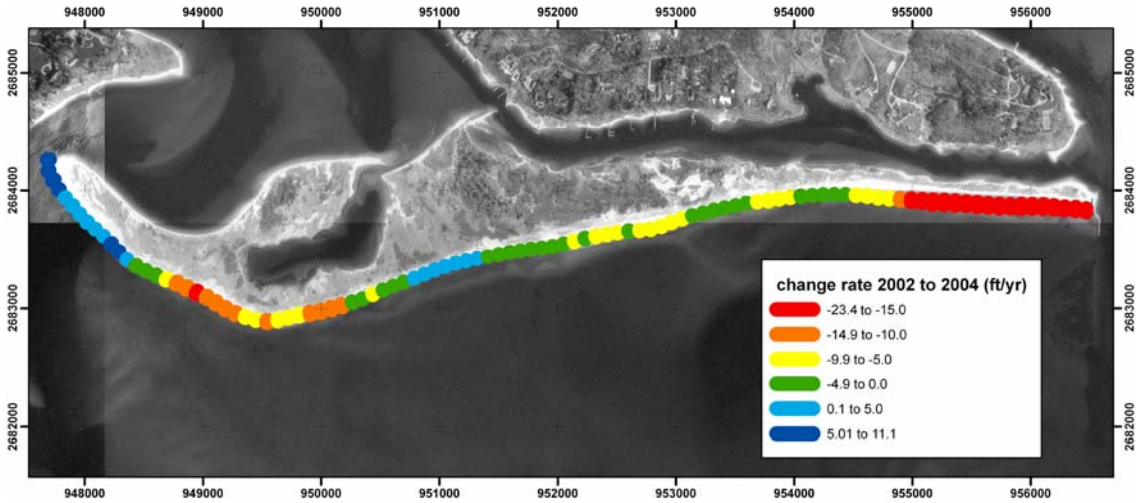


Figure V-7. Results of shoreline change analysis using the 2002 and 2004 GPS shorelines. Color bars indicate a range of shoreline change computed along Dead Neck. Negative rates indicate erosion, and are represented by the colors green, yellow, orange and red. Areas of accreting shoreline are indicated by light and dark blue.

V.3 DATA COLLECTION AND ANALYSIS

The field data collection portion of this study was performed to characterize the physical properties of the Three Bays estuary. Bathymetry were collected throughout the system so that it could be accurately represented as a computer hydrodynamic model, and so that flushing rates could be determined for the system sub-embayments. In addition to the bathymetry, tide data were also collected at seven locations, to run the circulation model with real tides, and also to calibrate and verify its performance.

V.3.1 Bathymetry Data Collection

Bathymetry data in Three Bays were collected during October 2002. Supplemental bathymetry were also available from a February 2002 survey of North and South Coves in Grand Island. The October 2002 survey employed a bottom tracking Acoustic Doppler Current Profiler (ADCP) mounted on a 12 ft motor skiff. Positioning data were collected using a differential GPS. The survey design included gridded transects at roughly 400 ft spacings in the main embayments, and finer spacings at the inlets. Survey paths are shown in Figure V-8. The resulting bathymetric surface created by interpolating the data to a finite element mesh is shown in Figure V-9. All bathymetry was tide corrected, and referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29), using survey benchmarks located in the project area.

Results from the survey show that the deepest point in the Three Bays system is located at Cotuit Inlet, and is –23.6 ft NAVD. The greatest depths (approximately 15 ft) of Cotuit Bay are located in its southern portion, near the village of Cotuit. The greatest depths of West Bay are in the dredged navigation channel (approximately 10 ft) from the West Bay inlet to the entrance to North Bay. The deepest depths of the entire Three Bays system (apart from the inlets) are located in North Bay (approximately 17 ft) near its entrance to Cotuit Bay.

V.3.2 Tide Data Collection and Analysis

Tide data records were collected at seven stations in the Three Bays estuary: 1) offshore Dead Neck, 2) West Bay (Grand Island), 3) Cotuit Bay (Bluff Point), 4) North Bay (Oyster Harbors Marina), 5) North Bay (Point Isabella), 6) Dam Pond, and 7) Prince's Cove. An eighth tide gauge had been deployed in Cotuit Bay of off Handy Point, but data were not recovered from this location due to failure of the gauge. The locations of the stations are shown in Figure V-8. The Temperature Depth Recorders (TDR) used to record the tide data were deployed for a 44-day period between October 2, 2002 and November 15, 2002. The elevation of each gauge was surveyed relative to NGVD 29. Two gauges were deployed together offshore Dead Neck by SCUBA divers using a screw anchor. Duplicate offshore gauges were deployed to ensure data recovery, since the offshore tide record is crucial for developing the open boundary condition of the hydrodynamic model of the Three Bays system. Data from the other six locations were used to calibrate the model.

Plots of the tide data from three representative gauges are shown in Figure V-10, for the entire 44-day deployment. The spring-to-neap variation in tide can be seen in these plots. From the plot of the data from offshore Dead Neck, the tide reaches its maximum spring tide range of approximately 4.0 feet around October 7, and about seven days later the neap tide range is much smaller, as small as 1.5 feet. The second spring tide should occur around October 21, but the tide range is not clearly larger than either seven days before or after this date. The largest spring tide range is expected to occur at the time of the new moon, which occurred October 6 and again on November 4. The muted spring tide of October 21 occurred during the full moon. The causes of this odd feature of the tide in this are discussed from the results of the harmonic analysis later in this section.

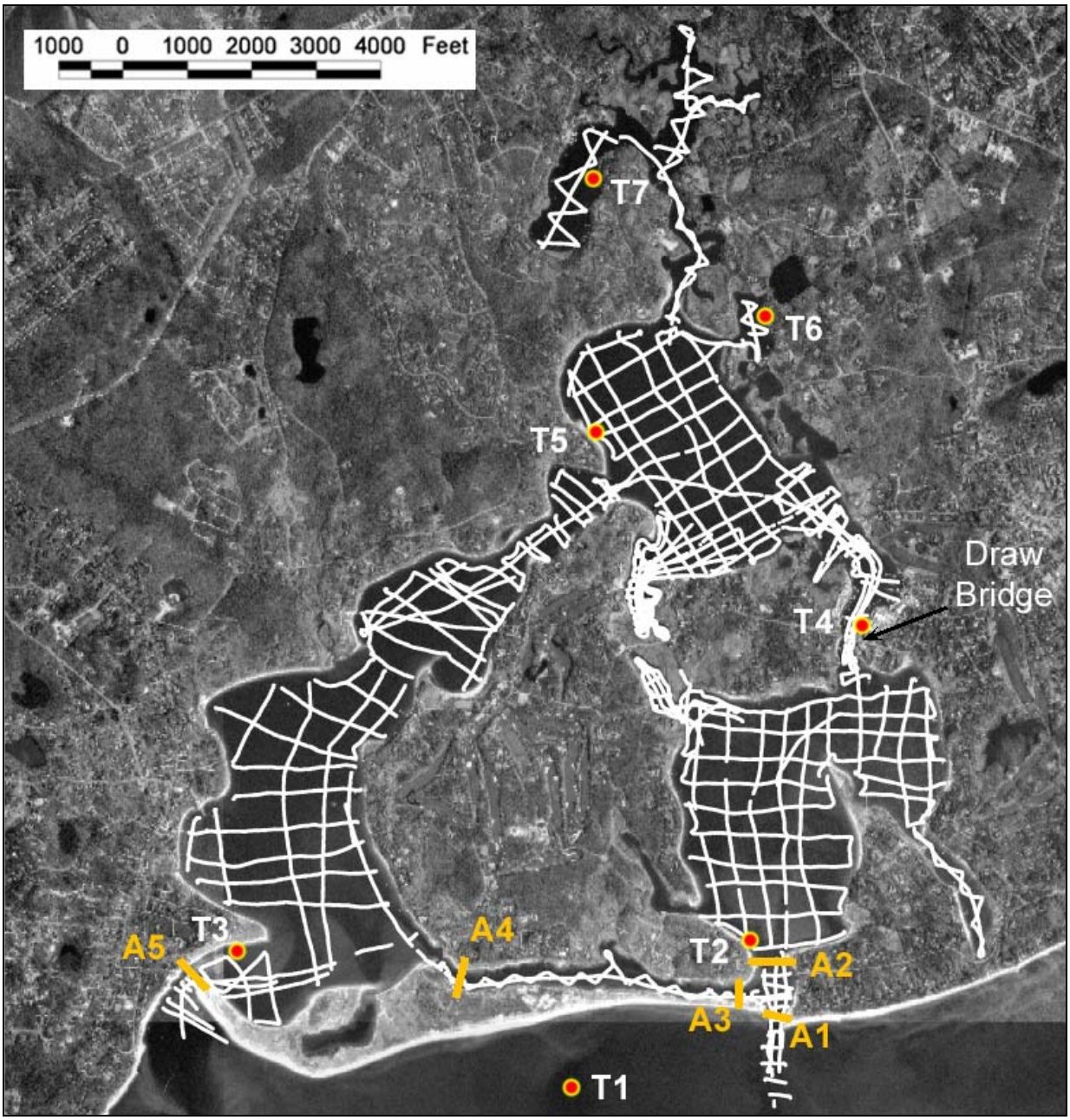


Figure V-8. Transects from the bathymetry survey of the Three Bays system. Red markers show the locations of the seven tide recorders deployed for this study.

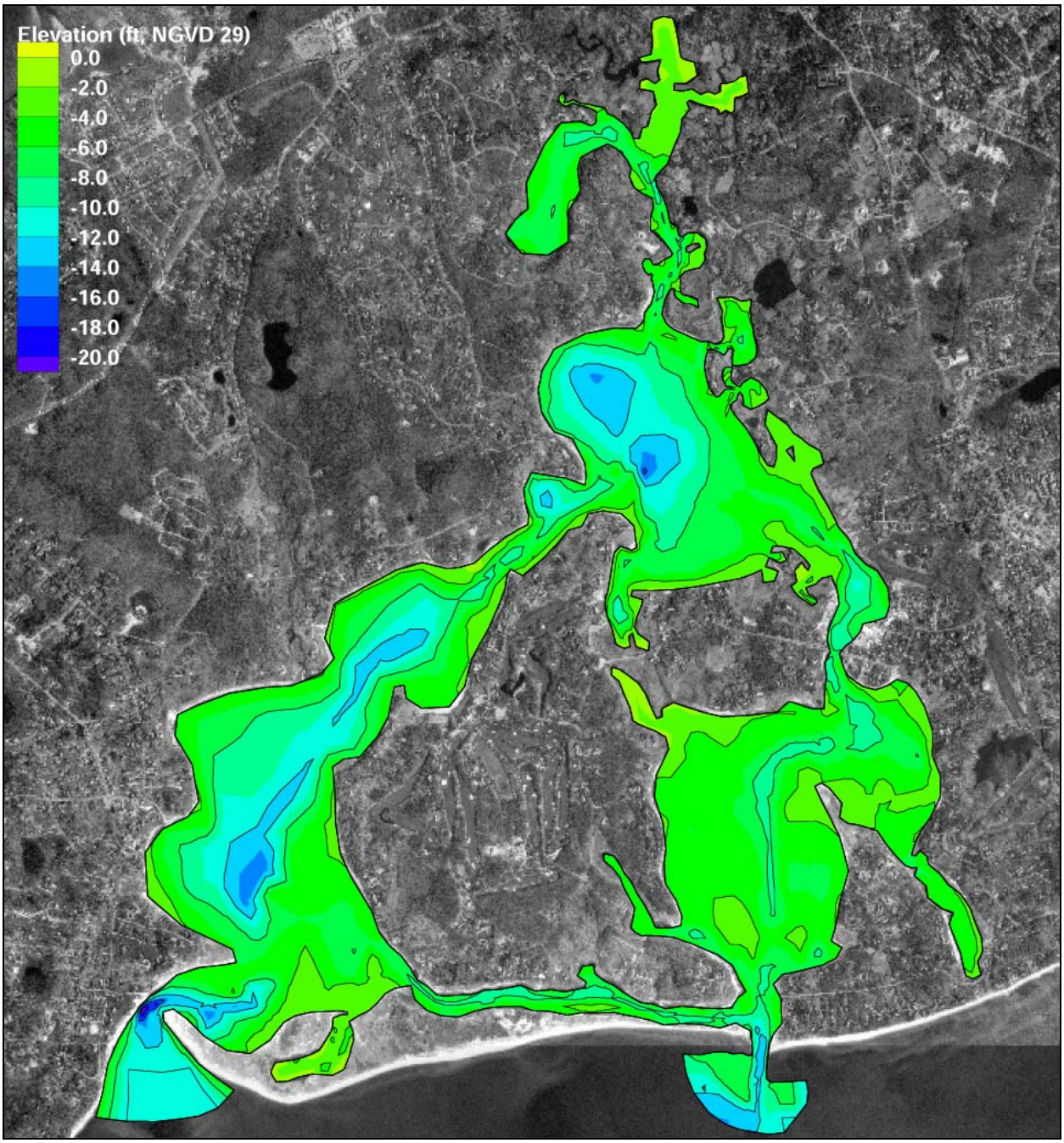


Figure V-9. Plot of interpolated finite-element grid bathymetry of the Three Bays system, shown superimposed on 1994 aerial photos of the system locale. Bathymetric contours are shown in color at two-foot intervals, and also as lines at four-foot intervals.

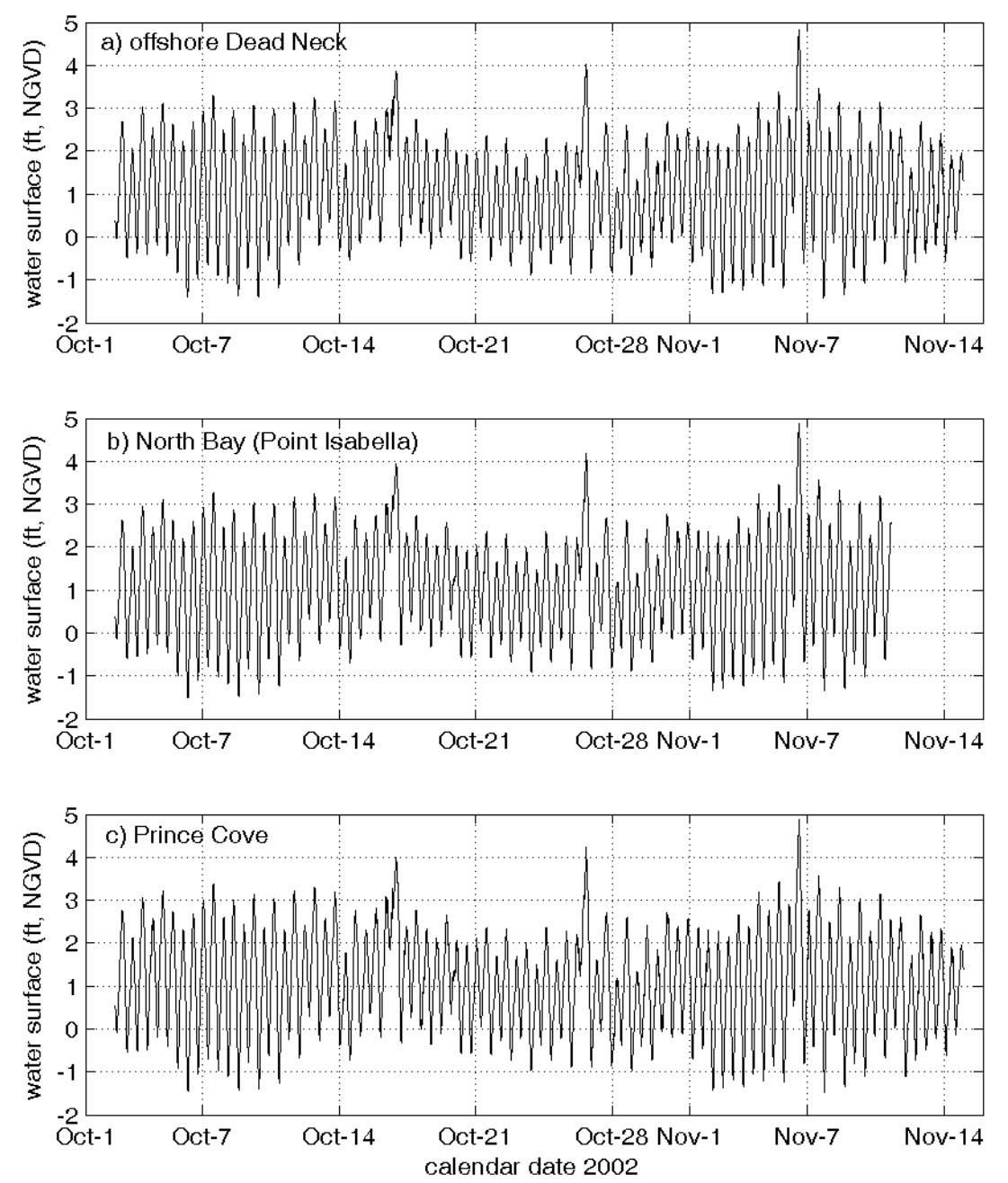


Figure V-10. Plots of observed tides for the Three Bays system, for the 44-day period between October 2 and November 15, 2002. The top plot shows tides offshore Dead Neck, in Nantucket Sound. The middle plot shows tides recorded in North Bay at Point Isabella, and the bottom plot shows tides recorded at Prince's Cove, in the upper reaches of the Three Bays system. All water levels are referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Also seen in this record are three distinct storm events, with peak storm surge levels occurring October 16, October 26, and November 6. Though the water level at peak surge is not substantially higher than the apparent normal peak spring tide levels, these surges stand out because of the relatively small tide range in this area of Nantucket Sound.

A visual comparison in Figure V-11 between tide elevations at the three stations shows that there negligible reduction in the tide range in the upper reaches of the Three Bays system. The loss of amplitude with distance from the inlet is described as tidal attenuation. Frictional mechanisms dissipate tidal flow energy, resulting in a reduction of the height of the tide. Tide attenuation is accompanied by a time delay (or phase lag) in the time of high and low tide (relative to the offshore tide), which becomes more pronounced farther into an estuary. The tide lag greatest in Prince's Cove, as seen in Figure V-10, where low tide in this sub-embayment occurs approximately 50 minutes after low tide in Nantucket Sound.

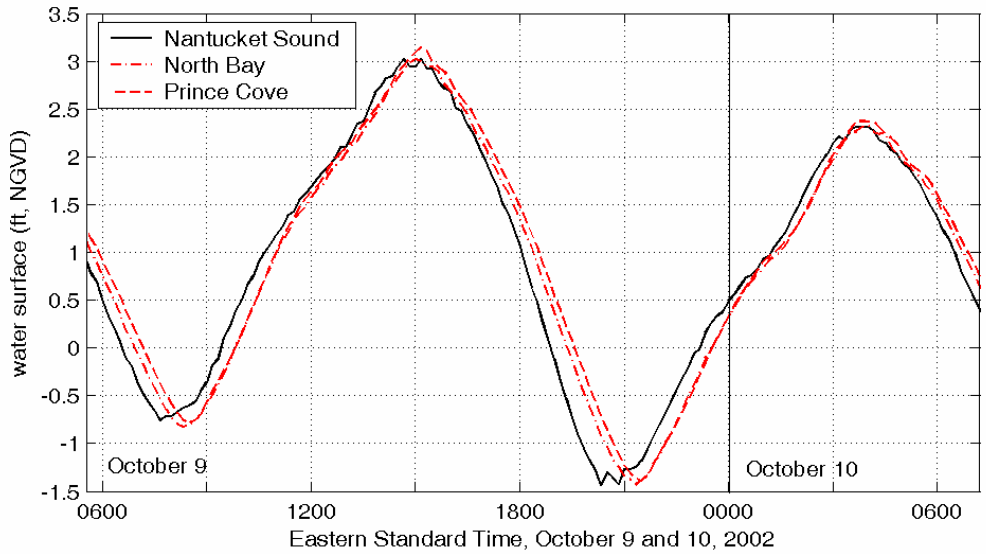


Figure V-11. Plot showing two tide cycles tides at three stations in the Three Bays system plotted together. Demonstrated in this plot is the minor frictional damping effect caused by flow restrictions at the inlets. The damping effects are seen only as a lag in time of high and low tides from Nantucket Sound. The time lag of low tide between the Sound and Prince's Cove in this plot is 50 Minutes.

Standard tide datums were computed from the 44-day records. These datums are presented in Table V-1. For most NOAA tide stations, these datums are computed using 19 years of tide data, the definition of a tidal epoch. For this study, a significantly shorter time span of data was available, however, these datums still provide a useful comparison of tidal dynamics within the system. The Mean Higher High (MHH) and Mean Lower Low (MLL) levels represent the mean of the daily highest and lowest water levels. The Mean High Water (MHW) and Mean Low Water (MLW) levels represent the mean of all the high and low tides of a record, respectively. The Mean Tide Level (MTL) is simply the mean of MHW and MLW. The lack of tide attenuation through the Three Bays estuary is apparent by how there is essentially no change in the elevation of each of the datums, from Nantucket Sound to Prince's Cove. This is true for even the maximum and minimum tide levels.

Table V-1. Tide datums computed from 44-day records collected offshore Dead Neck and in Cotuit Bay, West Bay, and Prince's Cove. Datum elevations are given relative to NGVD 29.

Tide Datum	Offshore	Cotuit Bay	West Bay	Prince's Cove
Maximum Tide	4.8	4.8	4.7	4.9
MHHW	2.8	2.8	2.8	2.9
MHW	2.4	2.4	2.4	2.4
MTL	1.0	1.0	1.0	1.0
MLW	-0.4	-0.4	-0.4	-0.5
MLLW	-0.7	-0.7	-0.7	-0.8
Minimum Tide	-1.4	-1.5	-1.4	-1.6

The tides in Nantucket Sound are semi-diurnal, meaning that there are typically two tide cycles in a day. There is usually a small variation in the level of the two daily tides. This variation can be seen in the differences between the MHHW and MHW, as well as the MLLW and MLW levels.

A more thorough harmonic analysis of the tidal time series was performed to produce tidal amplitude and phase of the major tidal constituents, and provide assessments of hydrodynamic 'efficiency' of the system in terms of tidal attenuation. This analysis also yielded a quantitative assessment of the relative influence of non-tidal, or residual, processes (such as wind forcing) on the hydrodynamic characteristics of each system.

A harmonic analysis was performed on the time series from each gauge location. Harmonic analysis is a mathematical procedure that fits sinusoidal functions of known frequency to the measured signal. The observed astronomical tide is therefore the sum of several individual tidal constituents, with a particular amplitude and frequency. For demonstration purposes a graphical example of how these constituents add together is shown in Figure V-12. The amplitudes and phase of 23 known tidal constituents result from this procedure. Table V-2 presents the amplitudes of eight tidal constituents in the Three Bays system.

The M_2, or the familiar twice-a-day lunar semi-diurnal tide, is the strongest contributor to the signal with an amplitude of 1.2 ft throughout the system. The total range of the M_2 tide is twice the amplitude, or 2.4 ft. The M_4 and M_6 tides are higher frequency harmonics of the M_2 lunar tide (exactly half the period of the M_2 for the M_4, and one third of the M_2 period for the M_6), results from frictional attenuation of the M_2 tide in shallow water. The M_4 has an amplitude of 0.2 feet in all sub-embayments of the system. The M_6 has a very small amplitude in the system (less than 0.1 feet). There is no change in the M_2 or its harmonics through the estuary, which is a further indication that friction losses in the system are minimal, and that Three Bays flushes effectively, even to its farthest reaches at Prince's Cove.

The other major tide constituents also show little variation across the system. The diurnal tides (once daily), K_1 and O_1, possess equal amplitudes of approximately 0.4 feet. Other semi-diurnal tides, the S_2 (12.00 hour period) and N_2 (12.66-hour period) tides, contribute significantly to the total tide signal, with amplitudes of 0.2 feet and 0.4 feet, respectively. The M_{sf} is a lunarsolar fortnightly constituent with a period of approximately 14 days, and is the result of the periodic conjunction of the sun and moon, and has an amplitude less than 0.1 ft.

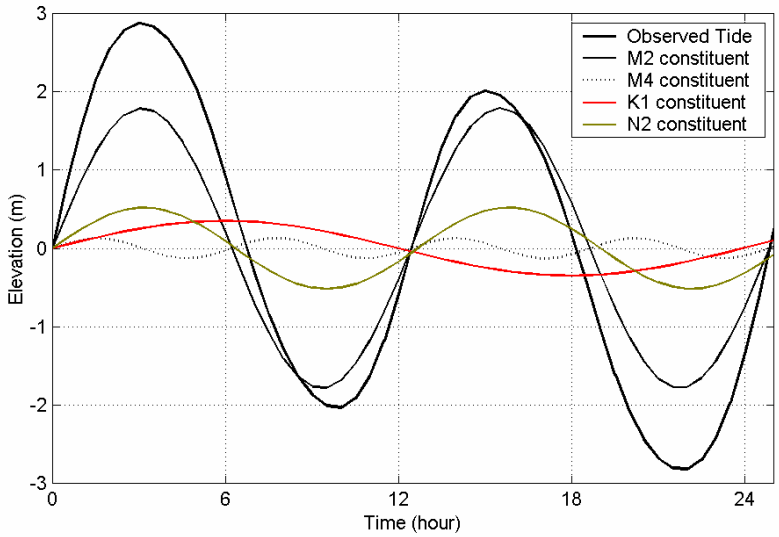


Figure V-12. Example of an observed astronomical tide as the sum of its primary constituents.

Table V-2. Major tidal constituents determined for gauge locations in Three Bays, October 2 through November 14, 2002.

	Amplitude (feet)							
Constituent	M2	M4	M6	S2	N2	K1	O1	Msf
Period (hours)	12.42	6.21	4.14	12.00	12.66	23.93	25.82	354.61
Nantucket Sound	1.20	0.17	0.07	0.15	0.41	0.35	0.35	0.06
Cotuit Bay	1.19	0.15	0.06	0.14	0.42	0.35	0.35	0.05
West Bay	1.20	0.15	0.07	0.15	0.41	0.35	0.35	0.06
Oyster Harbor Marine	1.20	0.14	0.08	0.15	0.41	0.35	0.35	0.05
North Bay	1.19	0.14	0.09	0.15	0.41	0.35	0.35	0.09
Dam Pond	1.17	0.14	0.08	0.14	0.40	0.35	0.35	0.05
Prince's Cove	1.20	0.14	0.09	0.15	0.41	0.35	0.35	0.05

Though there is no change in constituent amplitudes, the phase change of the tide is easily seen from the results of the harmonic analysis. Table V-3 shows the delay of the M_2 at different points in the Three Bays system, relative to the timing of the M_2 constituent in Nantucket Sound, offshore Dead Neck. The greatest delay is at the Dam Pond TDR station, which also showed the largest reduction of the M_2 amplitude (Table V-2). Compared to other locations instrumented in this study, Dam Pond shows the greatest tidal attenuation.

Table V-3. M_2 tidal constituent phase delay (relative to Nantucket Sound) for gauge locations in the Three Bay system, determine from measured tide data.

Station	Delay (minutes)
Cotuit Bay (Bluff Point)	7.1
West Bay	10.1
Oyster Harbor Marine (Draw Bridge)	15.3
North Bay (Point Isabella)	12.0
Dam Pond	23.1
Prince's Cove	20.5

Results of the harmonic analysis provide the reason why the transition from spring to neap tide ranges is not as apparent, as it is at other areas (e.g., Cape Cod Bay), as discussed earlier. The cause of the mute transition between spring and neap tide ranges is the relatively large amplitudes of the N_2 (larger lunar elliptic semidiurnal constituent) and O_1 (lunar diurnal constituent) constituents. From the analysis of other tide records from around southeastern Massachusetts, the N_2 has a typical amplitude that is less than 10% of the total tide, and the O_1 is typically less than 7% of the total tide amplitude. At Three Bays however, the N_2 and O_1 have much larger amplitudes relative to the total tide, at 15% and 13%, respectively. These constituents are slightly out of phase with the M_2 and K_1 (normally the greater contributors to the total tide amplitude), and therefore add and subtract from the total observed tide signal in cycles that are different (longer) than the 7 lunar day transition from spring to neap tides. In other areas (again, like Cape Cod Bay), the N_2 and O_1 represent a smaller percentage of the total observed tide, so their effect on the observed tide would be smaller.

In addition to the tidal analysis, the data were further evaluated to determine the importance of tidal versus non-tidal processes to changes in water surface elevation. These other processes include wind forcing (set-up or set-down) within the estuary, as well as sub-tidal oscillations of the sea surface. Variations in water surface elevation can also be affected by freshwater discharge into the system, if these volumes are relatively large compared to tidal flow. The results of an analysis to determine the energy distribution (or variance) of the original water elevation time series for the Three Bays system is presented in Table V-4 compared to the energy content of the astronomical tidal signal (re-created by summing the contributions from the 23 constituents determined by the harmonic analysis). Subtracting the tidal signal from the original elevation time series resulted with the non-tidal, or residual, portion of the water elevation changes. The energy of this non-tidal signal is compared to the tidal signal, and yields a quantitative measure of how important these non-tidal physical processes can be to hydrodynamic circulation within the estuary. Figure V-13 shows the comparison of the measured tide from Nantucket Sound, with the computed astronomical tide resulting from the harmonic analysis, and the resulting non-tidal residual.

Table V-4. Percentages of Tidal versus Non-Tidal Energy for Three Bays embayments, August to September 2001.

TDR LOCATION	Total Variance (ft^2)	Tidal (%)	Non-tidal (%)
Nantucket Sound (offshore)	1.048	86.9	13.1
Cotuit Bay (Bluff Point)	1.031	85.5	14.5
West Bay	1.035	86.6	13.4
Oyster Harbor Marina (North Bay)	1.042	86.3	13.7
North Bay (Point Isabella)	1.070	85.7	14.3
Dam Pond	1.001	85.8	14.2
Prince's Cove	1.042	85.9	14.1

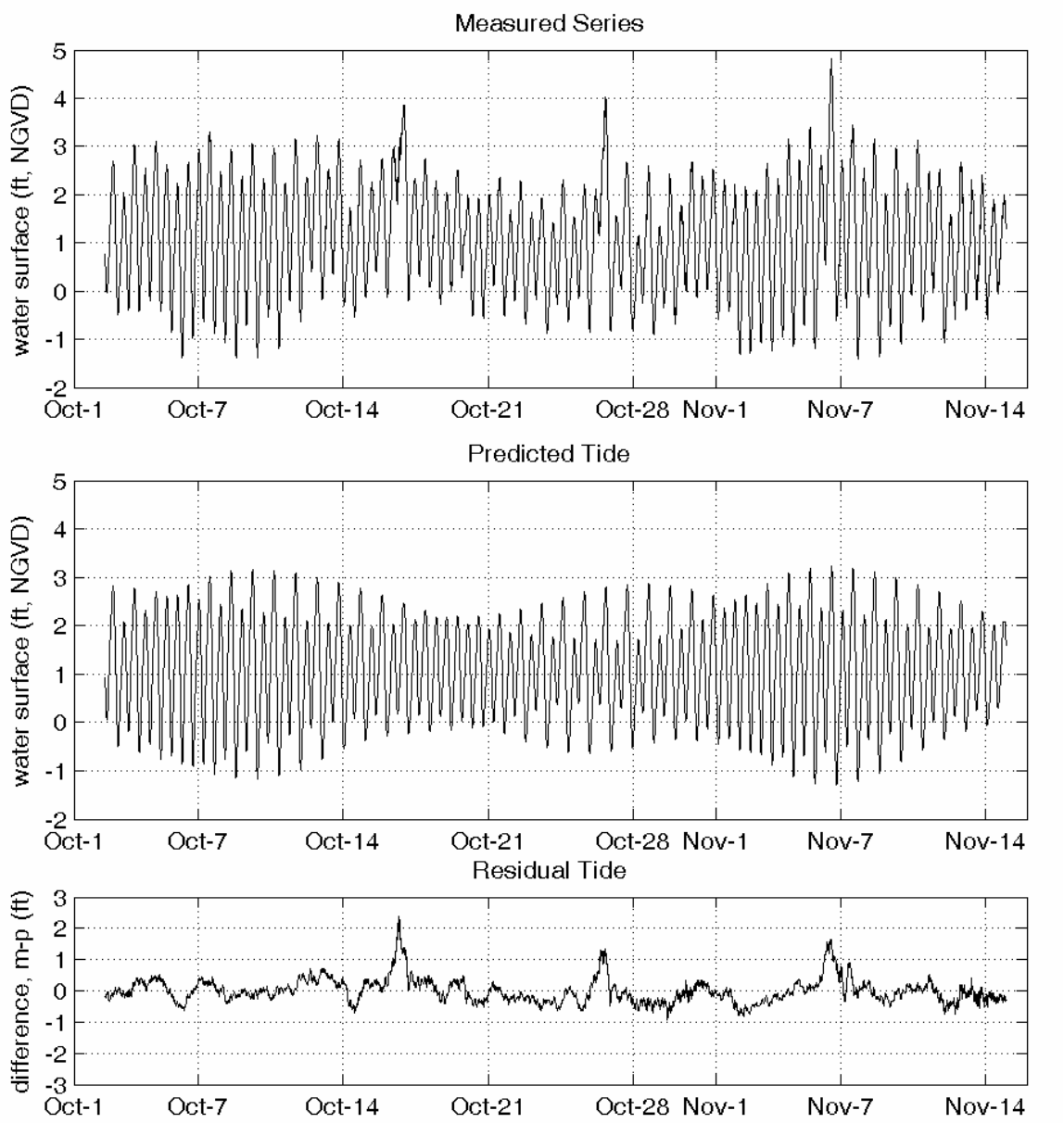


Figure V-13. Plot showing the comparison between the measured tide time series (top plot), and the predicted astronomical tide (middle plot) computed using the 23 individual tide constituents determine in the harmonic analysis of the Nantucket Sound (offshore Dead Neck) gauge data. The residual tide shown in the bottom plot is computed as the difference between the measured and predicted time series (r=m-p).

Table V-4 shows that the variance of tidal energy was essentially equal in all parts of the system; as should be expected given the minimal tidal attenuation through the system. The analysis also shows that tides are responsible for approximately 86% of the water level changes in Three Bays system. The remaining 14% was the result of atmospheric forcing, due to winds, or barometric pressure gradients. The largest tide residuals occurred at the three dates discussed earlier, October 16, October 26 and November 6. These are storm-induced surges caused by low pressure fronts moving through the area at those times, as indicated in regional meteorological data records.

V.3.3 ADCP Data Analysis

Cross-channel current measurements were surveyed through a complete tidal cycle in the Three Bays system on October 24, 2002 to resolve spatial and temporal variations in tidal current patterns. The survey was designed to observe tidal flow across five transects in the system at hourly intervals. These transects (indicated in Figure V-8) were located at the two system inlets, in the Seapuit River, as well as the entrance to West Bay, north of the eastern end of the Seapuit River. The data collected during this survey provided information that was necessary to model properly the hydrodynamics of the Three Bays system.

Figures V-15 through V-23 show color contours of the current measurements observed during the flood and ebb tides at each of the three transects. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. For example, at West Bay inlet, positive along-channel flow is to the north, and positive cross-channel flow is moving to east. In Figure V-14, the lower left panel shows depth-averaged currents across the channel projected onto a 1994 aerial photograph of the inlet. The lower right panel of each figure indicates the stage of the tide that the survey transect was taken by a vertical line through the water elevation curve.

At the inlets, maximum measured currents in the water column were between 2.5 and 3.0 ft/sec (1.5 and 1.8 knots), with the larger velocities occurring at West Bay inlet. Flow rates (computed using the ADCP velocity data) through both inlets were roughly the same during the measured tide cycle. Maximum flood flows in the morning of the October 24 were 3000 ft^3/sec at West Bay inlet, and 3200 ft^3/sec at Cotuit Bay inlet. In the afternoon, maximum ebb flows were 3500 ft^3/sec and 4700 ft^3/sec at West Bay inlet and Cotuit Bay inlet, respectively.

The ADCP data from the two Seapuit River transects were critical for the determination of the direction and magnitude of tidal flows within the river. The data show that as the tide floods into Cotuit Bay and West Bay inlets, the river flows from east to west. During the ebb stage of the tide, the flow direction in the river reverses, flowing to the east. Further analysis (Section 3) shows that the flow through the Seapuit River is driven by a slight difference in the timing of the stage of the tide between West Bay inlet and Cotuit Bay inlet.

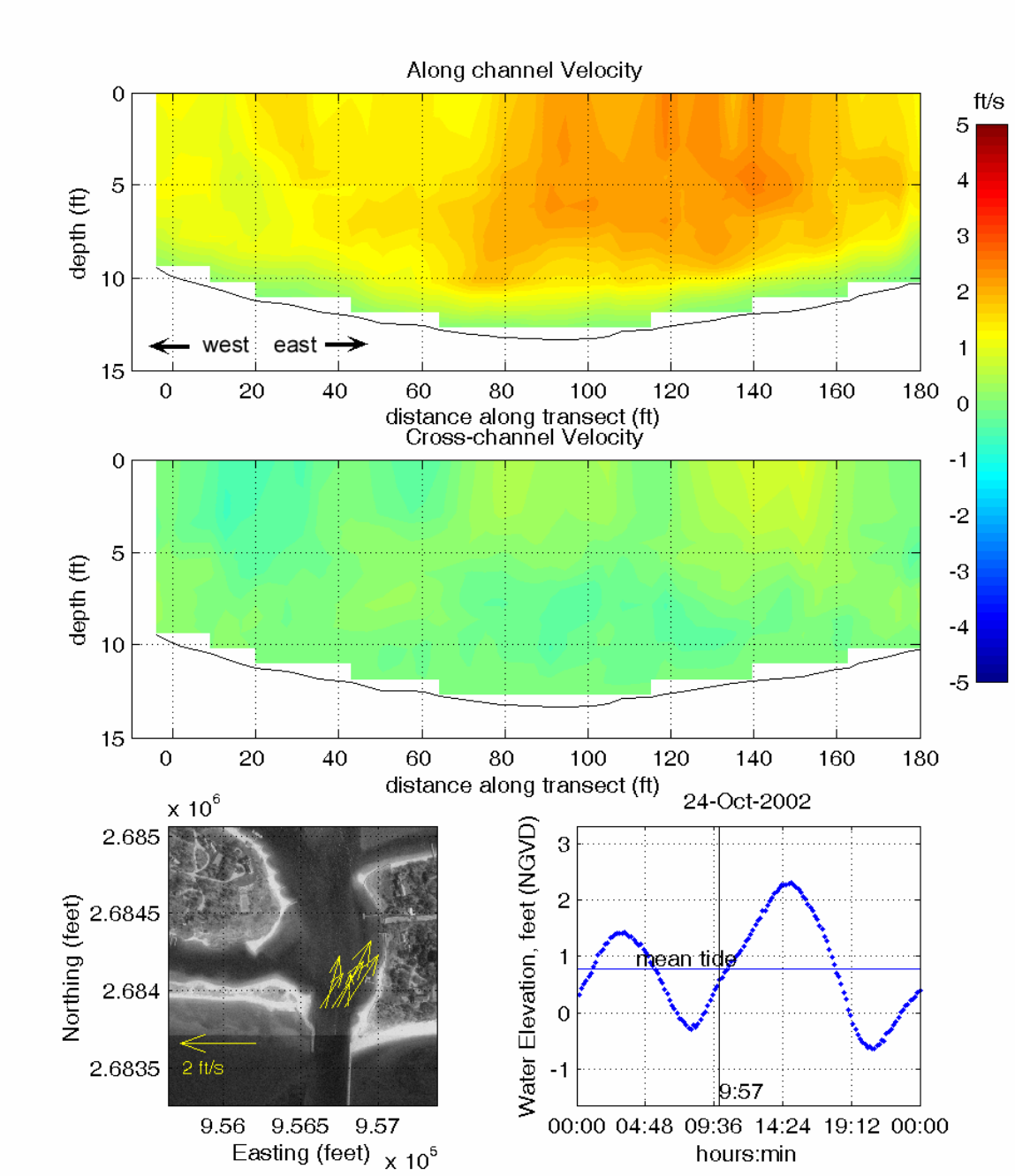


Figure V-14. Color contour plots of along-channel and cross-channel velocity components for transect line run east-to-west across West Bay inlet measured at 9:57 on October 24, 2001 during the period of maximum flood tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

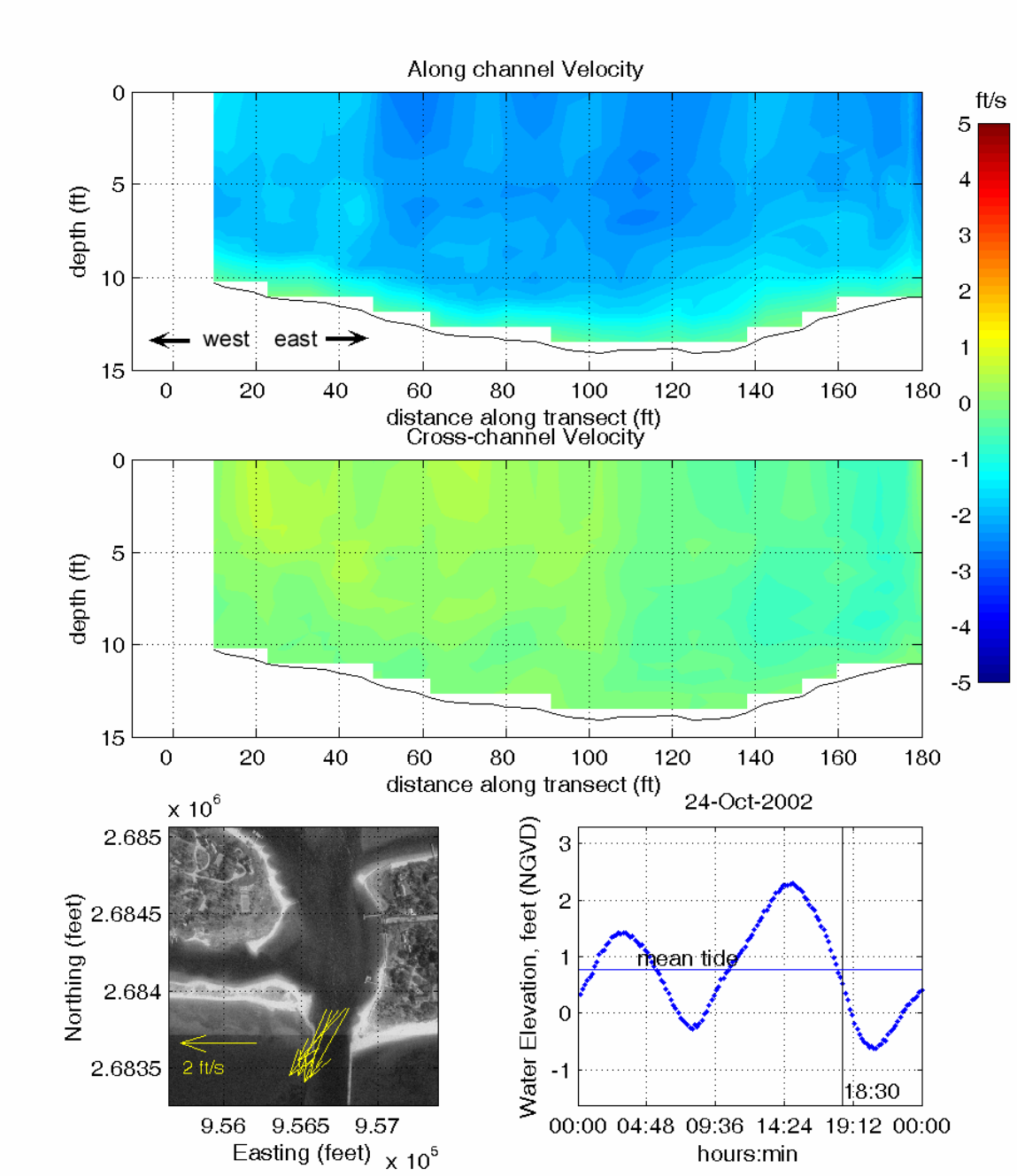


Figure V-15. Color contour plots of along-channel and cross-channel velocity components for transect line run east-to-west across West Bay inlet measured at 18:30 on October 24, 2001 during the period of maximum ebb tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

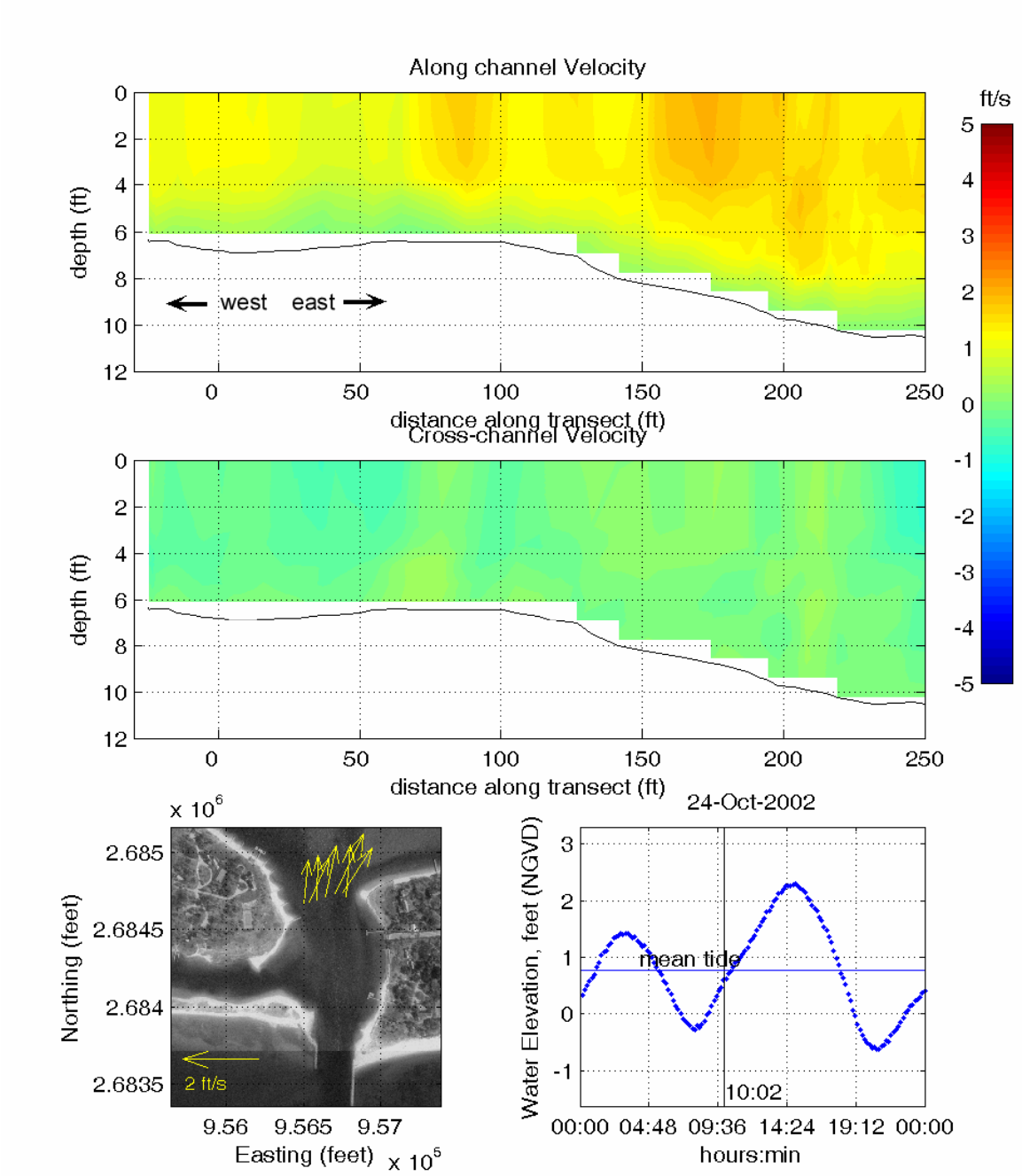


Figure V-16. Color contour plots of along-channel and cross-channel velocity components for transect line run east-to-west across the entrance to West Bay, measured at 10:02 on October 24, 2001 during the period of maximum flood tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

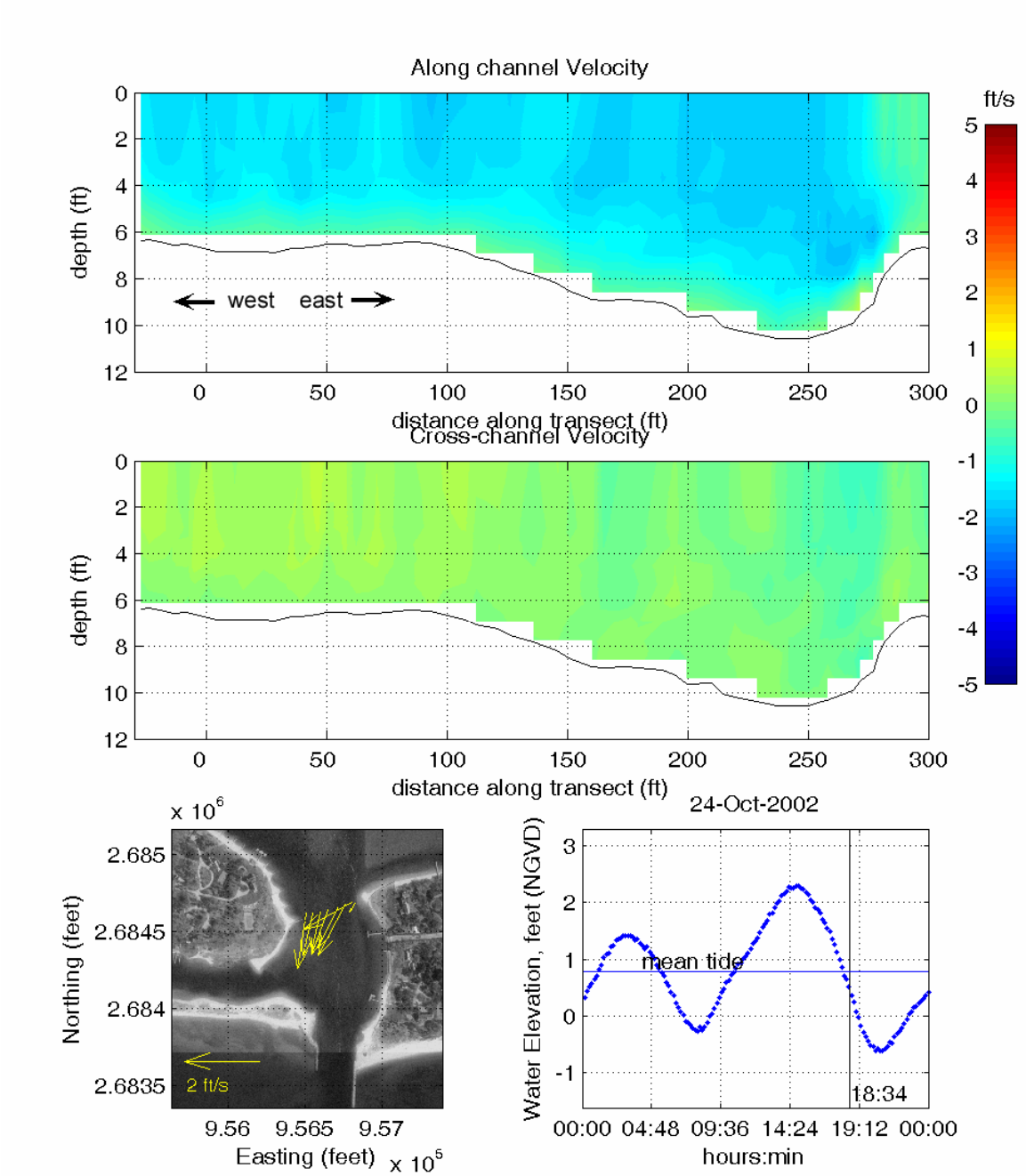


Figure V-17. Color contour plots of along-channel and cross-channel velocity components for transect line run east-to-west across the entrance to West Bay, measured at 18:34 on October 24, 2001 during the period of maximum ebb tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

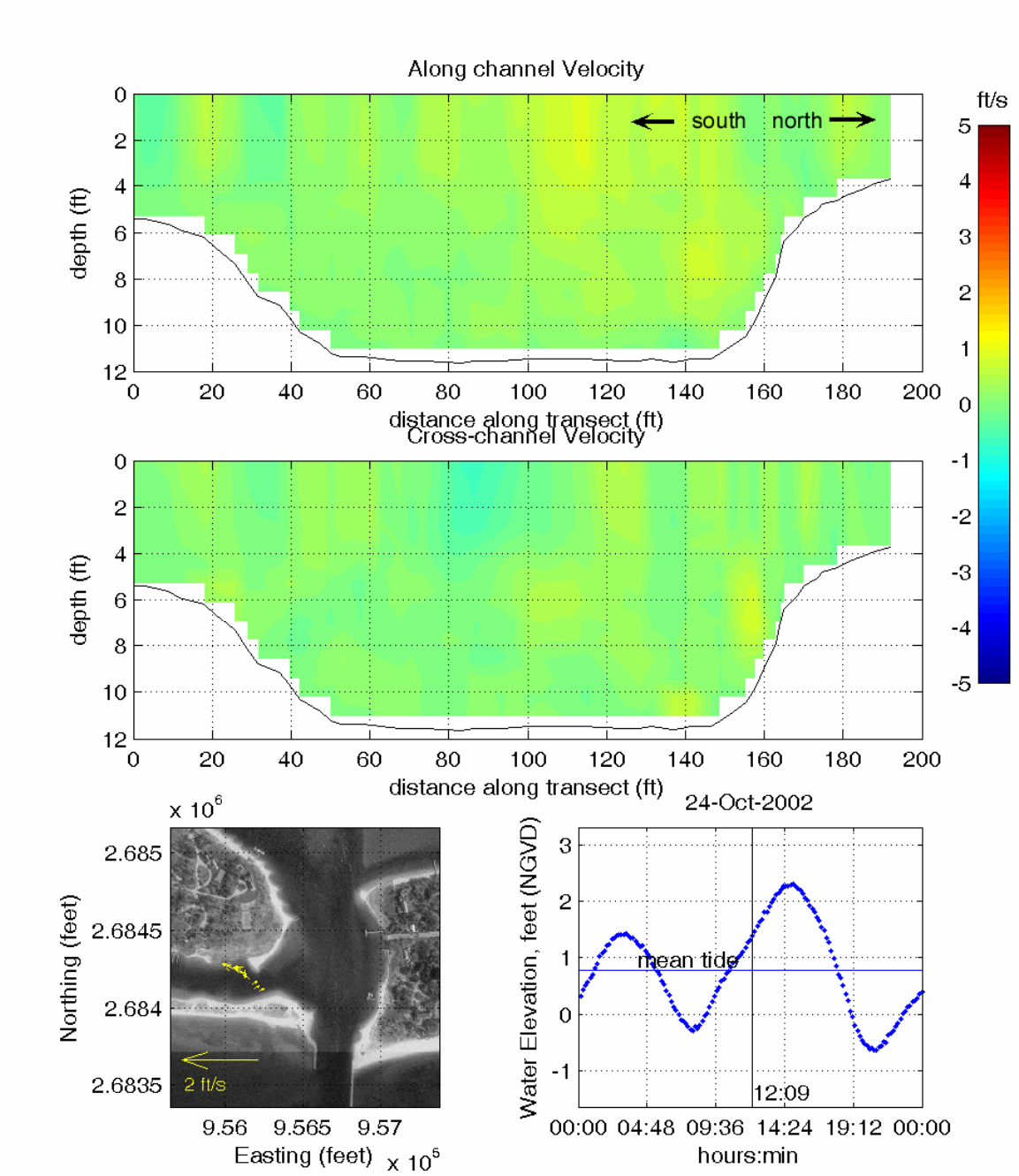


Figure V-18. Color contour plots of along-channel and cross-channel velocity components for transect line run north-to-south across the eastern end of the Seapuit River, measured at 12:09 on October 24, 2001 during the period of maximum flood tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

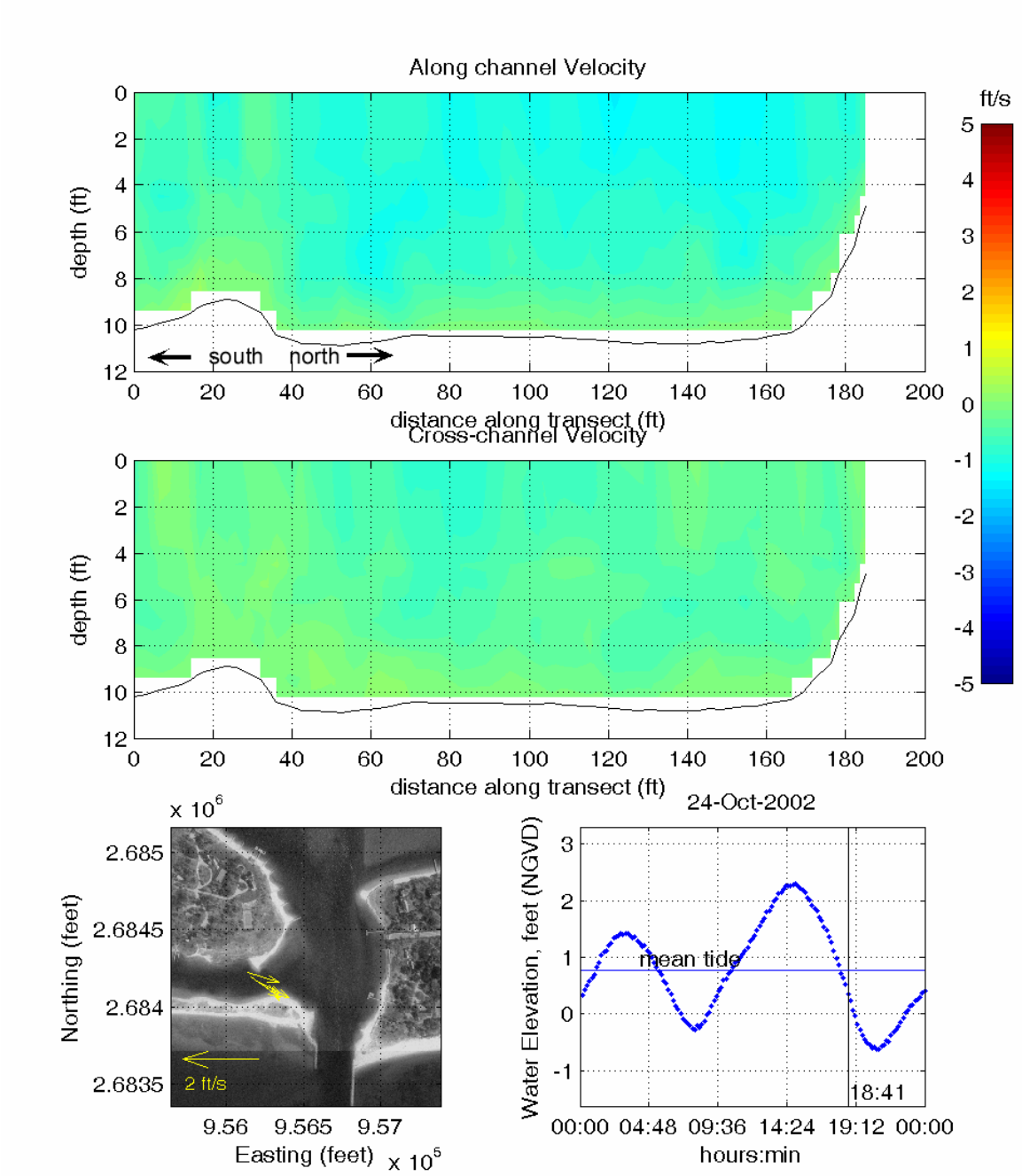


Figure V-19. Color contour plots of along-channel and cross-channel velocity components for transect line run east-to-west across the eastern end of the Seapuit River, measured at 18:41on October 24, 2001 during the period of maximum ebb tide currents. Positive along-channel currents (top panel) indicate the flow is moving into Cotuit Bay from the West Bay inlet, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

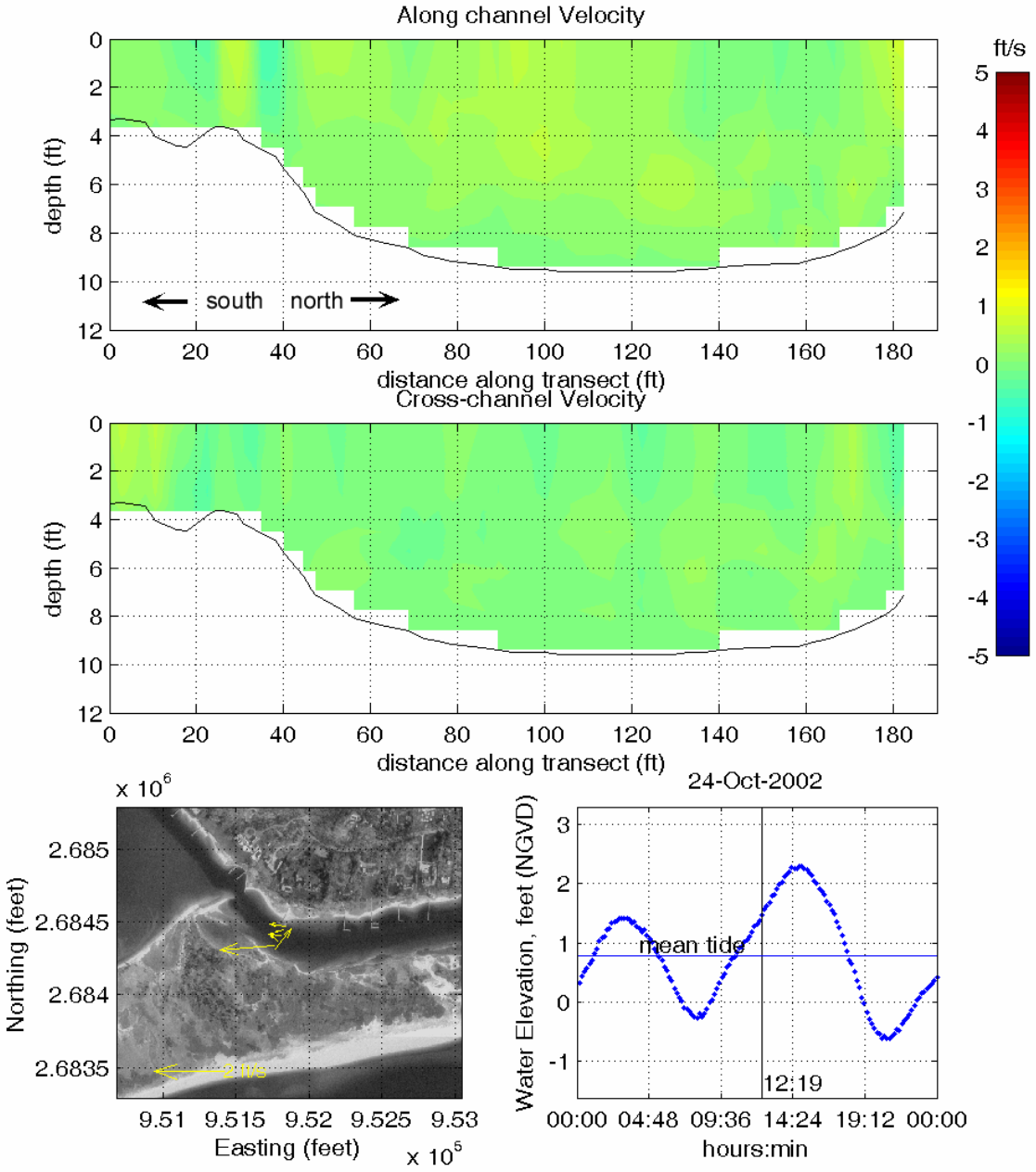


Figure V-20. Color contour plots of along-channel and cross-channel velocity components for transect line run north-to-south across the western end of the Seapuit River, measured at 12:19 on October 24, 2001 during the period of maximum flood tide currents. Positive along-channel currents (top panel) indicate the flow is moving into Cotuit Bay from the West Bay inlet, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

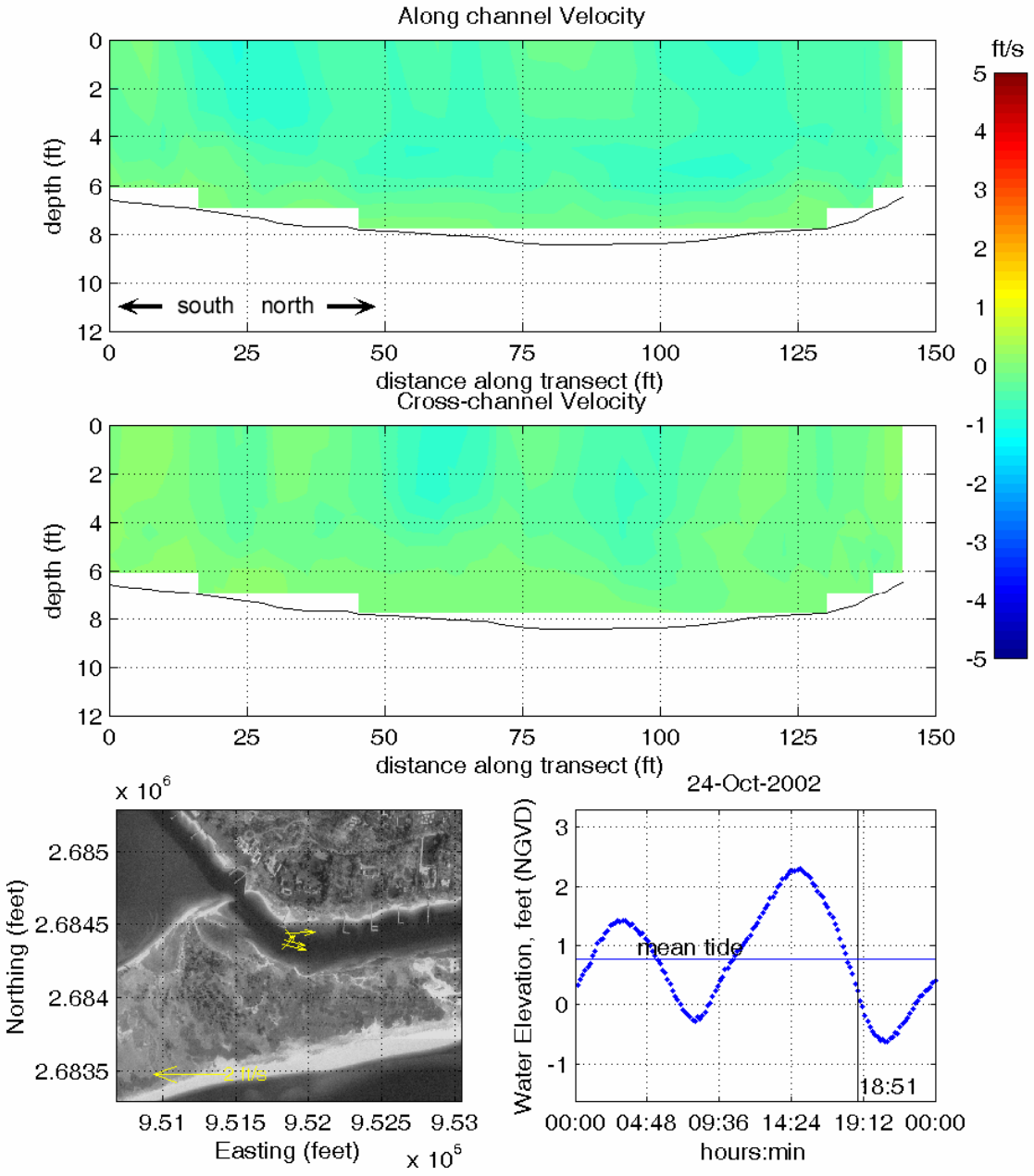


Figure V-21. Color contour plots of along-channel and cross-channel velocity components for transect line run north-to-south across the western end of the Seapuit River, measured at 18:51 on October 24, 2001 during the period of maximum ebb tide currents. Positive along-channel currents (top panel) indicate the flow is moving into Cotuit Bay from the West Bay inlet, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

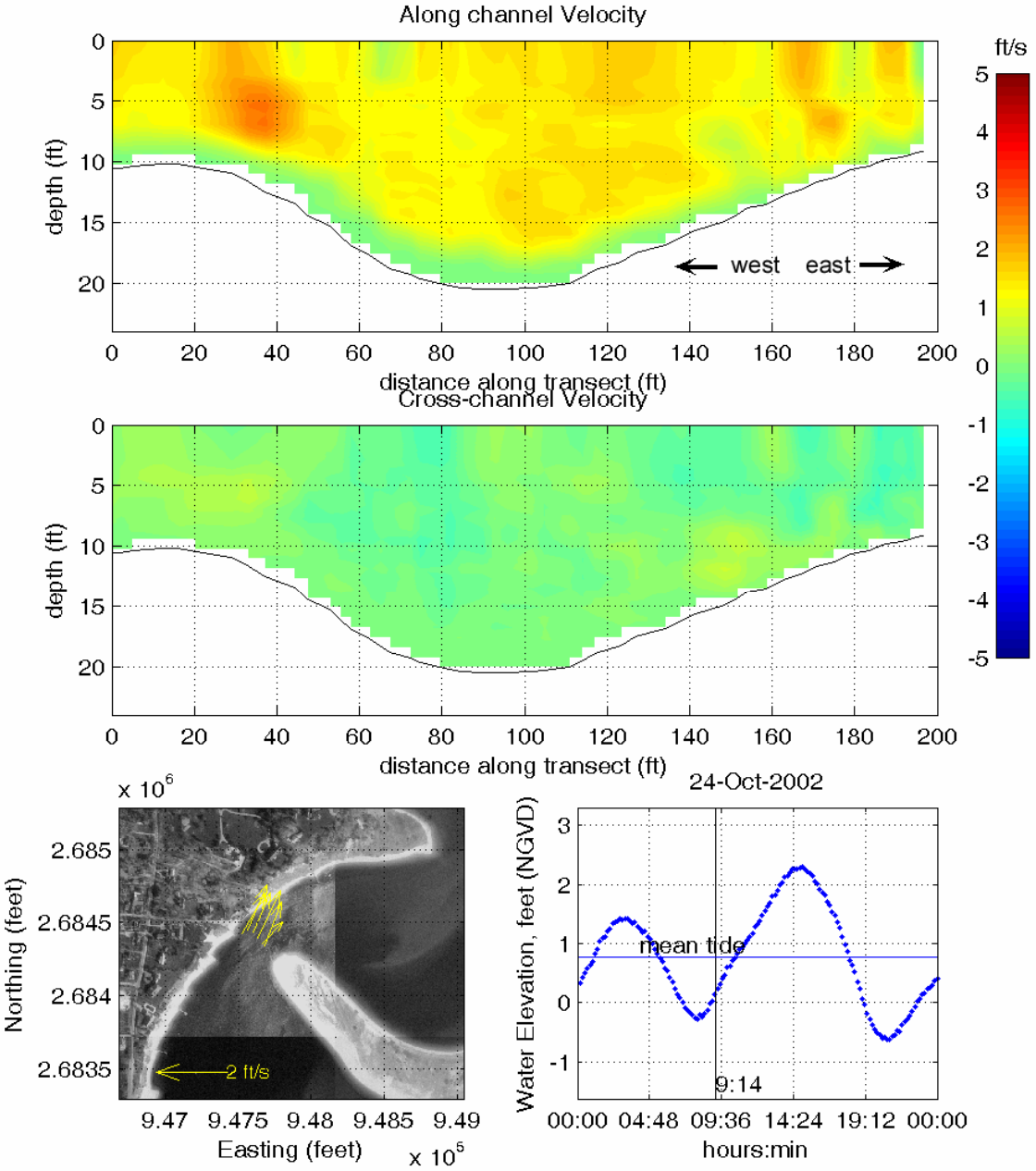


Figure V-22. Color contour plots of along-channel and cross-channel velocity components for transect line run west-to-east across Cotuit Bay Inlet, measured at 9:14 on October 24, 2001 during the period of maximum flood tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

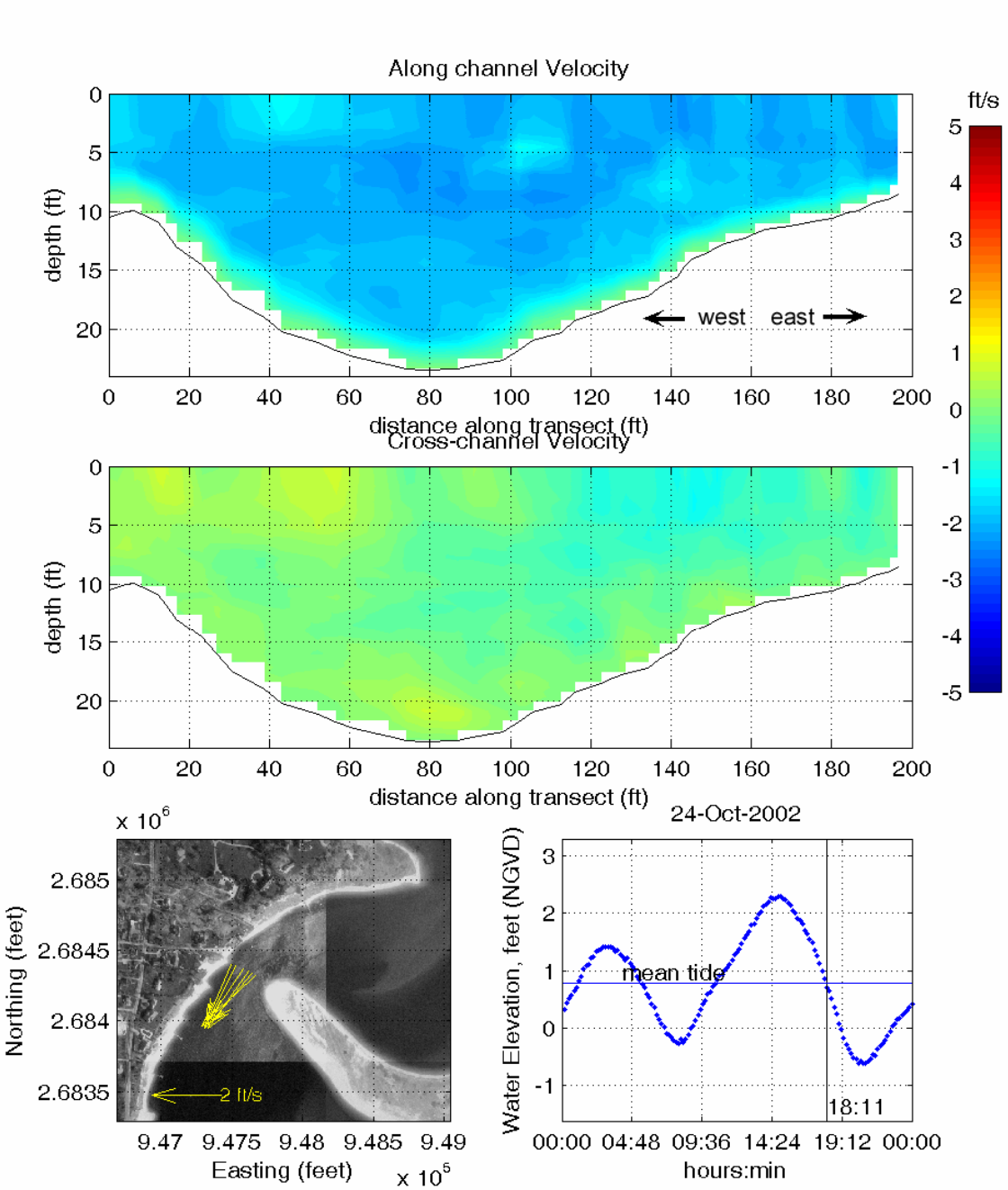


Figure V-23. Color contour plots of along-channel and cross-channel velocity components for transect line run west-to-east across Cotuit Bay Inlet, measured at 18:11 on October 24, 2001 during the period of maximum ebb tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo of the survey area. A tide plot for the survey day is also given.

V.4 HYDRODYNAMIC MODELING

For the modeling of the Three Bays system, Applied Coastal utilized a state-of-the-art computer model to evaluate tidal circulation and flushing in these systems. The particular model employed was the RMA-2 model developed by Resource Management Associates (King, 1990). It is a two-dimensional, depth-averaged finite element model, capable of simulating transient hydrodynamics. The model is widely accepted and tested for analyses of estuaries or rivers. Applied Coastal staff members have utilized RMA-2 for numerous flushing studies on Cape Cod, including West Falmouth Harbor, Popponesset Bay, Chatham embayments (Kelley, *et al*, 2001), Falmouth "finger" Ponds (Ramsey, *et al*, 2000), and Barnstable Harbor (Wood, *et al*, 1999).

V.4.1 Model Theory

In its original form, RMA-2 was developed by William Norton and Ian King under contract with the U.S. Army Corps of Engineers (Norton et al., 1973). Further development included the introduction of one-dimensional elements, state-of-the-art pre- and post-processing data programs, and the use of elements with curved borders. Recently, the graphic pre- and post-processing routines were updated by a Brigham Young University through a package called the Surfacewater Modeling System or SMS (BYU, 1998). Graphics generated in support of this report primarily were generated within the SMS modeling package.

RMA-2 is a finite element model designed for simulating one- and two-dimensional depth-averaged hydrodynamic systems. The dependent variables are velocity and water depth, and the equations solved are the depth-averaged Navier Stokes equations. Reynolds assumptions are incorporated as an eddy viscosity effect to represent turbulent energy losses. Other terms in the governing equations permit friction losses (approximated either by a Chezy or Manning formulation), Coriolis effects, and surface wind stresses. All the coefficients associated with these terms may vary from element to element. The model utilizes quadrilaterals and triangles to represent the prototype system. Element boundaries may either be curved or straight.

The time dependence of the governing equations is incorporated within the solution technique needed to solve the set of simultaneous equations. This technique is implicit; therefore, unconditionally stable. Once the equations are solved, corrections to the initial estimate of velocity and water elevation are employed, and the equations are re-solved until the convergence criteria is met.

V.4.2 Model Setup

There are three main steps required to implement RMA-2:

- Grid generation
- Boundary condition specification
- Calibration

The extent of each finite element grid was generated using 1994 digital aerial photographs from the MassGIS online orthophoto database. A time-varying water surface elevation boundary condition (measured tide) was specified at the entrances of the Three Bays system (i.e., Cotuit Bay Inlet and West Bay Inlet) based on the tide gauge data collected offshore Dead Neck, in Nantucket Sound. Once the grid and boundary conditions were set, the model was calibrated to ensure accurate predictions of tidal flushing. Various friction and eddy viscosity coefficients were adjusted, through several (10) model calibration simulations for each system,

to obtain agreement between measured and modeled tides. The calibrated model provides the requisite information for future detailed water quality modeling.

V.4.2.1 Grid generation

The grid generation process was aided by the use of the SMS package. 1994 digital aerial orthophotos and recent bathymetry survey data were imported to SMS, and a finite element grid was created to represent the estuary. The aerial photographs were used to determine the land boundary of the system. Bathymetry data were interpolated to the developed finite element mesh of the system. The completed grid consists of 5,190 nodes, which describe 1766 total 2-dimensional (depth averaged) quadratic elements, and covers 1337 acres. The maximum nodal depth is –22.9 ft (NGVD 29), in the throat of Cotuit Inlet. The completed grid mesh of the Three Bays system is shown in Figure V-24, and grid bathymetry was shown previously in Figure V-9.

The finite element grid for the system provided the detail necessary to evaluate accurately the variation in hydrodynamic properties throughout the Three Bays embayments. The SMS grid generation program was used to develop quadrilateral and triangular two-dimensional elements throughout the estuary. Grid resolution was governed by two factors: 1) expected flow patterns, and 2) the bathymetric variability of the system. Relatively fine grid resolution was employed where complex flow patterns were expected. For example, smaller node spacing in tidal creeks and channels was designed to provide a more detailed analysis in these regions of rapidly varying flow (e.g., the Cotuit Inlet, West Bay Inlet, and the Marstons Mills River). Widely spaced nodes were often employed in areas where flow patterns are not likely to change dramatically, such as in the main bodies of Cotuit Bay, West Bay, North Bay, and Prince's Cove. Appropriate implementation of wider node spacing and larger elements reduced computer run time with no sacrifice of accuracy.

V.4.2.2 Boundary condition specification

Two types of boundary conditions were employed for the RMA-2 model of the Three Bays system: 1) "slip" boundaries, and 2) tidal elevation boundaries. All of the elements with land borders have "slip" boundary conditions, where the direction of flow was constrained shore-parallel. The model generated all internal boundary conditions from the governing conservation equations. Tidal boundary conditions were specified at both inlets from Nantucket Sound, Cotuit Bay Inlet and West Bay Inlet. TDR measurements from a gauge deployed offshore Dead Neck provided the required data.

The rise and fall of the tide in Nantucket Sound is the primary driving force for estuarine circulation in this system. Dynamic (time-varying) model simulations specified a new water surface elevation at Cotuit Inlet and West Bay Inlet every model time step of 10 minutes, which corresponds to the time step of the TDR data measurements. A time lag of 3 minutes was added to the tidal boundary condition at Cotuit inlet (lagging relative to West Bay Inlet) to account for the propagation of the tide from east to west. Over the 1.7-mile distance between the two inlets, the slight difference in tidal phase subtly affects the flow dynamics within the Three Bays system. Results from the RMA-2 model of the system show that the phase difference drives the flow through the Seapuit River. The 3 minute lag was determined based on the typical difference in time of high and low tides between Hyannisport and Cotuit, as publish in tide tables by NOAA. By this method, the tide propagates an average 2800 ft/min. Alternately, a similar result can be computed using the shallow wave equation $C = \sqrt{gh}$, where C is the speed of the tidal wave computed from the gravitational constant g, and the typical

water depth *h*. This method results in a phase delay of 5 minutes. Model results discussed later in this section show that the 3-minute delay induces the correct magnitude and flow direction in the Seapuit River.

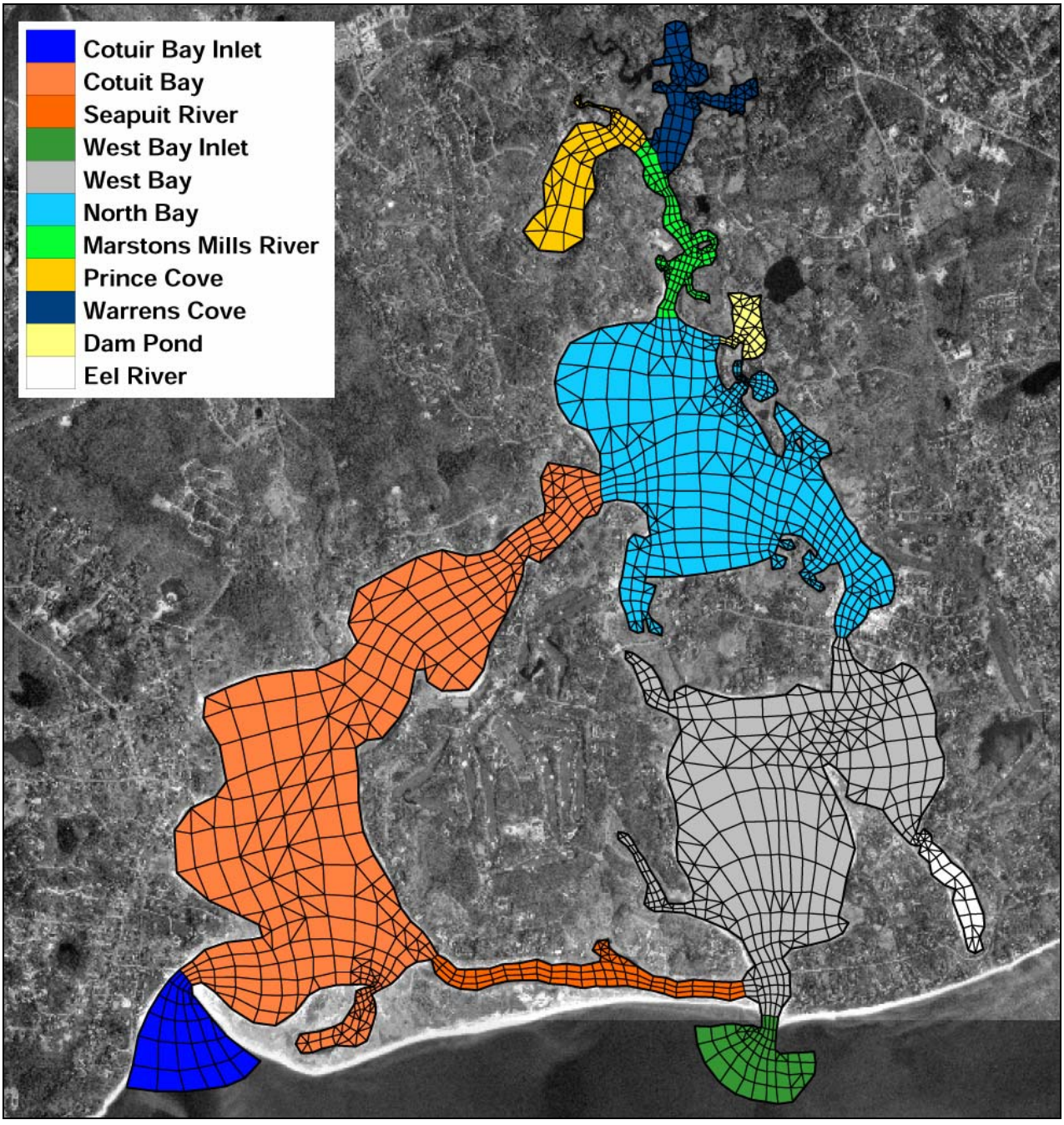


Figure V-24. Plot of hydrodynamic model grid mesh for the Three Bays system of Barnstable, MA. Color patterns designate the different model material types used to vary model calibration parameters and compute flushing rates.

V.4.2.3 Calibration

After developing the finite element grid, and specifying boundary conditions, the model for the Three Bays system was calibrated. The calibration procedure ensures that the model predicts accurately what was observed in nature during the field measurement program. Numerous model simulations are required (typically 20+) for an estuary model, specifying a range of friction and eddy viscosity coefficients, to calibrate the model.

Calibration of the hydrodynamic model required a close match between the modeled and measured tides in each of the sub-embayments where tides were measured (i.e., from the TDR deployments). Initially, the model was calibrated to obtain visual agreement between modeled and measured tides. Once visual agreement was achieved, a five lunar-day period (10 tide cycles) was modeled to calibrate the model based on dominant tidal constituents discussed in Section 3.2. The five-day period was extracted from a longer simulation to avoid effects of model spin-up, and to focus on average tidal conditions. Modeled tides for the calibration time period were evaluated for time (phase) lag and height damping of dominant tidal constituents.

The calibration was performed for a five-day period beginning October 8, 2002 1430 EST. This representative time period included the spring tide range of conditions, where the tide range and tidal currents are greatest, and model numerical stability is often most sensitive. To provide average tidal forcing conditions for model verification and the flushing analysis, a separate time period was chosen that spanned the transition between spring and neap tide ranges (bi-weekly maximum and minimum tidal ranges, respectively). For model verification and the flushing analysis, the 7 lunar-day period (14 tide cycles, or 7.25 solar days) beginning October 11, 2002 0000 EST was used.

The calibrated model was used to analyze system flow patterns and compute residence times. The ability to model a range of flow conditions is a primary advantage of a numerical tidal flushing model. For instance, average residence times were computed using the entire seven-day simulation. Other methods, such as dye and salinity studies, evaluate tidal flushing over relatively short time periods (less than one day). These short-term measurement techniques may not be representative of average conditions due to the influence of unique, short-lived atmospheric events.

V.4.2.3.1 Friction coefficients

Friction inhibits flow along the bottom of estuary channels or other flow regions where velocities are relatively high. Friction is a measure of the channel roughness, and can cause both significant amplitude damping and phase delay of the tidal signal. Friction is approximated in RMA-2 as a Manning coefficient, and is applied to grid areas by user specified material types. Initially, Manning's friction coefficient values of 0.03 were specified for all element material types. This values corresponds to typical Manning's coefficients determined experimentally in smooth earth-lined channels with no weeds (low friction) (Henderson, 1966).

During calibration, friction coefficients were incrementally changed throughout the model domain. Final model calibration runs incorporated various specific values for Manning's friction coefficients, depending upon flow damping characteristics of separate regions within the estuary system. Manning's values for different bottom types were initially selected based ranges provided by the Civil Engineering Reference Manual (Lindeburg, 1992), and values were incrementally changed when necessary to obtain a close match between measured and modeled tides. Final calibrated friction coefficients are summarized in the Table V-5.

Table V-5. Manning's Roughness coefficients used in simulations of modeled embayments. These embayment delineations correspond to the material type areas shown in Figure V-24.

System Embayment	Bottom Friction
Cotuit Bay Inlet	0.030
Cotuit Bay	0.030
Seapuit River	0.025
West Bay Inlet	0.030
West Bay	0.030
North Bay	0.030
Marstons Mills River	0.035
Prince's Cove	0.035
Warren's Cove	0.035
Dam Pond	0.030
Eel River	0.030

V.4.2.3.2 Turbulent exchange coefficients

Turbulent exchange coefficients approximate energy losses due to internal friction between fluid particles. The significance of turbulent energy losses increases where flow is swifter, such as inlets and bridge constrictions. According to King (1990), these values are proportional to element dimensions (numerical effects) and flow velocities (physics). Typically, model turbulence coefficients were set between 80 and 200 lb-sec/ft^2. In most cases, the Three Bays system was relatively insensitive to turbulent exchange coefficients. The exception was at the inlets, where higher exchange coefficient values (200 lb-sec/ft^2) were used to ensure numerical stability in these areas characterized by strong turbulent flows and large velocity magnitudes.

V.4.2.3.3 Wetting and Drying

Modeled hydrodynamics were complicated by wetting/drying cycles in shallow flats included in the model of the Three Bays system. A method was employed to simulate the periodic inundation and drying of tidal flats in the system. Nodal wetting and drying is a feature of RMA-2 that allows grid elements to be removed and re-inserted during the course of the model run. The wetting and drying feature has two keys benefits for the simulation, 1) it enhances the stability of the model by eliminating nodes that have bottom elevations that are higher than the water surface elevation at that time, and 2) it reduces total model run time because node elimination can reduce the size of the computational grid significantly during periods of a model run. Wetting and drying is employed for estuarine systems with relatively shallow borders and/or tidal flats.

V.4.2.3.4 Comparison of modeled tides and measured tide data

A best-fit of model predictions for the TDR deployment was achieved using the aforementioned values for friction and turbulent exchange. Figures V-25 through and V-31 illustrate the five-day calibration simulation along with a 50-hour sub-section. Modeled (solid line) and measured (dotted line) tides are illustrated at each model location with a corresponding TDR.

Although visual calibration achieved reasonable modeled tidal hydrodynamics, further tidal constituent calibration was required to quantify the accuracy of the models. Calibration of M_2

(principle lunar semidiurnal constituent) was the highest priority since M_2 accounted for a majority of the forcing tide energy in the modeled systems. Due to the duration of the model runs, four dominant tidal constituents were selected for constituent comparison: K_1, M_2, M_4, and M_6. Measured tidal constituent heights (H) and time lags (ϕ_{lag}) shown in Table V-6 for the calibration period differ from those in Table V-2 because constituents were computed for only the five-day section of the 38-days represented in Table W. Table V-6 compares tidal constituent amplitude (height) and relative phase (time) for modeled and measured tides at the TDR locations. The constituent phase shows the relative timing of each separate constituent at a particular location, and also the change (or phase lag) in timing of a single constituent at different locations in an estuary.

The constituent calibration resulted in excellent agreement between modeled and measured tides. The largest errors associated with tidal constituent amplitude were on the order of 0.01 ft, which is better than the order of accuracy of the tide gauges (±0.12 ft). Time lag errors were typically less than the time increment resolved by the model (1/6 hours or 10 minutes), indicating good agreement between the model and data.

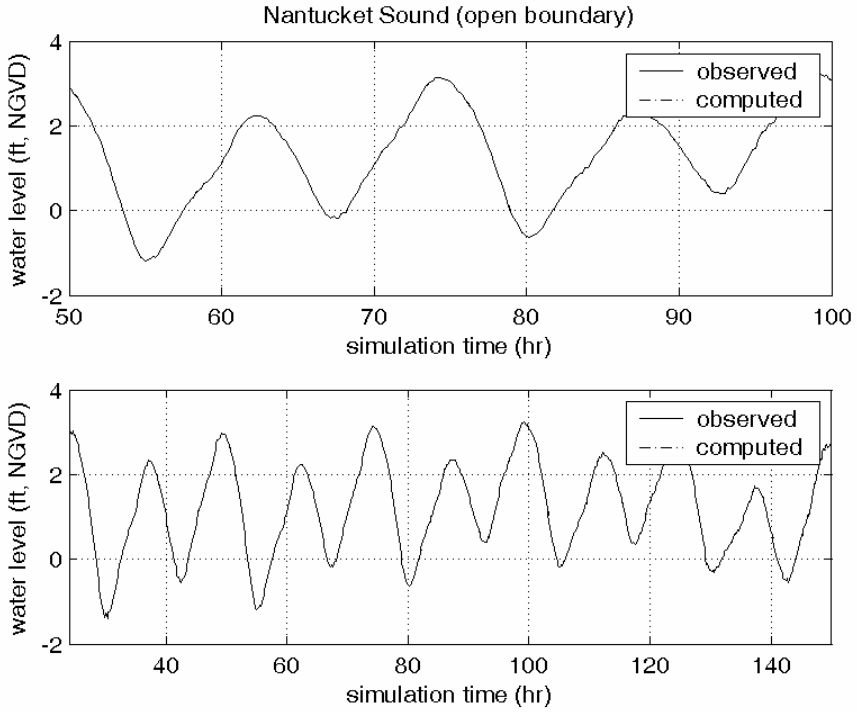


Figure V-25. Comparison of model output and measured tides for the TDR location offshore Dead Neck, in Nantucket Sound. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

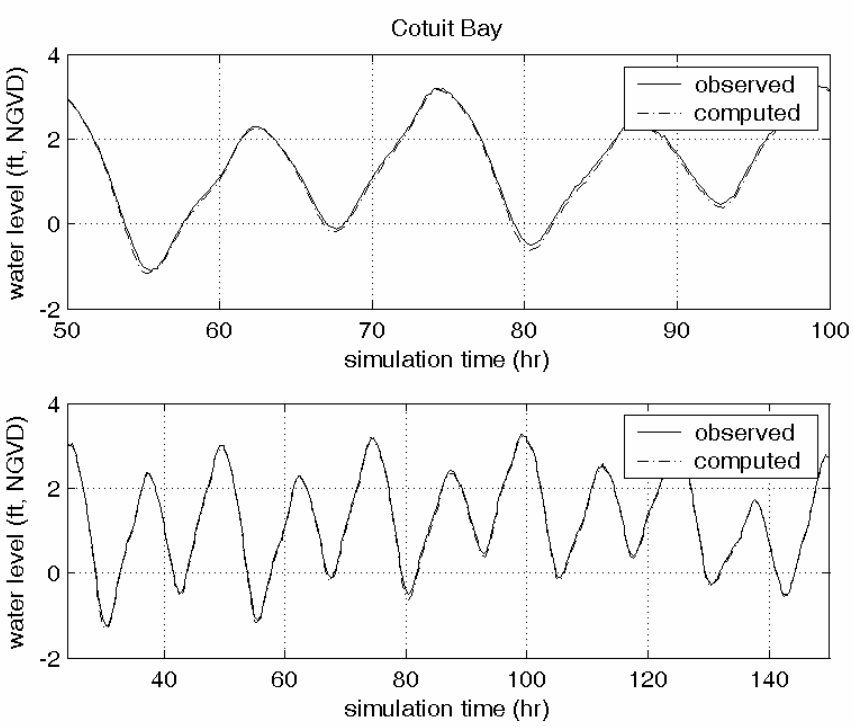


Figure V-26. Comparison of model output and measured tides for the TDR location in lower Cotuit Bay. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

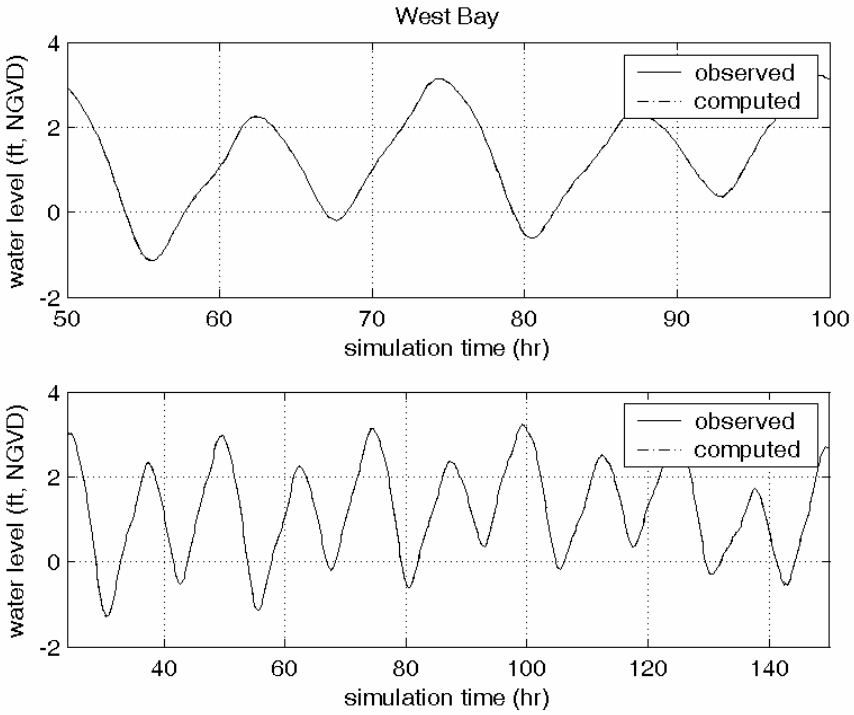


Figure V-27. Comparison of model output and measured tides for the TDR location in West Bay. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

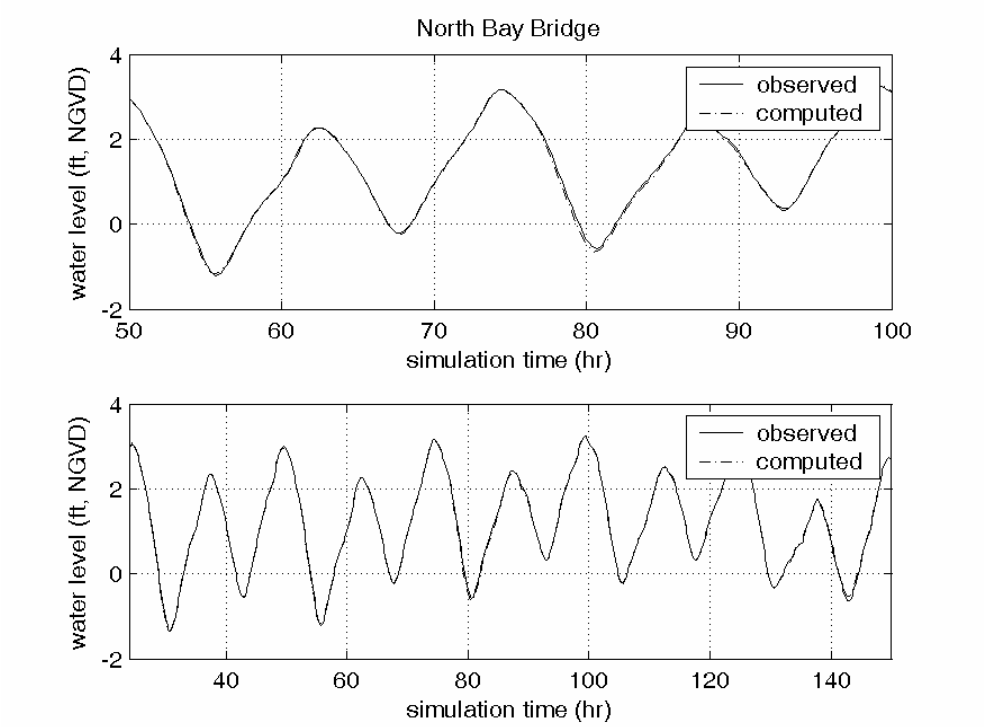


Figure V-28. Comparison of model output and measured tides for the TDR location at Oyster Harbors Marina, near the Little Island draw bridge. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

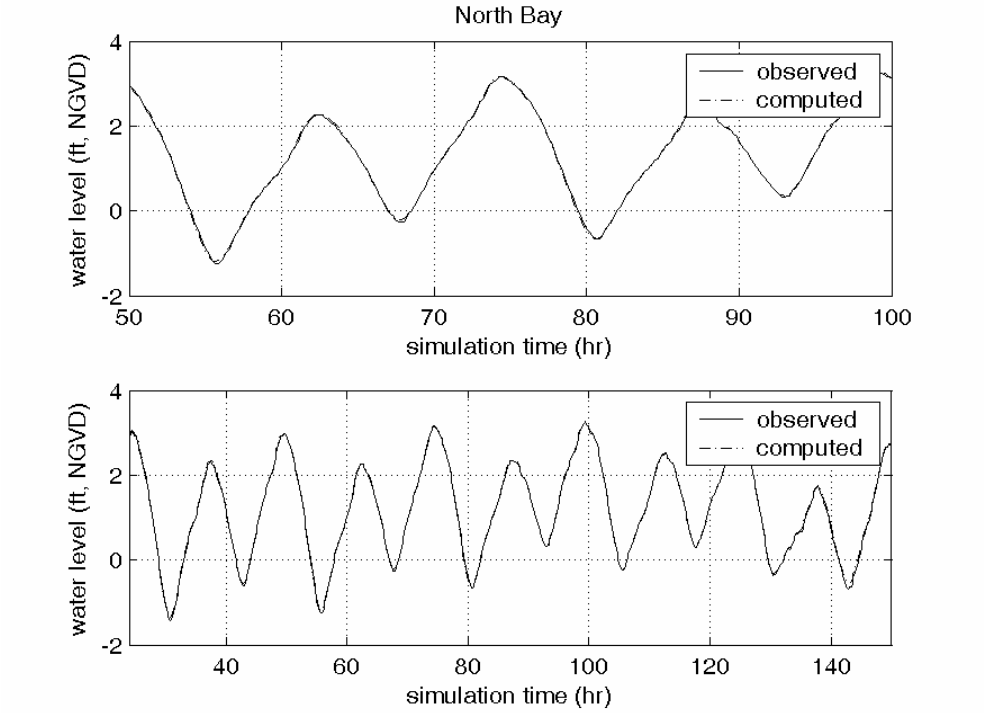


Figure V-29. Comparison of model output and measured tides for the TDR location in North Bay, off Point Isabelle. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

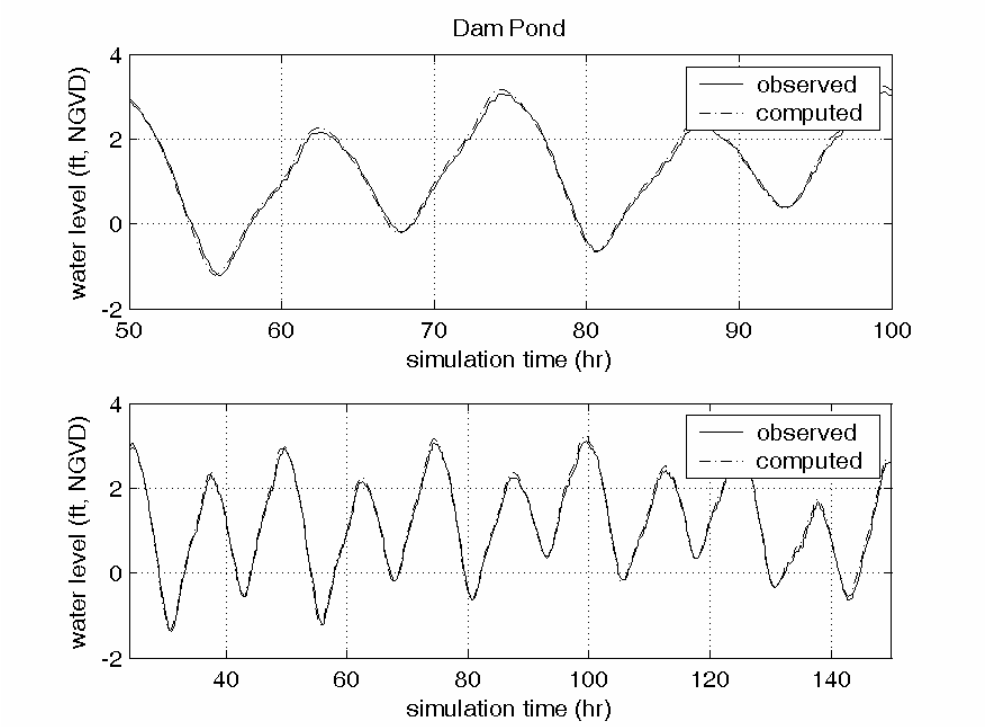


Figure V-30. Comparison of model output and measured tides for the TDR location in Dam Pond. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

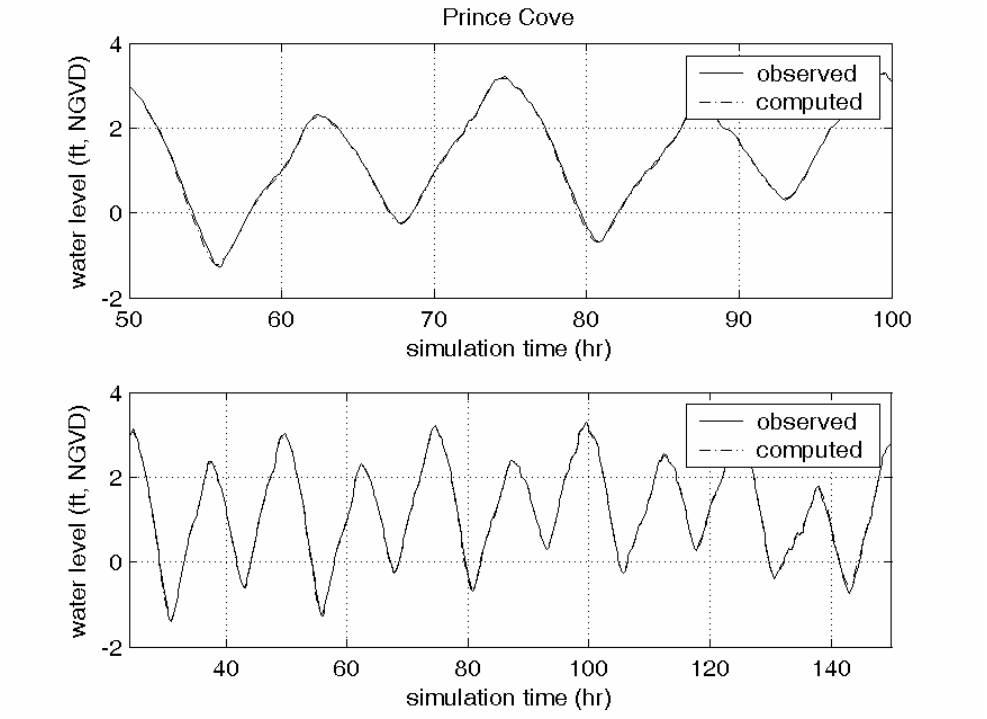


Figure V-31. Comparison of model output and measured tides for the TDR location in Prince's Cove. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

V.4.2.4 Model Verification

The calibration procedure used in the development of the Three Bays finite-element model required a match between measured and modeled tides. An additional model verification run was performed to verify the model performance during time periods different from the calibration time period. In this fashion, the calibrated model is tested to ensure its accuracy when run for any time period outside the calibration period. The results of the model verification runs are shown in Table V-7. The analysis of the verification model runs in this table shows that the model performs with a similar excellent degree of accuracy to the calibration runs.

Table V-6. Tidal constituents for measured water level data and calibrated model output, with model error amplitudes, for the Three-Bays system, during modeled calibration time period.

Model calibration run						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound*	1.39	0.20	0.09	0.41	26.0	152.8
Cotuit Bay	1.39	0.20	0.09	0.42	30.2	162.2
West Bay	1.39	0.18	0.10	0.42	31.2	165.7
North Bay Bridge	1.39	0.18	0.11	0.42	33.0	172.2
North Bay	1.40	0.17	0.11	0.42	33.4	174.0
Dam Pond	1.40	0.17	0.11	0.42	33.8	175.0
Prince's Cove	1.40	0.17	0.12	0.42	35.5	180.5
Measured tide during calibration period						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound*	1.39	0.20	0.09	0.41	26.0	152.7
Cotuit Bay	1.37	0.19	0.10	0.41	30.1	164.3
West Bay	1.38	0.18	0.10	0.41	31.0	167.4
North Bay Bridge	1.39	0.17	0.11	0.40	33.5	176.6
North Bay	1.38	0.18	0.10	0.41	33.8	178.8
Dam Pond	1.35	0.17	0.12	0.41	37.5	185.5
Prince's Cove	1.39	0.16	0.13	0.41	35.9	185.4
Error						
Location	Error Amplitude (ft)				Phase error (min)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound*	0.00	0.00	0.00	0.00	0	0
Cotuit Bay	0.02	0.01	-0.01	0.01	0	0
West Bay	0.01	0.00	0.00	0.01	0	2
North Bay Bridge	0.00	0.01	0.00	0.02	1	5
North Bay	0.02	-0.01	0.01	0.01	1	5
Dam Pond	0.05	0.00	-0.01	0.01	8	11
Prince's Cove	0.01	0.01	-0.01	0.01	1	5

*model open boundary

Table V-7. Tidal constituents for measured water level data and calibrated model output, with model error amplitudes, for the Three-Bays system, during modeled verification time period.

Model verification run						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound*	1.13	0.17	0.06	0.40	175.8	93.2
Cotuit Bay	1.13	0.16	0.07	0.40	179.7	102.2
West Bay	1.13	0.16	0.07	0.40	180.5	105.0
North Bay Bridge	1.13	0.15	0.07	0.40	182.1	110.0
North Bay	1.14	0.16	0.08	0.40	182.4	111.3
Dam Pond	1.14	0.15	0.08	0.40	182.7	112.1
Prince's Cove	1.14	0.15	0.08	0.40	184.4	116.7
Measured tide during verification period						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound*	1.13	0.17	0.07	0.40	176.1	92.1
Cotuit Bay	1.12	0.16	0.07	0.40	179.5	102.2
West Bay	1.13	0.16	0.08	0.39	184.5	119.8
North Bay Bridge	1.13	0.16	0.08	0.39	182.3	112.2
North Bay	1.13	0.16	0.07	0.39	180.4	105.7
Dam Pond	1.09	0.16	0.09	0.40	187.8	124.9
Prince's Cove	1.13	0.16	0.09	0.40	184.5	119.8
Error						
Location	Error Amplitude (ft)				Phase error (min)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound*	0.00	0.00	-0.01	0.00	1	-1
Cotuit Bay	0.01	0.00	0.00	0.00	-1	0
West Bay	0.00	0.00	-0.01	0.01	0	1
North Bay Bridge	0.00	-0.01	-0.01	0.01	1	2
North Bay	0.01	0.00	0.01	0.01	1	3
Dam Pond	0.05	-0.01	-0.01	0.00	10	13
Prince's Cove	0.01	-0.01	-0.01	0.00	0	3

*model open boundary

V.4.2.5 ADCP verification of the Three Bays system

An additional model verification check was possible by using collected ADCP velocity data to verify the performance of the Three Bays system model. Computed flow rates from the model were compared to flow rates determined using the measured velocity data. The ADCP data survey efforts are described in Section 2. For the model ADCP verification, the Three Bays model was run for the period covered during the ADCP survey on October 24, 2002. Model flow rates were computed in RMA-2 at continuity lines (channel cross-sections) that correspond to the actual ADCP transects followed in each survey (i.e., across each inlet, at the entrance to West Bay, and at the east and west ends of the Seapuit River).

Comparisons of the measured and modeled volume flow rates in the Three Bays system are shown in Figures V-32 through V-36. For each figure, the top plot shows the flow

comparison, and the lower plot shows the time series of tide elevation for the same period. Each ADCP point (blue triangles shown on the plots) is a summation of flow measured along the ADCP transect. The 'bumps' and 'skips' of the flow rate curve (more evident in the model output) can be attributed to the effects of winds (i.e., atmospheric effects) on the water surface and friction across the seabed periodically retarding or accelerating the flow through the inlets, and inside the system channels. If water surface elevations changed smoothly as a sinusoid, the volume flow rate would also appear as a smooth curve. However, since the rate at which water surface elevations change does not vary smoothly, the flow rate curve is expected to show short-period fluctuations.

Data comparisons at all five ADCP transect show exceptionally good agreement with the model predictions. The calibrated model accurately describes the discharge magnitude at each line, even in the Seapuit River where flow rates are an order of magnitude less than at each inlet. For all transects the R^2 correlation coefficients between data and model results are between 0.99 and 0.83. The lowest correlation is at the West Seapuit transect (R^2 value of 0.83) which is still good considering the low volume flow rates, which are more difficult to measure at this transect. Correlation statistics between the modeled and measured flows for each ADCP transect are presented in Table V-8.

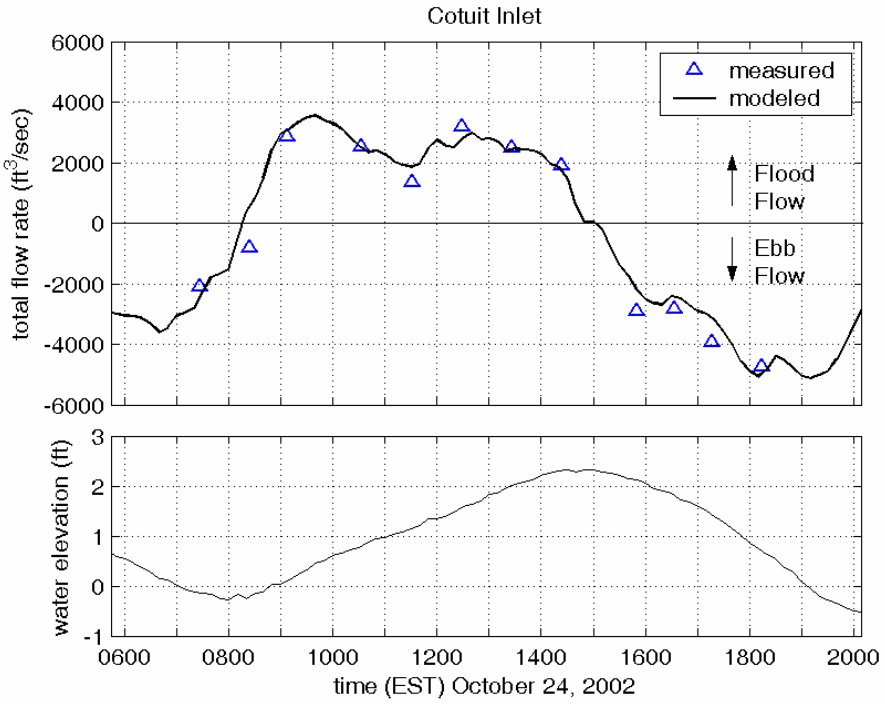


Figure V-32. Comparison of measured volume flow rates versus modeled flow rates (top plot) through the Cotuit Bay Inlet over a tidal cycle on October 24, 2001. Flood flows into the inlet are positive (+), and ebb flows out of the inlet are negative (-). The bottom plot shows the tide elevation offshore Dead Neck. (R^2 =0.96).

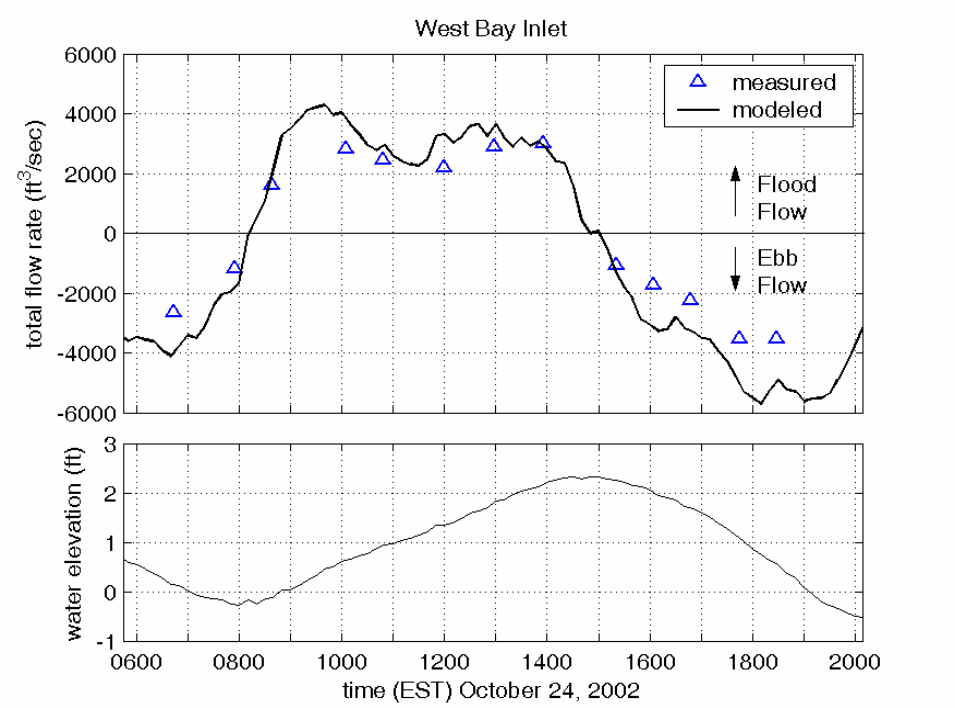


Figure V-33. Comparison of measured volume flow rates versus modeled flow rates (top plot) through West Bay Inlet over a tidal cycle on October 24, 2001. Flood flows into the inlet are positive (+), and ebb flows out of the inlet are negative (-). The bottom plot shows the tide elevation offshore Dead Neck. (R^2=0.84).

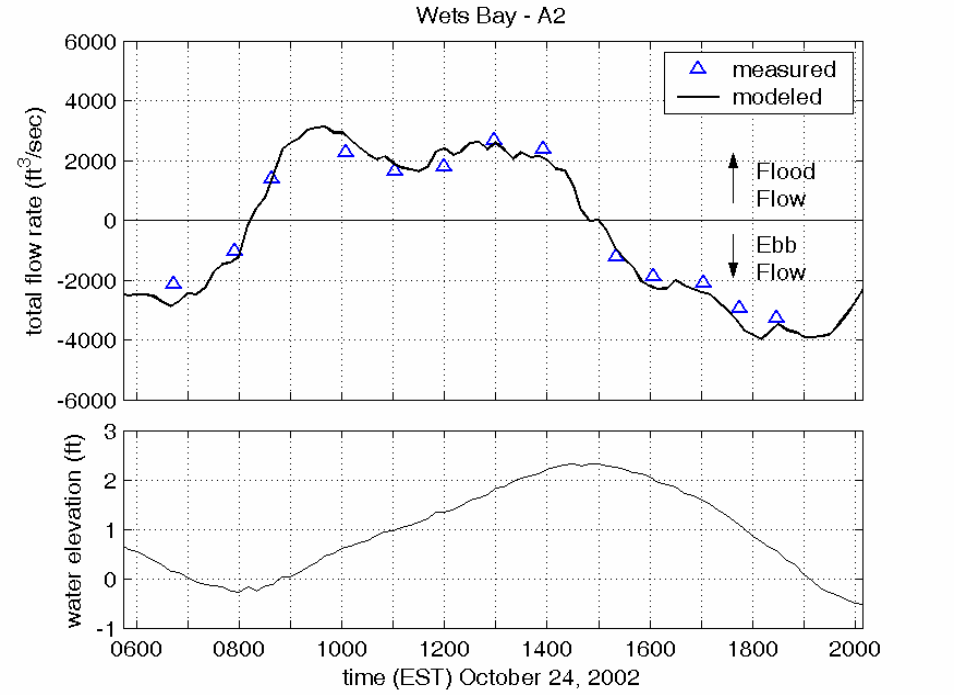


Figure V-34. Comparison of measured volume flow rates versus modeled flow rates (top plot) through the entrance to West Bay, at transect A2, over a tidal cycle on October 24, 2001. Flood flows into the bay are positive (+), and ebb flows out of the bay are negative (-). The bottom plot shows the tide elevation offshore Dead Neck. (R^2=0.97).

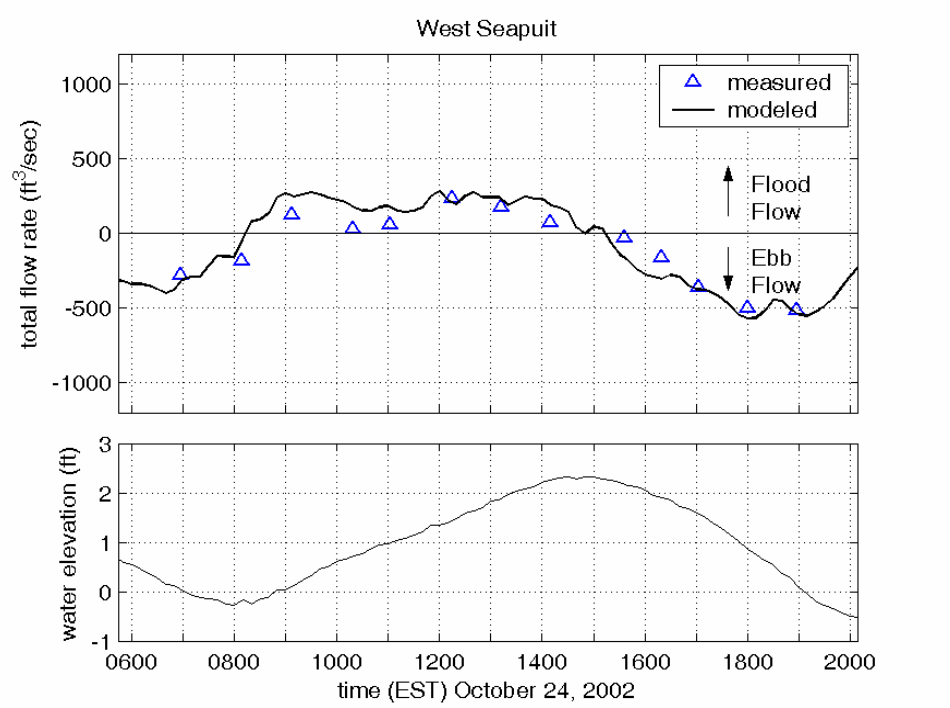


Figure V-35. Comparison of measured volume flow rates versus modeled flow rates (top plot) through the west entrance to the Seapuit River over a tidal cycle on October 24, 2001. Flood flows are positive (+), and ebb flows are negative (-). The bottom plot shows the tide elevation offshore Dead Neck. (R^2=0.83).

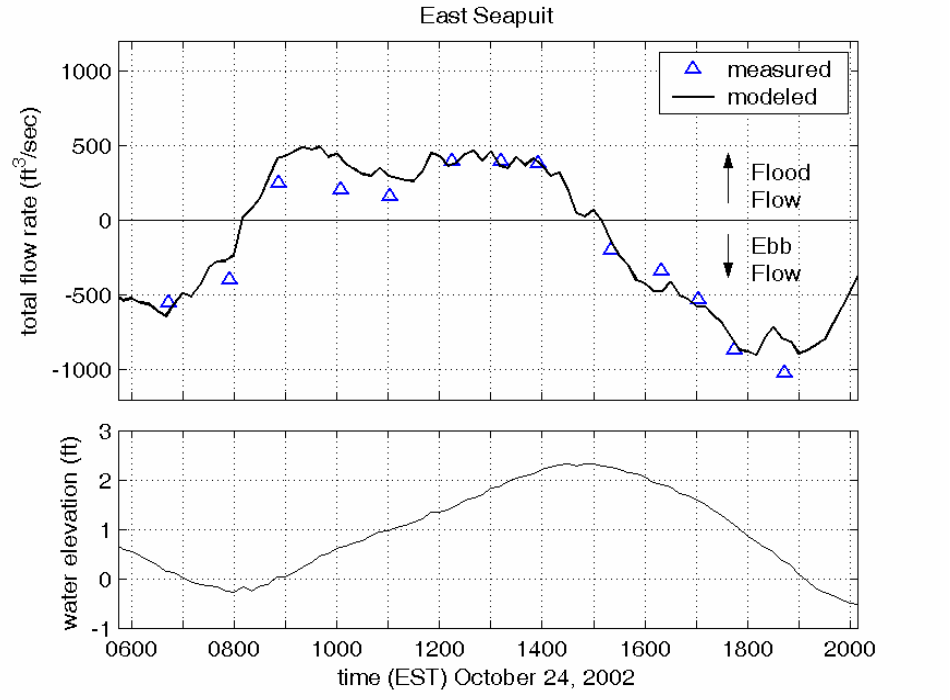


Figure V-36. Comparison of measured volume flow rates versus modeled flow rates (top plot) through the east entrance to the Seapuit River over a tidal cycle on October 24, 2001. Flood flows are positive (+), and ebb flows are negative (-). The bottom plot shows the tide elevation offshore Dead Neck. (R^2=0.94).

Table V-8. Correlation statistics between modeled and measured total flow rates at the five ADCP transects				
Transect	R^2 correlation	RMS error (ft^3/sec)	Max Error (ft^3/sec)	Min Error (ft^3/sec)
Cotuit Bay Inlet	0.96	595	1613	20
West Bay Inlet	0.84	1007	1784	203
West Bay – A2	0.97	369	740	65
West Seapuit	0.83	99	156	9
East Seapuit	0.94	114	212	2

V.4.2.6 Model Circulation Characteristics

The final calibrated model serves as a useful tool in investigating the circulation characteristics of the Three Bays system. Using model inputs of bathymetry and tide data, current velocities and flow rates can be determined at any point in the model domain. This is a very useful feature of a hydrodynamic model, where a limited amount of collected data can be expanded to determine the physical attributes of the system in areas where no physical data record exists.

From the model run of the Three Bays system, maximum ebb velocities in the inlet channels are slightly larger than velocities during maximum flood. Maximum depth-averaged flood velocities in the model are approximately 1.5 feet/sec at West Bay Inlet and 1.1 ft sec at Cotuit Bay inlet, while maximum ebb velocities are about 2.1 feet/sec at West Bay inlet and 1.7 ft/sec at Cotuit Bay Inlet. At both the Little Island Bridge and the Cotuit Bay entrance to North Bay, typical peak flood and ebb velocities are 0.8 ft/sec and 1.1 ft/sec, respectively. Close-up views of model output are presented in Figure V-37 and V-38, which show contours of velocity magnitude along with velocity vectors that indicate flow direction, each for a single model time-step, at the portion of the tide where maximum ebb velocities occur (in Figure V-37), and for maximum flood velocities in Figure V-38.

In addition to depth-averaged velocities, the total flow rate of water flowing through a channel can be computed with the hydrodynamic model. For the flushing analysis in the next section, flow rates were computed across 12 separate transects in the Three Bays system. The variation of flow as the tide floods and ebbs at the two system inlets is seen in the plot of flow rates in Figure V-39. Maximum flow rates occur during ebbing tides in this system. During spring tides, the maximum flood flow rates reach 4500 ft^3/sec at West Bay Inlet. Maximum ebb flow rates during spring tides are slightly greater at West Bay Inlet, about 6800 ft^3/sec. Minimum flood flows at West Bay Inlet during neap tides are 3300 ft^3/sec, and minimum ebb flows during neap tides are approximately 4300 ft^3/sec. The flow magnitudes through Cotuit Inlet are typically 10% less than the flows through West Bay Inlet.

The model is useful to demonstrate some of the unique hydrodynamic traits of the Three Bays system. The Seapuit River, for example, is a rare feature among estuaries in general. It is connected at both ends to separate embayments, which in turn have their own inlets to the ocean. It would be difficult to define the upstream and downstream portions of this tidal river based only on its geographical characteristics. However, ADCP measurements, and model results show that there is a definite “downstream” flow direction. Flow through the Seapuit River is driven by the time difference (lag) of the tide stage between Cotuit Inlet and West Bay Inlet. When the tide is flooding, the river will flow from east to west (the “upstream” direction), and *vice versa* for an ebbing tide. Both model and measurements show that peak flows at the west end of the river are less than peak flows at the east end. At first, this result may seem problematic,

as a violation of mass conservation. The expectation is that for a river without additional tributary input, flow across any cross-stream transect should be the same. However, for the Seapuit River, a large portion of the flow into the river during a flooding tide does not exit the other end because it stays within the river basin, resulting in an increase in water elevation. Integrating the flow curves over a half tide cycle (e.g., from slack low to slack high tide) and subtracting the total flow though the west transect from the total flow trough the east transect results in the total tide prism between the two transects (i.e., the tide prism of the Seapuit River). This can be expressed as

$$V_{prism} = \int \left[\left(\frac{dV}{dt} \right)_{east} - \left(\frac{dV}{dt} \right)_{west} \right] dt$$

where V_{prism} is the prism volume, and dV/dt is the volume flow rate across the indicated transect. During the ADCP survey time period, the tide prism is computed to be about 3.6×10^6 cubic feet.

Another feature of the Three Bays system model is a persistent tidal eddy (or gyre) in Cotuit Bay, which is set-up during flooding tides. The eddy can be seen in model output shown in Figure V-40, to the north of Bluff Point in Cotuit. The eddy has a faint counter-clock-wise rotation, with velocity magnitudes that are less than 0.2 ft/sec.

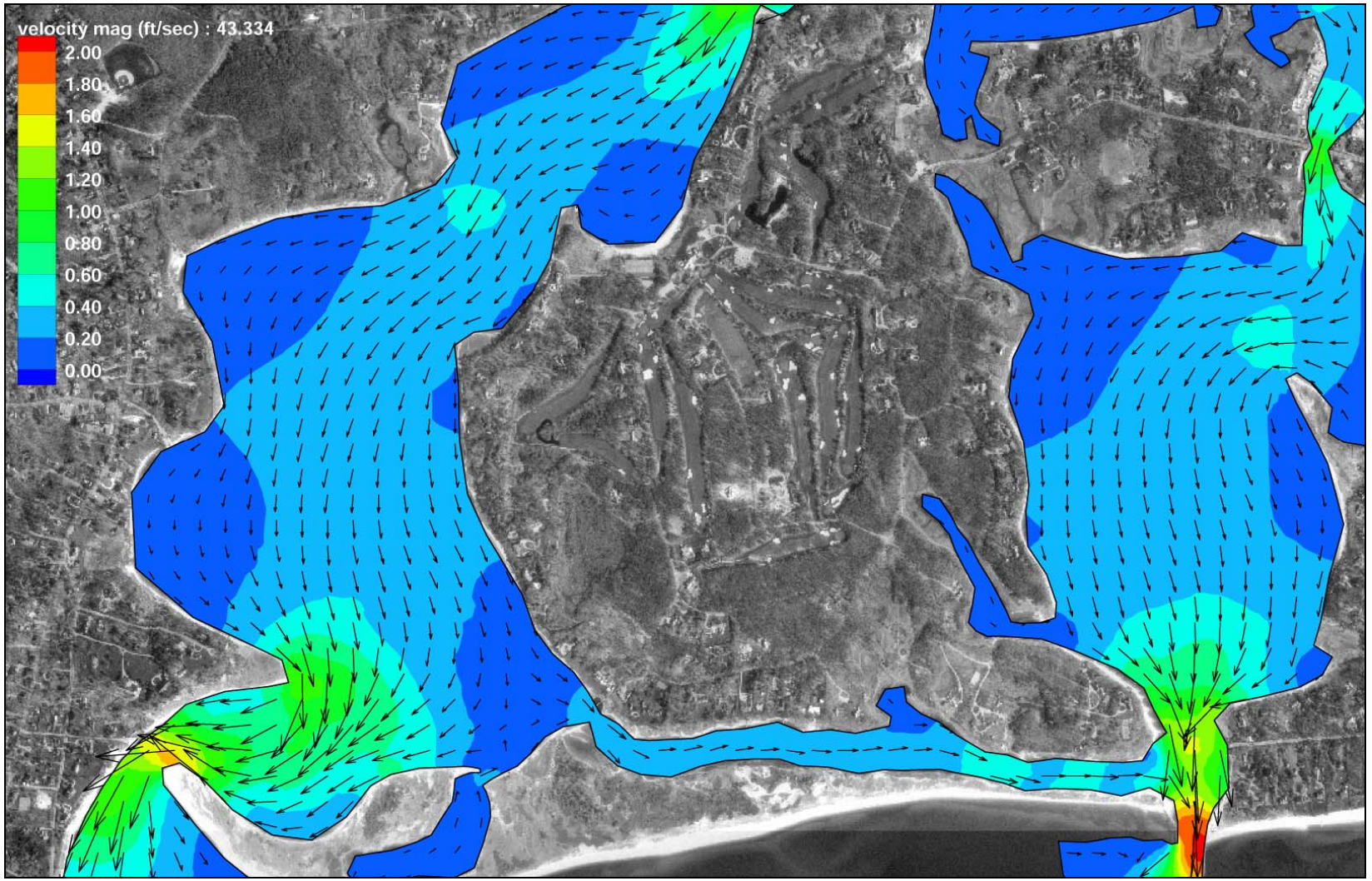


Figure V-37. Example of hydrodynamic model output for a single time step where maximum ebb velocities occur for this tide cycle. Color contours indicate velocity magnitude, and vectors indicate the direction of flow.

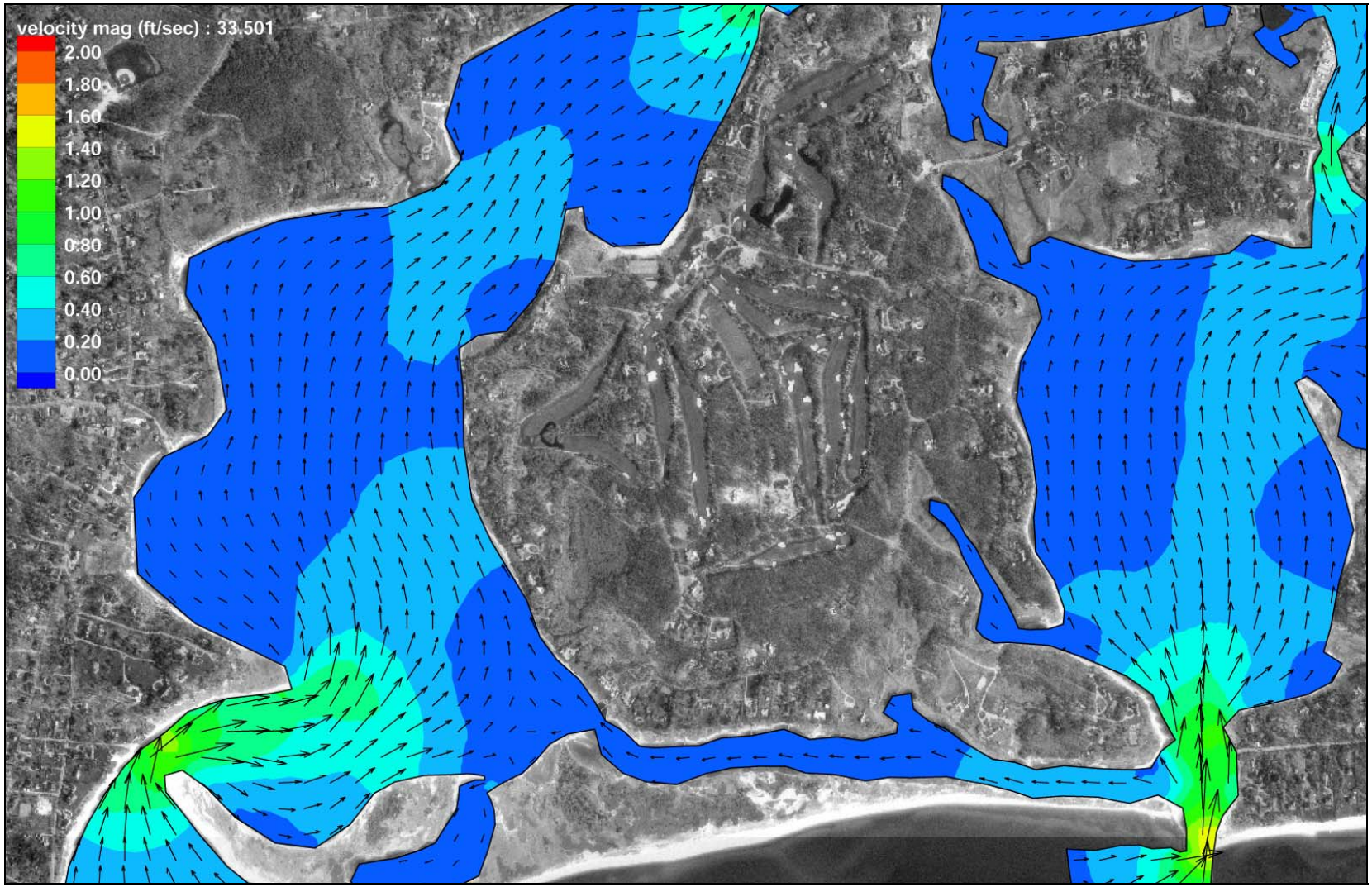


Figure V-38. Example of hydrodynamic model output for a single time step where maximum ebb velocities occur for this tide cycle. Color contours indicate velocity magnitude, and vectors indicate the direction of flow.

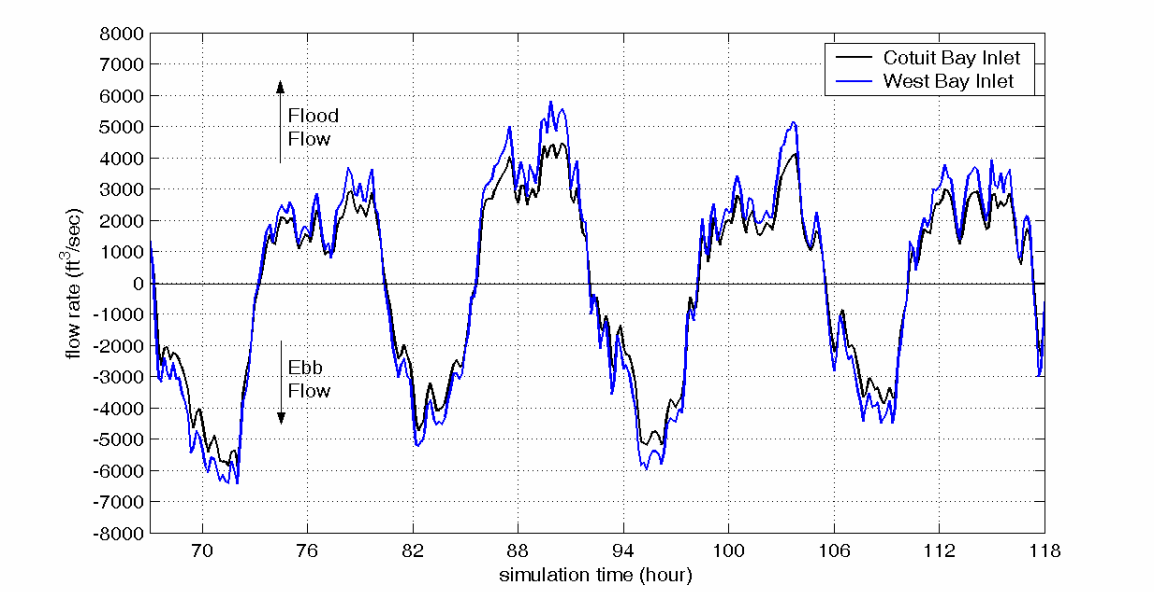


Figure V-39. Time variation of computed flow rates for the two inlets of the Three Bays system. . Plotted time period represents four tide cycles (12.42 h cycle). Positive flow indicated flooding tide, while negative flow indicates ebbing tide.

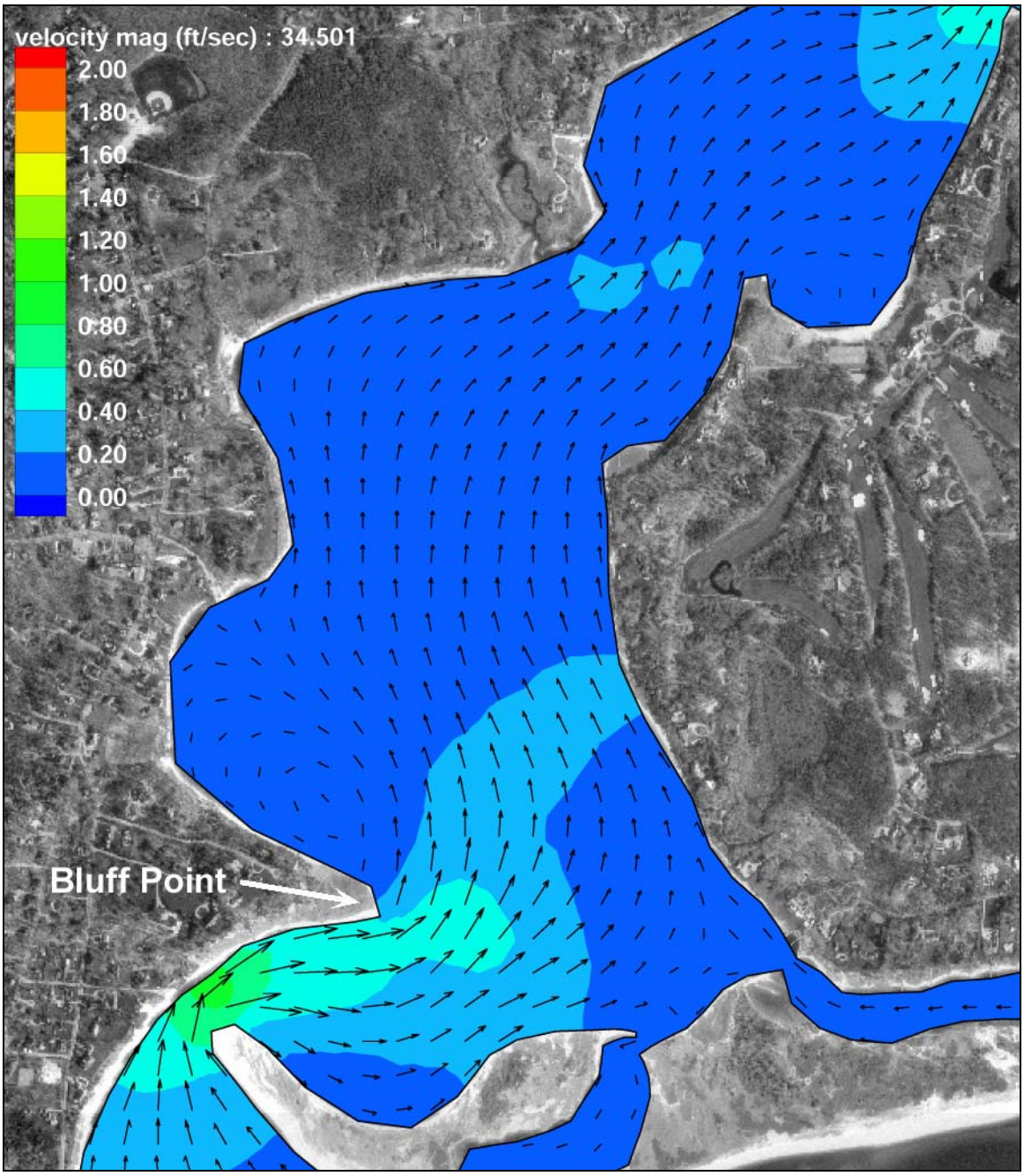


Figure V-40. Close-up of Cotuit Bay, showing output from the Three Bays hydrodynamic model at a single time step, where a recirculation eddy (or gyre) has set up on the north side of Bluff Point.

V.5 FLUSHING CHARACTERISTICS

Since the magnitude of freshwater inflow is much smaller in comparison to the tidal exchange through each inlet, the primary mechanism controlling estuarine water quality within the modeled Three Bays system is tidal exchange. A rising tide offshore in Nantucket Sound creates a slope in water surface from the ocean into the modeled systems. Consequently, water flows into (floods) the system. Similarly, the estuary drains into the open waters of Nantucket Sound on an ebbing tide. This exchange of water between the system and the

ocean is defined as tidal flushing. The calibrated hydrodynamic model is a tool to evaluate quantitatively tidal flushing of the Three Bays system, and was used to compute flushing rates (residence times) and tidal circulation patterns.

Flushing rate, or residence time, is defined as the average time required for a parcel of water to migrate out of an estuary from points within the system. For this study, **system residence times** were computed as the average time required for a water parcel to migrate from a point within the each embayment to the entrance of the system. System residence times are computed as follows:

$$T_{system} = \frac{V_{system}}{P} t_{cycle}$$

where T_{system} denotes the residence time for the system, V_{system} represents volume of the (entire) system at mean tide level, P equals the tidal prism (or volume entering the system through a single tidal cycle), and t_{cycle} the period of the tidal cycle, typically 12.42 hours (or 0.52 days). To compute system residence time for a sub-embayment, the tidal prism of the sub-embayment replaces the total system tidal prism value in the above equation.

In addition to system residence times, a second residence, the **local residence time**, was defined as the average time required for a water parcel to migrate from a location within a sub-embayment to a point outside the sub-embayment. Using Dam Pond as an example, the **system residence time** is the average time required for water to migrate from Dam Pond, through North Bay, out through West Bay or Cotuit Bay, and into Nantucket Sound, where the **local residence time** is the average time required for water to migrate from Dam Pond to just North Bay (not all the way to the Sound). Local residence times for each sub-embayment are computed as:

$$T_{local} = \frac{V_{local}}{P} t_{cycle}$$

where T_{local} denotes the residence time for the local sub-embayment, V_{local} represents the volume of the sub-embayment at mean tide level, P equals the tidal prism (or volume entering the local sub-embayment through a single tidal cycle), and t_{cycle} the period of the tidal cycle (again, 0.52 days).

Residence times are provided as a first order evaluation of estuarine water quality. Lower residence times generally correspond to higher water quality; however, residence times may be misleading depending upon pollutant/nutrient loading rates and the overall quality of the receiving waters. As a qualitative guide, **system residence times** are applicable for systems where the water quality within the entire estuary is degraded and higher quality waters provide the only means of reducing the high nutrient levels. For the Three Bays system this approach is applicable, since it assumes the main system has relatively lower quality water relative to Nantucket Sound.

The rate of pollutant/nutrient loading and the quality of water outside the estuary both must be evaluated in conjunction with residence times to obtain a clear picture of water quality. It is impossible to evaluate an estuary's health based solely on flushing rates. Efficient tidal flushing (low residence time) is not an indication of high water quality if pollutants and nutrients are loaded into the estuary faster than the tidal circulation can flush the system. Neither are low

residence times an indicator of high water quality if the water flushed into the estuary is of poor quality. Advanced understanding of water quality will be obtained from the calibrated hydrodynamic model by extending the model to include pollutant/nutrient dispersion. The water quality model will provide a valuable tool to evaluate the complex mechanisms governing estuarine water quality in the Three Bays system.

Since the calibrated RMA-2 model simulated accurate two-dimensional hydrodynamics in the system, model results were used to compute residence times. Residence times were computed for the entire estuary, as well the six sub-embayments within the system. In addition, **system** and **local residence times** were computed to indicate the range of conditions possible for the system.

Residence times were calculated as the volume of water (based on the mean volumes computed for the simulation period) in the entire system divided by the average volume of water exchanged with each sub-embayment over a flood tidal cycle (tidal prism). Units then were converted to days. The volume of the entire estuary was computed as cubic feet. Model divisions used to define the system sub-embayments include 1) the entire Three Bays system, 2) North Bay, including the Marstons Mills River, Prince's Cove and Warren's Cove, 3) the Marstons Mills River with Prince's Cove and Warren's Cove, 4) Prince's Cove, 5) Warren's Cove, 6) Dam Pond, and 7) Eel River. These system divisions follow the model material type areas designated in Figure V-24. Sub-embayment mean volumes and tide prisms are presented in Table V-9.

Residence times were averaged for the tidal cycles comprising a representative 7 lunar day period (14 tide cycles), and are listed in Table V-10. The modeled time period used to compute the flushing rates was that same as the model verification period, and included the transition from neap to spring tide conditions. The RMA-2 model calculated flow crossing specified grid lines for each sub-embayment to compute the tidal prism volume. Since the 7 lunar day period used to compute the flushing rates of the system represent average tidal conditions, the measurements provide the most appropriate method for determining mean flushing rates for the system sub-embayments.

Table V-9. Embayment mean volumes and average tidal prism during simulation period.

Embayment	Mean Volume (ft^3)	Tide Prism Volume (ft^3)
Three Bays System	429,117,000	140,570,000
North Bay	139,666,000	45,824,000
Marstons Mills River	25,236,000	10,834,000
Prince's Cove	13,007,000	4,553,000
Warren's Cove	5,047,000	3,614,000
Dam Pond	2,798,000	1,200,000
Eel River	4,035,000	1,702,000

Table V-10. Computed System and Local residence times for embayments in the Three Bays system.

Embayment	System Residence Time (days)	Local Residence Time (days)
Three Bays System	1.6	1.6
North Bay	4.8	1.6
Marstons Mills River	20.5	1.2
Prince's Cove	48.8	1.5
Warren's Cove	61.4	0.7
Dam Pond	185.1	1.2
Eel River	130.5	1.2

The computed flushing rates for the Three Bays system show that as a whole, the system flushes well. A flushing time of 1.6 days for the entire estuary shows that on average, water is resident in the system less than two days. All system sub-embayments have local flushing times that are equal to or less than 2 days. Warren's Cove has the shortest local flushing time, because of its small mean sub-embayment volume, relative to its tide prism.

The low local residence times in all areas of the Three Bays system show that they would likely have good water quality if the system water with which it exchanges also has good water quality. For example, the water quality of Eel River would likely be good as long as the water quality of West Bay was also good. Actual water quality would still also depend upon the total nutrient load to each embayment.

For the smaller sub-embayments of the Three Bays system, computed system residence times are typically one or two orders of magnitude longer than their corresponding local residence time. System residence times provide a qualitative measure that helps to identify the relative sensitivity of different sub-embayments to nutrient loading.

Based on our knowledge of estuarine processes, we estimate that the combined errors associated with the method applied to compute residence times are within 10% to 15% of "true" residence times, for the Three Bays system. Possible errors in computed residence times can be linked to two sources: the bathymetry information and simplifications employed to calculate residence time. In this study, the most significant errors associated with the bathymetry data result from the process of interpolating the data to the finite element mesh, which was the basis for all the flushing volumes used in the analysis. In addition, limited topographic measurements were available in some of the smaller sub-embayments of the system.

Minor errors may be introduced in residence time calculations by simplifying assumptions. Flushing rate calculations assume that water exiting an estuary or sub-embayment does not return on the following tidal cycle. For regions where a strong littoral drift exists, this assumption is valid. However, water exiting a small sub-embayment on a relatively calm day may not completely mix with estuarine waters. In this case, the "strong littoral drift" assumption would lead to an under-prediction of residence time. Since littoral drift along the shoreline of Nantucket Sound typically is strong because of the effects of the local winds and tidal induced mixing within Nantucket Sound, the "strong littoral drift" assumption only will cause minor errors in residence time calculations.

VI. WATER QUALITY MODELING

VI.1 DATA SOURCES FOR THE MODEL

Several different data types and calculations are required to support the water quality modeling effort for the Three Bays system. These include the output from the hydrodynamics model, calculations of external nitrogen loads from the watersheds, measurements of internal nitrogen loads from the sediment (benthic flux), and measurements of nitrogen in the water column.

VI.1.1 Hydrodynamics and Tidal Flushing in the Embayments

Extensive field measurements and hydrodynamic modeling of the embayments were an essential preparatory step to the development of the water quality model. The result of this work, among other things, was a calibrated hydrodynamic model representing the transport of water within the Three Bays system. Files of node locations and node connectivity for the RMA-2V model grids were transferred to the RMA-4 water quality model; therefore, the computational grid for the hydrodynamic model also was the computational grid for the water quality model. The period of hydrodynamic output for the water quality model calibration was a the 7 lunar-day period (14 tide cycles, or 7.25 solar days) beginning October 11, 2002 0000 EST. This period corresponds to that used in the flushing analysis presented in Chapter V. Each modeled scenario (e.g., present conditions, build-out) required the model be run for a 28-day spin-up period, to allow the model had reached a dynamic “steady state”, and ensure that model spin-up would not affect the final model output.

VI.1.2 Nitrogen Loading to the Embayments

Three primary nitrogen loads to sub-embayments are recognized in this modeling study: external loads from the watersheds, nitrogen load from direct rainfall on the embayment surface, and internal loads from the sediments. Additionally, there is a fourth load to the Three Bays system’s sub-embayments, consisting of the background concentrations of total nitrogen in the waters entering from Nantucket Sound. This load is represented as a constant concentration along the two seaward boundaries of the model grid (at Cotuit Bay and West Bay).

VI.1.3 Measured Nitrogen Concentrations in the Embayments

In order to create a model that realistically simulates the total nitrogen concentrations in a system in response to the existing flushing conditions and loadings, it is necessary to calibrate the model to actual measurements of water column nitrogen concentrations. The refined and approved data for each monitoring station used in the water quality modeling effort are presented in Table VI-1. Station locations are indicated in the area map presented in Figure VI-1. The multi-year averages present the “best” comparison to the water quality model output, since factors of tide, temperature and rainfall may exert short-term influences on the individual sampling dates and even cause inter-annual differences. Three years of baseline field data are the minimum required to provide a baseline for MEP analysis. Typically, six years of data (collected between 1999 and 2004) were available for stations monitored by SMAST and the Three Bays Alliance in the Three Bays system.

Table VI-1. Measured data and modeled Nitrogen concentrations for the Three Bays estuarine system used in the model calibration plots of Figures VI-2 and VI-3. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means. Data represented in this table were collected in the summers of 1999 through 2004, except the Vineyard sound station, which covers a longer time period.

Sub-Embayment	monitoring station	data mean	s.d. all data	N	model min	model max	model average
Mill Pond (fresh water)	TB1	1.022	0.246	36	-	-	-
Prince's Cove - south	TB2	0.699	0.192	38	0.685	0.699	0.695
Prince's Cove - north	TB3	0.602	0.131	37	0.612	0.666	0.639
Warren's Cove	TB4	0.642	0.151	36	0.561	0.642	0.595
North Bay - north	TB5	0.498	0.135	105	0.504	0.531	0.518
North Bay - south	TB6	0.515	0.129	36	0.483	0.517	0.500
North Windmill Cove	TB7	0.511	0.120	103	0.498	0.523	0.511
West Bay - north	TB8	0.383	0.117	34	0.327	0.418	0.363
West Bay - west	TB9	0.376	0.078	38	0.299	0.362	0.327
Eel River	TB10	0.481	0.125	34	0.468	0.500	0.486
Seapuit River	TB11	0.322	0.068	67	0.287	0.305	0.295
Cotuit Bay - north	TB12	0.438	0.076	64	0.364	0.484	0.414
Cotuit Bay - south	TB13	0.389	0.077	75	0.298	0.350	0.321
South Windmill Cove	TB15	0.431	0.090	27	0.369	0.467	0.402
Mellon Cove	TB16	0.411	0.094	24	0.369	0.417	0.392
Dam Pond	TB17	0.508	0.073	5	0.513	0.531	0.523
Vineyard Sound	NS	0.280	0.065	196	-	-	0.280

VI.2 MODEL DESCRIPTION AND APPLICATION

A two-dimensional finite element water quality model, RMA-4 (King, 1990), was employed to study the effects of nitrogen loading in the Three Bays estuarine system. The RMA-4 model has the capability for the simulation of advection-diffusion processes in aquatic environments. It is the constituent transport model counterpart of the RMA-2 hydrodynamic model used to simulate the fluid dynamics of Three Bays. Like RMA-2 numerical code, RMA-4 is a two-dimensional, depth averaged finite element model capable of simulating time-dependent constituent transport. The RMA-4 model was developed with support from the US Army Corps of Engineers (USACE) Waterways Experiment Station (WES), and is widely accepted and tested. Applied Coastal staff have utilized this model in water quality studies of other Cape Cod embayments, including systems in Falmouth (Howes *et al*., 2005); Mashpee, MA (Howes *et al*., 2004) and Chatham, MA (Howes *et al*., 2003).

The overall approach involves modeling total nitrogen as a non-conservative constituent, where bottom sediments act as a source or sink of nitrogen, based on local biochemical characteristics. This modeling represents summertime conditions, when algal growth is at its maximum. Total nitrogen modeling is based upon various data collection efforts and analyses presented in previous sections of this report. Nitrogen loading information was derived from the Cape Cod Commission watershed loading analysis (based on the USGS watersheds), as well as the measured bottom sediment nitrogen fluxes. Water column nitrogen measurements were utilized as model boundaries and as calibration data. Hydrodynamic model output (discussed in Section V) provided the remaining information (tides, currents, and bathymetry) needed to parameterize the water quality model of the Three Bays system.



Figure VI-1. Estuarine water quality monitoring station locations in the Three Bays estuary system. Station labels correspond to those provided in Table VI-1. Sentinel station for threshold development depicted with red symbol.

VI.2.1 Model Formulation

The formulation of the model is for two-dimensional depth-averaged systems in which concentration in the vertical direction is assumed uniform. The depth-averaged assumption is justified since vertical mixing by wind and tidal processes prevent significant stratification in the modeled sub-embayments. The governing equation of the RMA-4 constituent model can be

most simply expressed as a form of the transport equation, in two dimensions:

$$\left(\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y}\right) = \left(\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x} + \frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y} + \sigma\right)$$

where c in the water quality constituent concentration; t is time; u and v are the velocities in the x and y directions, respectively; D_x and D_y are the model dispersion coefficients in the x and y directions; and σ is the constituent source/sink term. Since the model utilizes input from the RMA-2 model, a similar implicit solution technique is employed for the RMA-4 model.

The model is therefore used to compute spatially and temporally varying concentrations c of the modeled constituent (i.e., total nitrogen), based on model inputs of 1) water depth and velocity computed using the RMA-2 hydrodynamic model; 2) mass loading input of the modeled constituent; and 3) user selected values of the model dispersion coefficients. Dispersion coefficients used for each system sub-embayment were developed during the calibration process. During the calibration procedure, the dispersion coefficients were incrementally changed until model concentration outputs matched measured data.

The RMA-4 model can be utilized to predict both spatial and temporal variations in total for a given embayment system. At each time step, the model computes constituent concentrations over the entire finite element grid and utilizes a continuity of mass equation to check these results. Similar to the hydrodynamic model, the water quality model evaluates model parameters at every element at 10-minute time intervals throughout the grid system. For this application, the RMA-4 model was used to predict tidally averaged total nitrogen concentrations throughout the sub-embayments of the Three Bays system.

VI.2.2 Water Quality Model Setup

Required inputs to the RMA-4 model include a computational mesh, computed water elevations and velocities at all nodes of the mesh, constituent mass loading, and spatially varying values of the dispersion coefficient. Because the RMA-4 model is part of a suite of integrated computer models, the finite-element meshes and the resulting hydrodynamic simulations previously developed for Three Bays also were used for the water quality constituent modeling portion of this study.

Based on measured surface water flow rates from SMAST and groundwater recharge rates from the USGS, the hydrodynamic model was set-up to include the latest estimates of flows from the Marstons Mills River (to Prince's Cove) and Little River (to Cotuit Bay). The Marstons Mills River has a mean measured flow rate of 6.6 ft^3/sec (16,100 m^3/day), which is 6.9% of the volume of the average tide prism of Prince's Cove. Little River has average flows of 1.1 ft^3/sec (3,500 m^3/day, which represents only 0.1% of the Cotuit Bay tide prism.

For each model, an initial total N concentration equal to the concentration at the open boundary was applied to the entire model domain. The model was then run for a simulated month-long (28 day) spin-up period. At the end of the spin-up period, the model was run for an additional 5 tidal-day (125 hour) period. Model results were recorded only after the initial spin-up period. The time step used for the water quality computations was 10 minutes, which corresponds to the time step of the hydrodynamics input for the Three Bays model.

VI.2.3 Boundary Condition Specification

Mass loading of nitrogen into each model included 1) sources developed from the results of the watershed analysis, 2) estimates of direct atmospheric deposition, 3) summer benthic regeneration, 4) point source inputs developed from measurements of the freshwater portions of

the Marstons Mills River and Little River. Nitrogen loads from each separate sub-embayment watershed were distributed across the sub-embayment. For example, the combined watershed and direct atmospheric deposition loads for Cotuit Bay were evenly distributed at grid cells that formed the perimeter of the sub-embayment. Benthic regeneration loads were distributed among another sub-set of grid cells which are in the interior portion of each basin.

The loadings used to model present conditions in the Three Bays estuary system are given in Table VI-2. Watershed and depositional loads were taken from the results of the analysis of Section IV. Summertime benthic flux loads were computed based on the analysis of sediment cores in Section IV. The area rate (g/sec/m^2) of nitrogen flux from that analysis was applied to the surface area coverage computed for each sub-embayment (excluding marsh coverages, when present), resulting in a total flux for each embayment (as listed in Table VI-2). Due to the highly variable nature of bottom sediments and other estuarine characteristics of coastal embayments in general, the measured benthic flux for existing conditions also is variable. For present conditions, some sub-embayments (e.g., North Bay) have more than twice the loading rate from benthic regeneration as from watershed loads. For other sub-embayments the benthic flux is relatively low or negative (Cotuit Bay and Seapuit River) indicating a net uptake of nitrogen in the bottom sediments.

In addition to mass loading boundary conditions set within the model domain, concentrations along the model open boundary were specified. The model uses concentrations at the open boundary during the flooding tide periods of the model simulations. TN concentrations of the incoming water are set at the value designated for the open boundary. The boundary concentration in the Nantucket Sound region offshore Three Bays was set at 0.280 mg/L, based on SMAST data from Vineyard Sound. The open boundary total nitrogen concentration represents long-term average summer concentrations found within Vineyard Sound.

Table VI-2. Sub-embayment and surface water loads used for total nitrogen modeling of the Three Bays system, with sub-watershed N loads, atmospheric N loads, and benthic flux. These loads represent **present loading conditions** for the listed sub-embayments. *Warren's Cove and Prince's Cove Channel direct atmospheric deposition is included in the Price Cove load.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Cotuit Bay	21.778	5.786	-54.443
West Bay	19.068	4.233	3.815
Seapuit River	3.767	0.452	-5.418
North Bay	29.447	3.953	67.522
Prince's Cove	13.362	1.230	0.512
Warren Cove	12.027	*	8.830
Prince's Cove Channel	5.537	*	2.345
Surface Water Sources			
Marstons Mills River	14.518	-	-
Little River	3.962	-	-

VI.2.4 Model Calibration

Calibration of the total nitrogen model of Three Bays proceeded by changing model dispersion coefficients so that model output of nitrogen concentrations matched measured data. Generally, several model runs of each system were required to match the water column

measurements. Dispersion coefficient (*E*) values were varied through the modeled system by setting different values of *E* for each grid material type, as designated in Section V. Observed values of *E* (Fischer, *et al.*, 1979) vary between order 10 and order 1000 m^2/sec for riverine estuary systems characterized by relatively wide channels (compared to channel depth) with moderate currents (from tides or atmospheric forcing). Generally, the relatively quiescent estuarine embayments of the south shore of Cape Cod require values of *E* that are lower compared to the riverine estuary systems evaluated by Fischer, *et al.*, (1979). Observed values of *E* in these calmer areas typically range between order 10 and order 0.001 m^2/sec (USACE, 2001). The final values of *E* used in each sub-embayment of the modeled system are presented in Table VI-3. These values were used to develop the "best-fit" total nitrogen model calibration. For the case of TN modeling, "best fit" can be defined as minimizing the error between the model and data at all sampling locations, utilizing reasonable ranges of dispersion coefficients within each sub-embayment.

Table VI-3. Values of longitudinal dispersion coefficient, E, used in calibrated RMA4 model runs of salinity and nitrogen concentration for the Three Bays estuary system.

Embayment Division	E m^2/sec
Cotuit Bay Inlet	5.0
Cotuit Bay	10.0
Seapuit River	5.0
West Bay Inlet	5.0
West Bay	10.0
South Windmill Cove	0.8
Mellon Cove	1.0
North Bay	10.0
Prince's Cove - north	5.0
Prince's Cove - south	1.0
Warren's Cove	5.0
Dam Pond	10.0
Eel River	0.5
Little River	1.0
Marstons Mills River	5.0

Comparisons between calibrated model output and measured nitrogen concentrations are shown in plots presented in Figures VI-2 and VI-3. In these plots, means of the water column data and a range of two standard deviations of the annual means at each individual station are plotted against the modeled maximum, mean, and minimum concentrations output from the model at locations which corresponds to the SMAST monitoring stations.

For model calibration, the mid-point between maximum modeled TN and average modeled TN was compared to mean measured TN data values, at each water-quality monitoring station. The calibration target would fall between the modeled mean and maximum TN because the monitoring data are collected, as a rule, during mid ebb tide.

Also presented in this figure are unity plot comparisons of measured data verses modeled target values for each system. Computed root mean squared (rms) error is less than 0.03 mg/L, which demonstrates the exceptional fit between modeled and measured data for this system.

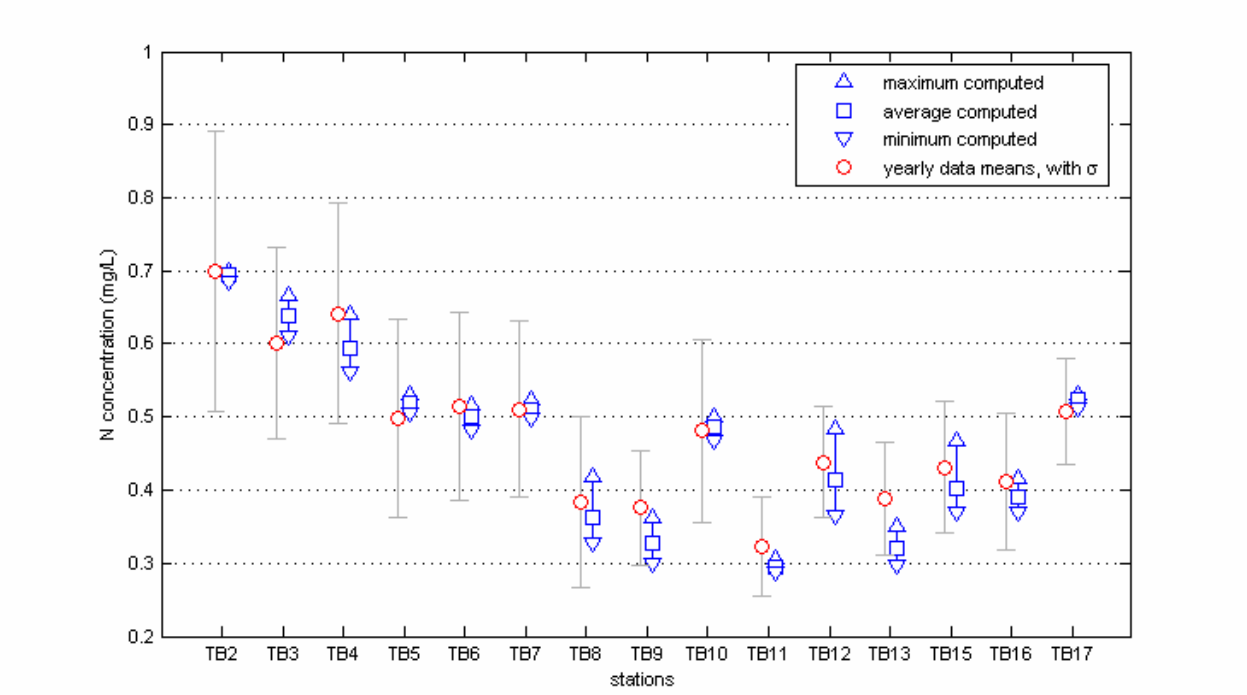


Figure VI-2. Comparison of measured total nitrogen concentrations and calibrated model output at stations in the Three Bays system. Station labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed concentration for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset

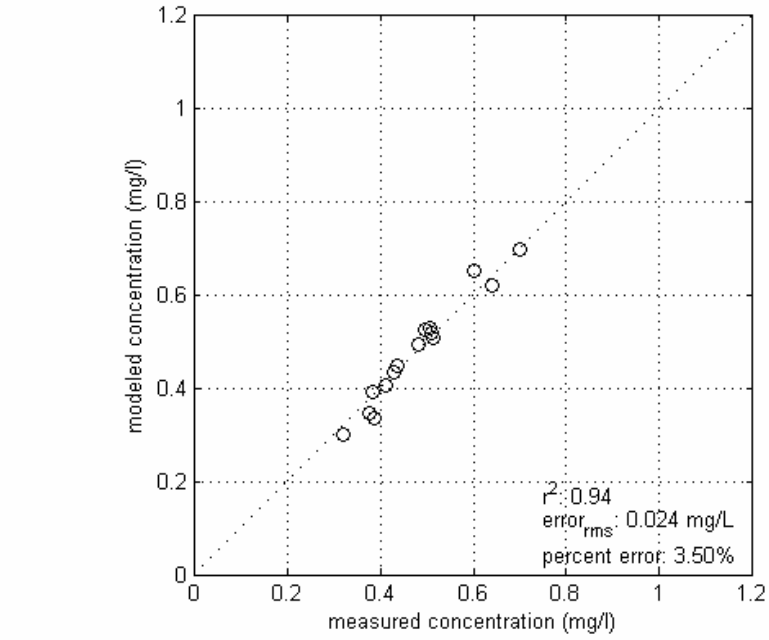


Figure VI-3. Model total nitrogen calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for the model are also presented.

A contour plot of calibrated model output is shown in Figures VI-4. In this figure, color contours indicate nitrogen concentrations throughout the model domain. The output in these figures show average total nitrogen concentrations, computed using the full 5-tidal-day model simulation output period.

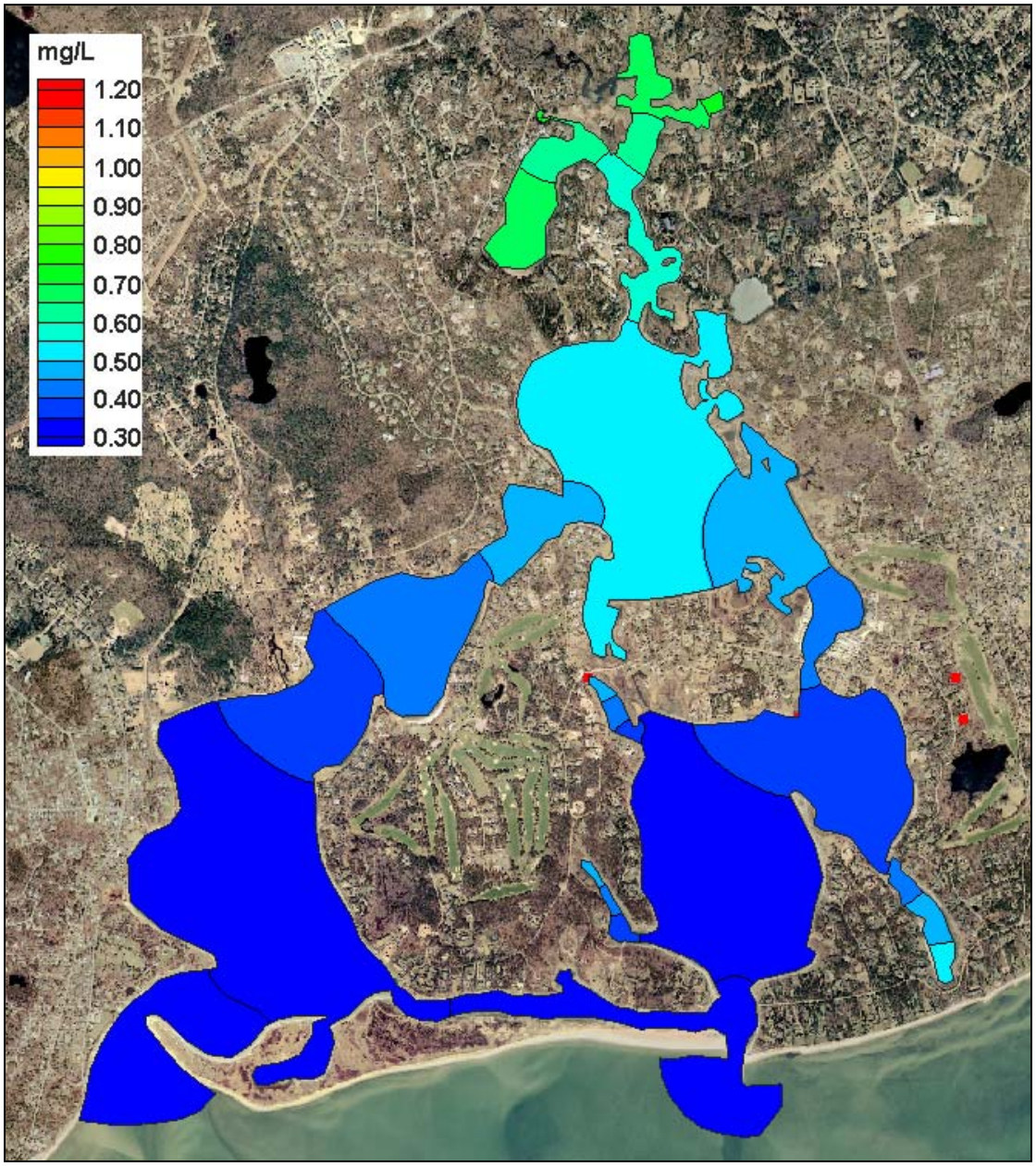


Figure VI-4. Contour plot of average total nitrogen concentrations from results of the present conditions loading scenario, for the Three Bays system.

VI.2.5 Model Salinity Verification

In addition to the model calibration based on nitrogen loading and water column measurements, numerical water quality model performance is typically verified by modeling salinity. This step was performed for the Three Bays system using salinity data collected at the same stations as the nitrogen data. The only required inputs into the RMA4 salinity model of

each system, in addition to the RMA2 hydrodynamic model output, were salinities at the model open boundary, at the freshwater stream discharges, and groundwater inputs. The open boundary salinity was set at 29.6 ppt. For surface water steams and groundwater inputs salinities were set at 0 ppt. Surface water stream flow rates for the streams were the same as those used for the total nitrogen model, as presented earlier in this section. Groundwater inputs used for each model were 16.01 ft^3/sec (39,100 m^3/day) for Prince's Cove, 5.40 ft^3/sec (13,200 m^3/day) for North Bay, 3.22 ft^3/sec (7,900 m^3/day) for West Bay, 6.57 ft^3/sec (16,100 m^3/day) for Cotuit Bay, and 0.77 ft^3/sec (1,900 m^3/day) for the Seapuit River. Groundwater flows were distributed evenly in the model through the use of several 1-D element input points positioned along each model's land boundary.

Comparisons of modeled and measured salinities are presented in Figures VI-5 and VI-6, with contour plots of model output shown in Figure VI-7. Though model dispersion coefficients were not changed from those values selected through the nitrogen model calibration process, the model skillfully represents salinity gradients throughout the Three Bays estuary system. The rms error of the three models is less than 0.8 ppt, and correlation coefficient between the model and measured salinity data is 0.78. The salinity verification provides a further independent confirmation that model dispersion coefficients and represented freshwater inputs to the model correctly simulate the real physical system.

VI.2.6 Build-Out and No Anthropogenic Load Scenarios

To assess the influence of nitrogen loading on total nitrogen concentrations within the Three Bays system, two standard water quality modeling scenarios were run: a "build-out" scenario based on potential development (described in more detail in Section IV) and a "no anthropogenic load" or "no load" scenario assuming only atmospheric deposition on the watershed and sub-embayment, as well as a natural forest within each watershed. Comparisons of the alternate watershed loading analyses are shown in Table VI-4. Loads are presented in kilograms per day (kg/day) in this Section, since it is inappropriate to show benthic flux loads in kilograms per year due to seasonal variability.

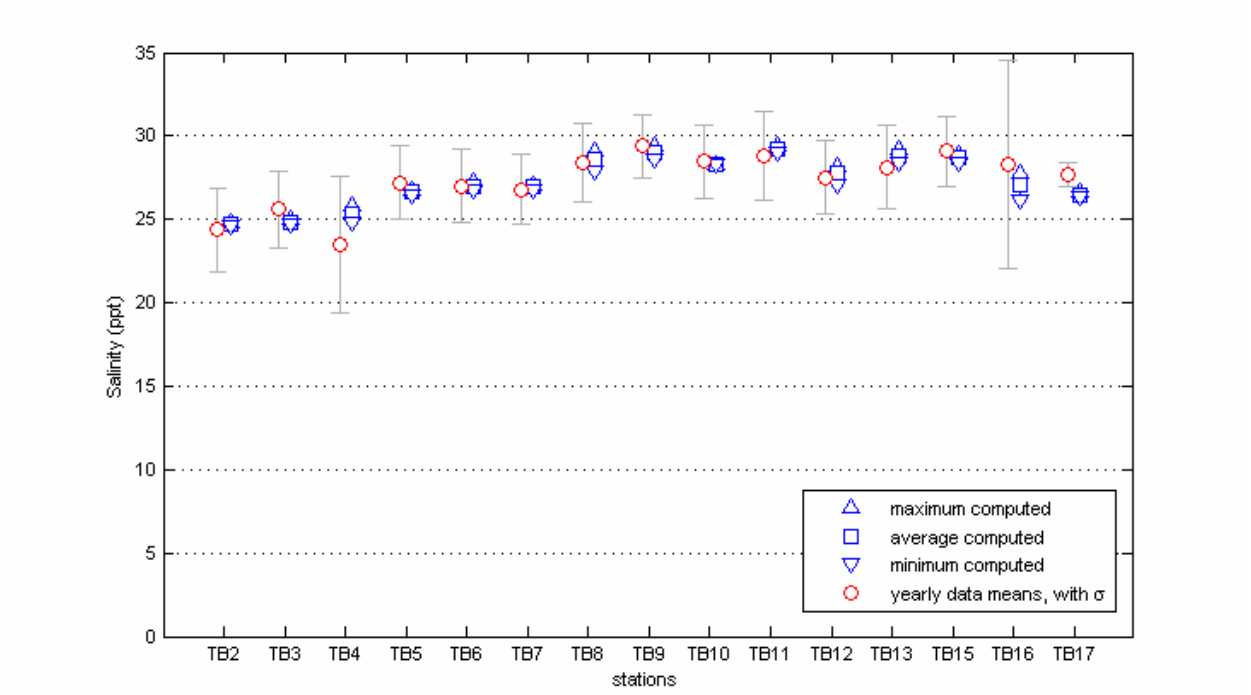


Figure VI-5. Comparison of measured and calibrated model output at stations in Three Bays. Stations labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed salinity for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset.

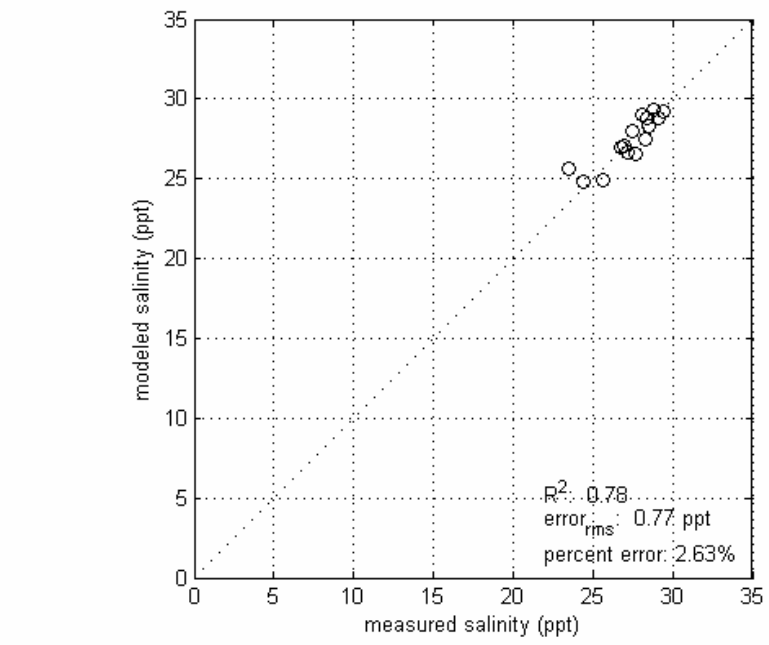


Figure VI-6. Model salinity target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for each model are also presented.

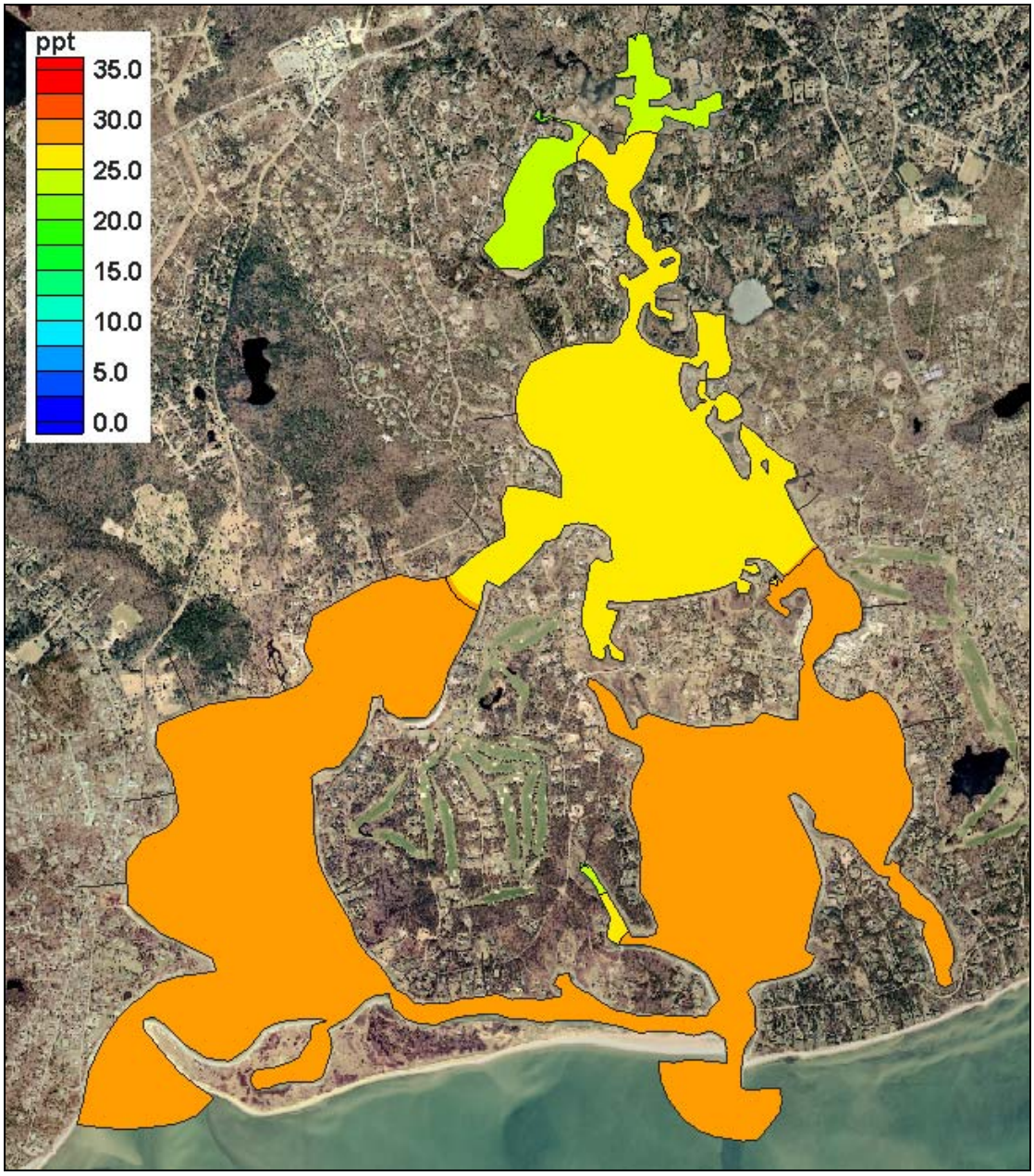


Figure VI-7. Contour Plot of modeled salinity (ppt) in the Three Bays system.

Table VI-4. Comparison of sub-embayment watershed loads used for modeling of present, build-out, and no-anthropogenic ("no-load") loading scenarios of the Three Bays system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	build out (kg/day)	build-out % change	no load (kg/day)	no load % change
Cotuit Bay	21.778	24.463	12.3%	1.975	-90.9%
West Bay	19.068	20.077	5.3%	1.170	-93.9%
Seapuit River	3.767	4.507	19.6%	0.452	-88.0%
North Bay	29.447	32.370	9.9%	1.970	-93.3%
Prince's Cove	13.362	15.197	13.7%	1.137	-91.5%
Warren's Cove	12.027	15.290	27.1%	1.945	-83.8%
Prince's Cove Channel	5.537	6.564	18.6%	0.515	-90.7%
Surface Water Sources					
Marstons Mills River	14.518	17.008	17.2%	1.641	-88.7%
Little River	3.962	4.830	21.9%	0.471	-88.1%

VI.2.6.1 Build-Out

In general, certain sub-embayments would be impacted more than others. The build-out scenario indicates that there would be less than a 6% increase in watershed nitrogen load West Bay as a result of potential future development. Other watershed areas would experience much greater load increases, for example the loads to the Little River would increase 22% from the present day loading levels. A maximum increase in watershed loading resulting from future development would occur in the Warren's Cove watershed, where the increase would be 3.263 kg/day, or 27% more than present conditions. For the no load scenarios, almost all of the load entering the watershed is removed; therefore, the load is generally lower than existing conditions by over 85%.

For the build-out scenario, a breakdown of the total nitrogen load entering each sub-embayment is shown in Table VI-5. The benthic flux for the build-out scenarios is assumed to vary proportional to the watershed load, where an increase in watershed load will result in an increase in benthic flux (i.e., a positive change in the absolute value of the flux), and *vise versa*.

Projected benthic fluxes (for both the build-out and no load scenarios) are based upon projected PON concentrations and watershed loads, determined as:

$$(Projected\ N\ flux) = (Present\ N\ flux) * [PON_{projected}]/[PON_{present}]$$

where the projected PON concentration is calculated by,

$$[PON_{projected}] = R_{load} * \Delta PON + [PON_{(present\ offshore)}],$$

using the watershed load ratio,

$$R_{load} = (Projected\ N\ load) / (Present\ N\ load),$$

and the present PON concentration above background,

$$\Delta PON = [PON_{(present\ flux\ core)}] - [PON_{(present\ offshore)}].$$

Table VI-5. Build-out sub-embayment and surface water loads used for total nitrogen modeling of the Three Bays system, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Cotuit Bay	24.463	5.786	-57.241
West Bay	20.077	4.233	3.821
Seapuit River	4.507	0.452	-5.562
North Bay	32.370	3.953	72.223
Prince's Cove	15.197	1.230	0.559
Warren's Cove	15.290	-	9.491
Prince's Cove Channel	6.564	-	2.526
Surface Water Sources			
Marstons Mills River	17.008	-	-
Little River	4.830	-	-

Following development of the nitrogen loading estimates for the build-out scenario, the water quality models of each system were run to determine nitrogen concentrations within each sub-embayment (Table VI-6). Total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios. Total N concentrations increased the most in the upper portions of the system, with the largest change at a station in Prince's Cove (+7.6% at TB2), with the least change occurring in West Bay (+1.3% at TB9) closer to the inlet to Nantucket Sound. Color contours of model output for the build-out scenario are present in Figure VI-8. The range of nitrogen concentrations shown are the same as for the plot of present conditions in Figure VI-4, which allows direct comparison of nitrogen concentrations between loading scenarios.

Table VI-6. Comparison of model average total N concentrations from present loading and the build-out scenario, with percent change, for the Three Bays system.

Sub-Embayment	monitoring station	present (mg/L)	build-out (mg/L)	% change
Prince's Cove - south	TB2	0.695	0.748	+7.6%
Prince's Cove - north	TB3	0.639	0.684	+7.1%
Warren's Cove	TB4	0.595	0.634	+6.6%
North Bay - north	TB5	0.518	0.545	+5.2%
North Bay - south	TB6	0.500	0.525	+4.8%
North Windmill Cove	TB7	0.511	0.536	+4.9%
West Bay - north	TB8	0.363	0.371	+2.2%
West Bay - west	TB9	0.327	0.331	+1.3%
Eel River	TB10	0.486	0.500	+2.9%
Seapuit River	TB11	0.295	0.297	+0.9%
Cotuit Bay - north	TB12	0.414	0.430	+3.8%
Cotuit Bay - south	TB13	0.321	0.327	+1.7%
South Windmill Cove	TB15	0.402	0.412	+2.3%
Mellon Cove	TB16	0.392	0.398	+1.7%
Dam Pond	TB17	0.523	0.551	+5.3%

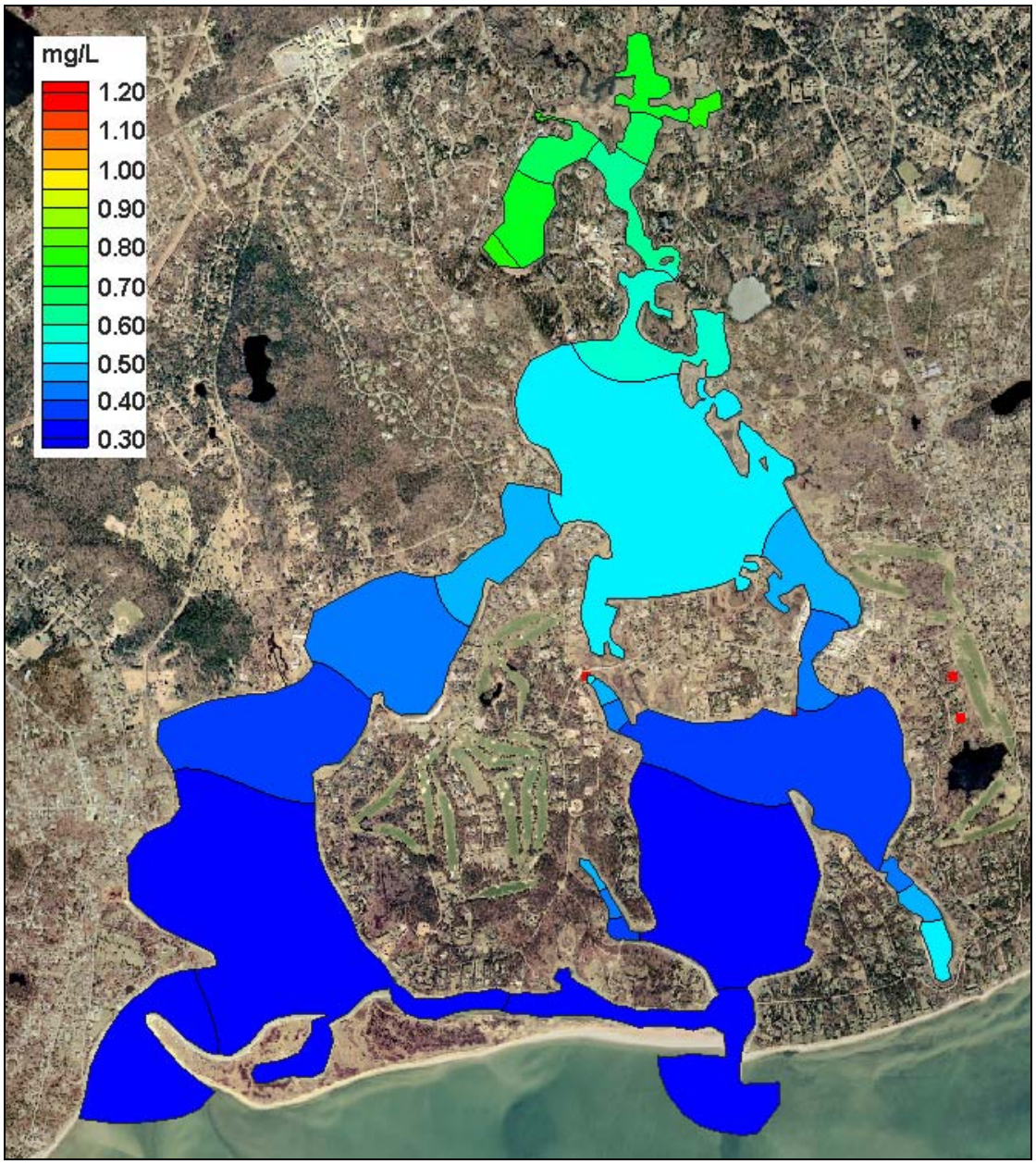


Figure VI-8. Contour plot of modeled total nitrogen concentrations (mg/L) in the Three Bays system, for projected build-out loading conditions.

VI.2.6.2 No Anthropogenic Load

A breakdown of the total nitrogen load entering each sub-embayment for the no anthropogenic load ("no load") scenarios is shown in Table VI-7. The benthic flux input to each embayment was reduced (toward zero) based on the reduction in the watershed load (as discussed in §VI.2.6.1). Compared to the modeled present conditions and build-out scenario, atmospheric deposition directly to each sub-embayment becomes a greater percentage of the total nitrogen load as the watershed load and related benthic flux decrease.

Table VI-7. "No anthropogenic loading" ("no load") sub-embayment and surface water loads used for total nitrogen modeling of the Three Bays system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Cotuit Bay	1.975	5.786	-35.901
West Bay	1.170	4.233	3.360
Seapuit River	0.452	0.452	-4.412
North Bay	1.970	3.953	36.481
Prince's Cove	1.137	1.230	0.224
Warren's Cove	1.945	-	4.409
Prince's Cove Channel	0.515	-	1.125
Surface Water Sources			
Marstons Mills River	1.641	-	-
Little River	0.471	-	-

Following development of the nitrogen loading estimates for the no load scenario, the water quality model was run to determine nitrogen concentrations within each sub-embayment. Again, total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios. The relative change in total nitrogen concentrations resulting from "no load" was significant as shown in Table VI-8, with reductions greater than 45% (at TB2) occurring the upper portions of the system. Results for each system are shown pictorially in Figure VI-9.

Table VI-8. Comparison of model average total N concentrations from present loading and the no anthropogenic ("no load") scenario, with percent change, for the Three Bays system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	no load (mg/L)	% change
Prince's Cove - south	TB2	0.695	0.379	-45.4%
Prince's Cove - north	TB3	0.639	0.370	-42.1%
Warren's Cove	TB4	0.595	0.365	-38.7%
North Bay - north	TB5	0.518	0.350	-32.4%
North Bay - south	TB6	0.500	0.346	-30.8%
North Windmill Cove	TB7	0.511	0.349	-31.6%
West Bay - north	TB8	0.363	0.305	-15.9%
West Bay - west	TB9	0.327	0.294	-10.0%
Eel River	TB10	0.486	0.336	-30.9%
Seapuit River	TB11	0.295	0.279	-5.4%
Cotuit Bay - north	TB12	0.414	0.315	-24.0%
Cotuit Bay - south	TB13	0.321	0.286	-10.9%
South Windmill Cove	TB15	0.402	0.315	-21.6%
Mellon Cove	TB16	0.392	0.310	-20.9%
Dam Pond	TB17	0.523	0.351	-32.9%

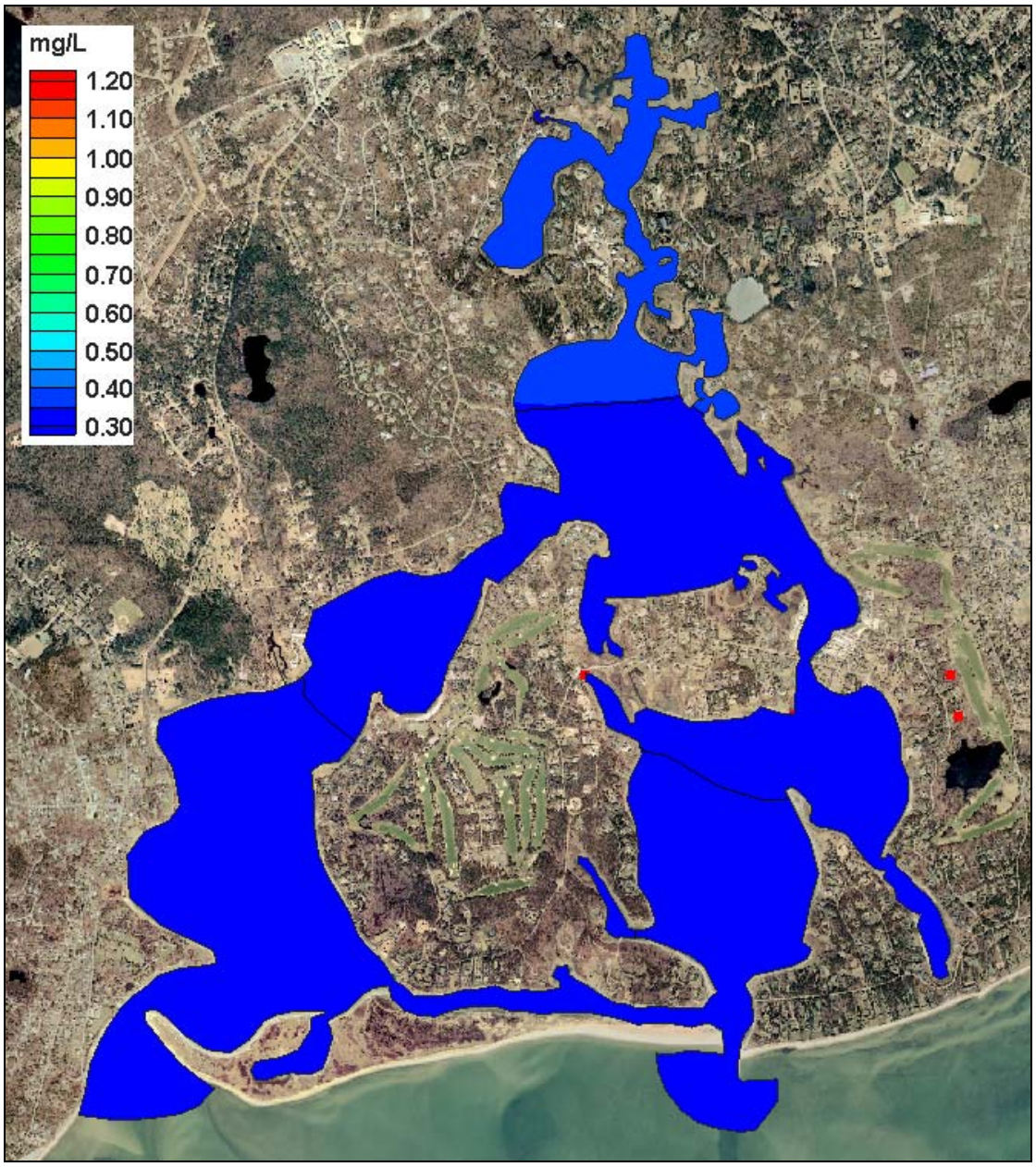


Figure VI-9. Contour plot of modeled total nitrogen concentrations (mg/L) in Three Bays, for no anthropogenic loading conditions.

VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll, and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (fish, shellfish, infauna) which it supports. For the Three Bays embayment systems, the MEP assessment is based upon data from the water quality monitoring database and MEP surveys of eelgrass distribution, benthic animal communities and sediment characteristics, and dissolved oxygen records conducted during the summers of 2000-2002. These data form the basis of an assessment of this system's present health, and when coupled with a full water quality synthesis and projections of future conditions based upon the water quality modeling effort, will support complete nitrogen threshold development for these systems (Chapter VIII).

VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS

There are a variety of indicators that can be used in concert with water quality monitoring data for evaluating the ecological health of embayment systems. The best biological indicators are those species which are non-mobile and which persist over relatively long periods, if environmental conditions remain constant. The concept is to use species, which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

As a basis for a nitrogen thresholds determination, MEP focused on major habitat quality indicators: (1) bottom water dissolved oxygen and chlorophyll a (Section VII.2), (2) eelgrass distribution over time (Section VII.3) and (3) benthic animal communities (Section VII.4). Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate cause being nitrogen loading). However, oxygen conditions can change rapidly and frequently show strong tidal and diurnal patterns. Even severe levels of oxygen depletion may occur only infrequently, yet have important effects on system health. To capture this variation, the MEP Technical Team deployed dissolved oxygen sensors within the upper portion of the Three Bays system (Prince's Cove and North Bay, 2002), as well as closer to the inlets to the Three Bays system (Cotuit bay and West Bay, 2002), to record the frequency and duration of low oxygen conditions during the critical summer period. This work was in association with Three Bays Preservation and the Town of Barnstable.

The MEP habitat analysis uses eelgrass as a sentinel species for indicating nitrogen over-loading to coastal embayments. Eelgrass is a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. Mapping of the eelgrass beds within the Three Bays System was conducted for comparison to historic records (DEP Eelgrass Mapping Program, C. Costello). Temporal trends in the distribution of eelgrass beds are used by the MEP to assess the stability of the habitat and to determine trends potentially related to nutrient related water quality. Eelgrass beds can decrease within embayments in response to a variety of causes, but throughout almost all of the embayments within southeastern Massachusetts, the primary cause appears to be related to increases in embayment nitrogen levels. Within the Three Bays System, temporal changes in eelgrass distribution provides a strong basis for evaluating recent increases (nitrogen loading) or decreases (increased flushing-new inlet) in nutrient enrichment.

In areas that do not naturally support eelgrass beds, benthic animal indicators were used to assess the level of habitat health from "healthy" (low organic matter loading, high D.O.) to "highly stressed" (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment samples were identified and the environments ranked based upon the fraction of healthy, transitional, and stressed indicator species. The analysis is based upon life-history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes *et al.* 1997). These data are coupled with the level of diversity (H') and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

VII.2 BOTTOM WATER DISSOLVED OXYGEN

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 3.8 mg L^{-1}. Massachusetts State Water Quality Classification indicates that SA (high quality) waters maintain oxygen levels above 6 mg L^{-1}. The tidal waters of the Three Bays System are currently listed under this Classification as SA. It should be noted that the Classification system represents the water quality that the embayment should support, not the existing level of water quality. It is through the MEP and TMDL processes that management actions are developed and implemented to keep or bring the existing conditions in line with the Classification.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates in summer than winter (Figure VII-1). It is not surprising that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute levels (mg L^{-1}) are found during the summer in southeastern Massachusetts embayments when water column respiration rates are greatest. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen conditions within shallow embayments (Taylor and Howes, 1994). To more accurately capture the degree of bottom water dissolved oxygen depletion during the critical summer period, autonomously recording oxygen sensors were moored 30 cm above the embayment bottom within key regions of the Three Bays System (Figure VII-2). The sensors (YSI 6600) were first calibrated in the laboratory and then checked with standard oxygen mixtures at the time of initial instrument mooring deployment. In addition periodic calibration samples were collected at the sensor depth and assayed by Winkler titration (potentiometric analysis, Radiometer) during each deployment. Each instrument mooring was serviced and calibration samples collected at least biweekly and sometimes weekly during a minimum deployment of 30 days within the interval from July through mid-September. All of the mooring data from the Three Bays embayment system was collected during the summers of 2000, 2001 and 2002.

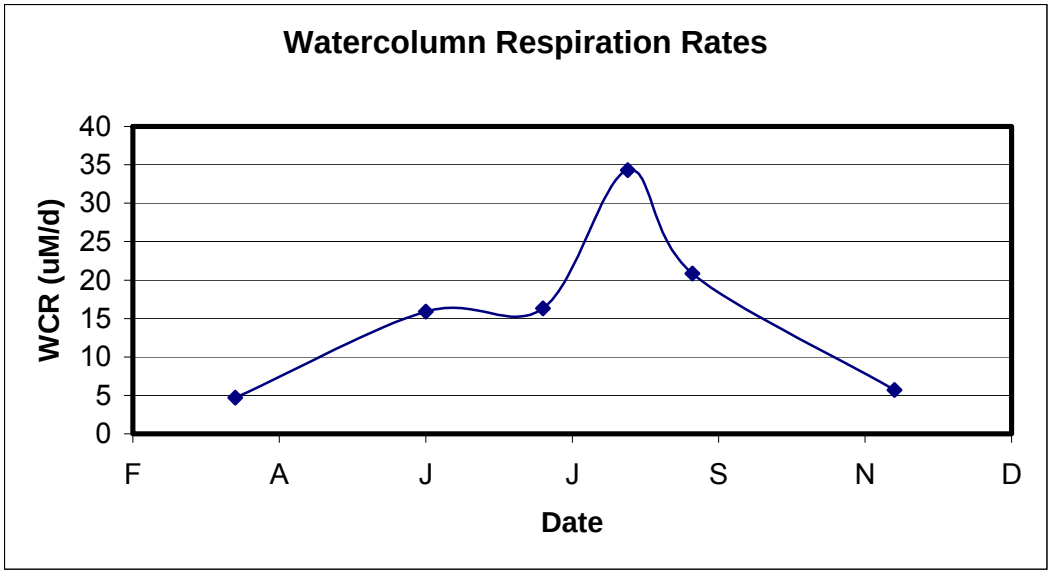


Figure VII-1. Average watercolumn respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System (Schlezinger and Howes, unpublished data). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Similar to other embayments in southeastern Massachusetts, the Three Bays system evaluated in this assessment showed high frequency variation, apparently related to diurnal and sometimes tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site, underscores the need for continuous monitoring within these systems.

Dissolved oxygen and chlorophyll a records were examined both for temporal trends and to determine the percent of the 25-30 day deployment period that these parameters were below/above various benchmark concentrations (Tables VII-1, VII-2). These data indicate both the temporal pattern of minimum or maximum levels of these critical nutrient related constituents, as well as the intensity of the oxygen depletion events and phytoplankton blooms. However, it should be noted that the frequency of oxygen depletion needs to be integrated with the actual temporal pattern of oxygen levels, specifically as it relates to daily oxygen excursions. The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality at all mooring sites within the estuary (Figures VII-3 through VII-12, Three Bays system). The oxygen data throughout the estuary is consistent with elevated organic matter loads from phytoplankton production (chlorophyll a levels) indicative of nitrogen enrichment and eutrophication of these estuarine systems. The oxygen records further indicate that the upper tidal reaches of each estuary have the largest daily oxygen excursion, with daily excursions in excess of 6 mg L-1 common. This further supports the assessment of a high degree of nutrient enrichment..

The use of only the duration of oxygen below, for example 4 mg L^{-1}, can underestimate the level of habitat impairment in these locations. The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production,

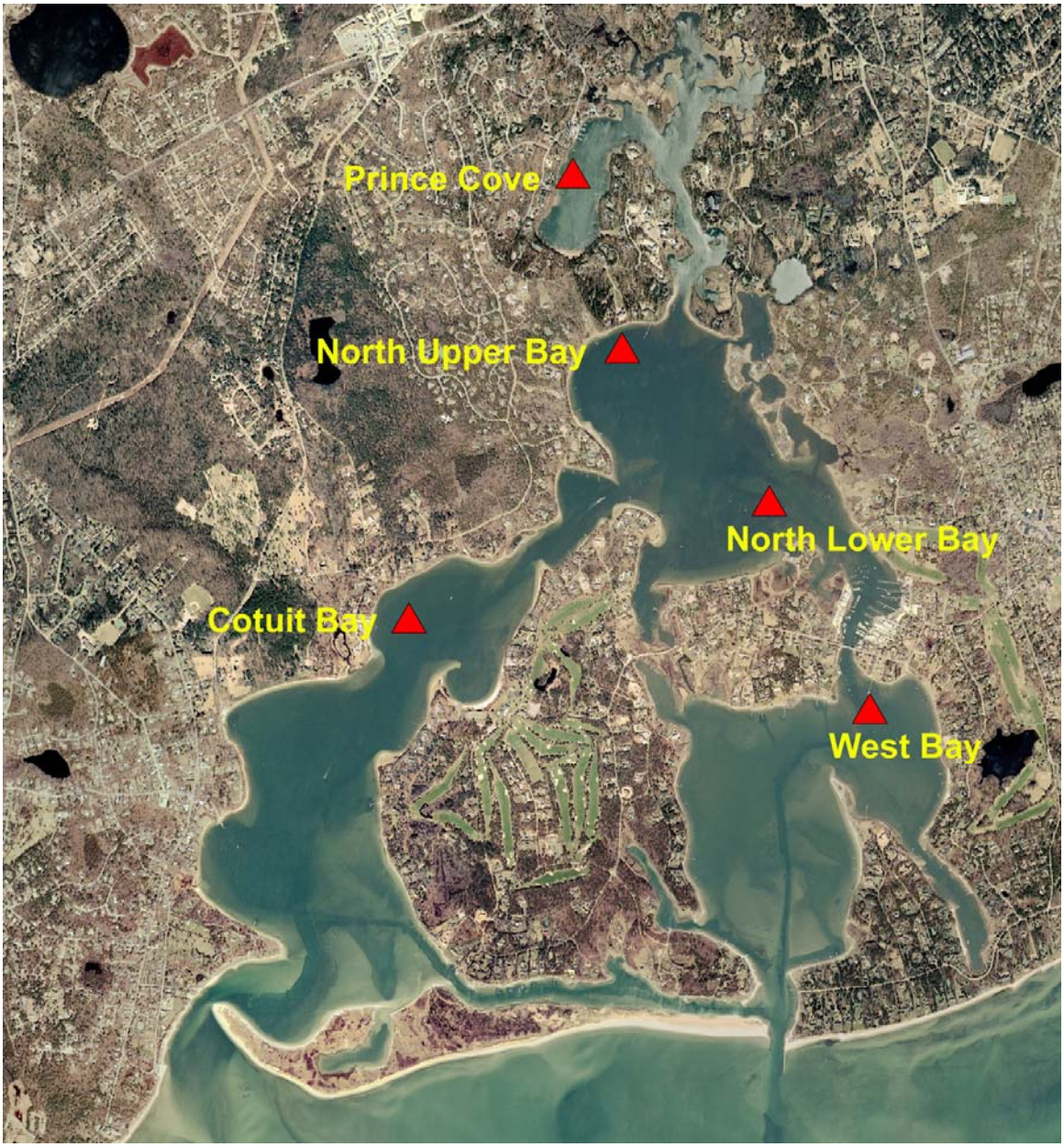


Figure VII-2. Aerial Photograph of the 3 Bays embayment system in the Towns of Mashpee and Barnstable showing locations of Dissolved Oxygen mooring deployments conducted in the Summer of 2002.

oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). This was also periodically within the upper basins, further supporting the contention that the upper basins are currently eutrophic. The mooring data also shows a gradient of impairment with high levels in the upper sub-embayments (Prince's Cove, Warren's Cove, North Bay) and better conditions in the lower basins (Cotuit Bay and West Bay). However, there was clear oxygen depletion at all mooring sites, which indicates that additional nitrogen loading will cause further habitat decline at all sites

The dissolved oxygen records indicate that the major subembayments to the Three Bays system (Cotuit Bay, West Bay, North Bay and Prince's Cove) are currently under seasonal

oxygen stress, consistent with nitrogen enrichment (Table VII-1). That the cause is nitrogen enrichment is supported by parallel observations of chlorophyll a (Table VII-2). Oxygen conditions and chlorophyll a levels generally improved with decreasing distance to the tidal inlet, although all basins showed oxygen depletions to <4 mg L^{-1}. There was also a clear gradient in chlorophyll a, with highest levels in the uppermost reaches and lowest levels near the tidal inlet to Vineyard Sound. The results of the summer oxygen and chlorophyll a studies are consistent with the absence of eelgrass throughout the Three Bays System and the near absence of animal communities throughout the upper basins where oxygen depletions routinely dropped below 3 mg/L (see below).

Table VII-1. Bottom water dissolved oxygen levels within the principal sub-embayments to the Three Bays Estuary. Percent of time during deployment of in situ sensors that bottom water oxygen levels were below various benchmark oxygen levels during summer deployments, 2000-02.

Sub-Embayment	Dissolved Oxygen: Continuous Record, Summer 2000- 2002				
	Deployment Days	**< 6 mg/L (% of days)**	**< 5 mg/L (% of days)**	**< 4 mg/L (% of days)**	**< 3 mg/L (% of days)**
Prince's Cove	14.3	60%	39%	27%	14%
North Bay Upper	31.1	66%	44%	24%	11%
North Bay Lower	27	46%	9%	1%	0%
Cotuit Bay	10.0	73%	25%	1%	0%
West Bay	25.8	49%	24%	19%	9%

Table VII-2. Duration (% of deployment time) that chlorophyll (a) levels exceed various benchmark levels within the embayment system. "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST. The mean in the final column is the average level over the deployment.

Sub-Embayment	Start Date	End Date	Total Deployment (Days)	> 5 ug/L Duration (Days)	> 10 ug/L Duration (Days)	> 15 ug/L Duration (Days)	> 20 ug/L Duration (Days)	> 25 ug/L Duration (Days)	Mean Chl a Level (ug/L)
Prince's Cove	8/9/2000	8/23/2000	14.3	**100%**	**93%**	**84%**	**63%**	**39%**	
		Mean		14.3	1.33	1.00	0.39	0.20	23.0
		S.D.		N/A	1.62	1.04	0.59	0.17	
North Bay									
Upper	8/19/2001	9/19/2001	31.1	**95%**	**68%**	**30%**	**10%**	**2%**	
		Mean		2.26	1.01	0.42	0.19	0.11	12.7
		S.D.		6.08	2.54	0.33	0.12	0.10	
Lower	8/16/2001	9/12/2001	27	**89%**	**24%**	**4%**	**0%**	**0%**	**8.3**
		Mean		0.89	0.20	0.13	N/A	N/A	
		S.D.		2.03	0.22	0.07	N/A	N/A	
Cotuit Bay	7/13/2002	8/10/2002	28.1	**81%**	**32%**	**8%**	**2%**	**0%**	
		Mean		1.26	0.25	0.13	0.08	0.04	8.8
		S.D.		3.08	0.29	0.15	0.05	N/A	
West Bay	7/15/2002	8/10/2002	25.8	**72%**	**14%**	**0%**	**0%**	**0%**	
		Mean		0.81	0.25	0.08	N/A	N/A	6.8
		S.D.		1.34	0.19	N/A	N/A	N/A	

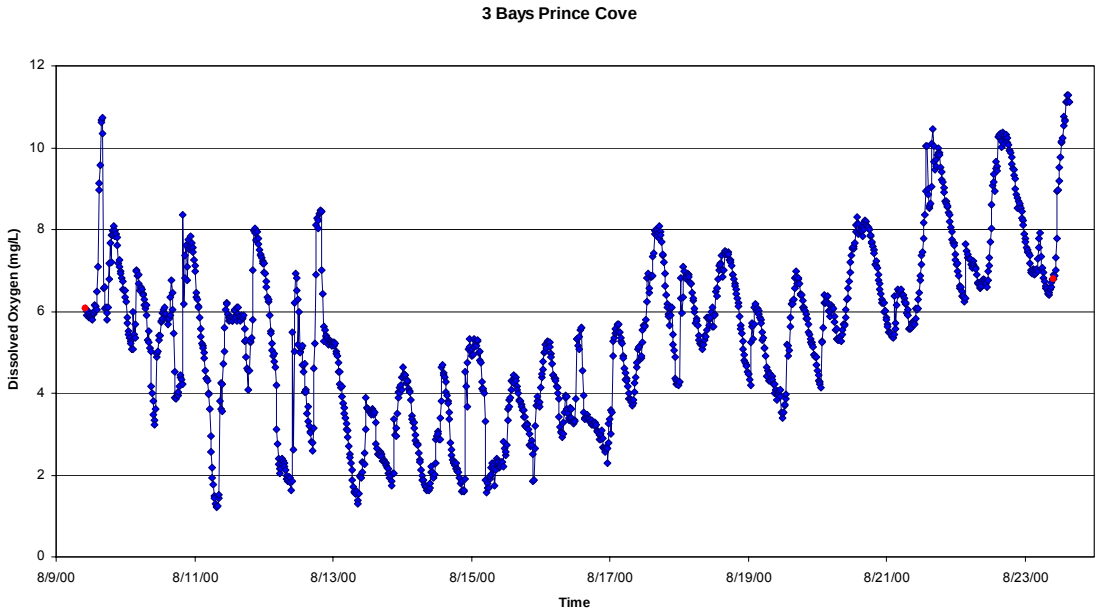


Figure VII-3. Bottom water record of dissolved oxygen at the Three Bays Prince's Cove station, Summer 2000. Calibration samples represented as red dots.

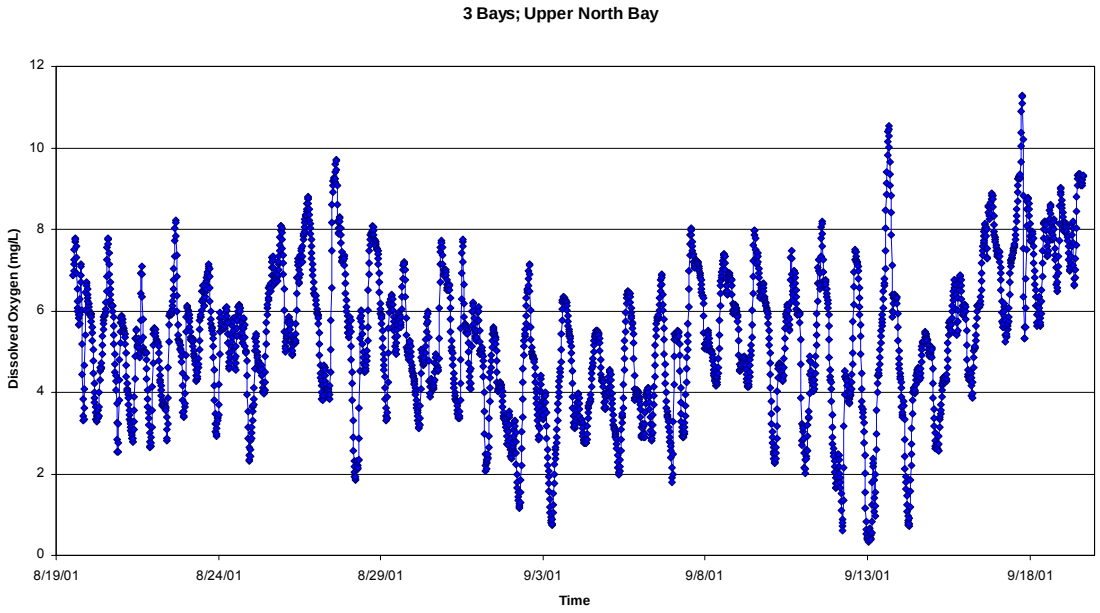


Figure VII-4. Bottom water record of dissolved oxygen in the Three Bays Upper North Bay station, Summer 2001. Calibration samples represented as red dots.

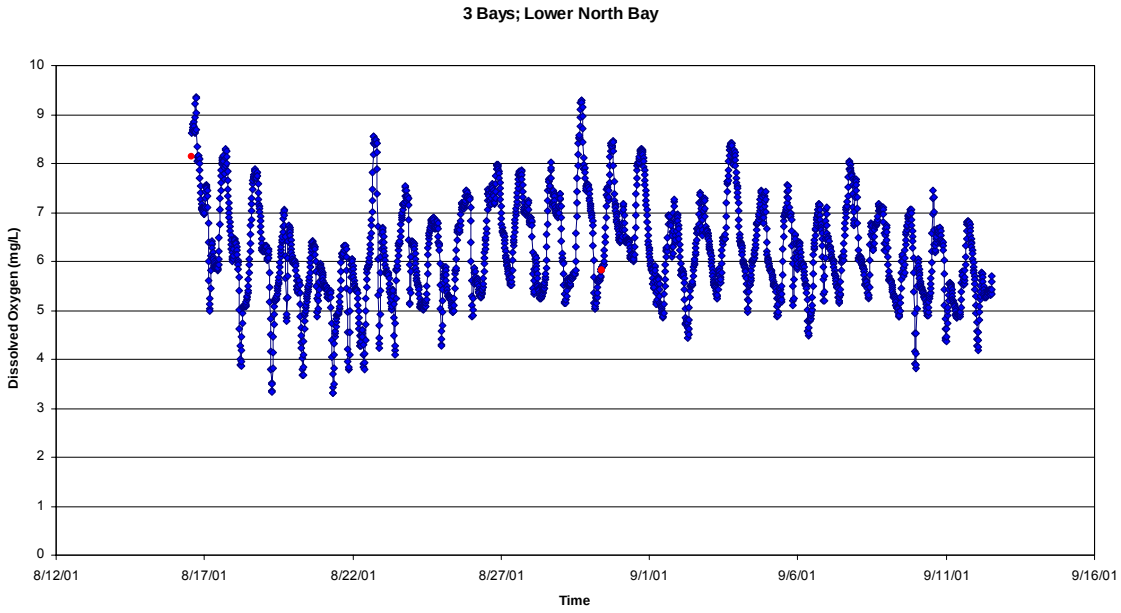


Figure VII-5. Bottom water record of dissolved oxygen in the Three Bays Lower North Bay station, Summer 2001. Calibration samples represented as red dots.

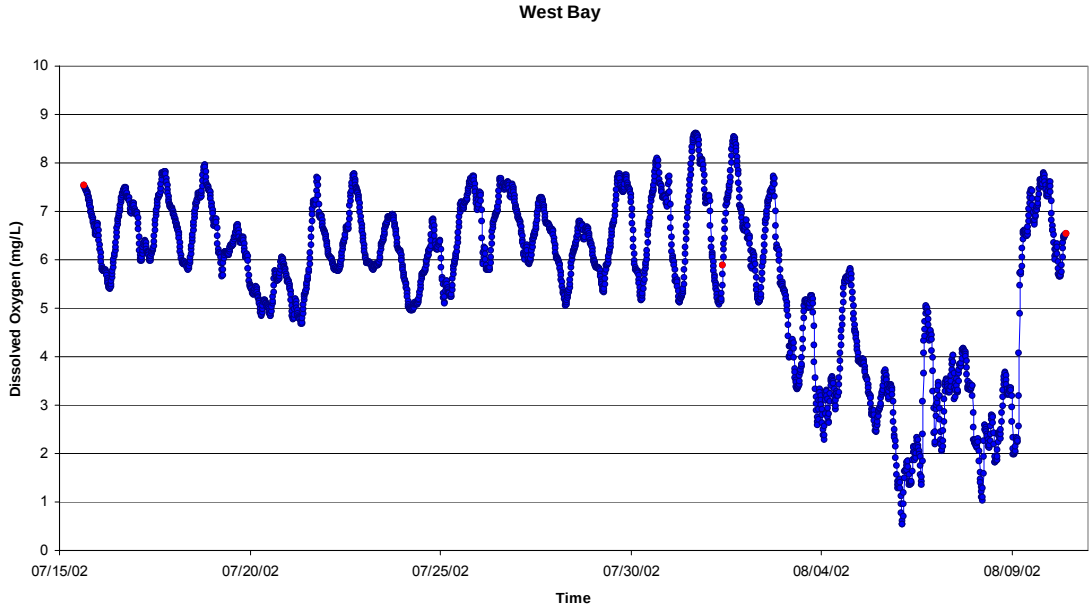


Figure VII-6. Bottom water record of dissolved oxygen in the Three Bays West Bay station, Summer 2002. Calibration samples represented as red dots.

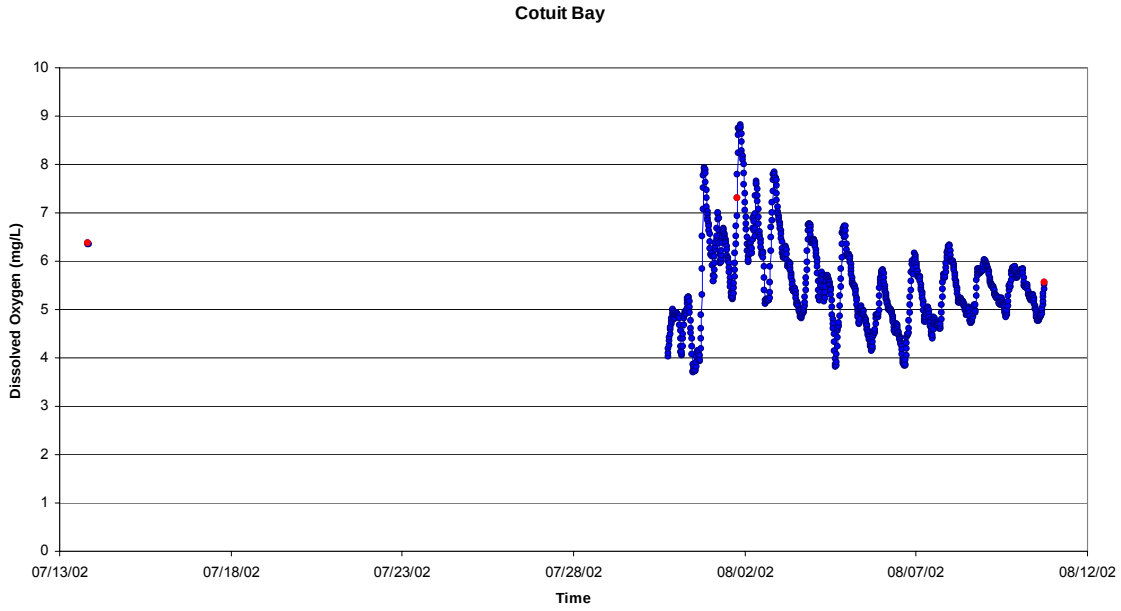
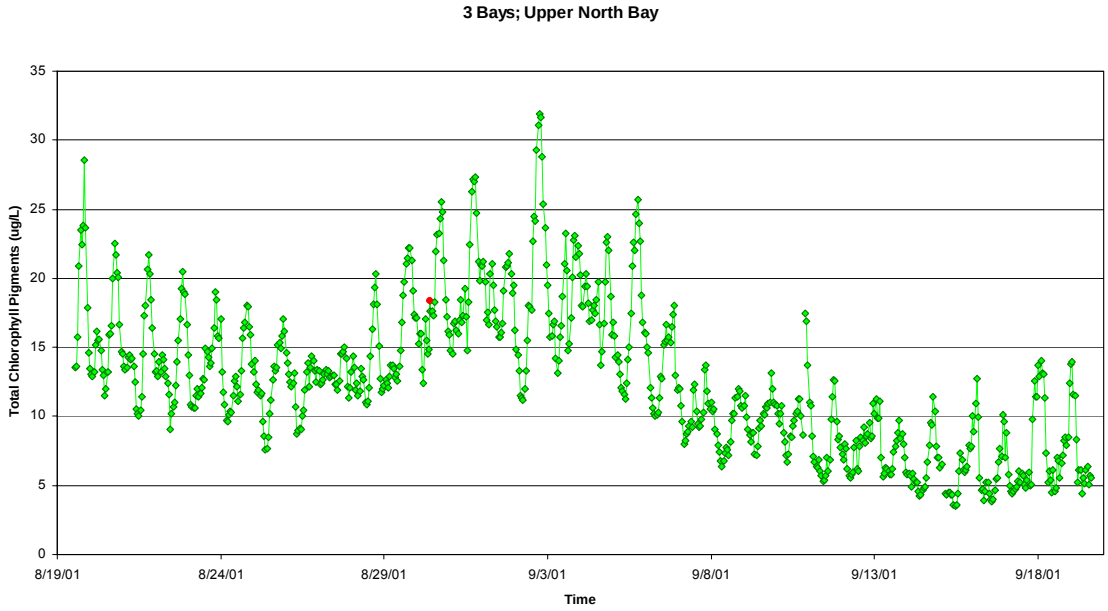


Figure VII-7. Bottom water record of dissolved oxygen in the Three Bays Cotuit Bay station, Summer.



2002 Calibration samples represented as red dots

Figure VII-8. Bottom water record of Chlorophyll-*a* at the Three Bays Prince's Cove station, Summer 2000. Calibration samples represented as red dots.

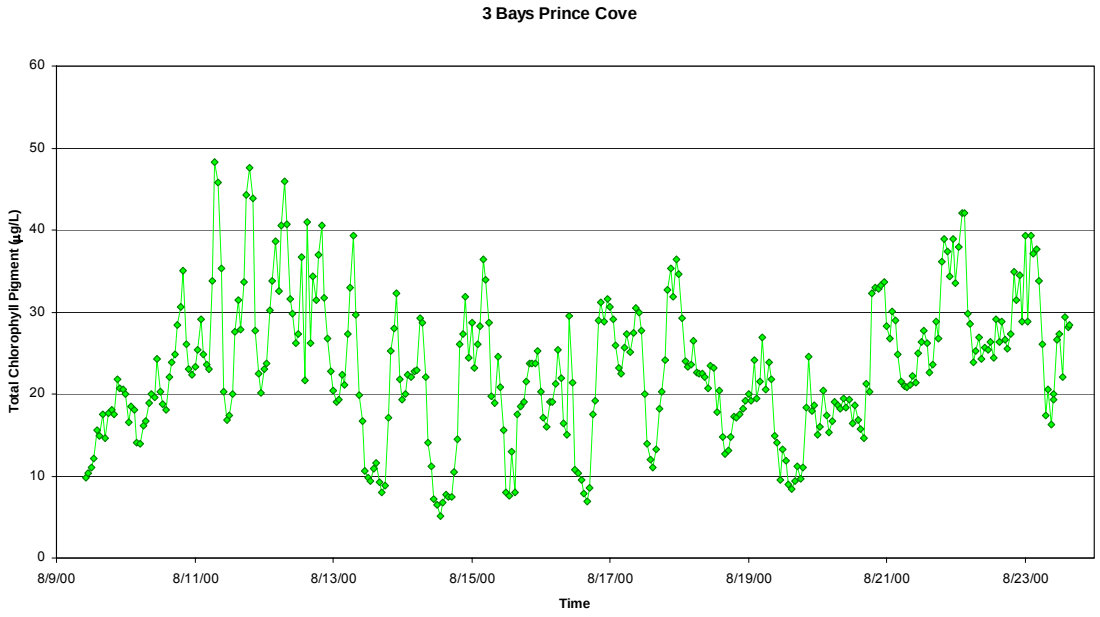


Figure VII-9. Bottom water record of Chlorophyll-*a* in the Three Bays Upper North Bay station, Summer 2001. Calibration samples represented as red dots.

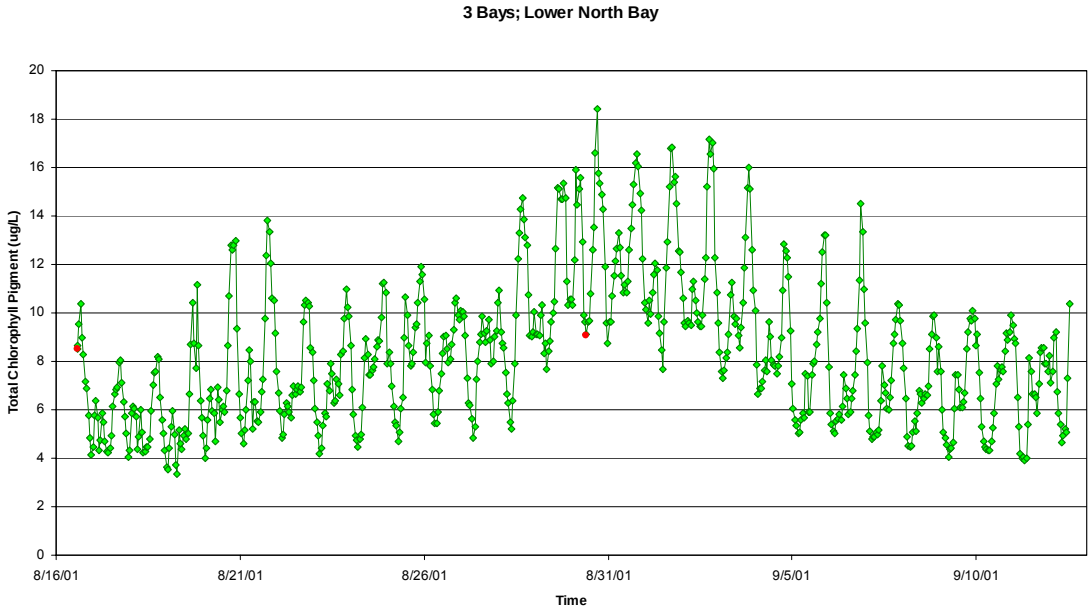


Figure VII-10. Bottom water record of Chlorophyll-*a* in the Three Bays Lower North Bay station, Summer 2001. Calibration samples represented as red dots.

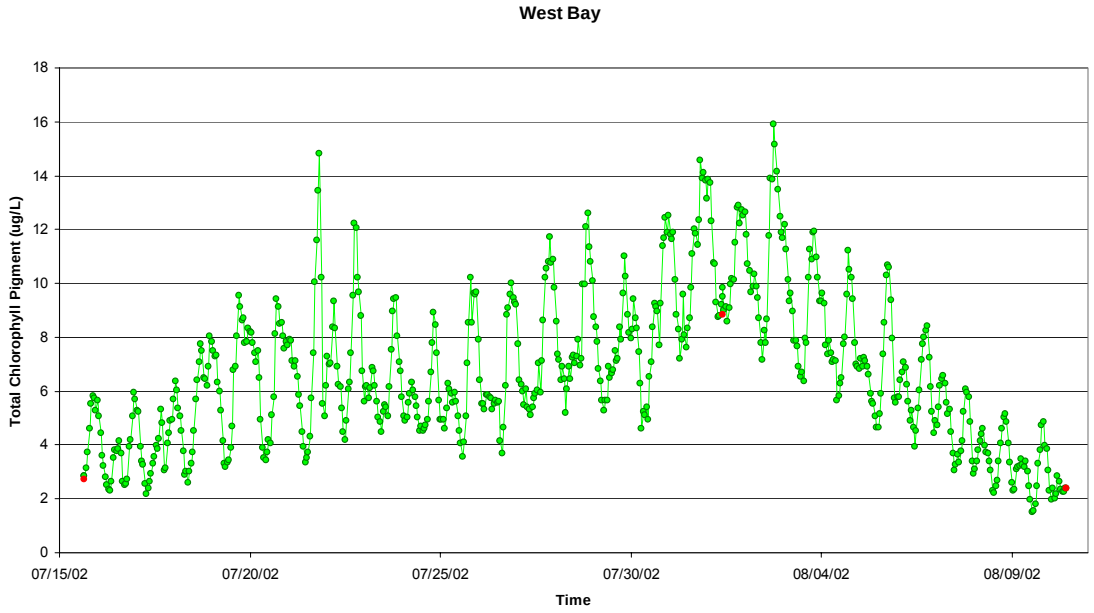


Figure VII-11. Bottom water record of Chlorophyll-*a* in the Three Bays West Bay station, Summer 2002. Calibration samples represented as red dots

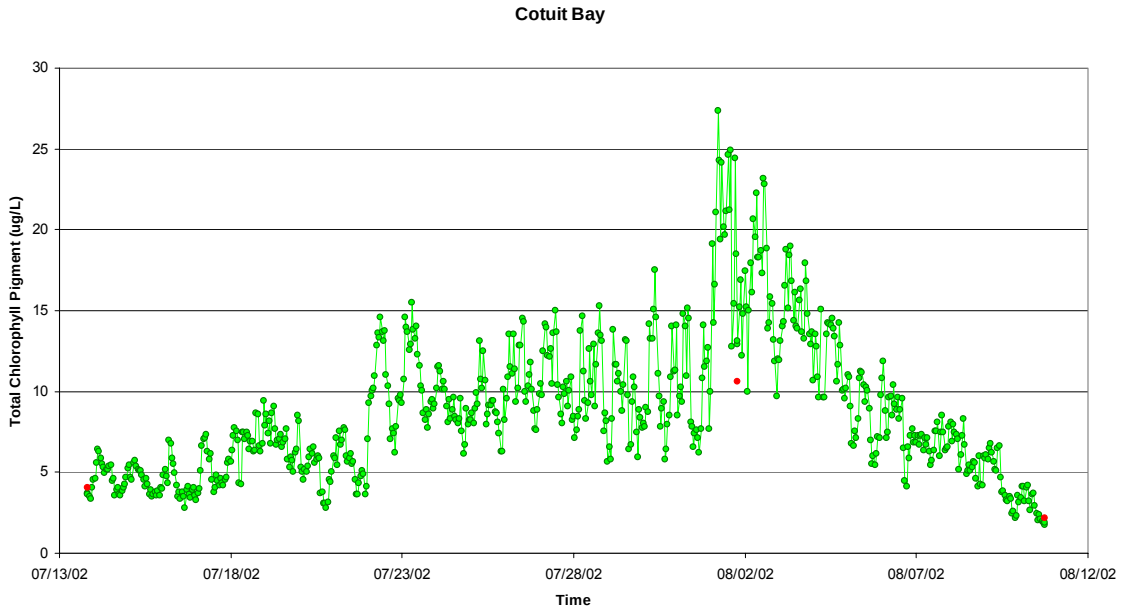


Figure VII-12. Bottom water record of Chlorophyll-*a* in the Three Bays Cotuit Bay station, Summer 2002. Calibration samples represented as red dots.

VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS

Eelgrass surveys and analysis of historical data was conducted for the Three Bays System by the DEP Eelgrass Mapping Program as part of the MEP Technical Team. Surveys were conducted in 1995 and 2001, as part of this program. Additional analysis of available aerial photos from 1951 was used to reconstruct the eelgrass distribution prior to any substantial development of the watershed. The 1951 data were only anecdotally validated, while the 1995 and 2001 maps were field validated. The primary use of the data is to indicate (a) if eelgrass once or currently colonizes a basin and (b) if large-scale system-wide shifts have occurred or are presently underway. Integration of these data sets provides a view of temporal trends in eelgrass distribution from 1951 to 1995 to 2001 (Figure VII-13 and VII-14); the period in which watershed nitrogen loading significantly increased to its present level. This temporal information can be used to determine the stability of the eelgrass community.

At present, eelgrass beds are not present within the Three Bays System. In addition, to the DEP mapping, this has been confirmed by the multiple MEP staff conducting the infaunal and sediment sampling and the mooring studies and by the Town of Barnstable Shellfish Department. The final remaining sparse patches in the shallows of Prince's Cove have not been seen since 2003. The current lack of eelgrass beds is expected given the high chlorophyll a and low dissolved oxygen levels and watercolumn nitrogen concentrations within this system. However, it appears that all of the major subembayments had water quality conditions capable of supporting eelgrass (except in the deeper channels and basin depths) in 1951. However, eelgrass appears to have been restricted to the shallows (North and Cotuit Bays) or to Prince's Cove and West Bay basins. If the issue in 1951 was nitrogen enrichment, the pattern of the beds would have been very different, with more eelgrass in lower Cotuit Bay and West Bay and much less in Prince's Cove and North Bay (except in the very shallows). Instead, it is likely that another factor may have been acting on the distribution, possibly related to the disturbance related to activities in North and Cotuit Bays associated with training during WWII. The landing craft training area in North Bay and the deep central basin of North Bay support distribution observed. However, whatever the cause, it is clear that Three Bays was once capable of supporting eelgrass within each of its major subembayments. It also appears that the recent losses (post 1951) are associated with nitrogen enrichment, as in virtually every other embayment in southeast Massachusetts.

The present absence of eelgrass in each of the major subembayments of the Three Bays System is consistent with the observed oxygen depletions in each basin and the high chlorophyll levels in the upper regions. The ability of the central deep basins in North Bay and Prince's Cove are particularly sensitive to eelgrass loss as it takes less intense phytoplankton blooms to reduce light penetration to the bottom, and thereby prevent eelgrass growth. At this time, it is not clear if these regions have historically (100 years) supported eelgrass. However, eelgrass beds fringing these basins are well documented.

Other factors which influence eelgrass bed loss in embayments may also be at play in the Three Bays System, though the recent loss seems completely in-line with nitrogen enrichment. However, a brief listing of non-nitrogen related factors is useful. Eelgrass bed loss does not seem to be directly related to mooring density, as boat mooring areas are relatively well constrained. Similarly, pier construction and boating pressure may be adding additional stress in nutrient enriched areas, but do not seem to be the overarching factor. It is not possible at this time to determine the potential effect of shellfishing on eelgrass bed distribution, although it should be noted that the Bay has been an important shellfish area for 100's of years during which eelgrass was prevalent.

As for the lack of eelgrass within the lowermost portion of Cotuit Bay, it is likely that it is associated with the highly dynamic coastal processes in this area. This is particularly true in the nearshore to the spit, where there have been several storm overwash events and the need for beach nourishment to maintain the spit. Also, this region needs periodic maintenance dredging of the tidal inlet, without which the tidal flushing of the Bay would be reduced, magnifying the eutrophic conditions of the entire system.

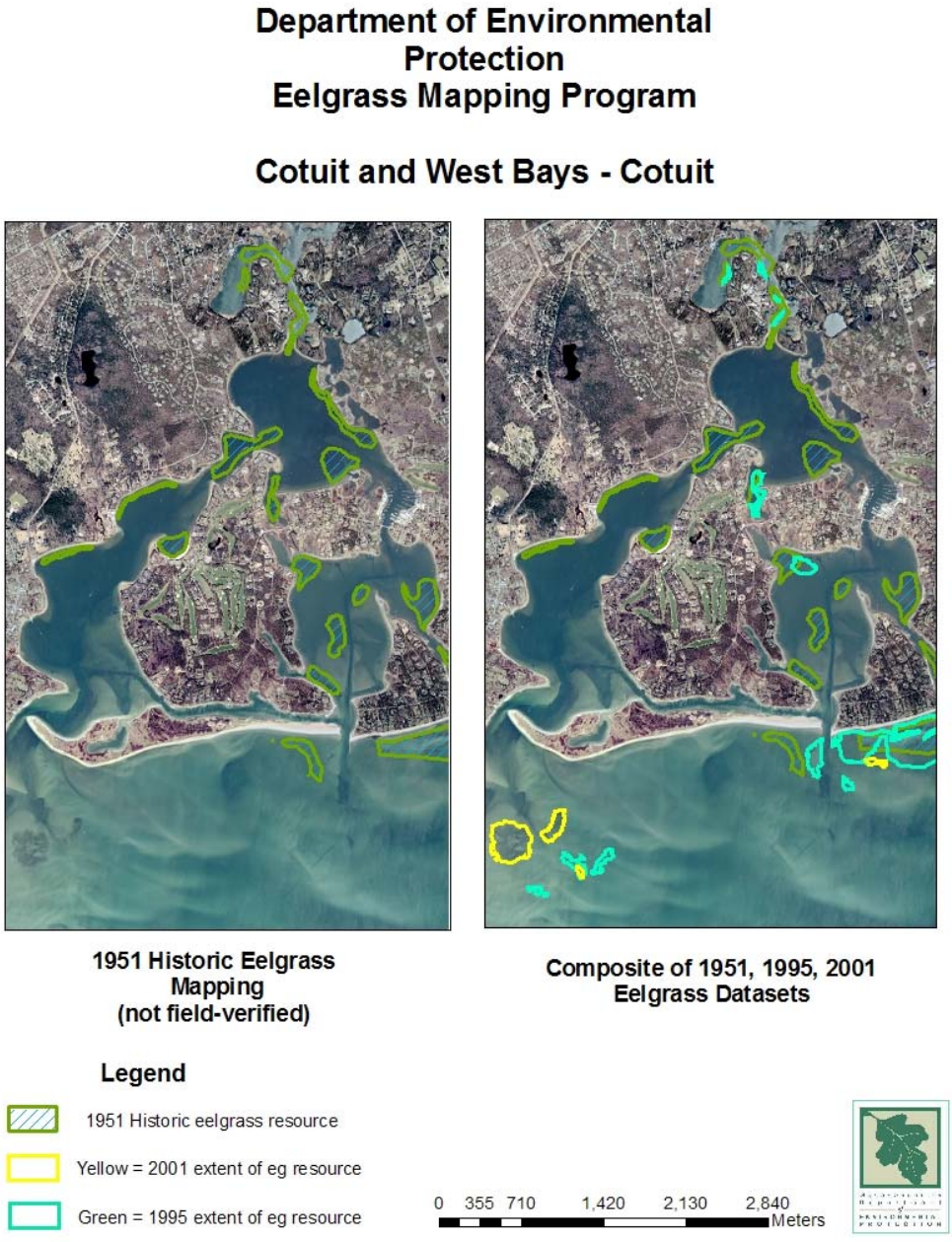


Figure VII-13. Eelgrass bed distribution within the Three Bays System. The 1951 coverage is depicted by the green thatched outline inside of which circumscribes the eelgrass beds. The green (1995) and yellow (2001) areas were mapped by DEP. All data was provided by the DEP Eelgrass Mapping Program.

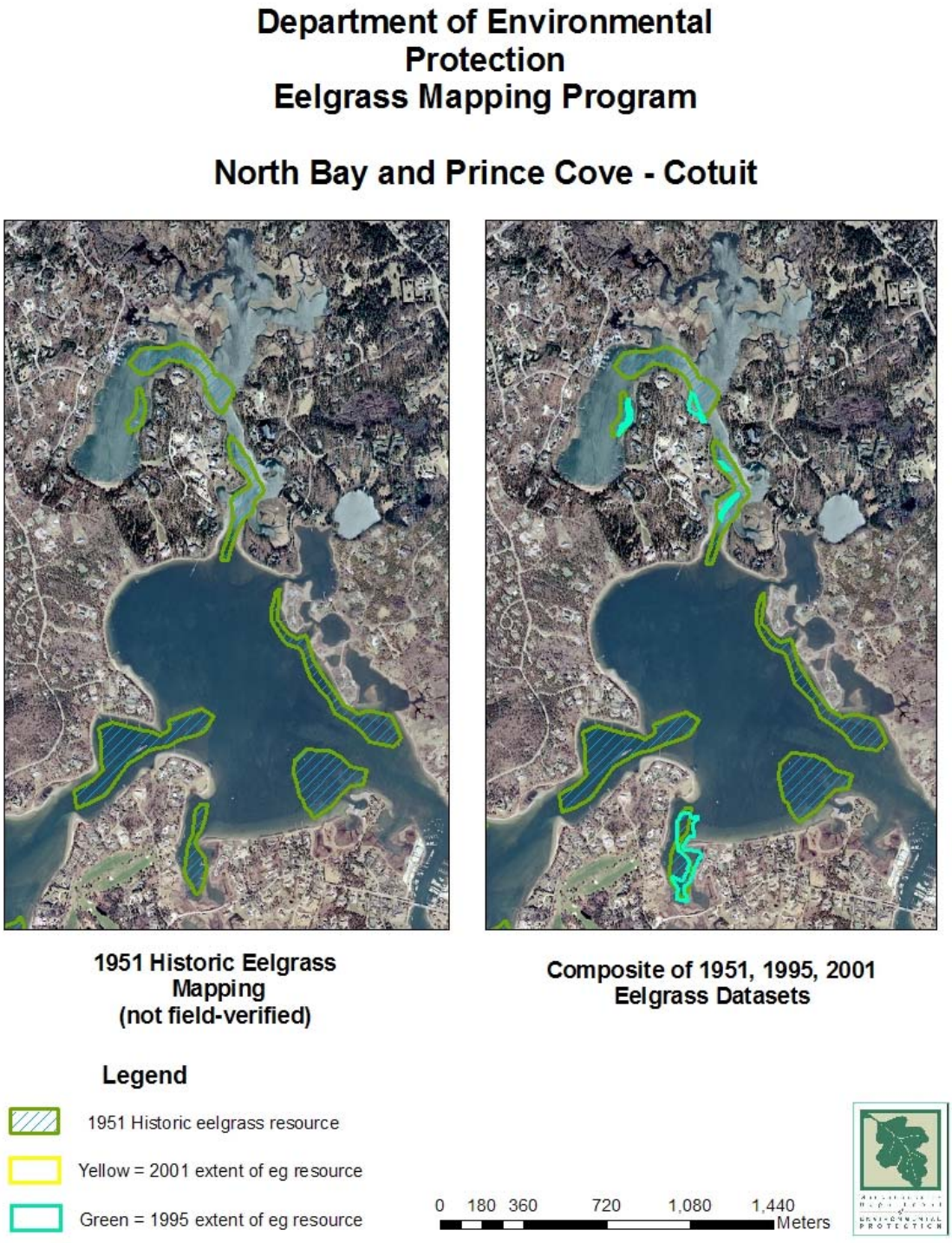


Figure VII-14. Eelgrass bed distribution within North Bay and Prince's Cove/Warren's Cove subembayments to the Three Bays System. The 1951 coverage is depicted by the green thatched outline inside of which circumscribes the eelgrass beds. The green (1995) and yellow (2001) areas were mapped by DEP. All data was provided by the DEP Eelgrass Mapping Program.

It is not possible to determine a general idea of short- and long-term rates of change in eelgrass coverage from the mapping data, since there is only limited temporal data and limited presence in recent surveys.. However, it is possible to utilize the 1951 coverage data as an indication that a minimum eelgrass bed area that might be recovered on the order of 130 acres, if nitrogen management alternatives were implemented (Table VII-3). Even more area is likely, if the "natural" pattern of marginal beds can be restored, that were not observed in the 1951 mapping. Even a restoration of fringing beds in North and Cotuit Bays and restoration of West Bay would result in several times the 1951 acreage. Note that restoration of this habitat will necessarily result in restoration of other resources throughout the Three Bays System and in the region of Prince's Cove. While it is unlikely that Warren's Cove will support eelgrass after restoration, given its salt marsh basin habitat, the present macroalgal problem would cease,(due to the nitrogen reductions required to restore the eelgrass.

The relative pattern of these data is consistent with the results of the oxygen and chlorophyll a patterns described in the previous section and the benthic infauna analysis, below.

Table VII-3. Changes in eelgrass coverage in the Three Bays system within the Town of Barnstable over the past half century (C. Costello).

EMBAYMENT	1951 (acres)	1995 (acres)	2001 (acres)	% Difference (1951 to 2001)
Three Bays	**130.36**	**11.19**	**0.00**	**100%**
There is presently no eelgrass in the Three Bays embayment system.				

VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling was conducted at 11 locations throughout the Three Bays System (Figure VII-15). In some cases multiple assays were conducted. In all areas and particularly those that do not support eelgrass beds, benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity and evenness of the community. It should be noted that, given the loss of eelgrass beds, portions of the Three Bays System are clearly impaired by nutrient overloading. However, to the extent that it can still support healthy infaunal communities, the benthic infauna analysis is important for determining the level of impairment (moderately impaired→significantly impaired→severely degraded). This assessment is also important for the establishment of site-specific nitrogen thresholds (Chapter VIII).

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas, as shown by the oxygen and chlorophyll records , have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5. However, the number of species and individuals must also be taken into account as a high diversity can be achieved in a population decimated by organic loading. Also, as stated above the specific species must also be examined as a large number of stress indicator species (e.g. Capitellids) would be indicative of a stressful environment, even if the number of individuals and species is relatively high.

The Infauna Study indicated that most of the upper areas of the Three Bays system are presently significantly impaired to severely degraded by nitrogen enrichment (Prince's Cove, Warren's Cove and portions of North Bay), while the lower basins of Cotuit Bay and West Bay are moderately impaired (Table VII-4).

Prince's Cove, Warren's Cove and 2 of 3 sites in North Bay are virtually devoid of infaunal animal communities. They support populations of <50 individuals per 0.0625 m^2, which is more than an order of magnitude less than in a healthy environment. Three of five locations had 11 or less individuals. The central region of North Bay currently supports a transitional community dominated by amphipods, indicative of organic matter enrichment. In contrast, Cotuit and West Bays generally have ~500-2000 individuals per grab and 16-26 species. While there are stress (generally *Capitella* or *Streblospio*) indicator species in numbers at these locations there are also other species indicative of a healthy environment and overall high diversity. Overall, the pattern of infaunal community quality is consistent with the pattern of oxygen depletion and chlorophyll a during summer and the absence of eelgrass. The Three Bays System is clearly significantly impaired to severely degraded in its uppermost basins with higher quality benthic habitat in the lower Cotuit and West Bays. However, all sites showed some level of degradation, either in number of individuals, diversity or the presence of stress indicator species. Lowering nitrogen inputs to this system should allow a relatively rapid recovery of communities in the 2 large lower basins, with higher levels of nitrogen management required to restore benthic habitat to North Bay and Prince's Cove and Warren's Cove. These upper basins currently support little to no viable benthic habitat.

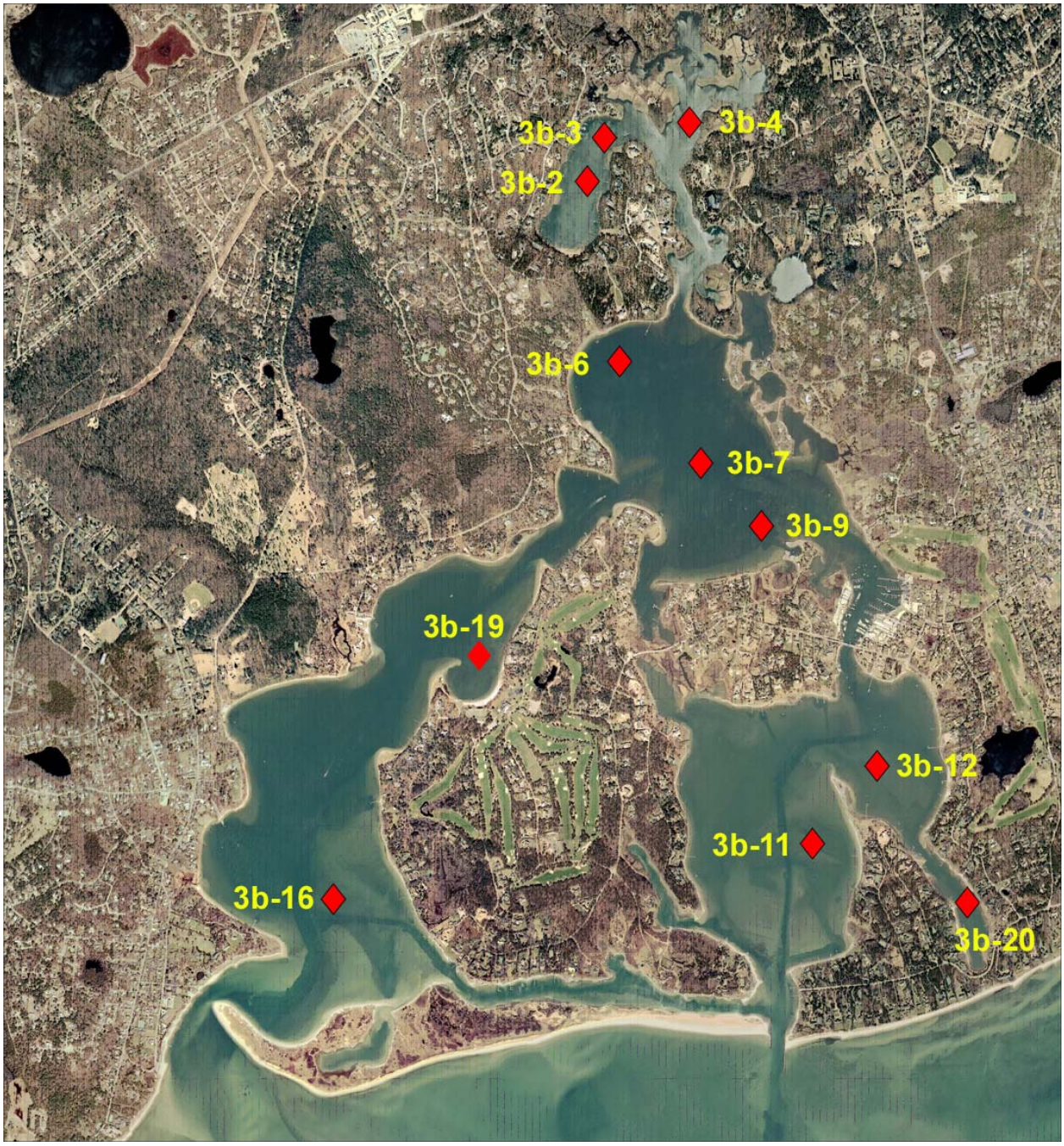


Figure VII-15. Aerial photograph of the Three Bays embayment system showing location of benthic infaunal sampling stations (red symbol).

Table VII-4. Benthic infaunal community data for the Three Bays embayment system. Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations (Samples represent surface area of 0.0625 m2). Values are averages of grab samples a-c.

Location	ID	Total Actual Species	Total Actual Individuals	Species Calculated @75 Indiv.	Weiner Diversity (H')	Evenness (E)	Infaunal Indicators
Prince's Cove							
Upper	2 a,b,c	4.7	43	NA	0.90	0.43	SI
Lower	3 a,b,c	9.3	50	NA	2.49	0.82	SI
Warren's Cove							
Mid	4 a,b,c	4.7	7	NA	2.01	0.86	SI
North Bay							
Upper	6 a,b,c	4.7	11	NA	1.90	0.85	SI
Mid Basin	7 a,b,c	14.3	821	7.5	1.35	0.36	MI
Lower	9 a,b,c	3.0	7	NA	1.91	0.92	SI
Cotuit Bay							
Upper Basin	19 a,b,c	16.3	535	12.6	2.99	0.75	H/MI
Lower Basin	16 a,b,c	16.0	233	14.1	3.26	0.82	H
West Bay							
Upper	12 a,b,c	17.3	501	13.5	3.39	0.82	H/MI
Mid/Lower	11 a,b,c	26.3	1895	10.5	2.02	0.42	H/MI
Eel Pond							
Upper	20 a,b,c	11.0	466	8.9	2.28	0.67	MI

VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS

VIII.1 ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires integration of key habitat parameters (infauna and eelgrass), sediment characteristics, and nutrient related water quality information (particularly dissolved oxygen and chlorophyll a). Additional information on temporal changes within each sub-embayment and its watershed further strengthen the analysis. These data were collected to support threshold development for the Three Bays System by the MEP Technical Team and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels determined from the baseline Three Bays Water Quality Monitoring Program collected by Three Bays Preservation and the Town of Barnstable. At present, Three Bays, is showing a gradient of significantly impaired (upper basins) to moderately impaired (Cotuit Bay, West Bay) habitat quality. The lower basins show moderate impairment based upon all 3 parameters (eelgrass, infauna, D.O.), in spite of their proximity to the tidal inlet and the high quality waters of Nantucket Sound. All of the habitat indicators show consistent patterns of habitat health in each of the major sub-embayments and that habitat impairments are consistent with nitrogen enrichment (Chapter VII).

Eelgrass: The Three Bays Estuary is relatively deep compared to others along the south shore of Cape Cod from Falmouth to Barnstable (Chapter V). Water depths are well within the range for eelgrass growth in Massachusetts, under suitable conditions of light penetration. However, the need for more transparent waters requires lower nitrogen loads to these deep basins, compared to shallower basins, to support this habitat.

Currently, there are no remaining eelgrass beds within the Three Bays System. However, it appears that all of the major sub-embayments had water quality conditions capable of supporting eelgrass (except in the deeper channels and basin depths) in 1951. However, eelgrass appears to have been restricted to the shallows (North and Cotuit Bays) or to Prince's Cove and West Bay basins. If the issue in 1951 was nitrogen enrichment, the pattern of the beds would have been very different, with more eelgrass in lower Cotuit Bay and West Bay and much less in Prince's Cove and North Bay (except in the very shallows). Instead, it is likely that disturbance related to activities in North and Cotuit Bays associated with training during WWII played a role in the North and Cotuit Bay pattern of beds in the 1951 assessment. Whatever the cause, it is clear that in the recent past, the Three Bays system was capable of supporting eelgrass within each of its major sub-embayments. It also appears that the recent losses (post 1951) are associated with nitrogen enrichment, as in virtually every other embayment in southeastern Massachusetts. The absence of eelgrass in each basin and the fact that they supported eelgrass in the recent past classifies each basins eelgrass habitat as "significantly impaired" (Table VIII-1).

The current absence of eelgrass in each of the major sub-embayments of the Three Bays System is consistent with the observed oxygen depletions in each basin and the high chlorophyll levels in the upper regions. The greater depths in the Three Bays Estuary also makes oxygen depletions more likely than in shallow basins with the same nitrogen levels. This results from the fact that deeper systems are more likely to periodically stratify. The central deep basins in North Bay and Prince's Cove are particularly sensitive to eelgrass loss as it takes less intense phytoplankton blooms to reduce light penetration to the bottom, and thereby prevent eelgrass growth. In addition, the basins are sensitive to periodic oxygen depletion. At

this time, it is not clear if these regions have historically (100 years) supported eelgrass. However, eelgrass beds fringing these basins are well documented. As regards the lack of eelgrass within the lowermost portion of Cotuit Bay and the Seapuit River, it is likely associated with the documented highly dynamic coastal processes in this area. The level of natural disturbance in this region is very high (sand transport, overwash, etc). Physical stability is important to the ability of eelgrass beds to form and persist. Nitrogen levels in lower Cotuit Bay would presently support eelgrass habitat (tidally averaged TN 0.32 mg L-1) as they are much lower than those in many other eelgrass beds in nearby systems that are physically stable. In addition, the persistence of eelgrass beds through 1995-2001 in the shallow waters of south Windmill Cove, but in a stable physical setting, were at much higher nitrogen levels (tidally averaged TN 0.40 mg L-1).

Table VIII-1. Summary of Nutrient Related Habitat Health within the Three Bays Estuary on the south shore of Barnstable , MA., based upon assessment data presented in Chapter VII.

Health Indicator	Three Bays Estuary						
	Princes Cove	Warrens Cove	North Bay		Cotuit Bay	West Bay	Eel Pond
			Upper	Lower			
Dissolved Oxygen	SI/SD[1]	SI/SD	SI/SD[1]	MI/SI[2]	MI/SI[2]	SI	H/MI[3]
Chlorophyll	SI	SI	MI/SI	MI/SI	MI	H/MI	--
Macroalgae	MI	SD[4]	--	--	MI[6]	MI	SI
Eelgrass	SI	SI	SI	SI	SI	SI	SI
Infaunal Animals	SD[7]	SD[8]	SD[8]	MI/SI	H/MI	H/MI	MI
Overall:	**SI/SD**	**SD**	**SI/SD**	**MI/SI**	**MI**	**MI**	**MI/SI**

1 – periodic oxygen depletions to <2 mg/L and frequently <4 mg/L.
2 – infrequent oxygen depletions to 3-4 mg/L, periodic 4-5 mg/L., generally >5 mg/L.
3 – generally >5 mg/L., grab sample data only.
4 – macroalgal floating accumulations during summer
5 – moderate macroalgal accumulations on bottom.
6 – low to moderate patches on bottom only.
7 – modest numbers of individuals dominated by stress indicator species.
8 – absence of infaunal community (<15 individuals/grab).
H = healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment; SD = Severe Degradation
-- = not applicable to this estuarine reach

Nitrogen management of this system is likely to restore at least an area equivalent to the 130 acres observed in 1951 (Table VII-3). Even more area is likely, if the "natural" pattern of marginal beds can be restored (not observed in the 1951 mapping). Even a restoration of fringing beds in North and Cotuit Bays and restoration of West Bay would result in several times the 1951 acreage. Note that restoration of this habitat will necessarily result in restoration of other resources throughout the Three Bays System and in the region of Prince's Cove. While it is unlikely that Warren's Cove will support eelgrass after restoration, given its salt marsh basin habitat, the present macroalgal problem would cease due to the nitrogen reductions required to

restore the eelgrass. Eelgrass recovery following nitrogen management would likely follow the pattern of beds first being re-established in the marginal areas in the lower basins and move to the deeper regions and the margins of the upper sub-embayments.

Water Quality: The dissolved oxygen (DO) records indicate that the major sub-embayments to the Three Bays system (Cotuit Bay, West Bay, North Bay and Prince's Cove) are currently under seasonal oxygen stress, consistent with nitrogen enrichment (Table VII-1). That the cause is nitrogen enrichment is supported by parallel observations of chlorophyll a (Table VII-2). Oxygen conditions and chlorophyll a levels generally improved with decreasing distance to the tidal inlet, although all basins showed oxygen depletions to <4 mg L^{-1}. There was also a clear gradient in chlorophyll a, with highest levels in the uppermost reaches and lowest levels near the tidal inlet to Nantucket Sound. The results of the summer oxygen and chlorophyll a studies are consistent with the absence of eelgrass throughout the Three Bays System and the near absence of animal communities throughout the upper basins where oxygen depletions routinely dropped below 3 mg/L (see below). These observations are consistent with a classification of the upper basins (North Bay and Prince's Cove and Warren's Cove) as generally "Significantly Impaired" and the lower basins (Cotuit Bay, West Bay) as "Moderately Impaired".

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 3.8 mg L^{-1}. Massachusetts State Water Quality Classification indicates that SA (high quality) waters maintain oxygen levels above 6 mg L^{-1}. The tidal waters of the Three Bays System are currently listed as SA under the State Classification.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality at all MEP DO mooring sites within the estuary (Figures VII-3 through VII-12). The oxygen data throughout the estuary is consistent with elevated organic matter loads from phytoplankton production (chlorophyll a levels) indicative of nitrogen enrichment and eutrophication of these estuarine systems. The oxygen records further indicate that the upper tidal reaches of each estuary have the largest daily oxygen excursion, with daily excursions in excess of 6 mg L-1 common. This further supports the assessment of a high degree of nutrient enrichment.

The use of only the duration of oxygen below, for example 4 mg L^{-1}, can underestimate the level of habitat impairment in these locations. The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). This was periodically observed within the upper basins, further supporting the contention that the upper basins are currently eutrophic. The oxygen and chlorophyll data also shows a gradient of impairment with high levels of impairment in the upper sub-embayments (Prince's Cove, Warren's Cove, North Bay) and better conditions in the lower basins (Cotuit Bay and West Bay). However, there was clear oxygen depletion at all mooring sites, which indicates that additional nitrogen loading will cause further habitat decline at all sites

Infaunal Communities: The Infauna Study indicated that most of the upper areas of the Three Bays system are presently significantly impaired to severely degraded by nitrogen enrichment

(Prince's Cove, Warren's Cove and portions of North Bay), while the lower basins of Cotuit Bay and West Bay are moderately impaired (Table VII-4).

Prince's Cove, Warren's Cove and 2 of 3 sites in North Bay are virtually devoid of infaunal animal communities. They support populations of <50 individuals per 0.0625 m^2, which is more than an order of magnitude less than in a healthy environment. Three of five locations had 11 or less individuals. The central region of North Bay currently supports a transitional community dominated by amphipods, indicative of organic matter enrichment. In contrast, Cotuit and West Bays generally have ~500-2000 individuals per grab and 16-26 species. While there are stress indicator species (generally *Capitella* or *Streblospio*) in numbers at these locations there are also other species indicative of a healthy environment and overall high diversity. Overall, the pattern of infaunal community quality is consistent with the pattern of oxygen depletion and chlorophyll a during summer and the absence of eelgrass. All sites showed some level of degradation, either in number of individuals, diversity or the presence of stress indicator species. Lowering nitrogen inputs to this system should allow a relatively rapid recovery of communities in the Cotuit and West Bays, with higher levels of nitrogen management required to restore benthic habitat to North Bay and Prince's Cove and Warren's Cove. These upper basins currently support little to no viable benthic habitat. The infaunal community based classification for each sub-embayment is fully supported by the water quality and eelgrass data discussed in the text above.

VIII.2 THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout an embayment system, is to first identify a sentinel location within the embayment. Secondly, it is necessary to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality. The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level are determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

For the Three Bays System, the restoration target should reflect both recent pre-degradation habitat quality and be reasonably achievable. Based upon the assessment data (Chapter VII), eelgrass bed restoration within Cotuit Bay and West Bay, with restoration of marginal beds in North Bay and Prince's Cove is supportable. In addition, in the central basins of North Bay and Prince's Cove, where eelgrass habitat has not been documented, as well as in Warren's Cove, restoration of infaunal habitat is necessary. Achieving these habitat quality targets will also result in mitigation of the present macroalgal accumulation problem in Warren's Cove.

To achieve these habitat restoration targets, for the Three Bays Estuary a single sentinel location was selected with secondary criteria that must be achieved at other locations. The secondary criteria serve only as checks to make sure that the targets are achieved when the nitrogen threshold at the sentinel station has been reached. The appropriate sentinel location within Three Bays was determined to be in the upper region of the narrows between North Bay and Cotuit Bay (at the entrance to the Narrows). This location was selected because (1) it is relatively deep (reflecting the larger Three Bays basins) and it supported a major eelgrass bed in the 1951 survey; (2) achieving the threshold nitrogen level at this location will result in high quality habitat conditions throughout Cotuit and West Bays; (3) restoration of nitrogen concentrations at this location should result in conditions similar to 1951 within Prince's and Warren's Coves and North Bay; (4) nitrogen levels restorative of eelgrass beds at the deeper

sentinel location should provide for marginal beds in the shallows of Prince's Cove and North Bay and (5) achieving the threshold nitrogen level at the sentinel location will require removal of sufficient nitrogen related stress as to restore infaunal animal habitat in the adjacent deeper waters of Prince's Cove and North Bay.

The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.38 mg TN L^{-1} at the sentinel location and 0.40 mg TN L^{-1} within the marginal regions (shallows) of North Bay. This secondary level to check restoration of marginal beds in North Bay (O.40 mg TN L^{-1}) is consistent with the analysis of restoration of fringing eelgrass beds in nearby Great Pond, and analysis where eelgrass beds in deep waters could not be supported at a tidally averaged TN of 0.412 mg TN L^{-1} at depths of 2 m. Similarly prior MEP analysis in Bournes Pond indicated that tidally averaged TN levels of 0.42 mg TN L^{-1} excluded beds from all but the shallowest water. The MEP Technical Team cannot specify the exact extent of marginal beds to be restored in the upper deep basins. At tidally averaged TN levels of 0.42 mg TN L^{-1} the eelgrass habitat would be restricted to very shallow waters, while at 0.40 mg TN L^{-1} the eelgrass habitat should reach to 1-2 meters depth, based upon the data from nearby systems. In addition, the persistence of eelgrass beds through 1995-2001 in the shallow waters of south Windmill Cove, but in a stable physical setting, were at nitrogen levels (tidally averaged TN ~0.40 mg L-1).

The target nitrogen concentration for restoration of eelgrass at the sentinel location system was determined to be 0.38 mg TN L^{-1}. It was not possible to make this determination based upon an analysis of the relationship of measured nitrogen levels to existing eelgrass beds in Three Bays, as all beds have been lost. Instead, the value stems from (1) the analysis of Stage Harbor, Chatham which also exchanges tidal water with Nantucket Sound and for which a MEP target has already been set), (2) analysis of nitrogen levels within the eelgrass bed in adjacent Waquoit Bay, near the inlet (measured TN of 0.395 mg N L^{-1}, tidally corrected <0.38 mg N L^{-1}), and (3) a similar analysis in West Falmouth Harbor. The sentinel station under present loading conditions supports a measured nitrogen level at mid-ebb tide of 0.438-0.498 mg TN L^{-1} and a tidally corrected average concentration of 0.485 mg TN L^{-1},

Since infaunal animal habitat is also a critical resource to the Three Bays System, the secondary metric for a successful restoration (after eelgrass) will be to restore the significantly impaired/severely degraded habitats in the Prince's Cove/Warren's Cove and North Bay basins. In the upper more muddy basins of other nearby systems, healthy infaunal habitat is associated with nitrogen levels of TN <0.5 mg TN L^{-1}. This was found for Popponesset Bay where based upon the infaunal analysis coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN L-1 were found supportive of high infaunal habitat quality in this system.

In the Three Bays System, present healthy infaunal areas are found at nitrogen levels of TN <0.42 mg TN L^{-1} (Cotuit Bay and West Bay) However, the impaired areas are at nitrogen levels of TN >0.5 mg TN L^{-1} (North Bay) and are severely degraded at nitrogen levels of TN >0.6 mg TN L^{-1}. This is consistent with the findings discussed above from other systems and fully supports a secondary nitrogen criteria for the upper muddy basins of 0.5 mg TN L^{-1}.

It must be stressed that the nitrogen threshold for the Three Bays System is at the sentinel location. The secondary criteria should be met when the threshold is met at the sentinel station and also serve as a "check". The nitrogen loads associated with the threshold concentration at the sentinel location are discussed in Section VIII.3, below.

VIII.3 DEVELOPMENT OF TARGET NITROGEN LOADS

The nitrogen thresholds developed in the previous section were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Three Bays system. The load reductions associated with the nitrogen thresholds developed in the previous section only represent one of many different ways to reduce load from the watershed in order to meet the threshold. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent one example from a suite of potential reduction approaches that need to be evaluated by the communities in the Three Bays system watershed. The purpose of the scenario presented is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

To develop the scenario, tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel stations chosen for Three Bays.

As shown in Table VIII-2 for the specific load reduction scenario (reductions in septic effluent discharges only), the nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations required 100% removal of septic load (associated with direct groundwater discharge to the embayment) for five of the eight total lower sub-watersheds of the system. In addition, a portion of the septic load entering the headwaters of the system from the Marstons Mills River also must be removed to meet the threshold nitrogen concentrations. For the load reduction scenario evaluated, the Marstons Mills River watershed required removal of approximately 25% of the septic load. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figures VIII-1 and VIII-2.

Tables VIII-3 and VIII-4 provide additional loading information associated with this thresholds scenario. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. For Example, removal of 100% of the septic load from the Warren's Cove sub-watershed results in an 58% reduction in total nitrogen load. For the Marstons Mills River, septic load reduction of 25% resulted in total attenuated watershed load reduction of 17%. Table VIII-4 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-4, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound.

Comparison of model results between existing loading conditions and the selected loading scenario to achieve the target TN concentrations at the sentinel station is shown in Table VIII-5. To achieve the threshold nitrogen concentrations at the sentinel station, a reduction in TN concentration of typically greater than 20% is required for the upper portions of the system, in North Bay and Prince's Cove.

The basis for the watershed nitrogen removal strategy utilized to achieve the embayment thresholds may have merit, since this example nitrogen remediation effort is focused on watersheds where groundwater is flowing directly into the estuary. For nutrient loads entering the systems through surface flow, natural attenuation in freshwater bodies (i.e., streams and ponds) can help by significantly reduce the load that finally reaches the estuary. Presently, this attenuation is occurring due to natural ecosystem processes and the extent of attenuation being determined by the mass of nitrogen which discharges to these systems. The nitrogen reaching these systems is currently "unplanned", resulting primarily from the widely distributed non-point nitrogen sources (e.g. septic systems, lawns, etc.). Future nitrogen management should take advantage of natural nitrogen attenuation, where possible, to ensure the most cost-effective nitrogen reduction strategies. However, "planned" use of natural systems has to be done carefully and with the full analysis to ensure that degradation of these systems will not occur. One clear finding of the MEP has been the need for analysis of the potential associated with restored wetlands or ecologically engineered ponds/wetlands to enhance nitrogen attenuation. Attenuation by ponds in agricultural systems has also been found to work in some cranberry bog systems, as well. Cranberry bogs, other freshwater wetland resources, and freshwater ponds provide opportunities for enhancing natural attenuation of their nitrogen loads. Restoration or enhancement of wetlands and ponds associated with the lower ends of rivers and/or streams discharging to estuaries are seen as providing a dual service of lowering infrastructure costs associated with wastewater management and increasing aquatic resources associated within the watershed and upper estuarine reaches.

Although the above modeling results provide one manner of achieving the selected threshold level for the sentinel site within the estuarine system, the specific example does not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading in one possible load reduction scenario for the Three Bays system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Cotuit Bay	17.022	13.618	-20.0%
West Bay	15.490	12.392	-20.0%
Seaptuit River	2.921	2.921	0.0%
North Bay	24.978	0.000	-100.0%
Prince's Cove	11.192	0.000	-100.0%
Warren's Cove	6.975	0.000	-100.0%
Prince's Cove Channel	4.767	0.000	-100.0%
Marstons Mills Crescent	3.573	0.000	-100.0%
Surface Water Sources			
Marstons Mills River	10.071	7.553	-25.0%
Little River	3.203	3.203	0.0%

Table VIII-3. Comparison of sub-embayment ***total watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading in one possible load reduction scenario for the Three Bays system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Cotuit Bay	21.778	18.374	-15.6%
West Bay	19.068	15.970	-16.2%
Seaptuit River	3.767	3.767	0.0%
North Bay	29.447	4.468	-84.8%
Prince's Cove	13.362	2.170	-83.8%
Warren's Cove	12.027	5.052	-58.0%
Prince's Cove Channel	5.537	0.770	-86.1%
Marstons Mills Crescent	7.293	3.721	-49.0%
Surface Water Sources			
Marstons Mills River	14.518	12.000	-17.3%
Little River	3.962	3.962	0.0%

Table VIII-4. Threshold sub-embayment and surface water loads used for total nitrogen modeling of the Three Bays system under one possible scenario, with sub-watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Cotuit Bay	18.374	5.786	-45.788
West Bay	15.970	4.233	3.469
Seaptuit River	3.767	0.452	-5.371
North Bay	4.468	3.953	45.202
Prince's Cove	2.170	1.230	0.323
Warren's Cove	5.052	-	6.225
Prince's Cove Channel	0.770	-	1.541
Marstons Mills Crescent	3.721	-	-
Surface Water Sources			
Marstons Mills River	12.000	-	-
Little River	3.962	-	-

Table VIII-5. Comparison of model average total N concentrations from present loading and the threshold scenario (reduction in septic effluent discharge only), with percent change, for the Three Bays system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions).

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Prince's Cove - south	TB2	0.695	0.460	-33.8%
Prince's Cove - north	TB3	0.639	0.446	-30.1%
Warren's Cove	TB4	0.595	0.433	-27.2%
North Bay - north	TB5	0.518	0.400	-22.9%
North Bay - south	TB6	0.500	0.392	-21.7%
North Windmill Cove	TB7	0.511	0.396	-22.5%
West Bay - north	TB8	0.363	0.326	-10.1%
West Bay - west	TB9	0.327	0.307	-6.1%
Eel River	TB10	0.486	0.427	-12.2%
Seapuit River	TB11	0.295	0.287	-2.6%
Cotuit Bay - north	TB12	0.414	0.346	-16.5%
Cotuit Bay - south	TB13	0.321	0.298	-7.1%
South Windmill Cove	TB15	0.402	0.364	-9.5%
Mellon Cove	TB16	0.392	0.367	-6.2%
Dam Pond	TB17	0.523	0.402	-23.3%

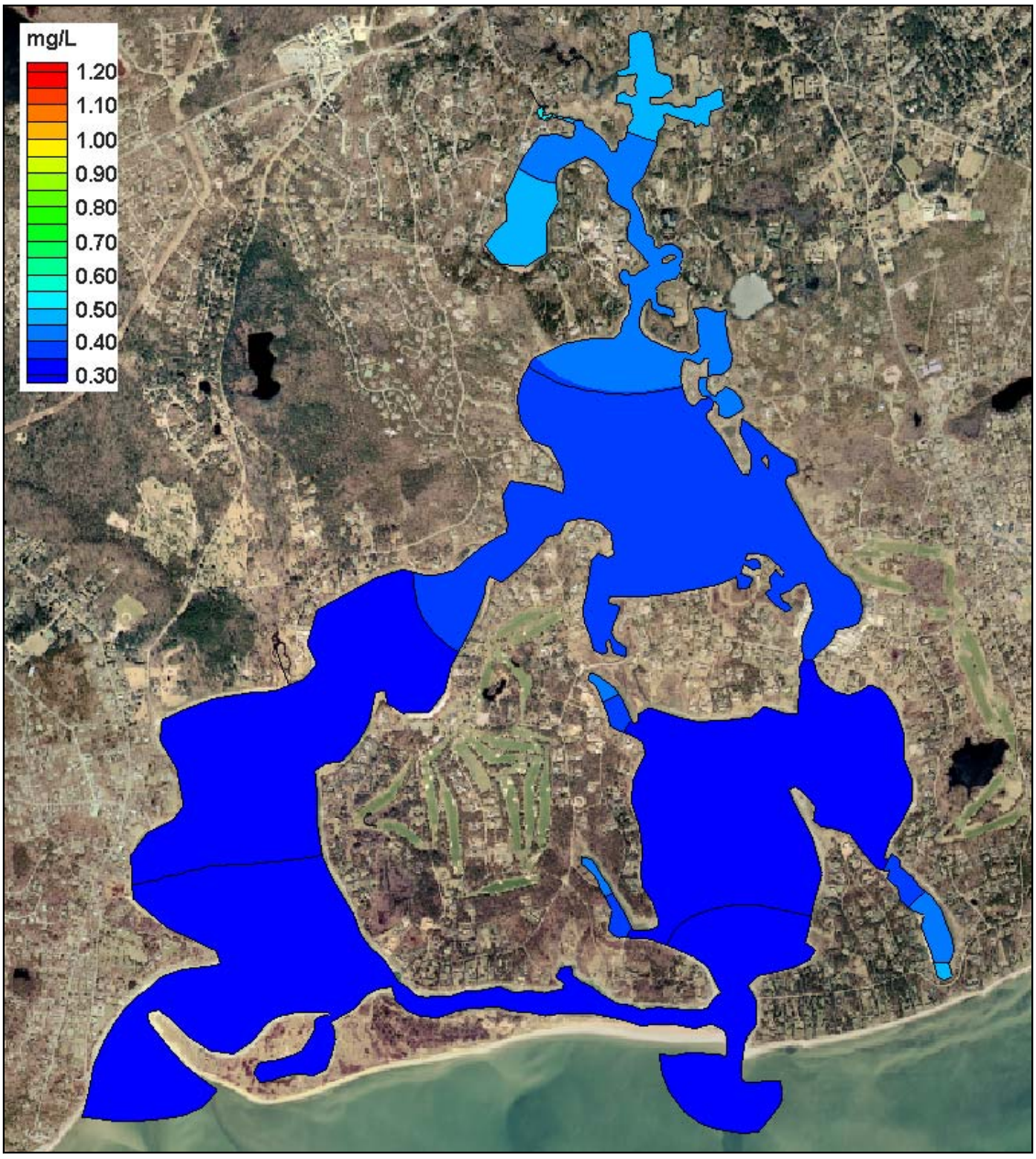


Figure VIII-1. Contour plot of modeled total nitrogen concentrations (mg/L) in the Three Bays system, for threshold conditions (0.38 mg/L at the narrows between North Bay and Cotuit Bay).

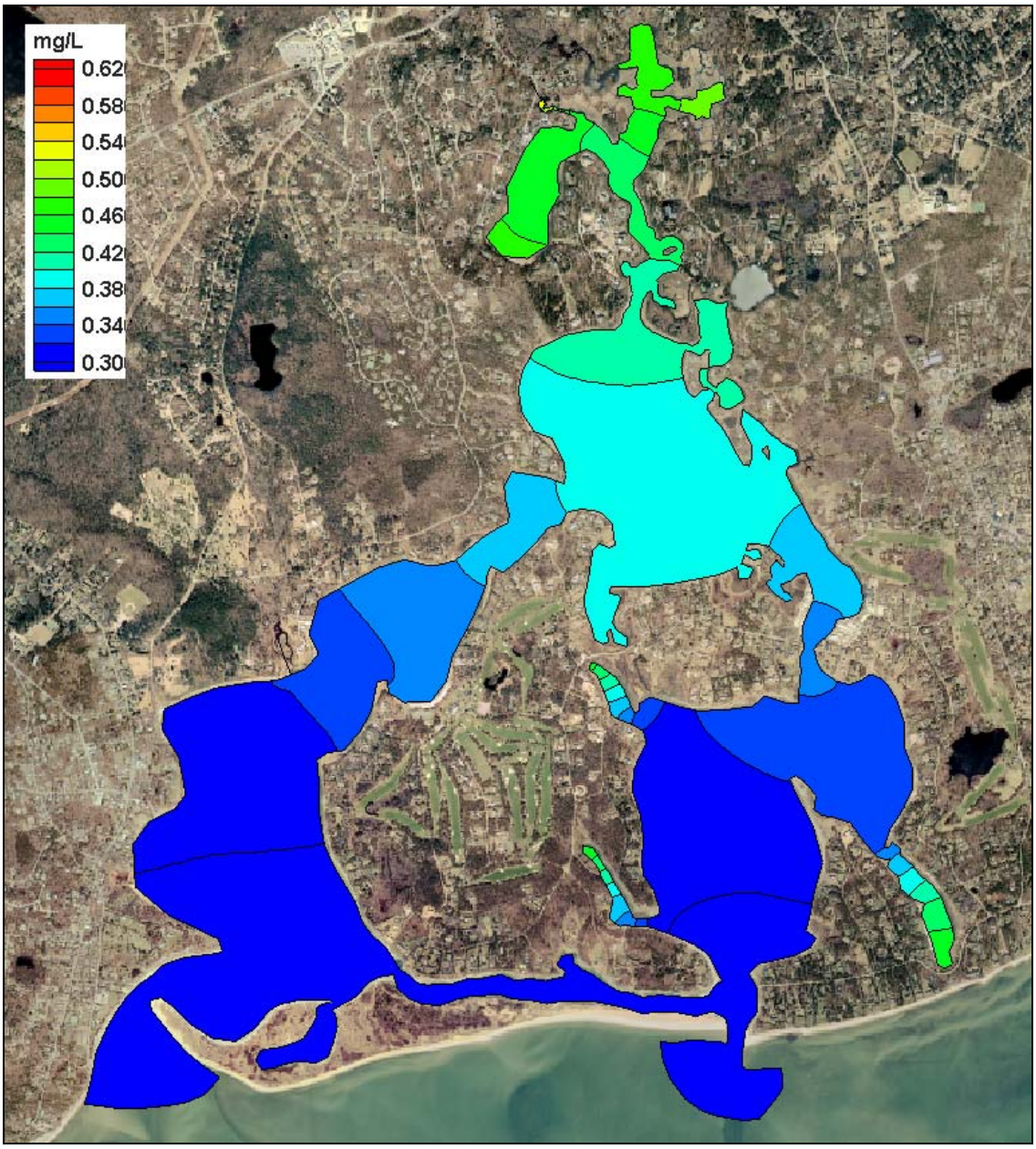


Figure VIII-2. Same results as for Figure VIII-1, but shown with finer contour increments for emphasis. Contour plot of modeled total nitrogen concentrations (mg/L) in the Three Bays system, for threshold conditions (0.38 mg/L at the narrows between North Bay and Cotuit Bay).

IX. ALTERNATIVES TO IMPROVE TIDAL FLUSHING AND WATER QUALITY

IX.1 DREDGING OF COTUIT BAY INLET

An investigation of water quality impacts resulting from a proposed widening of Cotuit Bay inlet was performed using the existing calibrated hydrodynamic and total nitrogen model of the Three Bays system. For this dredging scenario, the inlet to Cotuit Bay is widened by 300 feet, and to a depth of 8 feet NGVD. This would be achieved by removing the western tip of Sampsons Island (attached to Dead Neck), which is an accreting sand spit, supplied with sand from the updrift (eastern) portion of the island. Widening the inlet would alleviate erosional pressure on the western shore of the inlet, while returning the inlet to conditions that existed in the 1960's. It was also considered possible that the proposed dredging would benefit tidal exchange between Three Bays and Nantucket Sound, and therefore improve water quality in the system.

To quantitatively assess the water quality impacts resulting from dredging the inlet, the Three Bays hydrodynamic model was modified to include the improvements at the inlet and then re-run with the same offshore tidal boundary conditions as was used for the model runs of present conditions. A comparison of hydrodynamic model output for present and post-dredge model output is presented in Table IX-1. The resulting changes to the Three Bays system hydrodynamics due to dredging are very small. As an example, the tide prism of the entire Three Bays system increases only by 0.1%, while its mean volume is essentially unchanged. The resulting changes to computed flushing rates are similarly small.

Table IX-1. Comparison of modeled hydrologic conditions in the Three Bays system for present conditions and the Cotuit Bay Inlet dredging scenario. Computed residence times are shown to three decimal places in order to show the change resulting from the proposed dredging at the inlet.

Embayment	Mean Volume (ft^3)	Tide Prism Volume (ft^3)	Local Residence Time (days)	System Residence Time (days)
PRESENT				
Three Bays System	429,117,000	140,570,000	1.580	1.580
North Bay	139,666,000	45,824,000	1.577	4.846
Marstons Mills River	25,236,000	10,834,000	1.205	20.497
Prince's Cove	13,007,000	4,553,000	1.478	48.774
Warren's Cove	5,047,000	3,614,000	0.723	61.447
Dam Pond	2,798,000	1,200,000	1.207	185.057
Eel River	4,035,000	1,702,000	1.227	130.475
DREDGED COTUIT INLET				
Three Bays System	429,149,000	140,747,000	1.578	1.578
North Bay	139,655,000	45,887,000	1.575	4.840
Marstons Mills River	25,236,000	10,850,000	1.204	20.469
Prince's Cove	13,007,000	4,560,000	1.476	48.703
Warren's Cove	5,047,000	3,619,000	0.722	61.366
Dam Pond	2,797,000	1,202,000	1.204	184.763
Eel River	4,034,000	1,706,000	1.224	130.179

The small changes in total system tidal volume flux, resulting from widening the inlet, are not unexpected considering that the analysis of tidal energy distribution in the Three Bays system (section V.2.1) showed that there is very little tidal attenuation between the two inlets to Nantucket Sound and even in the most distant reaches of the system, in Prince's Cove. The small degree of tidal attenuation indicates that the system presently flushes efficiently, and therefore increasing the size of either inlet could not significantly increase tidal exchange with Nantucket Sound.

Although the total system-wide tidal volume does not change by a significant amount, there is a quantifiable change in how tidal flows are distributed within the Three Bays system. The distribution of tidal fluxes computed in the model at the two outlet channels from North Bay to West Bay (that the Little Island draw bridge) and Cotuit Bay (at the Narrows) are presented in Table IX-2. For present conditions, 63% of North Bay's total tidal exchange is through the Narrows to Cotuit Bay, for both ebb and flood tides. The remaining 36% is via the channel to West Bay. For the dredging scenario, tidal exchange between North Bay and Cotuit Bay increases further, to about 67% for both the ebb and flood portions of the tide.

A change in flow distribution can also be seen at the inlets to the Three Bays system. As shown in Table IX-3 for present conditions, the total tide exchange between the Three Bays system and Nantucket Sound is evenly split between the two inlets. Dredging of the Cotuit Bay entrance increases the flow through Cotuit inlet to approximately 55% of the system total. Because the total flow in and out of the system remains constant, the flow though West Bay inlet must decrease to 45%. Additional changes occur in the Seapuit River. Based upon the model results, dredging of Cotuit Bay inlet would cause the flow through the Seapuit River to be reduced by approximately 35%, which also means that the maximum velocities in the river channel would be reduced. Model results indicate that maximum channel velocities would be reduced be approximately 25% in the dredged inlet scenario.

Table IX-2. Comparison of the distribution of tidal flows ebbing from and flowing to North Bay (to Cotuit Bay and West Bay) for present conditions and for the Cotuit Bay inlet dredging scenario. Percentages are based on the total hydraulic flux entering or exiting North Bay .

Flow Pathway	Present		Dredged Cotuit Bay Inlet	
	Flood	Ebb	Flood	Ebb
North Bay via Cotuit Bay	62.5%	65.2%	65.9%	68.1%
North Bay via West Bay	37.5%	34.8%	34.1%	31.9%

Table IX-3. Comparison of the distribution of tidal flows ebbing from and flowing to the Three Bays system (via Cotuit Bay inlet and West Bay inlet) for present conditions and for the Cotuit Bay inlet dredging scenario. Percentages are based on the total hydraulic flux entering or exiting the entire Three Bays system .

Flow Pathway	Present		Dredged Cotuit Bay Inlet	
	Flood	Ebb	Flood	Ebb
Cotuit Bay Inlet	49.9%	51.3%	55.41%	54.65%
West Bay Inlet	50.1%	48.7%	44.59%	45.35%

Changes in the Three Bays system resulting from widening Cotuit Bay were further quantified by modeling TN using the modified hydrodynamics. The dredging scenario was modeled using the nitrogen loading distribution and model parameters determined previously for present conditions (Table VI-2). In Figure IX-1, a contour plot is presented that shows TN changes between the dredging scenario and present conditions.

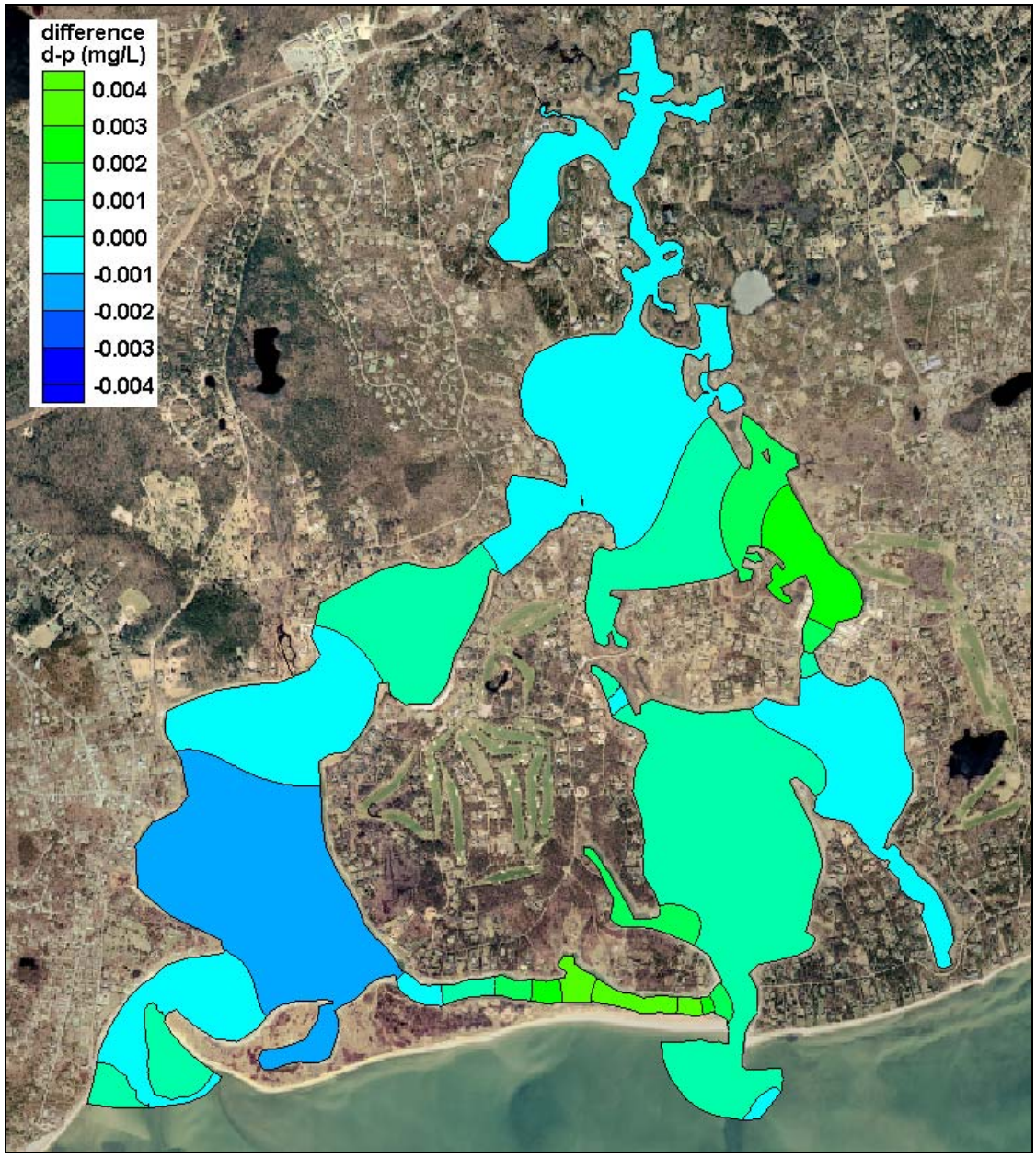


Figure IX-1. Contour plot of total nitrogen concentration change between present hydrodynamic conditions and the dredging scenario where Cotuit Bay inlet is widened to by approximately 300 ft to a depth of 8 ft NGVD. The difference is computed as dredged minus present (d-p) concentrations. Therefore, minus values indicate nitrogen concentration reductions associated with Cotuit Inlet dredging.

Similar to the hydrodynamic model results, changes to nitrogen concentrations throughout the Three Bays system are relatively small, with a maximum range of +0.004 to -0.002 mg/L, as

a result of Cotuit Inlet dredging. Pre- and post-dredge TN concentrations at each of the water quality monitoring stations are shown in Table IX-4. The largest increase in modeled TN occurs in the eastern end of the Seapuit River, near West Bay Inlet; however, this slight increase would not cause any type of ecological shift for this region. The greatest decrease in TN occurs in the southeastern extent of Cotuit Bay, specifically in Treasure Cove and near the western mouth of the Seapuit River. Generally, water quality improvements are seen in the main basin of Cotuit Bay, as well as in North Bay, Prince's Cove, and Warren's Cove. Small increases in average modeled TN concentrations are seen in West Bay, the Seapuit River, and the southeastern portion of North Bay. None of the changes are large enough to substantially impact water quality, either in a positive or negative way. However, it should be noted that dredging of the Cotuit Bay Inlet would return the system to similar conditions to the 1950s (the basis for the eelgrass restoration target). During this time period, Cotuit Inlet was the dominant inlet to the Three Bays estuarine system. Due to the larger overall volume and depth of Cotuit Bay relative to West Bay, it is beneficial from a water quality perspective to have the dominant inlet be the Cotuit Bay entrance. Based upon information from the Town of Barnstable, navigation and safety also remain concerns at the existing Cotuit Bay Inlet. These factors, along with the quantifiable improvements to Cotuit Bay water quality, may prove to be viable reasons for moving forward with Cotuit Inlet dredging.

Table IX-4. Comparison of model average total N concentrations from present loading and the threshold scenario, with percent change, for the Three Bays system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions).

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Prince's Cove - south	TB2	0.695	0.695	0.0%
Prince's Cove - north	TB3	0.639	0.638	-0.2%
Warren's Cove	TB4	0.595	0.594	-0.2%
North Bay - north	TB5	0.518	0.518	-0.2%
North Bay - south	TB6	0.500	0.501	+0.2%
North Windmill Cove	TB7	0.511	0.511	0.0%
West Bay - north	TB8	0.363	0.363	0.0%
West Bay - west	TB9	0.327	0.328	+0.3%
Eel River	TB10	0.486	0.485	-0.2%
Seapuit River	TB11	0.295	0.298	+1.0%
Cotuit Bay - north	TB12	0.414	0.415	+0.2%
Cotuit Bay - south	TB13	0.321	0.320	-0.3%
South Windmill Cove	TB15	0.402	0.402	0.0%
Mellon Cove	TB16	0.392	0.393	+0.3%
Dam Pond	TB17	0.523	0.523	-0.2%

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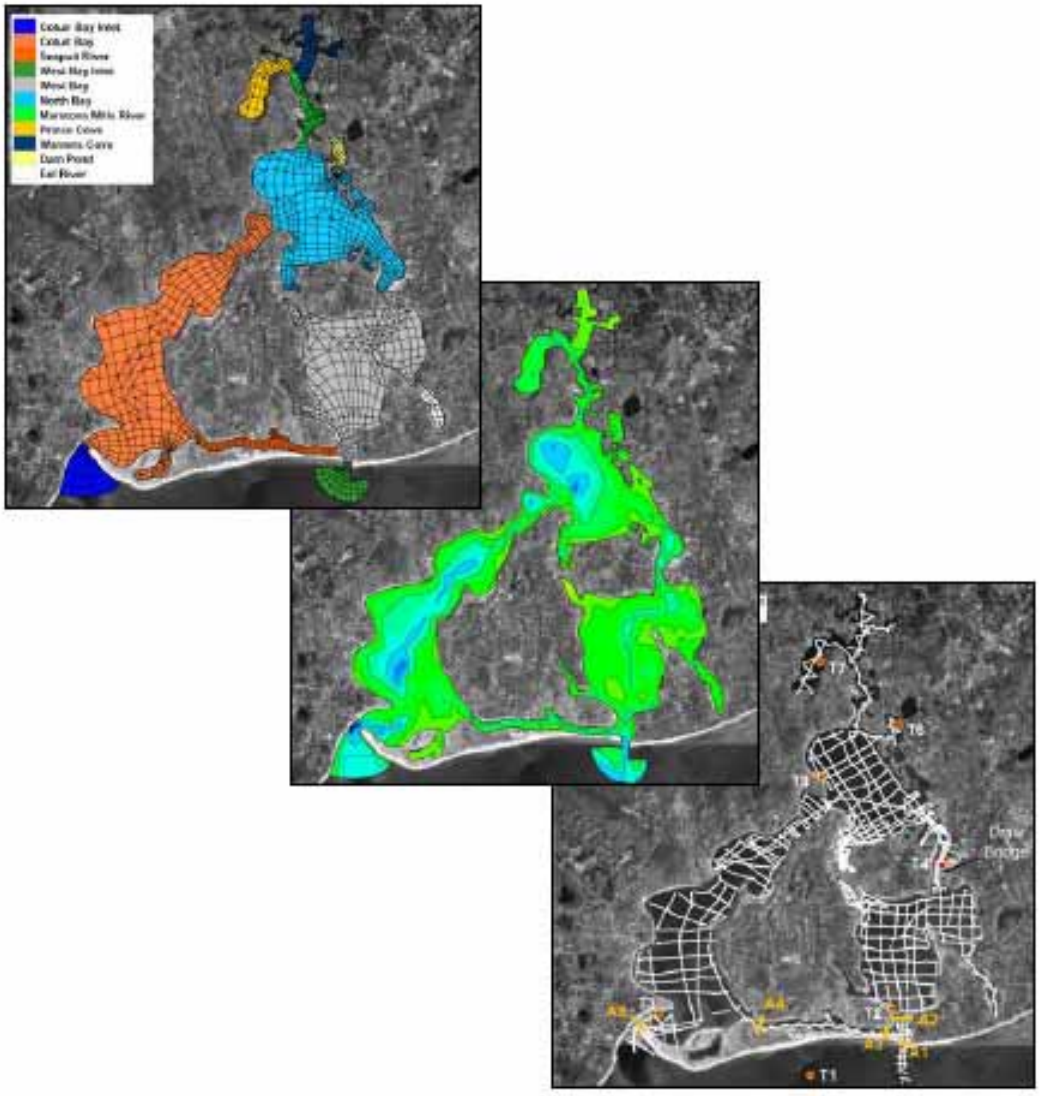
Appendix X

MassDEP TMDL Report for Three Bay System; MassDEP, September 7, 2007

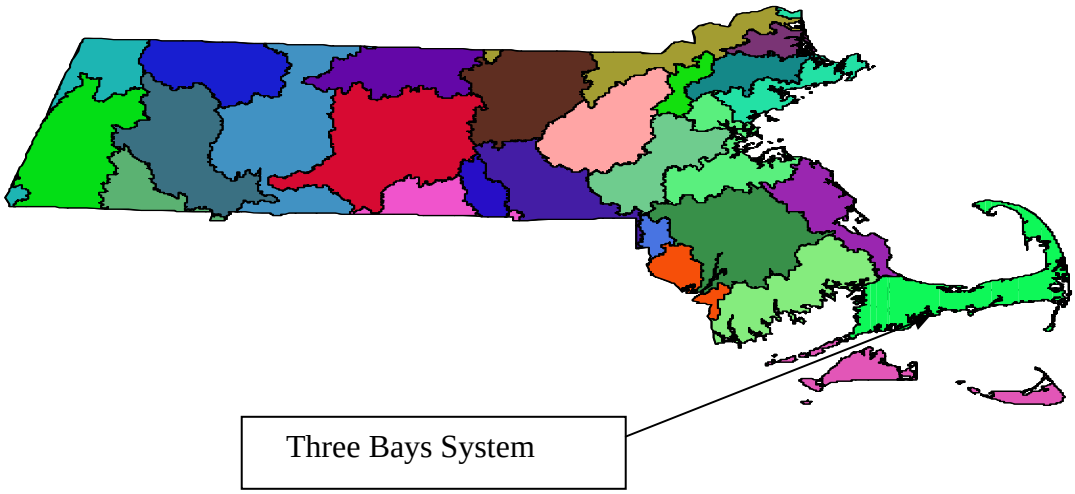
FINAL
Three Bays System
Total Maximum Daily Loads For Total Nitrogen
(Report # 96-TMDL-10 Control #242.0)



COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
IAN A. BOWLES, SECRETARY
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
LAURIE BURT, COMMISSIONER
BUREAU OF RESOURCE PROTECTION
ARLEEN O'DONNELL, ASSISTANT COMMISSIONER
DIVISION OF WATERESHED MANAGEMENT
GLENN HAAS, DIRECTOR

September 7, 2007

Three Bays System
Total Maximum Daily Loads
For Total Nitrogen



Key Feature: Total Nitrogen TMDL for Three Bays System
Location: EPA Region 1
Land Type: New England Coastal
303d Listing: The waterbody segments impaired and on the Category 5 list includes Cotuit Bay, North Bay, Prince Cove, Seapuit River, and West Bay.
Data Sources: University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Cape Cod Commission, Town of Barnstable, Town of Sandwich, and Town of Mashpee.
Data Mechanism: Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model
Monitoring Plan: Town of Barnstable monitoring program (possible assistance from SMAST)
Control Measures: Sewering, Storm Water Management, Attenuation by Impoundments and Wetlands, Fertilizer Use By-laws

EXECUTIVE SUMMARY

Problem Statement

Excessive nitrogen (N) originating primarily from on-site wastewater disposal (both conventional septic systems and innovative/alternative systems) has led to significant decreases in the environmental quality of coastal rivers, ponds, and harbors in many communities in southeastern Massachusetts. In the coastal waters of Massachusetts these problems include:

- Loss of eelgrass beds, which are critical habitats for macroinvertebrates and fish
- Undesirable increases in macro algae, which are much less beneficial than eelgrass
- Periodic extreme decreases in dissolved oxygen concentrations that threaten aquatic life
- Reductions in the diversity of benthic animal populations
- Periodic algae blooms

With proper management of nitrogen inputs these trends can be reversed. Without proper management more severe problems might develop, including:

- Periodic fish kills
- Unpleasant odors and scum
- Benthic communities reduced to the most stress-tolerant species, or in the worst cases, near loss of the benthic animal communities

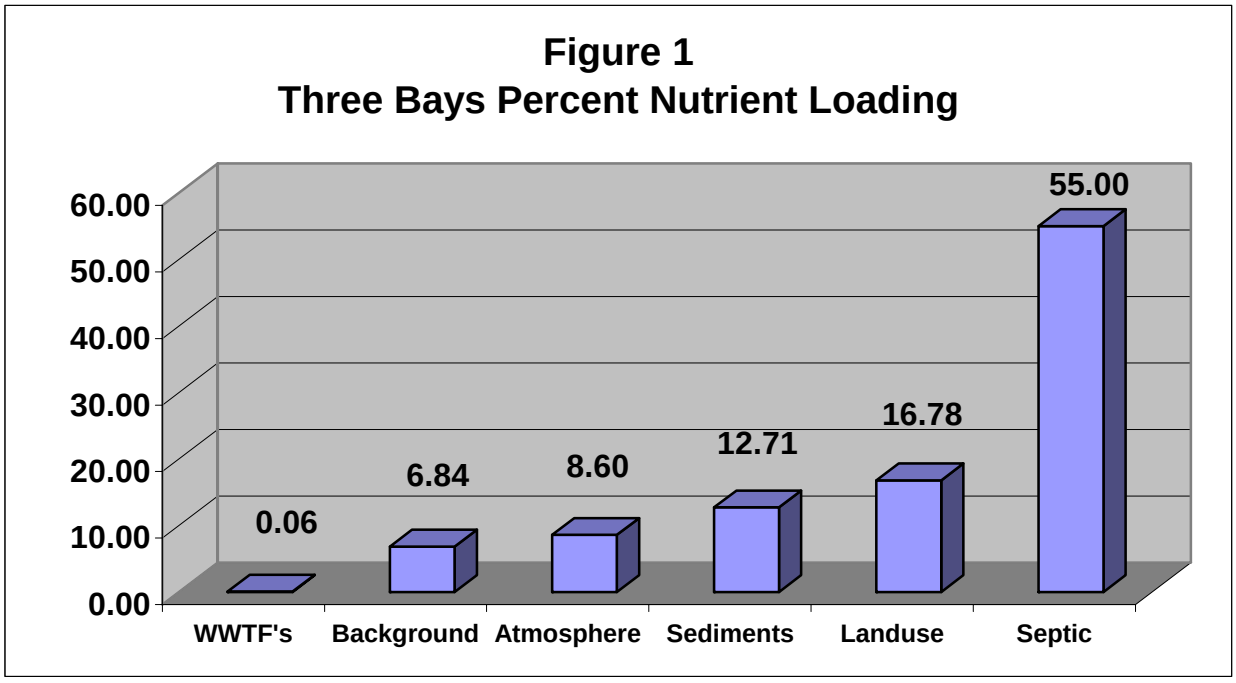
Coastal communities, including Barnstable, Sandwich and Mashpee, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings will result in complete replacement of eelgrass by macro-algae, a higher frequency of extreme decreases in dissolved oxygen concentrations and fish kills, widespread occurrence of unpleasant odors and visible scum, and a complete loss of benthic macroinvertebrates throughout most of the embayments. As a result of these environmental impacts, commercial and recreational uses of Three Bay's coastal waters will be greatly reduced, and could cease altogether.

Sources of nitrogen

Nitrogen enters the waters of coastal embayments from the following sources:

- The watershed
    - On-site subsurface wastewater disposal systems
    - Natural background
    - Runoff
    - Fertilizers
    - Wastewater treatment facilities
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments

Most of the present N load originates from individual subsurface wastewater disposal (septic) systems, primarily serving individual residences, as seen in Figure 1.



Target Threshold Nitrogen Concentrations and Loadings

The N loadings (the quantity of nitrogen) from the watersheds of the sub-embayments of the Three Bays "system" range from 3.8 kg/day in Seapuit River, to 35.2 kg/day in Prince Cove. The resultant concentrations of N in the areas studied range from 0.32 mg/L (milligrams of nitrogen per liter) in the Seapuit River to 0.70 mg/L in Prince Cove.

In order to restore and protect areas contained within Three Bays, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below the thresholds that cause the observed environmental impacts. The Department has determined that, for the waters contained within the Three Bays project area, N concentrations in the range from 0.38 to 0.50 mg/L are protective. The mechanism for achieving these target threshold N concentrations is to reduce the N loadings to the sub-embayments. The Massachusetts Estuaries Project (MEP) has determined through mathematical modeling, of each of the sub-embayment watersheds, which the Total Maximum Daily Loads (TMDL) of N that will meet the target thresholds range from 2-54 kg/day. The purpose of this document is to present TMDLs for the major sub-embayments and to provide guidance to the Towns on possible ways to reduce the N loadings to implement the proposed TMDLs.

Implementation

The primary goal of implementation will be lowering the concentrations of N by greatly reducing the loadings from on-site subsurface wastewater disposal systems through a variety of centralized or decentralized methods such as sewering with nitrogen removal technology, advanced treatment of septage, and/or installation of N-reducing on-site systems.

These strategies, plus ways to reduce N loadings from stormwater runoff and fertilizers, are explained in detail in the "MEP Embayment Restoration Guidance for Implementation Strategies", which is available on the DEP website at http://www.mass.gov/dep/water/resources/restore.htm. The appropriateness of any of the alternatives will depend on local conditions, and will have to be determined on a case-by-case basis, using an adaptive management approach.

Finally, growth within the communities of Barnstable, Sandwich, and Mashpee (part of the upper watershed only), which would exacerbate the problems associated with N loadings, should be guided by considerations of water quality-associated impacts.

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Introduction

Section 303(d) of the Federal Clean Water Act requires each state (1) to identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. The TMDL allocation establishes the maximum loadings (of pollutants of concern), from all contributing sources, that a water body may receive and still meet and maintain its water quality standards and designated uses, including compliance with numeric and narrative standards. The TMDL development process may be described in four steps, as follows:

1. Determination and documentation of whether or not a water body is presently meeting its water quality standards and designated uses.

2. Assessment of present water quality conditions in the water body, including estimation of present loadings of pollutants of concern from both point sources (discernable, confined, and concrete sources such as pipes) and non-point sources (diffuse sources that carry pollutants to surface waters through runoff or groundwater).

3. Determination of the loading capacity of the water body. EPA regulations define the loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. If the water body is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings.

4. Specification of load allocations, based on the loading capacity determination, for non-point sources and point sources, that will ensure that the water body will not violate water quality standards.

After public comment and final approval by the EPA, the TMDL will serve as a guide for future implementation activities. MassDEP will work with Towns to develop specific implementation strategies to reduce N loadings, and will assist in developing a monitoring plan for assessing the success of the nutrient reduction strategies.

In the Three Bays System, the pollutant of concern for this TMDL (based on observations of eutrophication) is the nutrient N. Nitrogen is the limiting nutrient in coastal and marine waters, which means that as its concentration is increased, so is the amount of plant matter. This leads to nuisance populations of macro-algae and increased concentrations of phytoplankton and epiphyton, which impair eelgrass beds and imperil the healthy ecology of the affected water bodies.

The TMDLs for total N for the coastal sub-embayments within the Three Bays System are based primarily on data collected, compiled, and analyzed by University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Cape Cod Commission, and others, as part of the Massachusetts Estuaries Project (MEP). The data were collected over a study period from 1999 to 2004. This study period will be referred to as the "Present Conditions" in the TMDL since it contains the most recent data available. The accompanying MEP Technical Report presents the results of the analyses of these coastal sub-embayments using the MEP Linked Watershed-Embayment Nitrogen Management Model (Linked Model). The accompanying MEP Technical Report can be found at http://www.oceanscience.net/estuaries/reports.htm. The analyses were performed to assist the Towns with decisions on current and future wastewater planning, wetland restoration, anadromous fish runs, shellfisheries, open-space, and harbor maintenance programs. A critical element of this approach is the assessment of water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure that was conducted on each sub-embayment. These assessments served as the basis for generating N loading thresholds for use as goals for watershed N management. The TMDLs are based on the site-specific thresholds generated

for each sub-embayment. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision-making process in the Towns of Barnstable, Sandwich and Mashpee.

Description of Water Bodies and Priority Ranking

The Three Bays System in Barnstable, Sandwich, and Mashpee, Massachusetts, at the southern edge of Cape Cod, faces Nantucket Sound to the south, and consists of a number of sub-embayments of varying size and hydraulic complexity, characterized by limited rates of flushing, shallow depths and heavily developed watersheds (Figure 2 and 3). The sub-embayments studied constitute important components of the Towns' natural and cultural resources. The nature of enclosed sub-embayments in populous regions brings two opposing elements to bear: 1) as protected marine shoreline they are popular regions for boating, recreation, and land development and 2) as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. Several waterbodies within the Three Bays system are already listed as waters requiring TMDLs (Category 5) in the MA 2004 Integrated List of Waters, as summarized in Table 1A. Several others were not listed because data was not available at that time. New data collected as part of this TMDL effort has indicated additional impaired segments. Table 1B identifies these segments previously listed by MassDEP and additional segments that were observed to be impaired through the MEP analysis.

Table 1A. Three Bays Waterbody Segments in Category 5 of the Massachusetts 2004 Integrated List[1]

NAME	WATERBODY SEGMENT	DESCRIPTION	SIZE	Pollutant Listed
Three Bays System				
Cotuit Bay	MA96-63_2004	From North Bay at Point Isabella oceanward to a line extended along Oyster Harbors Beach, Barnstable.	0.85 sq mi	-Nutrients -Pathogens[1]
North Bay	MA96-66_2004	From Fox Island to just south of Bridge Street and separated from Cotuit Bay at a line from Point Isabella southward to the opposite shore (including Dam Pond), Barnstable.	0.47 sq mi	-Nutrients -Pathogens[1]
Prince Cove	MA96-07_2004	Includes adjacent unnamed cove east of Prince Cove to North Bay at Fox Island, Barnstable.	0.14 sq mi	-Nutrients -Pathogens[1]
Seapuit River	MA96-64_2004	South of Osterville Grand Island to Cotuit Bay and West Bay, Barnstable.	0.06 sq mi	-Pathogens[1]
West Bay	MA96-65_2004	South of the Bridge Street bridge to Nantucket Sound including Eel River, Barnstable	0.52 sq m	-Nutrients

[1]Pathogens are not addressed as part of this TMDL analysis.

A complete description all sub-embayments is presented in Chapters I and IV of the accompanying MEP Technical Report from which the majority of the following information is drawn. Chapter VI and VII of the MEP Technical report provide assessment data on the individual waterbody segments listed in Table 1B (below). Please note that pathogens are listed in Tables 1A for completeness. Further discussion of pathogens is beyond the scope of this TMDL. TMDLs were prepared for Cotuit Bay, West Bay, Seapuit River, North Bay, Prince Cove, Warren Cove, and Prince Cove Channel.

The sub-embayments addressed by this document are determined to be high priorities based on three significant factors: (1) the initiative that these Towns have taken to assess the conditions of the entire Three Bays embayment system, (2) the commitment made by these Towns to restore and preserve the sub-embayments, and (3) the extent of eutrophication in the sub-embayments. In particular, these sub-embayments are at risk of

further degradation from increased N loads entering through groundwater and surface water from their increasingly developed watersheds. In both marine and freshwater systems, an excess of nutrients results

Figure 2 Overview of the Sub-embayments in Three Bays



in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources. The general conditions related to the major indicators of habitat impairment due to excess nutrient loadings, are tabulated in Table 1B. Observations are summarized in the Problem Assessment section below, and detailed in Chapter VII, Assessment of Embayment Nutrient Related Ecological Health, of the MEP Technical Report.

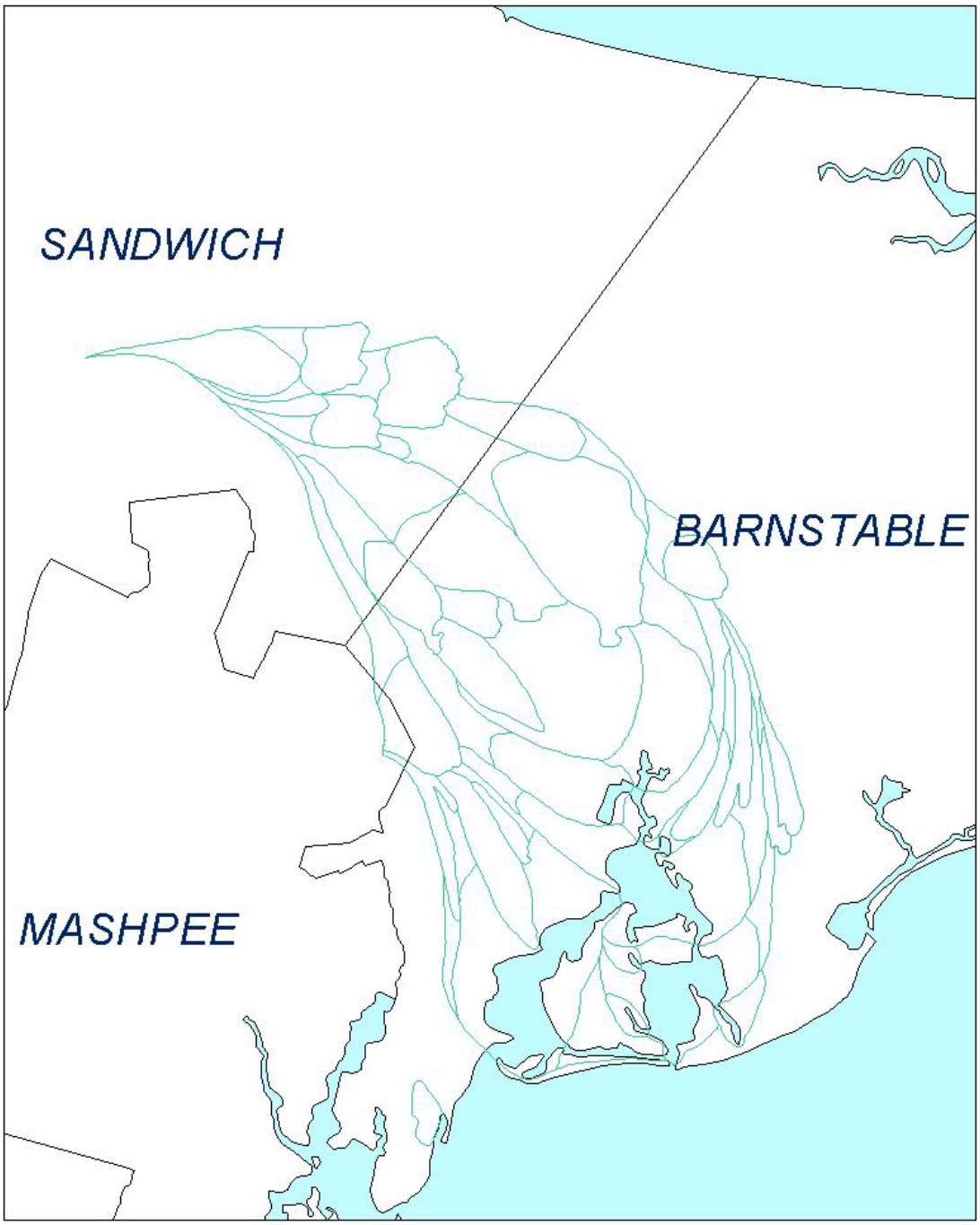


Figure 3 Three Bays Subwatershed Delineation

Table 1B. General summary of conditions related to the major indicators of habitat impairment observed in the Three Bays System

Embayment/ Sub-embayment	Eelgrass Loss[1]	Dissolved Oxygen Depletion	Chlorophyll *a*[2]	Macro-algae	Benthic Fauna[3]
Prince Cove	100%	<6 mg/L up to 60% of time <4 mg/L up to 27% of time SI/SD	>10ug/L up to 93% of time >20 ug/L up to 63% of time SI	MI	SD
North Bay					
Upper	100%	<6 mg/L up to 66% of time <4 mg/L up to 24% of time SI/SD	>10ug/L up to 68% of time >20 ug/L up to 10% of time MI/SI	No data	SD
Lower	100%	<6 mg/L up to 46% of time <4 mg/L up to 1% of time MI/SI	>10ug/L up to 24% of time >20 ug/L 0% of time MI/SI	No data	MI/SI
Cotuit Bay	100%	<6 mg/L up to 73% of time <4 mg/L up to 1% of time MI/SI	>10ug/L up to 32% of time >20 ug/L up to 2% of time MI	MI	GF/MI
West Bay	100%	<6 mg/L up to 49% of time <4 mg/L up to 19% of time SI	>10ug/L up to 14% of time >20 ug/L 0% of time GF/MI	MI	GF/MI
Warrens Cove	100%	SI/SD	SI	SD	SD

[1]Based on comparison of present conditions to 1951 Survey data.
[2]Algal blooms are consistent with chlorophyll *a* levels above 20ug/L
[3]Based on observations of the types of species, number of species, and number of individuals
GF – Good to Fair – little or no change from normal conditions*
MI – Moderately Impaired – slight to reasonable change from normal conditions*
SI – Significantly Impaired- considerably and appreciably changed from normal conditions*
SD – Severe Degraded – critically or harshly changed from normal conditions*
* - These terms are more fully described in MEP report "Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators"
December 22, 2003 (http://www.mass.gov/dep/water/resources/esttmdls.htm).

Problem Assessment

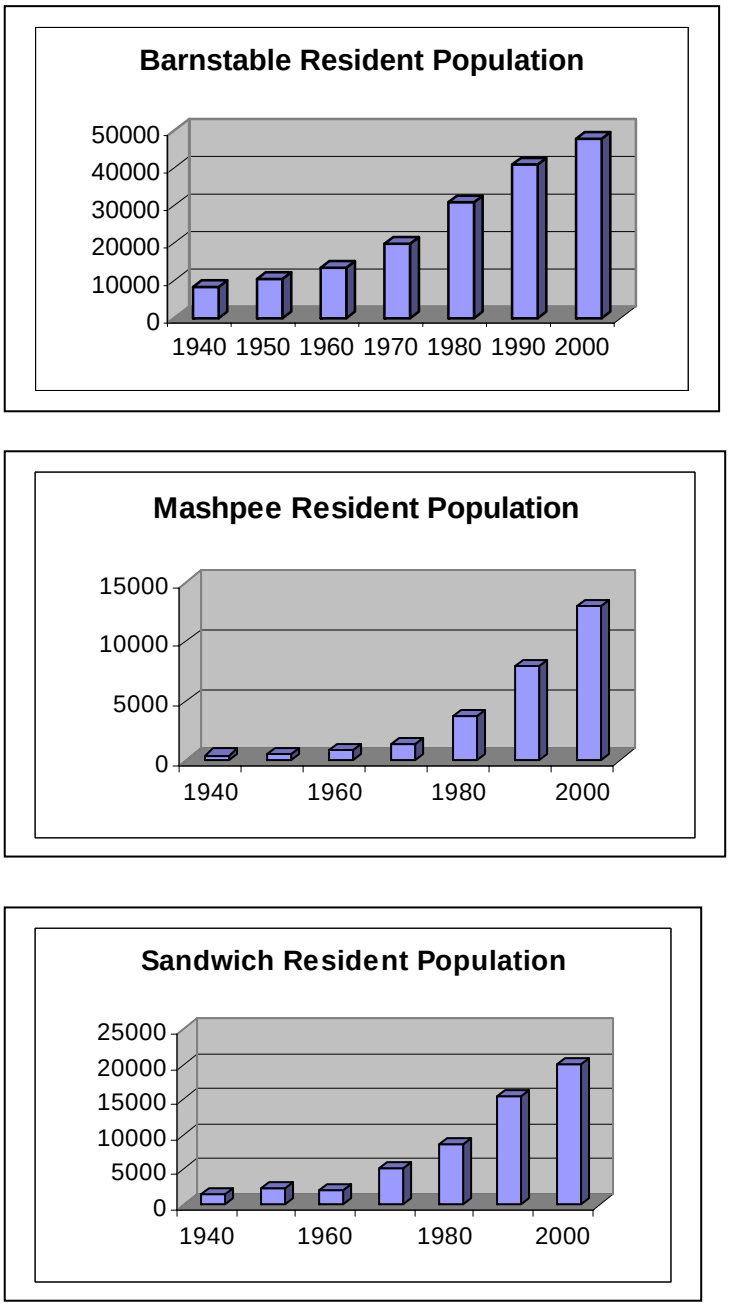
The watersheds of Three Bay's embayments have all had rapid and extensive development of single-family homes and the conversion of seasonal into full time residences. This is reflected in a substantial transformation of land from forest to suburban use between the years 1951 to 2000. Water quality problems associated with this development result primarily from on-site wastewater treatment systems, and to a lesser extent, from runoff including fertilizers from these developed areas.

On-site subsurface wastewater disposal system effluents discharge to the ground, enter the groundwater system and eventually enter the surface water bodies. In the sandy soils of Cape Cod, effluent that has entered the groundwater travel towards the coastal waters at an average rate of one foot per day. The nutrient load to the groundwater system is directly related to the number of subsurface wastewater disposal systems, which in turn are related to the population. The population of Barnstable, Sandwich and Mashpee, as with all of Cape Cod, has increased markedly since 1950. In addition, summertime residents and visitors swell the population of the

entire Cape by about 300% according to the Cape Cod Commission (http://www.capecodcommission.org/data/CapeIsl-Population1930-2000.pdf and http://www.capecodcommission.org/data/trends98.htm#population).

The increase in year round residents is illustrated in the following figure:

Figure 4



Dramatic declines in water quality, and the quality of the estuarine habitats, throughout Cape Cod, have paralleled its population growth. The problems in these particular sub-embayments studied generally include periodic decreases of dissolved oxygen, decreased diversity of benthic animals, and periodic algal blooms. Eelgrass beds, which are critical habitats for macroinvertebrates and fish, have greatly diminished from these

waters. All the sub-embayments which, historically supported eelgrass (as evidenced by the 1951 survey) have shown a 100% reduction in area. Furthermore, the eelgrass was replaced by macro algae, which are undesirable, because they do not provide high quality habitat for fish and invertebrates. In the most severe cases there are periodic fish kills, unpleasant odors and scums, and near loss of the benthic community and/or presence of only the most stress-tolerant species of benthic animals.

Coastal communities, including Barnstable, Sandwich, and Mashpee, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as commercial fin fishing and shellfishing. The continued degradation of these coastal sub-embayments, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources.

Habitat and water quality assessments were conducted throughout the Three Bays system based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present, the Three Bays system is showing significantly impaired to severely degraded habitat quality in the Prince Cove and Warrens Cove sub-embayments as well as the upper portion of North Bay. The lower portion of North Bay as well as Eel Pond are showing indications of moderate bordering on significant impairment while Cotuit Bay and West Bay are both showing signs of moderate impairment. All of the habitat indicators are consistent with this evaluation of the whole of the system.

The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels. In shallow systems this generally equates to an increase of about 7-8 mg/l at the mooring sites. The clear evidence of oxygen levels above atmospheric equilibration indicates that the Three Bays system is eutrophic.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality within the estuary. The major sub-embayments to the Three Bays system (Cotuit Bay, West Bay, North Bay and Prince cove) are currently under seasonal oxygen stress, consistent with nitrogen enrichment. Nitrogen enrichment is supported by parallel observations of elevated chlorophyll a. Currently there are no eelgrass beds within the Three Bays System. However, it appears that all of the major sub-embayments had water quality conditions capable of supporting eelgrass beds in 1951 although it appears that eelgrass was restricted to the shallows (North and Cotuit Bays) or to Prince Cove and West Bay basin. Based on this analysis it appears that the post 1951 losses are associated with nitrogen enrichment.

Pollutant of Concern, Sources, and Controllability

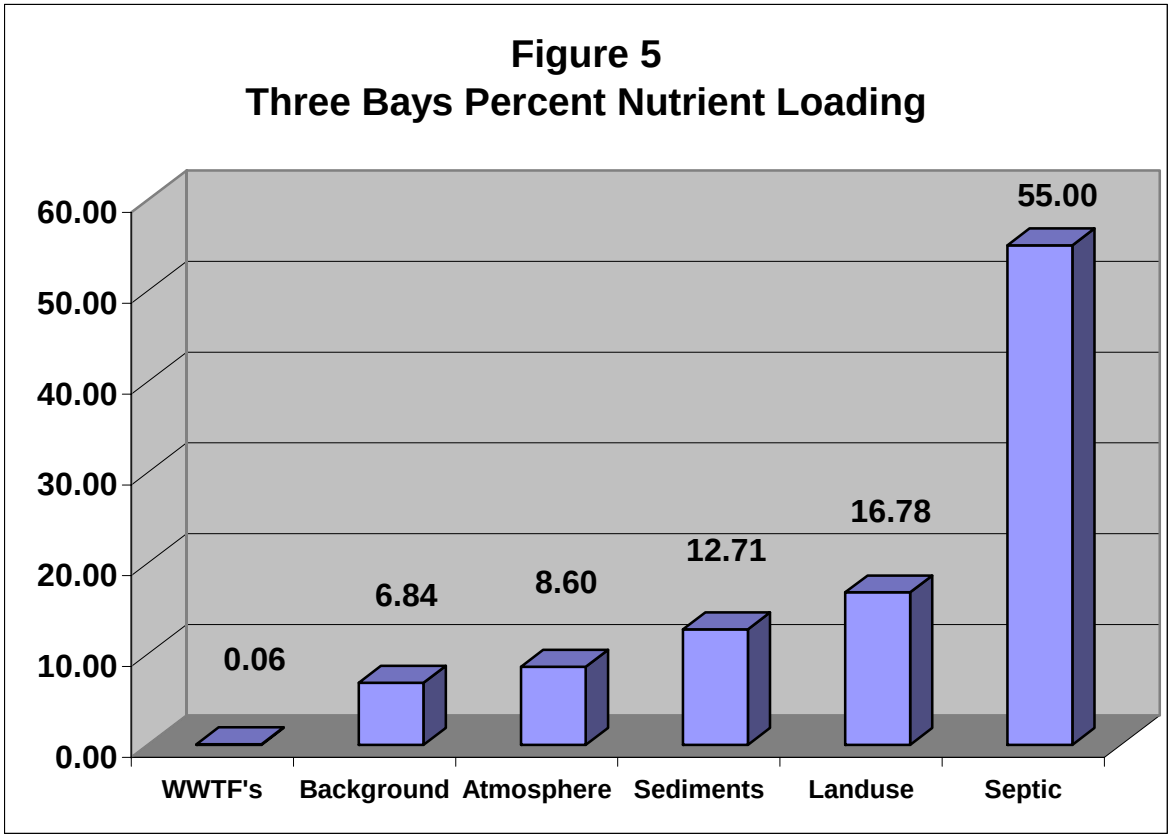
In the coastal embayments of the Towns of Barnstable, Sandwich, and Mashpee, as in most marine and coastal waters, the limiting nutrient is nitrogen. Nitrogen concentrations beyond those expected naturally contribute to undesirable conditions, including the severe impacts described above, through the promotion of excessive growth of plants and algae, including nuisance vegetation.

Each of the embayments covered in this TMDL has had extensive data collected and analyzed through the Massachusetts Estuaries Program (MEP) and with the cooperation and assistance from the towns, the USGS, and the Cape Cod Commission. Data collection included both water quality and hydrodynamics as described in Chapters I, IV, V, and VII, of the MEP Technical Report.

These investigations revealed that loadings of nutrients, especially N, are much larger than they would be under natural conditions, and as a result the water quality has deteriorated. A principal indicator of decline in water quality is the total disappearance of eelgrass from its natural habitat in these sub-embayments. This is a result

of nutrient loads causing excessive growth of algae in the water (phytoplankton) and algae growing on eelgrass (epiphyton), both of which result in the loss of eelgrass through the reduction of available light levels.

As is illustrated by Figure 5, most of the N affecting the sub-embayments to Three Bays originates from on-site subsurface wastewater disposal systems, with considerably less N originating from natural background sources, runoff, fertilizers, wastewater treatment facilities, and atmospheric deposition.



The level of "controllability" of each source, however, varies widely:

Atmospheric nitrogen cannot be adequately controlled locally – it is only through region- and nation-wide air pollution control initiatives that significant reductions are feasible;

Sediment nitrogen control by such measures as dredging is not feasible on a large scale. However, the concentrations of N in sediments, and thus the loadings from the sediments, will decline over time if sources in the watershed are removed, or reduced to the target levels discussed later in this document. Increased dissolved oxygen will help keep nitrogen form fluxing;

Fertilizer – related nitrogen loadings can be reduced through bylaws and public education;

Stormwater sources of N can be controlled by best management practices (BMPs), bylaws and stormwater infrastructure improvements;

Septic system sources of nitrogen are the largest controllable sources. These can be controlled by a variety of case-specific methods including: sewering and treatment at centralized or decentralized locations, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing nitrogen-reducing on-site wastewater treatment systems.

WWTF's effluent nitrogen can be reduced by advanced treatment processes that include denitrification.

Natural Background is the background load as if the entire watershed were still forested and contains no anthropogenic sources. It cannot be controlled locally.

Cost/benefit analyses will have to be conducted on all of the possible N loading reduction methodologies in order to select the optimal control strategies, priorities, and schedules.

Description of the Applicable Water Quality Standards

Water quality standards of particular interest to the issues of cultural eutrophication are dissolved oxygen, nutrients, aesthetics, excess plant biomass, and nuisance vegetation. The Massachusetts water quality standards (314 CMR 4.0) contain numeric criteria for dissolved oxygen, but have only narrative standards that relate to the other variables, as described below:

314 CMR 4.05(5)(a) states "Aesthetics – All surface waters shall be free from pollutants in concentrations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances, produce objectionable odor, color, taste, or turbidity, or produce undesirable or nuisance species of aquatic life."

314 CMR 4.05(5)(c) states, "Nutrients – Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication".

314 CMR 4.05(b) 1:

(a) Class SA

1. Dissolved Oxygen -
a. Shall not be less than 6.0 mg/l unless background conditions are lower;
b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 75% of saturation due to a discharge; and
c. site-specific criteria may apply where background conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

(b) Class SB

1. Dissolved Oxygen -
a. Shall not be less than 5.0 mg/L unless background conditions are lower;
b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 60% of saturation due to a discharge; and
c. site-specific criteria may apply where back-ground conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

Thus, the assessment of eutrophication is based on site-specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is recommended by the US Environmental Protection Agency in their draft Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (EPA-822-B-01-003, Oct 2001). The Guidance Manual notes that lakes, reservoirs, streams, and rivers, may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management. However, individual estuarine and coastal marine waters have unique characteristics, and development of individual water body criteria is typically required.

It is this framework, coupled with an extensive outreach effort that the MassDEP, with the technical support of SMAST, is employing to develop nutrient TMDLs for coastal waters.

Methodology - Linking Water Quality and Pollutant Sources

Extensive data collection and analyses have been described in detail in the MEP Technical Report. Those data were used by SMAST to assess the loading capacity of each sub-embayment. Physical (Chapter V), chemical and biological (Chapters IV, VII, and VIII**)** data were collected and evaluated. The primary water quality objective was represented by conditions that:

1) restore the natural distribution of eelgrass because eel grass provides valuable habitat for shellfish and finfish
2) prevent algal blooms
3) protect benthic communities from impairment or loss
4) maintain dissolved oxygen concentrations that are protective of the estuarine communities.

The details of the data collection, modeling and evaluation are presented and discussed in Chapters IV, V, VI, VII and VIII of the MEP Technical Report. The main aspects of the data evaluation and modeling approach are summarized below, taken from pages 4 through 7 of that report.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. This approach fully links watershed inputs with embayment circulation and N characteristics, and is characterized as follows:

- requires site specific measurements within the watershed and each sub-embayment;
- uses realistic “best-estimates” of N loads from each land-use (as opposed to loads with built-in “safety factors” like Title 5 design loads);
- spatially distributes the watershed N loading to the embayment;
- accounts for N attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes N regenerated within the embayment;
- is validated by both independent hydrodynamic, N concentration, and ecological data;
- is calibrated and validated with field data prior to generation of “what if” scenarios.

The Linked Model has been applied previously to watershed N management in numerous embayments throughout Southeastern Massachusetts. In these applications it became clear that the model can be calibrated and validated, and has use as a management tool for evaluating watershed N management options.

The Linked Model, when properly calibrated and validated for a given embayment, becomes a N management planning tool as described in the model overview below. The model can assess solutions for the protection or restoration of nutrient-related water quality and allows testing of management scenarios to support cost/benefit evaluations. In addition, once a model is fully functional it can be refined for changes in land-use or embayment characteristics at minimal cost. In addition, since the Linked Model uses a holistic approach that incorporates the entire watershed, embayment, and tidal source waters, it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

The Linked Model provides a quantitative approach for determining an embayment's: (1) N sensitivity, (2) N threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2 of the MEP Technical Report). This methodology integrates a variety of field data and models, specifically:

• Monitoring - multi-year embayment nutrient sampling

• Hydrodynamics -

- embayment bathymetry (depth contours throughout the embayment)
- site specific tidal record (timing and height of tides)
- water velocity records (in complex systems only)
- hydrodynamic model

• Watershed Nitrogen Loading

- watershed delineation
- stream flow (Q) and N load
- land-use analysis (GIS)
- watershed N model

• Embayment TMDL - Synthesis

- linked Watershed-Embayment Nitrogen Model
- salinity surveys (for linked model validation)
- rate of N recycling within embayment
- dissolved oxygen record
- macrophyte survey
- infaunal survey (in complex systems)

Application of the Linked Watershed-Embayment Model

The approach developed by the MEP for applying the linked model to specific sub-embayments, for the purpose of developing target N loading rates, includes:

1) selecting one or two sub-embayments within the embayment system, located close to the inland-most reach or reaches, which typically has the poorest water quality within the system. These are called “sentinel” stations;

2) using site-specific information and a minimum of three years of sub-embayment-specific data to select target threshold N concentrations for each sub-embayment. This is done by refining the draft target threshold N concentrations that were developed as the initial step of the MEP process. The target

threshold N concentrations that were selected generally occur in higher quality waters near the mouth of the embayment system;

3) running the calibrated water quality model using different watershed N loading rates, to determine the loading rate which will achieve the target threshold N concentration at the sentinel station. Differences between the modeled N load required to achieve the target N concentration, and the present watershed N load, represent N management goals for restoration and protection of the embayment system as a whole.

Previous sampling and data analyses, and the modeling activities described above, resulted in four major outputs that were critical to the development of the TMDLs. Two outputs are related to N **concentration**:

- the present N concentrations in the sub-embayments
- site-specific target threshold N concentrations

and two outputs are related to N **loadings:**

- the present N loads to the sub-embayments
- load reductions necessary to meet the site specific target threshold N concentrations

In summary: meeting the water quality standards by reducing the nitrogen concentration (and thus the nitrogen load) at the sentinel station(s), the water quality goals will be met throughout the entire system.

A brief overview of each of the outputs follows:
Nitrogen concentrations in the sub-embayments
a) Observed "present" conditions:

Table 2 presents the average concentrations of N measured in the sub-embayments from 1999 through 2004. Concentrations of N are the highest in Prince Cove (0.70 mg/L). Nitrogen in the other sub-embayments ranges in concentration from 0.32 to 0.64 mg/L, resulting in overall ecological habitat quality ranging from moderately high to poor. The individual yearly means and standard deviations of the averages are presented in Appendix A.

Table 2. Observed present nitrogen concentrations for the major Sub-embayments of the Three Bays System

Three Bay System Sub-embayment	Observed TN Concentration (mg/L) [1]	Threshold TN Concentration (mg/L)
Cotuit Bay	0.39 – 0.44	
West Bay	0.38 – 0.48	
Seapuit River	0.32	
North Bay	0.50 – 0.52	
Prince Cove	0.60 – 0.70	
Warren Cove	0.64	
Prince Cove Channel	0.64	
Three Bays Sentinel Station		0.38 [2]
Nantucket Sound (Boundary Condition)	0.28	

[1] ranges represent the upper to lower regions (highest – lowest) of a sub-embayment, calculated as the average of the separate yearly means of 1999-2004 data. Individual yearly means and standard deviations of the average are presented in Tables A-1 Appendix A
[2] at the sentinel station located between Cotuit Bay and North Bay

b) Modeled site-specific target threshold nitrogen concentrations:
A major component of TMDL development is the determination of the maximum concentrations of N (based on field data) that can occur without causing unacceptable impacts to the aquatic environment. Prior to conducting the analytical and modeling activities described above, SMAST selected appropriate nutrient-related environmental indicators and tested the qualitative and quantitative relationship between those indicators and N concentrations. The Linked Model was then used to determine site-specific threshold N concentrations, by using the specific physical, chemical, and biological characteristics of each sub-embayment.

The findings of the analytical and modeling investigations for this embayment system are discussed and explained below:

The threshold N concentrations represent the tidally-averaged water column concentration of N that will support the habitat quality being sought. The water column N level is ultimately controlled by the integration of the watershed N load, the N concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column N concentration is modified by the extent of sediment uptake and/or regeneration and by direct atmospheric deposition.

Threshold N levels for each of the sub-embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. In these systems, high habitat quality was defined as supportive of eelgrass and/or diverse benthic animal communities as described below. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed N loads (Tables ES-1 and ES-2 of the MEP Technical Report) for the Towns of Barnstable, Sandwich and Mashpee Three Bays embayment system were comprised primarily of wastewater N. Land-use and wastewater analysis found that generally 76% of the controllable watershed N load to embayment was from septic system effluent.

The threshold N levels for the Three Bays System were determined as follows:
The target N concentration for restoration of eelgrass in this system was determined to be 0.38 mg/L Total Nitrogen (TN) at the sentinel location and 0.40 mg/l TN within the marginal regions (shallows) of North Bay. This secondary level to check restoration of marginal beds in North Bay (0.40 mg/l TN) is consistent with the analysis of restoration of fringing eelgrass beds in nearby Great Pond, and analysis where eelgrass beds in deep waters could not be supported at a tidally averaged TN of 0.41 mg/l TN at depths of 2 meters. Similarly prior MEP analysis in Bournes Pond indicated that tidally averaged TN levels of 0.42 mg TN excluded beds from all but the shallowest water. The MEP Technical Team cannot specify the exact extent of marginal beds to be restored in the upper deep basins. At tidally averaged TN levels of 0.42 mg/l TN the eelgrass habitat would be restricted to very shallow waters, while at 0.40 mg/l TN the eelgrass habitat should reach to 1-2 meters depth, based upon the data from nearby systems. In additional, the persistence of eelgrass beds through 1995-2001 in the shallow waters of south Windmill Cove, but in a stable physical setting, were at nitrogen levels (tidally averaged TN ~0.40 mg/l).

Since infaunal animal habitat is also a critical resource to the Three Bays System, the secondary metric for a successful restoration (after eelgrass) will be to restore the significantly impaired/severely degraded habitats in the Prince Cove/Warrens Cove and North Bay basins. In the upper more muddy basins of other nearby systems, healthy infaunal habitat is associated with nitrogen levels of TN<0.5 mg/l. This was found for Popponesset Bay where based upon the infaunal analysis coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg/l TN were found supportive of high infaunal habitat quality in this system. In the Three Bays System, present healthy infaunal areas are found at nitrogen levels of TN<0.42 mg/l (Cotuit Bay and West Bay). However, the impaired areas are at nitrogen levels of TN>0.5 mg/l (North Bay) and are

severely degraded at nitrogen levels of TN>0.6 mg/l. This is consistent with the findings discussed above from other systems and fully supports a secondary nitrogen criteria for the Upper Muddy Basins of 0.5 mg/l TN.

Based upon sequential reductions in watershed N loading in the analysis described in the Section VIII-3 of the MEP Technical Report, the sentinel station was projected to achieve an average TN level of 0.38 mg/l, and 0.40 mg/l TN within the marginal regions (shallows) of North Bay.

It is important to note that the analysis of future N loading to the Three Bays System focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the analysis (as described in Chapter VI of the accompanying technical report) indicates that significant increases in N loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round usage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine N management must include management approaches to prevent increased N loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The conclusion of the analysis of the Three Bays System is that restoration will necessitate a reduction in the present (2004) N inputs and management options to negate additional future N inputs.

Nitrogen loadings to the sub-embayments

a) Present loading rates:

In the Three Bays System overall, the highest N loading from controllable sources is from on-site wastewater treatment systems, which is almost always the highest N loading source in each sub-embayment. On-site system loadings range from 3 kg/day to as high as 25 kg/day. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) is very significant in the North Bay sub-embayment. As discussed previously, however, the direct control of N from sediments is not considered feasible. However, the magnitude of the benthic contribution is related to the watershed load. Therefore, reducing the incoming load should reduce the benthic flux. A further breakdown of the total N loading, by source, is presented in Table 3.

Table 3. Nitrogen loadings to the Three Bays sub-embayments

Sub-Embayments	Present Land Use[1] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load (kg/day)	Direct Atmospheric Deposition [2] (kg/day)	Present Benthic Load[3] (kg/day)	**Present Total Load** (kg/day)
Cotuit Bay	5.52	20.23	0	5.79	0	31.53
West Bay	3.58	15.49	0	4.23	3.82	27.12
Seapuit R	0.85	2.92	0.02	0.45	0	4.24
North Bay	4.47	24.98	0	3.95	67.52	100.92
Prince Cove	10.34	24.84	0.09	1.23	0.51	37.01
Warren Cove	5.05	6.98	0	--	8.83	20.86
Prince Cove Channel	0.77	4.77	0	--	2.35	7.88

[1] Includes stormwater runoff and fertilizers

[2] Warren Cove and Prince Cove Channel loads are included in Prince Cove

[3] Nitrogen loading from sediments, negative fluxes have been set to zero

As previously indicated, the present N loadings to the three Three Bays sub-embayments studied must be reduced in order to restore conditions and to avoid further nutrient-related adverse environmental impacts. The critical final step in the development of the TMDL is modeling and analysis to determine the loadings required to achieve the target N concentrations.

b) Nitrogen loads necessary for meeting the site-specific target nitrogen concentrations.

Table 4 lists the present controllable watershed N loadings from Three Bays embayment system. The last two columns indicate one scenario of the reduced loads and percentage reductions that could achieve the target concentrations in the sentinel system (see following section). It is very important to note that load reductions can be produced through reduction of any or all sources of N, potentially increasing the natural attenuation of nitrogen within the freshwater systems to the embayment, and/or modifying the tidal flushing through inlet reconfiguration (where appropriate). The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the communities involved. This presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of these N impaired embayments.

Table 4. Present Controllable Watershed nitrogen loading rates, calculated loading rates that are necessary to achieve target threshold nitrogen concentrations, and the percent reductions of the existing loads necessary to achieve the target threshold loadings.

Sub-embayments	Present Controllable Watershed Load [1] (kg/day)	Target Threshold Watershed Load [2] (kg/day)	Percent controllable watershed reductions needed to achieve threshold load levels
Cotuit Bay	23.77	22.34	6 %
West Bay	17.90	15.97	11 %
Seapuit River	3.77	3.77	0 %
North Bay	27.48	4.47	84 %
Prince Cove	31.30	17.89	43 %
Warren Cove	10.08	5.05	50 %
Prince Cove Channel	5.02	0.77	85 %

[1] Composed of combined fertilizer, runoff, WWTF, and septic system loadings.
[2] Target threshold watershed load is the load from the watershed needed to meet the embayment target threshold concentration

The loadings presented in Table 4 represent one, but not the only, loading reduction scenario that can meet the TMDL goal. Other alternatives may also achieve the desired threshold concentration as well and can be explored using the MEP modeling approach. In the scenario presented, the percentage reductions in N loadings to meet the target threshold concentrations range from 0% in the Seapuit River to 85 % in Prince Cove Channel. Table VIII-2 of the MEP Technical Report (and rewritten as Appendix B of this document) summarizes the present loadings from on-site subsurface wastewater disposal systems and the reduced loads that would be necessary to achieve the threshold N concentrations in the Three Bays embayment system, under the scenario modeled here. In this scenario only the on-site subsurface wastewater disposal system loads were reduced to the level of the target threshold watershed load. It should be emphasized once again that this is only one scenario that will meet the target N concentrations in the sentinel systems, which is the ultimate goal of the TMDL. There can be variations depending on the chosen sub-watershed and which controllable source is

selected for reduction. Alternate scenarios will result in different amounts of nitrogen being reduced in different sub-watersheds. For example, taking out additional nitrogen upstream will impact how much nitrogen has to be taken out downstream. The towns should take any reasonable effort to reduce the controllable nitrogen sources.

Total Maximum Daily Loads

As described in EPA guidance, a total maximum daily load (TMDL) identifies the loading capacity of a water body for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. The TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass, the leading indicator of ecological health, thus meeting water quality goals for aquatic life support. Because there are no "numerical" water quality standards for N, the TMDLs for the three Three Bays sub-embayments studied are aimed at determining the loads that would correspond to sub-embayment-specific N concentrations determined to be protective of the water quality and ecosystems.

The effort includes detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time), for each sub-embayment. The results of the mathematical model are correlated with estimates of impacts on water quality, including negative impacts on eelgrass (the primary indicator), as well as dissolved oxygen, chlorophyll, and benthic infauna

The TMDL can be defined by the equation:

TMDL = BG + WLAs + LAs + MOS

Where

TMDL = loading capacity of receiving water
BG = natural background
WLAs = portion allotted to point sources
LAs = portion allotted to (cultural) non-point sources
MOS = margin of safety

Background Loading

Natural background N loading estimates are presented in Table ES-1 of the accompanying MEP Technical Report. Background loading was calculated on the assumption that the entire watershed is forested, with no anthropogenic sources of N.

Wasteload Allocations

Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of storm water be included in the waste load component of the TMDL. On Cape Cod the vast majority of storm water percolates into the ground and aquifer and proceeds into the embayment systems through groundwater migration. The Linked Model accounts for storm water loadings and groundwater loading in one aggregate allocation as a non-point source – combining the assessments of waste water and storm water (including storm water that infiltrates into the soil and direct discharge pipes into water bodies) for the purpose of developing control strategies. Although the vast majority of storm water percolates into the ground, there are a few storm water pipes that discharge directly to water bodies that are subject to the requirements of the Phase II Storm Water NPDES Program. Therefore, any storm water discharges subject to the requirements of storm water

Phase II NPDES permit must be treated as a waste load allocation. Since the majority of the nitrogen loading comes from septic systems, fertilizer, and storm water that infiltrates into the groundwater, the allocation of nitrogen for any storm water pipes that discharge directly to any of the embayments is insignificant as compared to the overall groundwater load. Based on land use, the Linked Model accounts for loading for storm water, but does not differentiate storm water into a load and waste load allocation. Nonetheless, based on the fact that there are few storm water discharge pipes within NPDES Phase II communities that discharge directly to embayments or waters that are connected to the embayments, the total waste load allocation for these sources is considered to be insignificant. This is based on the percent of impervious surface within 200 feet of the waterbodies and the relative load from this area compared to the overall load. Although most stormwater infiltrates into the ground on Cape Cod, some impervious areas within approximately 200 feet of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of waste load allocation it was assumed that all impervious surfaces within 200ft of the shoreline discharge directly to the waterbody. This calculated load is 0.23% of the total load or 124 kg/year as compared to the total nitrogen load of 54,657 kg/year to the embayments. Looking at individual sub-embayments this load ranged from 0.08-0.58%. (see Appendix C for details). This conservative calculated load is obviously negligible when compared to other sources.

EPA and MassDEP authorized the Towns of Barnstable, Sandwich and Mashpee for coverage under the NPDES Phase II General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003. While communities need to comply with the Phase II permit only in the mapped Urbanized Areas, the Towns of Barnstable and Sandwich have decided to extend all the stormwater permit requirements throughout the entire town, including this watershed area. The portion of the watershed, which is in Mashpee is entirely in the mapped Urbanized Areas.

The Phase II general permit requires the permittee to determine whether the approved TMDL is for a pollutant likely to be found in storm water discharges from the MS4. The MS4 is required to implement the storm water waste load allocation, BMP recommendations, or other performance requirements of a TMDL and assess whether the waste load allocation is being met through implementation of existing stormwater control measures or if additional control measures are necessary.

Load Allocations

Load allocations identify the portion the loading capacity allocated to existing and future nonpoint sources. In the case of the Three Bays System sub-embayments studied, the nonpoint source loadings are primarily from on-site subsurface wastewater disposal systems. Additional N sources include: natural background, stormwater runoff (including N from fertilizers), the two WWTF's groundwater discharges, atmospheric deposition, and nutrient-rich sediments.

Generally, stormwater that is subject to the EPA Phase II Program would be considered a part of the wasteload allocation, rather than the load allocation. As presented in Chapter IV, V, and VI, of the MEP Technical Report, on Cape Cod the vast majority of stormwater percolates into the aquifer and enters the embayment system through groundwater. Given this, the TMDL accounts for stormwater loadings and groundwater loadings in one aggregate allocation as a non-point source, thus combining the assessments of wastewater and storm water for the purpose of developing control strategies. Ultimately, when the Phase II Program is implemented in Barnstable, Sandwich, and Mashpee, new studies, and possibly further modeling, will identify what portion of the stormwater load may be controllable through the application of Best Management Practices (BMPs).

The two Wastewater Treatment Facilities (WWTFs) currently discharge about 0.11 kg N/day into the groundwater. If towns shifted loads from on-site systems to these facilities, it would lead to overall decline in N loadings to the sub-embayments.

The sediment loading rates incorporated into the TMDL are lower than the existing sediment flux rates listed in Table 3 above because projected reductions of N loadings from the watershed will result in reductions of nutrient concentrations in the sediments, and therefore, over time, reductions in loadings from the sediments will occur. Benthic N flux is a function of N loading and particulate organic nitrogen (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed N loads, and are calculated by multiplying the present N flux by the ratio of projected PON to present PON, using the following formulae:

Projected N flux = (present N flux) (PON projected / PON present) When:

$$PON_{projected} = (R_{load}) (D_{PON}) + PON_{present\ offshore}$$

When R_{load} = (projected N load) / (Present N load)

And D_{PON} is the PON concentration above background determined by:

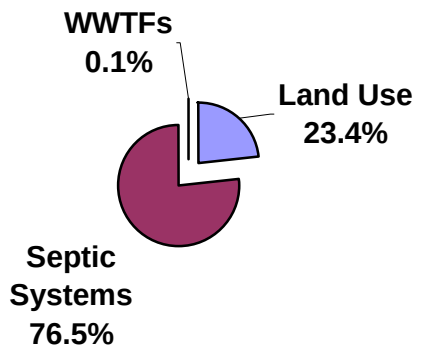
$$D_{PON} = (PON_{present\ embayment} - PON_{present\ offshore})$$

The benthic flux modeled for the Three Bays System is reduced from existing conditions based on the load reduction and the observed PON concentrations within each sub-embayment relative to Nantucket Sound (boundary condition). The benthic flux input to each sub-embayment was reduced (toward zero) based on the reduction of N in the watershed load.

The loadings from atmospheric sources incorporated into the TMDL, however, are the same rates presently occurring, because, as discussed above, local control of atmospheric loadings is not considered feasible.

Locally controllable sources of N within the watersheds are categorized as on-site subsurface wastewater disposal system wastes, land use (which includes stormwater runoff and fertilizers) and wastewater treatment facilities. Figure 6 emphasizes the fact that the overwhelming majority of locally controllable N comes from on-site subsurface wastewater disposal systems.

Figure 6
Percent Contribution of Locally Controllable Sources of Nitrogen



Margin of Safety

Statutes and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA para 303 (d)(20©, 40C.G.R. para 130.7©(1)]. The EPA's 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. The MOS for the Three Bays System TMDL is implicit, and the conservative assumptions in the analyses that account for the MOS are described below.

1. Use of conservative data in the linked model

The watershed N model provides conservative estimates of N loads to the embayments. Nitrogen transfer through direct groundwater discharge to estuarine waters is based upon studies indicating negligible aquifer attenuation, i.e. 100% of load enters embayment. This is a conservative estimate of loading because studies have also shown that in some areas less than 100% of the load enters the estuary. Nitrogen from the upper watershed regions, which travel through ponds or wetlands, almost always enter the embayment via streamflow, are directly measured (over 12-16 months) to determine attenuation. In these cases the land-use model has shown a slightly higher predicted N load than the measured discharges, which have been assessed to date. Therefore, the watershed model as applied to the surface water watershed areas again presents a conservative estimate of N loads because the actual measured N in streams was lower than the modeled concentrations.

The hydrodynamic and water quality models have been assessed directly. In the many instances where the hydrodynamic model predictions of volumetric exchange (flushing) have also been directly measured by field measurements of instantaneous discharge, the agreement between modeled and observed values has been $\geq$95%. Field measurement of instantaneous discharge was performed using acoustic doppler current profilers (ADCP) at key locations within the embayment (with regards to the water quality model, it was possible to conduct a quantitative assessment of the model results as fitted to a baseline dataset - a least squares fit of the modeled versus observed data showed an R^2>0.95, indicating that the model accounted for 95% of the variation in the field data). Since the water quality model incorporates all of the outputs from the other models, this excellent

fit indicates a high degree of certainty in the final result. The high level of accuracy of the model provides a high degree of confidence in the output, therefore, less of a margin of safety is required.

In the case of N attenuation by freshwater ponds, attenuation was derived from measured N concentrations, pond delineations and pond bathymetry. These attenuation factors were higher than that used in the land-use model. The reason was that the pond data were temporally limited and a more conservative value of 40% was more protective and defensible.

Similarly, the water column N validation dataset was also conservative. The model is validated to measured water column N. However, the model predicts average summer N concentrations. The very high or low measurements are marked as outliers. The effect is to make the N threshold more accurate and scientifically defensible. If a single measurement 2 times higher than the next highest data point in the series, raises the average 0.05 mg N/L, this would allow for a higher "acceptable" load to the embayment. Marking the very high outlier is a way of preventing a single and rare bloom event from changing the N threshold for a system. This effectively strengthens the data set so that a higher margin of safety is not required.

Finally, the reductions in benthic regeneration of N are most likely underestimates, i.e. conservative. The reduction is based solely on a reduced deposition of PON, due to lower primary production rates under the reduced N loading in these systems. As the N loading decreases and organic inputs are reduced, it is likely that rates of coupled remineralization-nitrification, denitrification and sediment oxidation will increase.

Benthic regeneration of N is dependant upon the amount of PON deposited to the sediments and the percentage that is regenerated to the water column versus being denitrified or buried. The regeneration rate projected under reduced N loading conditions was based upon two assumptions:

(1) PON in the embayment in excess of that of inflowing tidal water (boundary condition) results from production supported by watershed N inputs and
(2) Presently enhanced production will decrease in proportion to the reduction in the sum of watershed N inputs and direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON levels if watershed N loading and direct atmospheric deposition could be reduced to zero (an impossibility of course). This proportional reduction assumes that the proportion of remineralized N will be the same as under present conditions, which is almost certainly an underestimate. As a result, future N regeneration rates are overestimated which adds to the margin of safety.

2. Conservative threshold sites/nitrogen concentrations

Conservatism was used in the selection of the threshold sites and N concentrations. Sites were chosen that had stable eelgrass or benthic animal (infaunal) communities, and not those just starting to show impairment, which would have slightly higher N concentrations. Meeting the target thresholds in the sentinel sub-embayments will result in reductions of N concentrations in the rest of the systems.

3 Conservative approach

The target loads were based on tidally averaged N concentrations on the outgoing tide, which is the worst case because that is when the N concentrations are the highest. The N concentrations will be lower on the flood tides, therefore this approach is conservative.

Seasonal Variation

Since the TMDL for the waterbody segment is based on the most critical time period, i.e. the summer growing season, the TMDL is protective for all seasons. The daily loads can be converted to annual loads by multiplying by 365 (the number of days in a year). Nutrient loads to the embayment are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Second, as a practical matter, the types of controls necessary to control the N load, the nutrient of primary concern, by their very nature do not lend themselves to intra-annual manipulation since the majority of the N is from non-point sources. Thus, the annual loads make sense, since it is difficult to control non-point sources of nitrogen on a seasonal basis and nitrogen sources can take considerable time to migrate to impacted waters.

TMDL Values for Three Bays Sub-Embayments

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of each sub-embayment were calculated by considering all sources of N grouped by natural background, point sources, and non-point sources. A more meaningful way of presenting the loadings data, from an implementation perspective, is presented in Table 5. In this table the N loadings from the atmosphere and nutrient-rich sediments are listed separately from the target watershed threshold loads, which are composed of natural background N along with locally controllable N from the WWTP's, on-site subsurface wastewater disposal systems, stormwater runoff, and fertilizers. In the case of the Three Bays sub-embayments, which were studied, the TMDLs were calculated by projecting reductions in locally controllable on-site subsurface wastewater disposal system, stormwater runoff, and fertilizer sources. Once again the goal of this TMDL is to achieve the identified target threshold N concentration at the identified sentinel station. The target load identified in this table represents one alternative loading scenario to achieve that goal but other scenarios may be possible and approvable as well. These waterbody segment TMDLs are also presented in Appendix D.

Table 5. The Total Maximum Daily Loads (TMDL) for the Three Bays System, represented as the sum of the calculated target thresholds loads (from controllable watershed sources), atmospheric deposition, and sediment sources (benthic load).

Three Bay System Sub-embayment	Target Threshold Watershed Load [1] (kg/day)	Atmospheric Deposition [2] (kg/day)	Benthic load [3] (kg/day)	TMDL [4] (kg/day)
Cotuit Bay	22.34	5.79	0	28
West Bay	15.97	4.23	3.47	24
Seapuit River	3.77	0.45	0	4
North Bay	4.47	3.95	45.20	54
Prince Cove	17.89	1.23	0.32	19
Warren Cove	5.05	--	6.23	11
Prince Cove Channel	0.77	--	1.54	2

[1] Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table 2.
[2] Atmospheric deposition to embayment surfaces only. Warren Cove and Prince Cove Channel are included in Prince Cove
[3] Projected sediment N loadings obtained by reducing the present loading rates (Table 3) proportional to proposed watershed load reductions and factoring in the existing and projected future concentrations of PON. Negative loads have been set to zero.
[4] Sum of target threshold watershed load, atmospheric deposition load, and benthic load.

The waterbody segment, Seapuit River was not found to be impaired for nitrogen, but it was determined that a "pollution prevention" TMDL for nitrogen was needed since this waterbody segment is linked to the larger embayment system and any future impairment of this segment could further contribute to impairment of the segments at issue in this TMDL (Appendix D). A "pollution prevention" TMDL on this waterbody segment will encourage the maintenance and protection of existing water quality and help prevent further degradation to waterbodies that are downstream or linked. This pollution prevention TMDL will serve as a guide to help ensure that this waterbody does not become impaired for nitrogen.

Implementation Plans

Growth should be guided by a consideration of water quality-associated impacts.

The critical element of this TMDL process is achieving the sub-embayment specific N concentrations presented in Table 2 above, that are necessary for the restoration and protection of water quality and eelgrass habitat within the Three Bays sub-embayments. In order to achieve those target concentrations, N loading rates must be reduced throughout the Embayment System. Table 5, above, lists target watershed threshold loads for each sub-embayment. If those threshold loads are achieved, the sub-embayments studied will be protected.

This loading reduction scenario is not the only way to achieve the target threshold N concentrations. The Towns are free to explore other loading reduction scenarios through additional modeling as part of the Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated, however, that any alternative implementation strategies will be protective of the overall Three Bays System, and that none of the sub-embayments will be negatively impacted. To this end, additional linked model runs can be performed by the MEP at a nominal cost to assist the planning efforts of the Towns in achieving target N loads that will result in the desired threshold concentrations.

The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, the DEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results.

Because the vast majority of controllable N load is from individual on-site subsurface wastewater disposal systems for private residences, the CWMP should assess the most cost-effective options for achieving the target N watershed loads, including but not limited to, sewering and treatment for N control of sewage and septage at either centralized or de-centralized locations, and denitrifying systems for all private residences.

The Towns, however, are urged to meet the target threshold N concentrations by reducing N loadings from any and all sources, through whatever means are available and practical, including reductions in stormwater runoff and/or fertilizer use within the watershed through the establishment of local by-laws and/or the implementation of stormwater BMPs, in addition to reductions in on-site subsurface wastewater disposal system loadings.

Although it is not explained in detail previously in this TMDL, it should be noted here that parts of the Town of Mashpee and Sandwich are in the watershed of the Three Bays sub-embayments. A very small portion of the upper western watershed is located in Mashpee. A significant portion of the upper watershed is in Sandwich. Thus the development of any implementation plan should keep in mind that Mashpee and Sandwich need to be included in coordinating efforts to maximize the reduction in TN loading.

MassDEP's MEP Implementation Guidance report (http://www.mass.gov/dep/smerp/restore.htm) provides N loading reduction strategies that are available to the Towns of Barnstable, Sandwich and Mashpee, and that

could be incorporated into the implementation plans. The following topics related to N reduction are discussed in the Guidance:

- Wastewater Treatment
    - On-Site Treatment and Disposal Systems
    - Cluster Systems with Enhanced Treatment
    - Community Treatment Plants
    - Municipal Treatment Plants and Sewers
- Tidal Flushing
    - Channel Dredging
    - Inlet Alteration
    - Culvert Design and Improvements
- Stormwater Control and Treatment *
    - Source Control and Pollution Prevention
    - Stormwater Treatment
- Attenuation via Wetlands and Ponds
- Water Conservation and Water Reuse
- Management Districts
- Land Use Planning and Controls
    - Smart Growth
    - Open Space Acquisition
    - Zoning and Related Tools
- Nutrient Trading

* The Towns of Barnstable, Sandwich and Mashpee are three of 237 communities in Massachusetts covered by the Phase II stormwater program requirements. Barnstable and Sandwich have extended the coverage to the entire area of the town.

Monitoring Plan for TMDL Developed Under the Phased Approach

MassDEP is of the opinion that there are two forms of monitoring that are useful to determine progress towards achieving compliance with the TMDL keeping in mind that MassDEP's position is that implementation will be needed along the way. The two forms of monitoring include 1) tracking implementation progress as approved in the Town CWMP plan and 2) monitoring ambient water quality conditions at the sentinel stations identified in the MEP Technical Report.

The CWMP will evaluate various options to achieve the goals set out in the TMDL and Technical Report. It will also make a final recommendation based on existing or additional modeling runs, set out required activities, and identify a schedule to achieve the most cost effective solution that will result in compliance with the TMDL. Once approved by the Department tracking progress on the agreed upon plan will, in effect, also be tracking progress towards water quality improvements in conformance with the TMDL.

Relative to water quality, MassDEP believes that an ambient monitoring program, much reduced from the data collection activities needed to properly assess conditions and to populate the model, will be important to determine actual compliance with water quality standards. Although the TMDL load values are not fixed, the target threshold nitrogen concentrations at the sentinel stations are fixed. In addition, there are target threshold N concentrations that are provided for many other non-sentinel locations in subembayments to protect nearshore benthic habitat. These are the water quality targets, and a monitoring program should encompass these stations at a minimum. Through discussions amongst the MEP it is generally agreed that existing monitoring programs, which were designed to thoroughly assess conditions and populate water quality models, can be substantially reduced for compliance monitoring purposes. Although more specific details need to be developed on a case by case basis MassDEP's current thinking is that about half the current effort (using the same data collection procedures) would be sufficient to monitor compliance over time and to observe trends in water quality

changes. In addition, the benthic habitat and communities would require periodic monitoring on a frequency of about every 3-5 years. Finally, in addition to the above, existing monitoring conducted by MassDEP for eelgrass should continue into the future to observe any changes that may occur to eelgrass populations as a result of restoration efforts.

The MEP will continue working with the Towns to develop and refine monitoring plans that remain consistent with the goals of the TMDL. It must be recognized however that development and implementation of a monitoring plan will take some time, but it is more important at this point to focus efforts on reducing existing watershed loads to achieve water quality goals.

Reasonable Assurances

MassDEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act (CWA), to implement and enforce the provisions of the TMDL through its many permitting programs, including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Barnstable, Sandwich, and Mashpee have demonstrated this commitment through the comprehensive wastewater planning that they initiated well before the generation of the TMDL. The Towns expect to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers), and to prevent any future degradation of these valuable resources. Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations; availability of financial incentives; and local, state, and federal programs for pollution control. Storm water NPDES permit coverage will address discharges from municipally owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act; Title 5 regulations for on-site subsurface wastewater disposal systems, and other local regulations such as the Town of Rehoboth's stable regulations. Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement between MassDEP and EPA. Other potential funds and assistance are available through Massachusetts' Department of Agriculture's Enhancement Program and the United States Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

As the towns implement this TMDL, the TMDL values (kg/day of nitrogen) will not be used by MassDEP as an enforcement tool by MassDEP, but may be used by local communities as a management tool. There will be slight variations in these values depending on the scenario the towns use to implement it. They are also modeled values and thus would be inappropriate to use as an enforcement tool. There could also be slight variations between the actual nitrogen concentration at the sentinel stations and the site-specific target threshold nitrogen concentration at the sentinel stations as the nitrogen load is reduced and the waterbodies begin to approach the water quality standards (Description of the Applicable Water Quality Standards section**).** It will be these latter two standards, the nitrogen concentration at the sentinel station and more importantly, the applicable water quality standards that will be used as the measure of full implementation and compliance with these water quality standards.

Appendix A

Summarizes the nitrogen concentrations for Three Bays sub-embayments (from Chapter VI of the accompanying MEP Technical Report)

Table VI-1. Measured data and modeled Nitrogen concentrations for the Three Bays estuarine system used in the model calibration plots of Figures VI-2 and VI-3. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means. Data represented in this table were collected in the summers of 1989 through 2004, except the Vineyard sound station, which covers a longer time period.

Sub-Embayment	monitoring station	data mean	s.d. all data	N	model min	model max	model average
Mill Pond (fresh water)	TB1	1.022	0.246	36	-	-	-
Prince Cove - south	TB2	0.699	0.192	38	0.685	0.699	0.695
Prince Cove - north	TB3	0.602	0.131	37	0.612	0.666	0.639
Warrens Cove	TB4	0.642	0.151	36	0.561	0.642	0.595
North Bay - north	TB5	0.498	0.135	105	0.504	0.531	0.518
North Bay - south	TB6	0.515	0.129	36	0.483	0.517	0.500
North Windmill Cove	TB7	0.511	0.120	103	0.498	0.523	0.511
West Bay - north	TB8	0.383	0.117	34	0.327	0.418	0.363
West Bay - west	TB9	0.376	0.078	38	0.299	0.362	0.327
Eel River	TB10	0.481	0.125	34	0.468	0.500	0.486
Seapuit River	TB11	0.322	0.068	67	0.287	0.305	0.295
Cotuit Bay - north	TB12	0.438	0.076	64	0.364	0.484	0.414
Cotuit Bay - south	TB13	0.389	0.077	75	0.298	0.350	0.321
South Windmill Cove	TB15	0.431	0.090	27	0.369	0.467	0.402
Mellon Cove	TB16	0.411	0.094	24	0.369	0.417	0.392
Dam Pond	TB17	0.508	0.073	5	0.513	0.531	0.523
Vineyard Sound	NS	0.280	0.065	196	-	-	0.280

Appendix B

Summarizes the present on-site subsurface wastewater disposal system loads, and the loading reductions that would be necessary to achieve the TMDL by reducing on-site subsurface wastewater disposal system loads, ignoring all other sources.

Table VIII-2. Comparison of sub-embayment watershed *septic loads* (attenuated) used for modeling of present and threshold loading scenarios of the Three Bays system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Cotuit Bay	17.022	13.618	-20.0%
West Bay	15.490	12.392	-20.0%
Seapuit River	2.921	2.921	0.0%
North Bay	24.978	0.000	-100.0%
Prince Cove	11.192	0.000	-100.0%
Warrens Cove	6.975	0.000	-100.0%
Prince Cove Channel	4.767	0.000	-100.0%
Marstons Mills Crescent	3.573	0.000	-100.0%
Surface Water Sources			
Marstons Mills River	10.071	7.553	-25.0%
Little River	3.203	3.203	0.0%

Appendix C

The Three Bays Embayment System estimated wasteload allocation (WLA) from runoff of all impervious areas within 200 feet of waterbodies.

Subwatershed Name	Impervious subwatershed buffer areas[1]		Total subwatershed Impervious areas		Total Impervious subwatershed load	Total subwatershed load	Impervious subwatershed buffer area WLA	
	Acres	%	Acres	%	Kg/year	Kg/year	Kg/year[2]	%[3]
Cotuit Bay	17.6	11.4	153.7	9.6	589	11653	67.45	0.58
Seapuit River	3.7	9.2	18.9	9.1	39	1540	7.63	0.50
West Bay	10.9	10.8	114.5	13.1	260	8505	24.75	0.29
North Bay	11.7	10.9	159.5	12.2	477	12191	34.99	0.29
Princes Cove	8.0	6.5	737.6	8.7	1463	20768	15.87	0.08
TOTAL	51.9	11.6	1184.2	9.2	2828	54657	123.94	0.23

[1]The entire impervious area within a 200 foot buffer zone around all waterbodies as calculated from GIS. Due to the soils and geology of Cape Cod it is unlikely that runoff would be channeled as a point source directly to a waterbody from areas more than 200 feet away. Some impervious areas within approximately 200 feet of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of the wasteload allocation (WLA) it was assumed that all impervious surfaces within 200 feet of the shoreline discharge directly to the waterbody.

[2]The impervious subwatershed buffer area (acres) divided by total subwatershed impervious area (acres) then multiplied by total impervious subwatershed load (kg/year).

[3]The impervious subwatershed buffer area WLA (kg/year) divided by the total subwatershed load (kg/year) then multiplied by 100.

Appendix D
6 Total Nitrogen TMDLs, 1 Pollution Prevention TMDLs

Sub-Embayment	Segment ID	Description	TMDL (kg/day)
Cotuit Bay[1]	MA96-63_2004	Previously determined to be impaired for nutrients by MassDEP.	28
West Bay[1]	MA96-65_2004	Previously determined to be impaired for nutrients by MassDEP.	24
Seapuit River	MA96-64_2004	Not impaired for total nitrogen, but a nitrogen TMDL needed since embayments are linked. (Pollution Prevention TMDL) Previously determined to be impaired for pathogens by MassDEP.	4
North Bay[1]	MA96_66_2004	Previously determined to be impaired for nutrients by MassDEP.	54
Prince Cove[1]	MA96-07_2004	Previously determined to be impaired for nutrients by MassDEP.	19
Warren Cove		Determined to be impaired for nutrients during the development of this TMDL.	11
Prince Cove Channel		Determined to be impaired for nutrients during the development of this TMDL.	2

[1]Impaired for nutrients on 2002 , 2004, and proposed 2006 CWA §303(d) list.

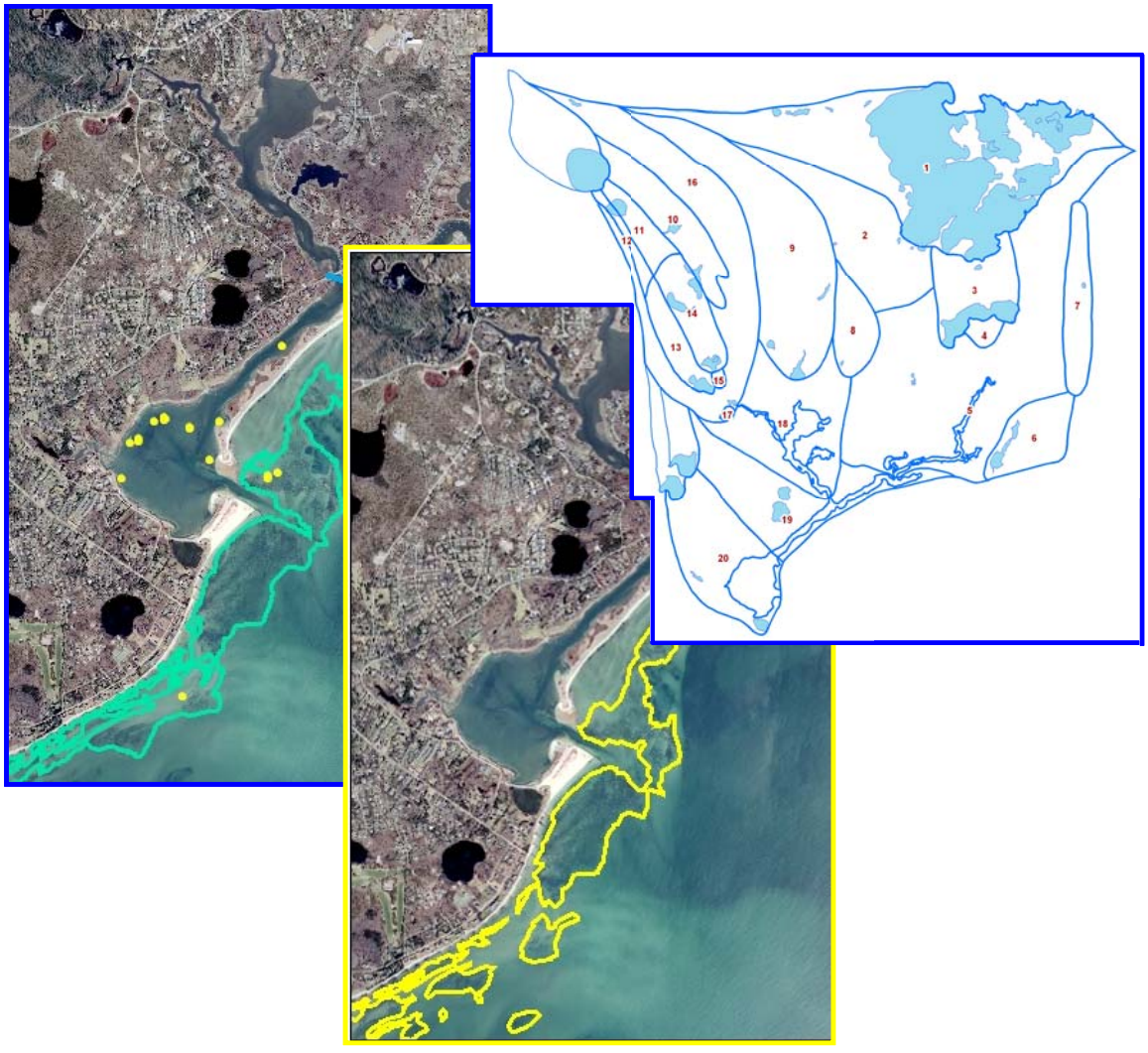
Appendix E

Appendix Y

MEP Technical Report for Centerville River System; MEP, November 2006

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Centerville River, Town of Barnstable, Massachusetts



University of Massachusetts Dartmouth
School of Marine Science and Technology

Massachusetts Department of Environmental Protection

FINAL REPORT – NOVEMBER 2006

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Centerville River System, Barnstable, Massachusetts

FINAL REPORT – November 2006

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I. INTRODUCTION

The Centerville River Embayment System is a complex estuary located within the Town of Barnstable on Cape Cod, Massachusetts with a southern shore bounded by water from Nantucket Sound (Figure I -1). The estuary is composed of a lagoon formed behind a barrier spit and running parallel to the shoreline, comprised of the Centerville River and East Bay, and a drowned river valley estuary, Bumps River/Scudder Bay. The Bay's watershed is distributed entirely within the Town of Barnstable. A large portion of the overall watershed includes the sub-watersheds contributing direct groundwater discharge to the estuary and contributing to the four surface water discharges flowing with to the estuarine reach of the Bumps River (Skunknett River, Bumps River) or directly into Centerville River (stream from Long Pond, stream from Lake Elizabeth). Although land-uses closest to an embayment generally have greater impact than those in the upper portions of the watershed, which are subject to nitrogen attenuation during transport through natural aquatic systems (e.g. ponds, rivers, wetlands etc.) prior to discharge to the embayment, effective restoration of the Centerville River System, will require the Town of Barnstable to be active in nutrient management throughout the watershed to the overall system. This will be made easier by virtue of the fact that the watershed to the Centerville River System resides entirely within the boundary of the Town of Barnstable.

The number of sub-embayments (East Bay, Centerville River, Bumps River, Scudder Bay, Centerville River marshes) to the Centerville River System greatly increases the shoreline and decreases the travel time of groundwater (and its pollutants) from the watershed recharge areas to bay regions of discharge. The nature of enclosed embayments in populous regions brings two opposing elements to bear: as protected marine shoreline they are popular regions for boating, recreation, and land development; as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the Centerville River system and its sub-embayments along the Barnstable shores are at risk of eutrophication (over enrichment) from high nitrogen loads in the groundwater and runoff from their watersheds.

The Centerville River Embayment System is a complex estuary with one inlet connecting Centerville Harbor-Nantucket Sound to Centerville River and a number of sub-embayments (East Bay, Centerville River, Bumps River, Scudder Bay, Centerville River marshes) as depicted in Figure I-1. Centerville Harbor abuts Nantucket Sound and is bounded to the west by Dowes Beach in the vicinity of the inlet to the estuary and Halls Creek Salt Marsh located along the most eastern boundary of the Harbor. The Centerville River Estuary receives tidal waters from Nantucket Sound which flow into a single lower basin (East Bay) located on the western end of Centerville River. East Bay and Centerville River are separated from Centerville Harbor by a barrier beach. The barrier beach is commonly known as Dowes Beach to the west of the inlet to Centerville River, Long Beach immediately to the east of the inlet and then Long Beach transitions into Craigville Beach. Moving east from Craigville Beach is Coville Beach which terminates in a small tidal inlet which allows Nantucket Sound flood waters to enter the Halls Creek Salt Marsh system (Figure I-2). The inlet connecting Centerville Harbor and East Bay – Centerville River is a feature that has very likely migrated along the barrier beach as a function of longshore transport of sediments and coastal storms. Currently, the inlet is armored and stable and the Town of Barnstable periodically dredges the inlet channel to keep the inlet and East Bay navigable. Centerville River runs west to east behind the barrier beach and terminates in a salt marsh system commonly referred to as the Centerville Marshes. Midway along the west-east axis of the Centerville River, the Centerville River is joined with the Bumps River flowing south from the up reaches of the estuarine system. The confluence of the

estuarine Bumps River with Centerville River is a very shallow area of the Centerville River reach and has periodically been dredged to keep the waterway navigable as described in Section II. At the uppermost end of the estuarine reach of Bumps River is located Scudder Bay, a terminal sub-embayment that receives direct fresh surfacewater inflow from the watershed via the Bumps River. The estuarine reach of the Bumps River also receives fresh surfacewater inflow from the watershed via the Skunknett River. Unlike the more upland habitat that characterizes the shores of Scudder Bay, salt marsh dominates the shoreline at the eastern most end of the Centerville River estuarine reach. Centerville River proceeds in a northeasterly direction upwards towards Long Pond and receives direct fresh surface water discharge from Long Pond and Lake Wequaquet. Lower in the salt marsh system is located another fresh surface water input that discharge from Lake Elizabeth to the east. These smaller sub-embayments (including Bumps River and Scudder Bay) constitute important components of the Town's natural and cultural resources.



Figure I-1. Study region for the Massachusetts Estuaries Project analysis of the Centerville River Embayment System. Tidal waters enter the Bay through one inlet from Nantucket Sound. Freshwaters enter from the watershed primarily through 4 surface water discharges (Skunknett River, Bumps River, a stream from Long Pond and a stream from Lake Elizabeth) and direct groundwater discharge.



Figure I-2. Topographic Map of the Centerville River System depicting major geographic features.

The present Centerville River system results from tidal flooding of drowned river valleys formed primarily by the Bumps River discharging to Scudder Bay and Skunknett River discharging to estuarine reach of the Bumps River. In the northeast portion of the Centerville River system, the stream flowing from Long Pond likely contributed to the morphology of this portion of the system as would also be so for the small stream flowing from Lake Elizabeth (a small coastal kettle pond). Drowning of the river valleys occurred gradually as a result of rising sea level following the last glaciation approximately 18,000 years BP. Coastal processes, including the formation of a barrier spit (beach and dune deposits) have altered the positions of the tidal inlet(s) to the Centerville River system and affecting tidal exchange between the open water Centerville Harbor and the enclosed Centerville River. Most of the estuarine reach of the Centerville River and East Bay comprise a lagoon formed behind a barrier spit (Long Beach - Craigville Beach), which separates the estuary from Centerville Harbor and Nantucket Sound. The barrier spit grew from the southeastern shore, and is a very dynamic geomorphic feature.

The primary ecological threat to the Centerville River System as a coastal resource is degradation resulting from nutrient enrichment. Although the enclosed estuarine system has some bacterial contamination issues related to stormwater run-off from the watershed, these do not appear to be having large system-wide impacts. Bacterial contamination causes closures of shellfish harvest areas within the East Bay and Bumps River sub-embayments as well as portions of Centerville River. In contrast, loading of the critical eutrophying nutrient, nitrogen, to the Centerville River System has been greatly increased over the past few decades with further increases certain unless nitrogen management is implemented. The nitrogen loading to the Centerville River Estuary, like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater.

The Town of Barnstable has been among the fastest growing towns in the Commonwealth over the past two decades and does have a centralized wastewater treatment system located in Hyannis. Even so, the vast majority of the Centerville River System watershed is not connected to any municipal sewerage system and wastewater treatment and disposal is primarily based on privately maintained septic systems. As existing and probable increasing levels of nutrients impact Barnstable's coastal embayments, water quality degradation will accelerate, with further harm to invaluable environmental resources.

As the primary stakeholder to the Centerville River System, the Town of Barnstable was among the first communities to become concerned over perceived degradation of Bay waters. The concern over declining habitat quality led directly to the establishment of a comprehensive water quality monitoring program aimed at determining the degree to which waters of the Town's embayments maybe be impaired. The Town of Barnstable Water Quality Monitoring Program was provided technical assistance by the Coastal Systems Program at SMAST-UMD and over the past several years has had the Water Quality Monitoring Program of the Three Bays Preservation Trust merged into Barnstable's Town-wide embayment monitoring program. This effort provides the quantitative watercolumn nitrogen data (2001-2005) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study.

The common focus of the Barnstable Water Quality Monitoring effort has been to gather site-specific data on the current nitrogen related water quality throughout the Centerville River System and determine its relationship to watershed nitrogen loads. This multi-year effort has provided the baseline information required for determining the link between upland loading, tidal flushing, and estuarine water quality. The MEP effort builds upon the Water Quality Monitoring

Program, and previous hydrodynamic and water quality analyses conducted in support of an Environmental Impact Report for the Centerville River Dredging Project that got underway in the early part of 2002. The details of the EIR are presented in Section II. The MEP approach includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for each major sub-embayment. These critical nitrogen targets and the link to specific ecological criteria form the basis for the nitrogen threshold limits necessary to complete wastewater planning and nitrogen management alternatives development needed by the Town of Barnstable. While the completion of this complex multi-step process of rigorous scientific investigation to support watershed based nitrogen management has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, the results stem directly from the efforts of large number of Town staff and volunteers over many years, most notably from members of the local non-governmental organization (NGO) Three Bays Preservation. The modeling tools developed as part of this program provide the quantitative information necessary for the Town of Barnstable to develop and evaluate the most cost effective nitrogen management alternatives to restore this valuable coastal resource which is currently being degraded by nitrogen overloading. It is important to note that the Centerville River System has been significantly altered by human activities over the past ~100 years or more (see Section I.2, below). As a result, the present nitrogen "overloading" appears to result partly from alterations to the geomorphology and ecological systems. These alterations subsequently affect nitrogen loading and transport within the watershed and influence the degree to which nitrogen loads impact the estuary. Therefore, restoration of this system should focus on managing nitrogen through both management of nitrogen loading within the watershed and restoration/management of processes which serve to lessen the amount or impact of nitrogen entering the estuary.

I.1 THE MASSACHUSETTS ESTUARIES PROJECT APPROACH

Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The nutrients are primarily related to changes in watershed land-use associated with increasing population within the coastal zone over the past half century. Many of Massachusetts' embayments have nutrient levels that are approaching or are currently over this assimilative capacity, which begins to cause declines in their ecological health. The result is the loss of fisheries habitat, eelgrass beds, and a general disruption of benthic communities and the food chain which they support. At higher levels, nitrogen loading from surrounding watersheds causes aesthetic degradation and inhibits even recreational uses of coastal waters. In addition to nutrient related ecological declines, an increasing number of embayments are being closed to swimming, shellfishing and other activities as a result of bacterial contamination. While bacterial contamination does not generally degrade the habitat, it restricts human uses. However like nutrients, bacterial contamination is frequently related to changes in land-use as watersheds become more developed. The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities.

The primary nutrient causing the increasing impairment of the Commonwealth's coastal embayments is nitrogen and the primary sources of this nitrogen are wastewater disposal, fertilizers, and changes in the freshwater hydrology associated with development. At present there is a critical need for state-of-the-art approaches for evaluating and restoring nitrogen sensitive and impaired embayments. Within southeastern Massachusetts alone, almost all of the municipalities (as is the case with the Town of Barnstable) are grappling with

Comprehensive Wastewater Planning and/or environmental management issues related to the declining health of their estuaries.

Municipalities are seeking guidance on the assessment of nitrogen sensitive embayments, as well as available options for meeting nitrogen goals and approaches for restoring impaired systems. Many of the communities have encountered problems with "first generation" watershed based approaches, which do not incorporate estuarine processes. The appropriate method must be quantitative and directly link watershed and embayment nitrogen conditions. This "Linked" Modeling approach must also be readily calibrated, validated, and implemented to support planning. Although it may be technically complex to implement, results must be understandable to the regulatory community, town officials, and the general public.

The Massachusetts Estuaries Project represents the next generation of watershed based nitrogen management approaches. The Massachusetts Department of Environmental Protection (MassDEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool for watershed-embayment management for communities throughout Southeastern Massachusetts.

The Massachusetts Estuary Project is founded upon science-based management. The Project is using a consistent, state-of-the-art approach throughout the region's coastal waters and providing technical expertise and guidance to the municipalities and regulatory agencies tasked with their management, protection, and restoration. The overall goal of the Massachusetts Estuaries Project is to provide the DEP and municipalities with technical guidance to support policies on nitrogen loading to embayments. In addition, the technical reports prepared for each embayment system will serve as the basis for the development of Total Maximum Daily Loads (TMDLs). Development of TMDLs is required pursuant to Section 303(d) of the Federal Clean Water Act. TMDLs must identify sources of the pollutant of concern (in this case nitrogen) from both point and non-point sources, the allowable load to meet the state water quality standards and then allocate that load to all sources taking into consideration a margin of safety, seasonal variations, and several other factors. In addition, each TMDL must contain an outline of an implementation plan. For this project, the DEP recognizes that there are likely to be multiple ways to achieve the desired goals, some of which are more cost effective than others and therefore, it is extremely important for each Town to further evaluate potential options suitable to their community. As such, DEP will likely be recommending that specific activities and timelines be further evaluated and developed by the Towns (sometimes jointly) through the Comprehensive Wastewater Management Planning process.

In appropriate estuaries, bacterial technical reports will be developed in support of a Cape Cod wide TMDL for bacterial contamination. As possible, these analyses of bacterial contamination will be conducted in concert with the nutrient effort (particularly if there is a 303d listing), as was the case for the Prince's Cove sub-embayment to the Three Bays system. Currently, the MEP (through SMAST) has not been tasked with a technical assessment of bacterial contamination in the Centerville River System for inclusion of this system into the Cape Cod wide bacterial TMDL that the MassDEP is in the process of producing.

The MEP nitrogen threshold analysis includes site-specific habitat assessments and watershed/embayment modeling approaches to develop and assess various nitrogen management alternatives for meeting selected nitrogen goals supportive of restoration/protection of embayment health.

The major MEP nitrogen management goals are to:

- provide technical analysis and supporting documentation to Towns as a basis for sound nutrient management decision making towards embayment restoration
- develop a coastal TMDL working group for coordination and rapid transfer of results,
- determine the nutrient sensitivity of each of the 89 embayments in Southeastern MA
- provide necessary data collection and analysis required for quantitative modeling,
- conduct quantitative TMDL analysis, outreach, and planning,
- keep each embayment's model "alive" to address future municipal needs.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. This approach represents the "next generation" of nitrogen management strategies. It fully links watershed inputs with embayment circulation and nitrogen characteristics. The Linked Model builds on and refines well accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied for watershed nitrogen management in approximately 23 embayments throughout southeastern Massachusetts. In these applications it has become clear that the Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options.

The Linked Watershed-Embayment Model when properly parameterized, calibrated and validated for a given embayment becomes a nitrogen management planning tool, which fully supports TMDL analysis. The Model facilitates the evaluation of nitrogen management alternatives relative to meeting water quality targets within a specific embayment. The Linked Watershed-Embayment Model also enables Towns to evaluate improvements in water quality relative to the associated cost. In addition, once a model is fully functional it can be "kept alive" and updated for continuing changes in land-use or embayment characteristics (at minimal cost). In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

Linked Watershed-Embayment Model Overview: The Model provides a quantitative approach for determining an embayment's: (1) nitrogen sensitivity, (2) nitrogen threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is both calibrated and fully field validated and unlike many approaches, accounts for nutrient sources,

attenuation, and recycling and variations in tidal hydrodynamics (Figure I-3). This methodology integrates a variety of field data and models, specifically:

- Watercolumn Monitoring - multi-year embayment nutrient sampling
- Hydrodynamics -
  - embayment bathymetry
  - site specific tidal record
  - current records (in complex systems only)
  - hydrodynamic model
- Watershed Nitrogen Loading
  - watershed delineation
  - stream flow (Q) and nitrogen load
  - land-use analysis (GIS)
  - watershed N model
- Embayment TMDL - Synthesis
  - linked Watershed-Embayment N Model
  - salinity surveys (for linked model validation)
  - rate of N recycling within embayment
  - D.O record
  - Macrophyte survey
  - Infaunal survey

I.2 SITE DESCRIPTION

The Centerville River Embayment System exchanges tidal water with Nantucket Sound through one inlet at the west end of a barrier beach referred to as Long – Craigville Beach. The inlet connecting Centerville Harbor to East Bay was opened by dredging in the early 1900's and is armored on the west side (Dowes Beach) and remains in a "natural" un-stabilized state on the east side (Long Beach). For the MEP analysis, the Centerville River Estuarine System has been partitioned into four general sub-embayment groups: the 1) East Bay 2) Centerville River West 3) Centerville River East, including the marshes northeast of bridge, and 4) Bumps River (inclusive of Scudder Bay) as depicted in Figure I-1.

Within the overall Centerville River System is seen a diversity of estuarine habitats, including the tidal portion of East Bay and Centerville River which operates as an embayment, the Bumps River and Scudder Bay with associated fringing wetlands and the large salt marsh area at the eastern end of the Centerville River. Most of the System's salt marsh area is to the east and associated with Bumps River and has shallow tidal flats and large salinity fluctuations. In contrast, East Bay and Centerville River show more typical embayment characteristics with a mixture of open water areas and channels, small fringing salt marshes and relatively stable salinity gradients. Although the upper sub-embayment system of Bumps River and Scudder Bay up-gradient of Centerville River exhibit different hydrologic characteristics (river dominated versus tidally dominated), the tidal forcing for these systems is generated from Nantucket Sound. Nantucket Sound exhibits a moderate to low tide range, with a mean range of about 2.5 ft. Since the water elevation difference between Nantucket Sound and the Centerville River System is the primary driving force for tidal exchange, the local tide range naturally limits the volume of water flushed during a tidal cycle (note the tide range off Stage Harbor Chatham is ~4.5 ft, Wellfleet Harbor is ~10 ft).

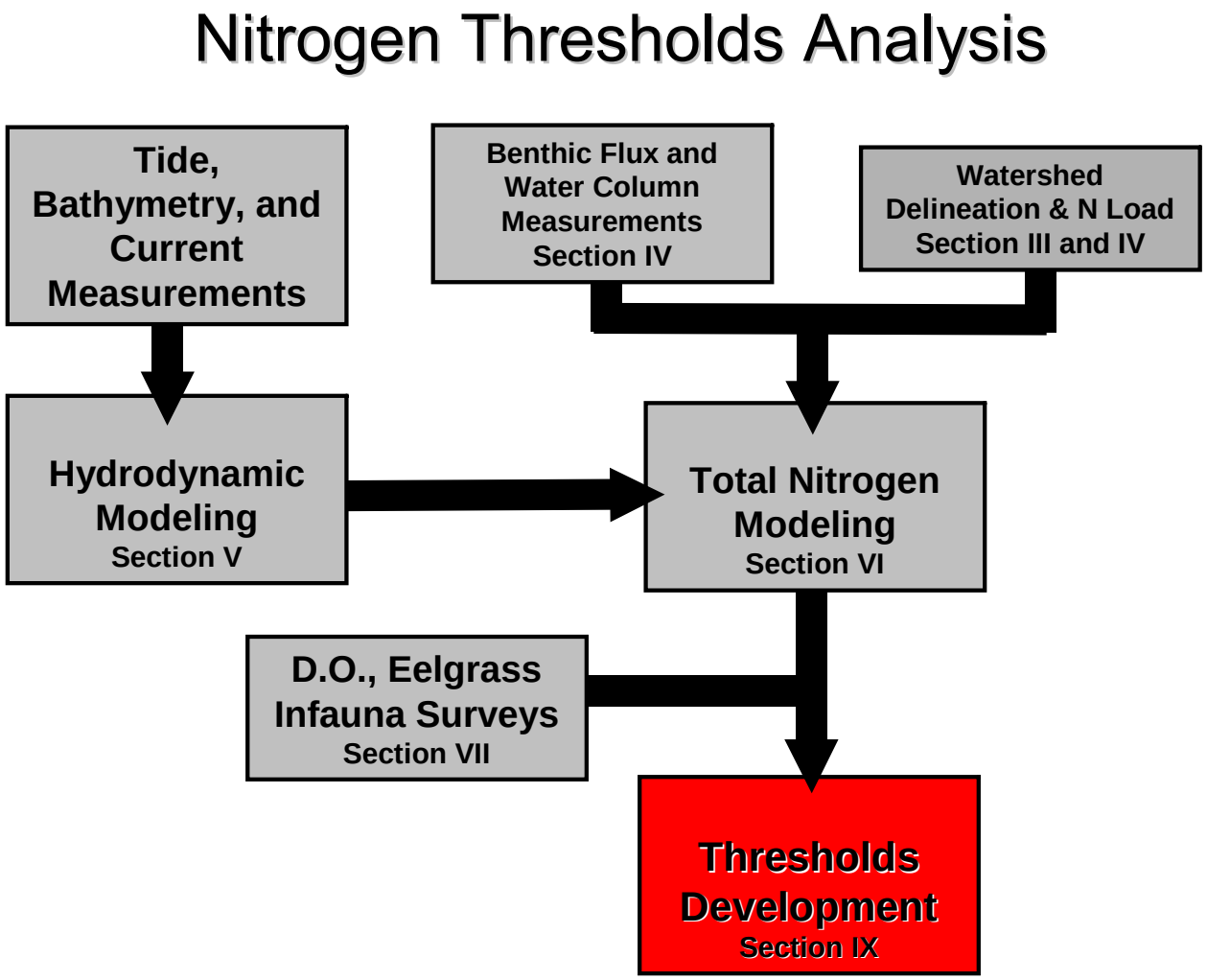


Figure I-3. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

Tidal damping (reduction in tidal amplitude) through an embayment can range from negligible, indicating "well-flushed" conditions, or show tidal attenuation caused by constricted channels and marsh plains, indicating a "restrictive" system, where tidal flow and the associated flushing are inhibited. Tidal data indicate only minimal tidal damping through the inlet into the East Bay – Centerville River. It appears that the tidal inlet is operating efficiently having recently been dredged in the 2002 to 2003 time frame during the most recent Centerville River Dredging Project. Within the Bumps River and Centerville Marshes portion of the System, the tide propagates to the sub-embayments with negligible attenuation, consistent with generally well-flushed conditions throughout.

I.3 NUTRIENT LOADING

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the Centerville River System, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even Cape Cod "rivers" are primarily groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1998, Weiskel and Howes 1992, Smith *et al.* 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within the Centerville River Estuary follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. This point can be termed the "nutrient threshold" and in estuarine management this threshold sets the target nutrient level for restoration or protection. Because nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 and in press, Ramsey et al., 1995, Howes and Taylor, 1990, and the Falmouth Coastal Pond Overlay District Bylaw). While each approach may be different, they all focus on changes in nitrogen loading

from watershed to embayment, and aim at projecting the level of increase in nitrogen concentration within the receiving waters. Each approach depends upon estimates of circulation within the embayment; however, few directly link the watershed and hydrodynamic models, and virtually none include internal recycling of nitrogen (as was done in the present effort). However, determination of the "allowable N concentration increase" or "threshold nitrogen concentration" used in previous studies had a significant uncertainty due to the need for direct linkage of watershed and embayment models and site-specific data. In the present effort we have integrated site-specific data on nitrogen levels and the gradient in N concentration throughout the Centerville River System monitored by the Town of Barnstable/Three Bays Preservation. Data from the Water Quality Monitoring Program combined with site-specific habitat quality data (D.O., eelgrass, phytoplankton blooms, benthic animals) was utilized to "tune" general nitrogen thresholds typically used by the Cape Cod Commission, Buzzards Bay Project, and Massachusetts State Regulatory Agencies.

Unfortunately, almost all of the estuarine reaches within the Centerville River System are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout the System and eelgrass beds have not been observed within the Centerville system for over a decade. Nitrogen related habitat impairment within the Centerville River Estuary shows a gradient of high to low moving from the inland reaches to the tidal inlet. The result is that nitrogen management of the primary sub-embayments to the Centerville River system is aimed at restoration, not protection or maintenance of existing conditions. In general, nutrient over-fertilization is termed "eutrophication" and in certain instances can occur naturally over long periods of time. When the nutrient loading is rapid and primarily from human activities leading to changes in a coastal watershed, nutrient enrichment of coastal waters is termed "cultural eutrophication". Although the influence of human-induced changes has increased nitrogen loading to the systems and contributed to the degradation in ecological health, it is sometimes possible that eutrophication within the Centerville River sub-embayments (e.g. Scudder Bay) could potentially occur without human influence and must be considered in the nutrient threshold analysis. While this finding would not change the need for restoration, it would change the approach and potential targets for management. As part of future restoration efforts, it is important to understand that it may not be possible to turn each embayment into a "pristine" system.

I.4 WATER QUALITY MODELING

Evaluation of upland nitrogen loading provides important "boundary conditions" (e.g. watershed derived and offshore nutrient inputs) for water quality modeling of the Centerville System; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within each component of the system. Therefore, water quality modeling of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. The spread of pollutants may be analyzed from tidal current information developed by the numerical models.

The MEP water quality evaluation examined the potential impacts of nitrogen loading into the Centerville River System, including the tributary sub-embayments of East Bay, Centerville

River, Bumps River, Scudder Bay and the Centerville River Marshes. A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for each of the systems. Once the hydrodynamic properties of each estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates.

Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic models were then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis, based upon watershed delineations by USGS using a modification of the West Cape model for sub-watershed areas designated by MEP. Almost all watershed sourced nitrogen entering the Centerville River System is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Nantucket Sound source waters and throughout the Centerville River system were provided by the Town of Barnstable/Three Bays Water Quality Monitoring Program (a coordinated effort between the Town of Barnstable, Three Bays Preservation and the Coastal Systems Program at SMAST). Measurements of the salinity and nitrogen distributions throughout estuarine waters of the Centerville River System (2000-2005) were used to calibrate and validate the water quality model (under existing loading conditions).

I.5 REPORT DESCRIPTION

This report presents the results generated from the implementation of the Massachusetts Estuaries Project linked watershed-embayment approach to the Centerville River System for the Town of Barnstable. A review of existing water quality studies is provided (Section II). The development of the watershed delineations and associated detailed land use analysis for watershed based nitrogen loading to the coastal system is described in Sections III and IV. In addition, nitrogen input parameters to the water quality model are described. Since benthic flux of nitrogen from bottom sediments is a critical (but often overlooked) component of nitrogen loading to shallow estuarine systems, determination of the site-specific magnitude of this component also was performed (Section IV). Nitrogen loads from the watershed and sub-watershed surrounding the estuary were derived from Cape Cod Commission data and offshore water column nitrogen values were derived from an analysis of monitoring stations in Nantucket Sound (Section IV). Intrinsic to the calibration and validation of the linked-watershed embayment modeling approach is the collection of background water quality monitoring data (conducted by municipalities) as discussed in Section IV. Results of hydrodynamic modeling of embayment circulation are discussed in Section V and nitrogen (water quality) modeling, as well as an analysis of how the measured nitrogen levels correlate to observed estuarine water quality are described in Section VI. This analysis includes modeling of current conditions, conditions at watershed build-out, and with removal of anthropogenic nitrogen sources. In addition, an ecological assessment of the component sub-embayments was performed that included a review of existing water quality information and the results of a benthic analysis (Section VII). The modeling and assessment information is synthesized and nitrogen threshold levels developed for restoration/protection of the River in Section VIII. Additional modeling is conducted to produce an example of the type of watershed nitrogen reduction required to meet the determined system threshold for restoration or protection. This latter assessment represents only one of many solutions and is produced to assist the Town in developing a variety of alternative nitrogen management options for this system. Finally, analyses of the Centerville River System were undertaken relative to potential alterations of circulation and flushing, including an analysis to identify hydrodynamic restrictions and an examination of

dredging options to improve nitrogen related water quality. The results of the nitrogen modeling for each scenario have been presented in Section IX.

II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

Nutrient additions to aquatic systems cause shifts in a series of biological processes that can result in impaired nutrient related habitat quality. Effects include excessive plankton and macrophyte growth, which in turn lead to reduced water clarity, organic matter enrichment of waters and sediments with the concomitant increased rates of oxygen consumption and periodic depletion of dissolved oxygen, especially in bottom waters, and the limitation of the growth of desirable species such as eelgrass. Even without changes to water clarity and bottom water dissolved oxygen, the increased organic matter deposition to the sediments generally results in a decline in habitat quality for benthic infaunal communities (animals living in the sediments). This habitat change causes a shift in infaunal communities from high diversity deep burrowing forms (which include economically important species), to low diversity shallow dwelling organisms. This shift alone causes significant degradation of the resource and a loss of productivity to both the local shellfisherman and to the sport-fishery and offshore finfishery, which are dependant upon these highly productive estuarine systems as a habitat and food resource during migration or during different phases of their life cycles. This process is generally termed “eutrophication” and in embayment systems, unlike in shallow lakes and pond, it is not a necessarily a part of the natural evolution of a system.

In most marine and estuarine systems, such as the Centerville River System, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if nitrogen addition is controlled, then eutrophication is controlled. This approach has been formalized through the development of tools for predicting nitrogen loads from watersheds and the concentrations of water column nitrogen that may result. Additional development of the approach generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2002).

These tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specifics for any given water body. The present Massachusetts Estuaries Project (MEP) study focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species. The linked watershed-embayment model is built using embayment specific measurements, thus enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including the Centerville River System. As the MEP approach requires substantial amounts of site specific data collection, part of the program is to review previous data collection and modeling efforts. These reviews are both for purposes of “data mining” and to gather additional information on an estuary’s habitat quality or unique features.

A number of studies relating to nitrogen loading, hydrodynamics (mostly in the context of dredging) and habitat health have been conducted within the Centerville River System over the past 10 years. The most directly applicable study relative to the objectives of the MEP focused on nitrogen fluxes and mitigation strategies in the Audubon Skunknett River Wildlife Sanctuary (Hamersley, 2004). The study is significant relative to elucidating the potential for natural attenuation within the Centerville River watershed as well as being an independent confirmation of the MEP stream gaging effort on the Skunknett River. The study was undertaken by an SMAST-Coastal Systems Program scientist directly involved in researching biogeochemical aspects of nutrient cycling to the direct benefit of the MEP analytical approach utilized in this analysis of the Centerville River System. As described in the Skunknett River Wildlife

Sanctuary Report, increasing development in the watershed of Scudder Bay (tributary sub-embayment to Centerville River) has led to algal blooms and eutrophication of the estuarine receiving water. Two point sources for nutrients entering the bay are the Skunknett and Bumps Rivers. The Skunknett River flows through the Audubon Skunknett River Wildlife Sanctuary (ASRWS), the site of four former or existing ponds. The former ponds were created in the 19th century by dams which washed out in the early 1990's. Restoring these ponds has the potential to support the removal of nitrogen from the Skunknett River via the natural bioremediation processes of denitrification and storage. The removal by denitrification is primarily dependent on contact with organic-rich sediments. Restoring the ponds would increase the contact time of the sediments, as well as their organic content through deposition. Hydrological and nutrient fluxes into and out of the Sanctuary were measured in the summer of 2002 and through most of the year 2003 in order to perform a preliminary evaluation of the feasibility of restoring one or more of the ponds to enhance the removal of nitrogen from the Skunknett River.

The preliminary analysis of the Skunknett River aquatic system (inclusive of the associated pond system) suggested that the Skunknett River represents a significant source of nitrogen to Scudder Bay, and that much of this nitrogen is in the form of nitrate, making it amenable to removal through denitrification. As measured at the time of the study (2002-2003) the Skunknett River generated a total nitrogen load to Scudder Bay of 8,490 kg N/yr. Housing development in the Skunknett River watershed will likely increase that N load over time. Well monitoring by the town in the watershed is showing very high and increasing levels of nitrate (up to 6.2 mg L^{-1}, Craig Crocker, Centerville-Osterville-Marstons Mills Water Superintendent, personal communication) indicating the potential for increased N flows in the future. The Skunknett River currently flows through the ASRWS in 2.2 hours, permitting little time for natural N uptake and removal processes which occur during contact of water with sediments. The rapid flow scours stream sediments of organic material, further decreasing N removal. The present residence time of the river (as determined in the 2004 Hamersley study) in the Sanctuary is too low to allow significant removal. Restoring the former ponds and raising the level of Mill Pond could increase the residence time of the Skunknett River by eleven-fold. Summer total nitrogen removals under these conditions might approach 3,400 kg N y^{-1}. Summer reductions of TN flows into Scudder Bay resulting from pond restoration could be the equivalent of the N output of 565 houses. Although our preliminary study demonstrates the potential feasibility of hydrological manipulations in the ASRWS in mitigating N flows to Scudder Bay, any such manipulations would be require further topographical, wildlife, land use, and water quality data, as well as agreements with the landowner, Massachusetts Audubon.

In addition to the study on nitrogen fluxes and mitigation strategies in the Audubon Skunknett River Wildlife Sanctuary (Hamersley, 2004) up-gradient of the Centerville River System, a Draft Environmental Impact Report (DEIR) was developed by the Woods Hole Group in December 2003. The DEIR was developed in regards to a planned dredging of the Centerville River portion of the System as well as associated Craigville Beach nourishment activities. The DEIR focused on the Town of Barnstable developed two phased project approach to conduct maintenance and improvement dredging in the Centerville River/East Bay estuarine system. The proposed dredge project was initiated in September 2000 with the submittal of an Environmental Notification Form (ENF) to the Massachusetts Environmental Policy Act (MEPA) Unit. The ENF specified a two phased approach with a request for a waiver from the requirements of an EIR for Phase I of the project. The Phase I record of decision waiving the EIR requirements for Phase I of the project was issued in April of 2001.

Phase I of the Centerville River dredge and beach nourishment project including dredging material from the Centerville River west of the confluence of the estuarine reach of the Bumps

River and Centerville River. The Phase I dredging would extend into East Bay including removal of material from the East Bay inlet channel adjacent Dowes Beach. Dredge planning, engineering and permitting was completed by October of 2002 and dredging by the Barnstable County dredge commenced that fall. During the initial part of the Phase I dredge more than 20,000 cubic yards of sand was removed from the Centerville River leading to East Bay and that sand was subsequently used to nourish the Long Beach barrier separating Centerville River from Centerville Harbor. An additional 10,700 cubic yards of silty material was planned for removal from East Bay in the fall/winter of 2003 and subsequent dewatering and disposal.

Phase II of the dredge project involved additional maintenance and improvement dredging of the Centerville River east of the confluence of the Bumps River and Centerville River and extended into the most upgradient salt marsh areas (Centerville Marshes). Phase II of the overall project was the basis of the DEIR as required by the Secretary's Certificate on the ENF issued in March of 2001. The Phase II portion of the project was also required to be reviewed as a District of Regional Impact as specified under the Cape Cod Commission Act, Section 12(i). Under Phase II, an estimated 31,180 cubic yards of sediment would be removed from the eastern end of the Centerville River. Analyses of sediment disposal alternatives as well as environmental impact studies were conducted under the DEIR to elucidate preferred design and construction approaches for the dredge project. Sandy sediments would be used for beach nourishment (Long Beach and Craigville Beach). Silt/sand sediments would be dewatered in basins constructed on Craigville Beach and the sandy fraction of the dewatered sediments would be used for nourishment of Craigville Beach while silty sediments would be transported to a waste recycling facility in Sandwich, MA. The strictly silty sediments removed from the Centerville Marshes area of the system would be transported to the waste recycling facility for reuse.

As part of the DEIR, a summary of the existing environment was conducted combining a variety of data findings from studies carried out prior to initiation of the dredge project. Based on the summary provided in the DEIR it is apparent that the bathymetry of the Centerville River system had been characterized on 5 separate occasions between 1930 and 1969. Nearly twenty five years elapsed before the next bathymetric survey was conducted in 1996 as a condition survey for development of a hydrodynamic model of the Centerville River system (ACI, 1996). The 1996 hydro model was developed to examine tidal flushing characteristics within East Bay and Centerville River estuary with specific attention being given to the effects of proposed dredging on existing and future conditions. The MEP Technical Team captured the most recent elements of the historical record on bathymetry of the Centerville River system as well as details of the dredging activity in the system as has occurred in the past several years such that this knowledge could be incorporated into the development of the MEP hydrodynamic model. Moreover, details of the ACI, 1996 hydrodynamic model have also been captured by the MEP Technical Team in order to leverage any pertinent information generated under that effort which may be useful in the MEP analysis of the Centerville River System.

In addition to the summary of bathymetric data collection and description of the results of the 1996 hydrodynamic model runs for the Centerville River system, the DEIR also presents a discussion of the water quality characteristics of the estuarine system. It suffices to say that a large part of the discussion on water quality in the Centerville River system is based on the water quality monitoring program developed by the SMAST-Coastal Systems Program for the Town of Barnstable and in support of the Massachusetts Estuaries Project. An ancillary sampling program undertaken specifically in support of Phase II of the dredging project was developed and described in the DEIR. This dredge related sampling program focused primarily on nutrients within sediments. The sediment nutrient sampling program was developed and

executed by Dr. Dror Angel from the Department of Civil Engineering located at the Massachusetts Institute of Technology (MIT). The purpose of the sediment sampling program was to quantify the nutrient content of bottom sediments in the Centerville River system and to evaluate the extent to which nutrients could be released during resuspension of these sediments during a proposed dredge event. While this information is useful to the purpose that it was intended (i.e. dredging impacts), it does not relate to nutrient release associated with the undisturbed sediments of an estuarine basin.

While the DEIR covers a wide variety of other environmental factors that are of general interest, it does include specific information on shellfish and other invertebrates present in the system that was of interest to the MEP given the MEP's data collection on benthic infauna as a biological indicator of habitat health. A shellfish and benthic survey was developed in support of the DEIR and the proposed Phase II dredge project. The shellfish and benthic survey was conducted during August and September of 2003. A series of survey transects were established at 300 foot intervals across the Centerville River system west to east starting at the confluence with the Bumps River and extending up to the Centerville Marshes area. Shellfish and benthic data was collected at a total of 21 transects with three benthic sampling stations located along each transect. Sampling was conducted with rake hauls and clam rakes. As summarized in the DEIR, sections of Centerville River show signs of well oxygenated sediments that contain abundant benthic life including shellfish, *Mercenaria* and other species. Based on the DEIR benthic survey, other areas of the Centerville River system show signs of reduced flushing, anoxic sediments (black and sulphidic) and an embayment bottom with reduced and, in some instances, depopulated of benthic infauna. This information has been captured and considered by the MEP for use as appropriate.

The common focus of the Town of Barnstable Water Quality Monitoring Program effort has been to gather site-specific data on the current nitrogen related water quality throughout all the embayments of the Town (including the Centerville River System) to support evaluations of observed water quality and habitat health. This multi-year effort was initiated in 2001 for the Centerville River, with support from the Town of Barnstable and technical assistance from Three Bays Preservation and the Coastal Systems Programs at SMAST-UMD. The Barnstable Water Quality Monitoring Program in Centerville River developed a data set at sampling stations (Figure II-1) that elucidated the long-term water quality of the river system. Additionally, as remediation plans for this and other various systems are implemented throughout the Town of Barnstable, the continued monitoring is planned to provide quantitative information to the Town relative to the efficacy of remediation efforts. The MEP effort builds upon the water quality monitoring program, previous hydrodynamic evaluations conducted during the development of the EIR developed for the Centerville River Dredging Project and water quality analyses conducted by SMAST. Additionally, the MEP approach includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for the Centerville River System.

The Town of Barnstable Water Quality Monitoring Program provided the quantitative water column nitrogen data (2001-2005) required for the implementation of the MEP's Linked Watershed-Embayment Approach. The MEP effort also builds upon previous watershed delineation and land-use analyses and the embayment water quality and eelgrass surveys. This information is integrated with MEP higher order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for the Centerville River Estuarine System. The MEP has incorporated all appropriate data from all previous studies to enhance the determination of nitrogen thresholds for the Centerville River System and to reduce costs to the Town of Barnstable.

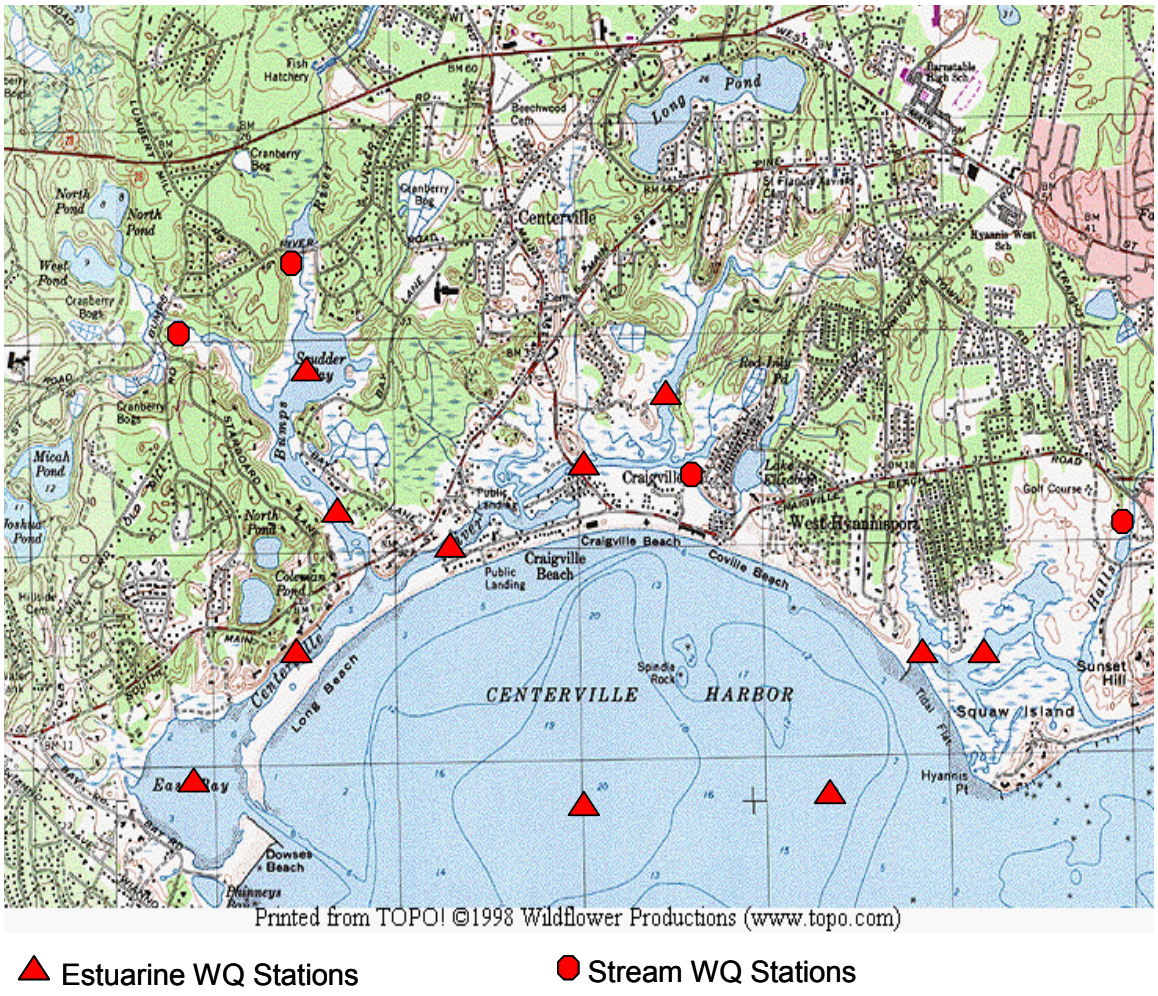


Figure II-1. Town of Barnstable Water Quality Monitoring Program. Estuarine water quality monitoring stations sampled by the Town and volunteers. Stream water quality stations sampled weekly by the MEP. Halls Creek along the eastern shore of Centerville Harbor will be assessed in a future MEP Technical Report on the Lewis Bay System.

III. DELINEATION OF WATERSHEDS

III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). These USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. The USGS has a long history of developing regional models for the six-groundwater flow cells on Cape Cod. Through the years, advances in computing, lithologic information from well installations, water level monitoring, stream flow measurements, and reconstruction of glacial history have allowed the USGS to update and refine the groundwater models. The MODFLOW and MODPATH models utilized by the USGS organize and analyze the available data using up-to-date mathematical codes and create better tools to answer the wide variety of questions related to watershed delineation, surface water/groundwater interaction, groundwater travel time, and drinking water well impacts that have arisen during the MEP analysis of southeastern Massachusetts estuaries, including the Centerville River/East Bay embayment system located in Barnstable, Massachusetts. The Centerville River/East Bay watershed is situated along the southern edge of Cape Cod and is bounded by Vineyard/Nantucket Sound.

In the present investigation, the USGS was responsible for the application of its groundwater modeling approach to define the watershed or contributing area to the Centerville River/East Bay embayment system under evaluation by the Project Team. The Centerville River/East Bay estuarine system is a moderately complex estuary and includes significant wetland dominated eastern portion. Further watershed modeling was undertaken to sub-divide the overall watershed to the Centerville River/East Bay system into functional sub-units based upon: (a) defining inputs from contributing areas to each major portion within the embayment system, (b) defining contributing areas to major freshwater aquatic systems which generally attenuate nitrogen passing through them on the way to the estuary (lakes, streams, wetlands), and (c) defining 10 year time-of-travel distributions within each sub-watershed as a procedural check to gauge the potential mass of nitrogen from “new” development, which has not yet reached the receiving estuarine waters. The three-dimensional numerical model employed is also being used to evaluate the contributing areas to public water supply wells in the Sagamore flow cell on Cape Cod. Model assumptions for calibration were matched to surface water inputs and flows from MEP stream flow measurements (2003 to 2004).

The relatively transmissive sand and gravel deposits that comprise most of Cape Cod create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994a,b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the sources of nitrogen that they carry requires determination of the portion of the watershed that contributes directly to a stream and the portion of the groundwater system that discharge directly into an estuary as groundwater seepage.

III.2 MODEL DESCRIPTION

Contributing areas to the Centerville River/East Bay system were delineated using a regional model of the Sagamore Lens flow cell (Walter and Whealan, 2004). The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh, *et al.*, 2000) was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program

MODPATH4 (Pollock, 1994), which uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. This approach was used to determine the contributing areas to Centerville River/East Bay system including a subwatershed to Scudder Bay/Bumps River and also to determine portions of recharged water that may flow through fresh water ponds and streams prior to discharging into coastal water bodies.

The Sagamore Flow Model grid consists of 246 rows, 365 columns and 20 layers. The horizontal model discretization, or grid spacing, is 400 by 400 feet. The top 17 layers of the model extend to a depth of 100 feet below NGVD 29 and have a uniform thickness of 10 ft. The top of layer 8 resides at NGVD 29 with layers 1-7 stacked above and layers 8-20 below. Layer 18 has a thickness of 40 feet and extends to 140 feet below NGVD 29, while layer 19 extends to 240 feet below NGVD 29. The bottom layer, layer 20, extends to the bedrock surface and has a variable thickness depending upon site characteristics (up to 519 feet below NGVD 29); since bedrock is 300 to 400 feet below NGVD 29 in the Centerville River/East Bay area the two lowest model layers were active in this area of the model. The rewetting capabilities of MODFLOW-2000, which allows drying and rewetting of model cells, was used to simulate the top of the water table, which varies in elevation depending on the location in the Lens.

The glacial sediments that comprise the aquifer of the Sagamore Lens consist of gravel, sand, silt, and clay that were deposited in a variety of depositional environments. The sediments generally show a fining downward with sand and gravel deposits deposited in glaciofluvial (river) and near-shore glaciolacustrine (lake) environments underlain by fine sand, silt and clay deposited in deeper, lower-energy glaciolacustrine environments. Most groundwater flow in the aquifer occurs in shallower portions of the aquifer dominated by coarser-grained sand and gravel deposits. The Centerville River/East Bay watershed (including Scudder Bay/Bumps River) is generally split between the Mashpee Outwash Plain Deposits to the west and Barnstable Plain Deposits to the east; modeling and field measurements of contaminant transport at the MMR has shown that similar deposited materials are highly permeable (*e.g.*, Masterson, *et al*., 1996). Given their high permeability, direct rainwater run-off is typically rather low for this type of coastal system. Lithologic data used to determine hydraulic conductivities used in the groundwater model were obtained from a variety of sources including well logs from USGS, local Town records and data from previous investigations. Final aquifer parameters were determined through calibration to observed water levels and stream flows. Hydrologic data used for model calibration included historic water-level data obtained from USGS records and local Towns and streamflow data collected in 1989-1990 as well as 2003.

The model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Large withdrawals of groundwater from pumping wells may have a significant influence on water tables and watershed boundaries and therefore the flow and distribution of nitrogen within the aquifer. After accounting for the consumptive loss and measured discharge at municipal treatment facilities, water withdrawn from the modeled aquifer by public drinking water supply wells is evenly returned within designated residential areas utilizing on-site septic systems. Since no municipal wastewater treatment facilities discharge within the Centerville River/East Bay watershed, modeled return flow is returned to the groundwater in developed areas as septic system recharge.

III.3 CENTERVILLE RIVER/EAST BAY CONTRIBUTORY AREAS

Newly revised watershed and sub-watershed boundaries were determined by the United States Geological Survey (USGS) for the Centerville River/East Bay embayment system, including Scudder Bay/Bumps River sub-embayment and Lake Wequaquet (Figure III-1). Model outputs of MEP watershed boundaries were "smoothed" to (a) correct for the grid spacing, (b) to enhance the accuracy of the characterization of the pond and coastal shorelines, (c) to include water table data in the lower regions of the watersheds near the coast (as available), and (d) to more closely match the sub-embayment segmentation of the tidal hydrodynamic model. The smoothing refinement was a collaborative effort between the USGS and the rest of the MEP Technical Team. The MEP sub-watershed delineation includes 10 yr time of travel boundaries. Overall, twenty-two (22) sub-watershed areas, including nine freshwater ponds, were delineated within the watershed to the Centerville River/East Bay embayment system.

Table III-1 provides the daily discharge volumes for various sub-watersheds as calculated from the groundwater model; these volumes were used to assist in the salinity calibration of the tidal hydrodynamic models and to determine hydrologic turnover in the lakes/ponds, as well as for comparison to measured surface water discharges. The overall estimated groundwater flow into Centerville River/East Bay from the MEP delineated watershed is 54,416 m3/d.

The delineations completed for the MEP project are the second watershed delineation completed in recent years for portions of the Centerville River/East Bay estuary. Figure III-2 compares the delineation completed under the current effort with the Centerville River/East Bay delineation completed by the Cape Cod Commission in 1998 as part of the Coastal Embayment Project (Eichner, *et al*., 1998). The delineation completed in 1998 was defined based on regional water table measurements collected from available wells over a number of years and normalized to average conditions; delineations based on this previous effort were incorporated into the Commission's regulations through the Regional Policy Plan (CCC, 1996 & 2001).

The MEP watershed area for the Centerville River/East Bay system as a whole is 11% smaller (913 acres) than the 1995 CCC delineation. The differences are largely attributable to a more southern location for the Cape Cod Bay/Vineyard Sound groundwater divide and a more eastern location for the western boundary of the system watershed in the MEP watershed. The change in the western boundary is generally due to the refinements of the Three Bays watershed documented in that system's MEP Technical Report (Howes, *et al*., 2005). It should also be noted that the Three Bays watersheds to Micah and Joshua's ponds were corrected in the Centerville River/East Bay analysis in order to better account for the measured streamflow in Skunknet River (see section IV.2.2). Subwatersheds to individual freshwater ponds were not delineated in the CCC watershed.

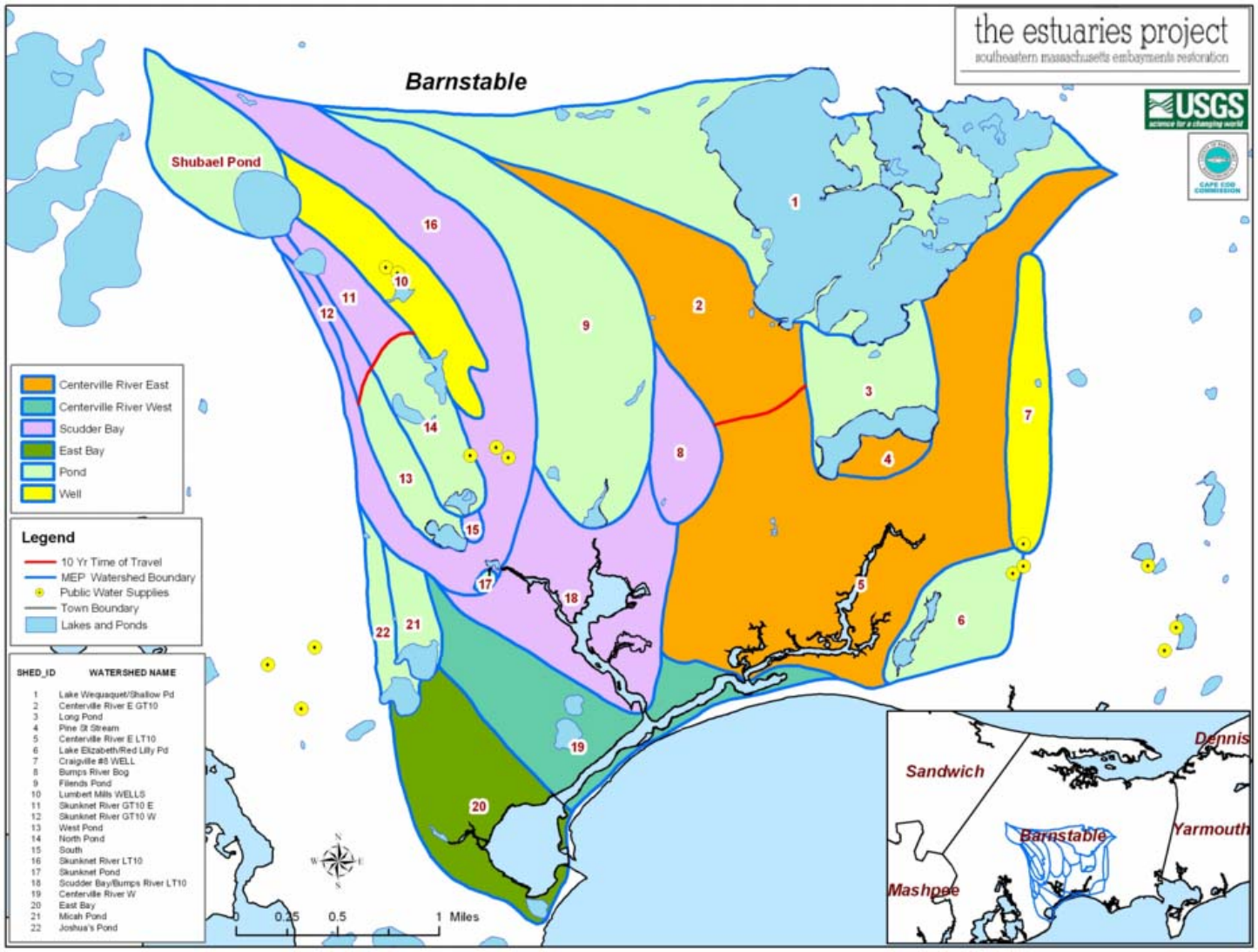


Figure III-1. Watershed and sub-watershed delineations for the Centerville River/East Bay estuary system. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a "10" in the watershed names (above). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

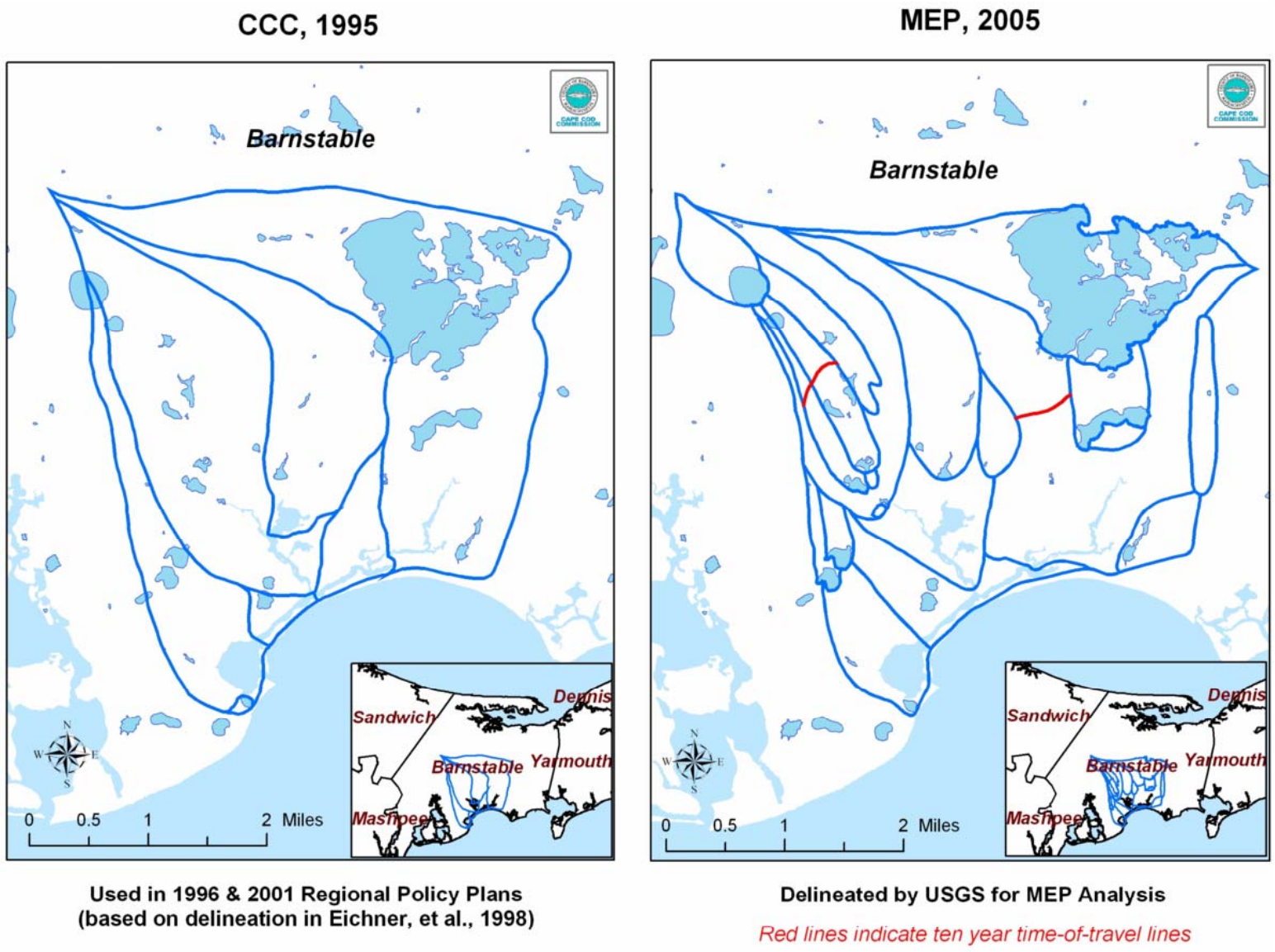


Figure III-2. Comparison of 1998 Cape Cod Commission and current Centerville River/East Bay watershed and subwatershed delineations.

Table III-1. Daily groundwater discharge from each of the sub-watersheds to the Centerville River/East Bay Estuary, as determined from the USGS groundwater model.

Watershed	Watershed #	Discharge	
		m^3/day	ft^3/day
Lake Wequaquet/Shallow Pond	1	10,637	375,647
Centerville River E GT10	2	3,202	113,086
Long Pond	3	1,804	63,715
Pine Street Stream	4	345	12,174
Centerville River E LT10	5	9,615	339,559
Lake Elizabeth/Red Lilly Pond	6	1,358	47,946
Craigville #8 WELL	7	638	22,514
Bumps River Bog	8	1,006	35,514
Filends Pond	9	5,217	184,254
Lumbert Mills WELLS	10	1,769	62,472
Skunknet River GT10 E	11	695	24,532
Skunknet River GT10 W	12	298	10,523
West Pond	13	794	28,053
North Pond	14	1,160	40,979
South	15	61	2,150
Skunknet River LT10	16	4,894	172,833
Skunknet Pond	17	40	1,405
Scudder Bay/Bumps River LT10	18	3,147	111,121
Centerville River W	19	2,752	97,185
East Bay	20	2,430	85,805
Micah Pond	21	483	17,041
Joshua's Pond	22	430	15,194
Shubael Pond		1,642	57,997
TOTAL		54,416	1,921,697

NOTE: Discharge rates are based on 27.25 inches per year of recharge (Walter and Whealan, 2005); discharge flows from Shubael, Micah, and Joshua's Ponds and Craigville #8 WELL are adjusted to account for flow out of the system watershed.

The evolution of the Centerville River/East Bay watershed has allowed increasing accuracy as each new version adds new hydrologic data to that previously collected; the model allows all this data to be organized and to be brought into congruence with adjacent watersheds. The evaluation of older data and incorporation of new data during the development of the model is important as it decreases the level of uncertainty in the final calibrated and validated linked watershed-embayment model used for the evaluation of nitrogen management alternatives. Errors in watershed delineations do not necessarily result in proportional errors in nitrogen loading as errors in loading depend upon the land-uses that are included/excluded within the contributing areas. Small errors in watershed area can result in large errors in loading if a large source is counted in or out. Conversely, large errors in watershed area that involve only natural woodlands have little effect on nitrogen inputs to the downgradient estuary. The MEP watershed delineation was used to develop the watershed nitrogen loads to each of the aquatic systems and ultimately to the estuarine waters of the Centerville River/East Bay system (Section V.1).

IV. WATERSHED NITROGEN LOADING TO EMBAYMENT: LAND USE, STREAM INPUTS, AND SEDIMENT NITROGEN RECYCLING

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS

Management of nutrient related water quality and habitat health in coastal waters requires determination of the amount of nitrogen transported by freshwaters (surface water flow, groundwater flow) from the surrounding watershed to the receiving embayment of interest. In southeastern Massachusetts, the nutrient of management concern for estuarine systems is nitrogen and this is true for the Centerville River/East Bay system. Determination of watershed nitrogen inputs to these embayment systems requires the (a) identification and quantification of the nutrient sources and their loading rates to the land or aquifer, (b) confirmation that a groundwater transported load has reached the embayment at the time of analysis, and (c) quantification of nitrogen attenuation that can occur during travel through lakes, ponds, streams and marshes. This latter natural attenuation process results from biological processes that naturally occur within ecosystems. Failure to account for attenuation of nitrogen during transport results in an over-estimate of nitrogen inputs to an estuary and an underestimate of the sensitivity of a system to new inputs (or removals). In addition to the nitrogen transport from land to sea, the amount of direct atmospheric deposition on each embayment surface must be determined as well as the amount of nitrogen recycling within the embayment, specifically nitrogen regeneration from sediments. Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms, which may be released to the overlying waters or lost to denitrification within the sediments. Burial of nitrogen is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters or in some cases a sink for nitrogen reaching the bottom. Failure to include the nitrogen balance of estuarine sediments generally leads to errors in predicting water quality, particularly in determination of summertime nitrogen load to embayment waters.

The MEP Technical Team includes technical staff from the Cape Cod Commission (CCC). In coordination with other MEP Technical Team members, CCC staff developed nitrogen-loading rates (Section IV.1) to the Centerville River/East Bay embayment system. The Centerville River/East Bay watershed was sub-divided to define contributing areas to each of the major inland freshwater systems and to each major sub-embayment to Centerville River/East Bay. Further sub-divisions were made to identify watershed areas where a nitrogen discharge reaches embayment waters in less than 10 years or greater than 10 years. A total of 22 sub-watersheds were delineated for the Centerville River/East Bay Estuarine System. The nitrogen loading effort also involved further refinement of watershed delineations to accurately reflect shoreline areas to freshwater ponds and each embayment (see Section III).

The initial task in the MEP land use analysis is to gage whether or not nitrogen discharges to the watershed have reached the embayment. This involves a temporal review of land use changes, the time of groundwater travel provided by the USGS watershed model, and review of data at natural collections points, such as streams and ponds. After reviewing the percentage of nitrogen loading in the less than 10 year time of travel (LT10) and greater than 10 year time of travel (GT10) watersheds (Table IV-1), land use development records, and water quality modeling, it was determined that Centerville River/East Bay is currently in balance with its watershed load. The bulk (86%) of the watershed nitrogen load is within 10 years flow to Centerville River/East Bay and its sub-estuaries. The overall result of the timing of development

relative to groundwater travel times is that the present watershed nitrogen load appears to accurately reflect the present nitrogen sources to the estuaries (after accounting for natural attenuation, see below).

Table IV-1. Percentage of unattenuated nitrogen loads in less than 10-year time of travel subwatersheds to Centerville River/East Bay.

WATERSHED	LT10	GT10	TOTAL	%LT10
Name	kg/yr	kg/yr	kg/yr	
Centerville River E	24,744	6,164	30,908	80%
Scudder Bay	21,399	2,499	23,898	90%
Centerville River W	3,454		3,454	100%
East Bay	3,486		3,486	100%
TOTAL	53,082	8,663	61,745	86%

In order to determine nitrogen loads from the watersheds, detailed individual lot-by-lot data is used for some portion of the loads, while information developed from other detailed studies is applied to other portions. The Linked Watershed-Embayment Management Model (Howes, Ramsey, Kelley, 2001) uses a land-use Nitrogen Loading Sub-Model based upon subwatershed-specific land uses and pre-determined nitrogen loading rates. For the Centerville River/East Bay embayment system, the model used Town of Barnstable land-use data transformed to nitrogen loads using both regional nitrogen loading factors and local watershed specific data (such as parcel by parcel water use or groundwater monitoring wells). Determination of the nitrogen loads required obtaining watershed specific information regarding wastewater, fertilizers, runoff from impervious surfaces and atmospheric deposition. The primary regional factors were derived for southeastern Massachusetts from direct measurements. The resulting nitrogen loads represent the “potential” or unattenuated nitrogen load to each receiving embayment, since attenuation during transport has not yet been included.

Natural attenuation of nitrogen during transport from land-to-sea (Section IV.2) within the Centerville River/East Bay System watershed was determined based upon a site-specific study of streamflow from the Skunknett River, Bumps River Bog and flow coming from the Lake Elizabeth/Red Lilly Pond system and the Lake Wequaquet/Long Pond system. Subwatersheds to these various portions allowed comparisons between field collected data from the streams and ponds and estimates from the nitrogen-loading sub-model. Attenuation through the ponds were conservatively assumed to equal 50% based on available monitoring of selected Cape Cod lakes; calculations for individual ponds were also determined. Streamflow and associated surface water attenuation is included in the MEP’s nitrogen attenuation and freshwater flow investigation presented in Section IV.2.

Natural attenuation during stream transport or in passage through fresh ponds of sufficient size to affect groundwater flow patterns (area and depth) is a standard part of the data collection effort of the MEP. In the present effort, measurements were made of attenuation in Lake Wequaquet, Long Pond, Shubael Pond, Micah Pond, Joshua’s Pond and in the stream complexes to Skunknett River, Bumps River Bog and stream flow coming from the Lake Elizabeth/Red Lilly Pond system and the Lake Wequaquet/Long Pond system. However, if smaller aquatic features that have not been included in this MEP analysis are providing additional attenuation of nitrogen, nitrogen loading to the estuary would only be slightly (~10%) overestimated given the distribution of nitrogen sources within the watershed. Based upon

these considerations, the MEP Technical Team used the Nitrogen Loading Sub-Model estimate of nitrogen loading for the seven sub-watersheds that directly discharge groundwater to the estuary without flowing through one of the interim measuring points. Internal nitrogen recycling was also determined throughout the tidal reaches of the Centerville River/East Bay Estuarine System; measurements were made to capture the spatial distribution of sediment nitrogen regeneration from the sediments to the overlying water-column. Nitrogen regeneration focused on summer months, the critical nitrogen management interval and the focal season of the MEP approach and application of the Linked Watershed-Embayment Management Model (Section IV.3).

IV.1.1 Land Use and Water Use Database Preparation

Estuaries Project staff obtained digital parcel and tax assessors data from the Town of Barnstable Geographic Information Systems Department. Digital parcels and land use/assessors data are from 2004. These land use databases contain traditional information regarding land use classifications (MADOR, 2002) plus additional information developed by the town. The parcel data and assessors' databases were combined for the MEP analysis by using the Cape Cod Commission Geographic Information System (GIS).

Figure IV-1 shows the land uses within the Centerville River/East Bay Estuary watershed area. Land uses in the study area are grouped into seven land use categories: 1) residential, 2) commercial, 3) industrial, 4) undeveloped, 5) agricultural, 6) public service/government, including road rights-of-way, and 7) freshwater features (e.g. ponds and streams). These land use categories, except the freshwater features, are aggregations derived from the major categories in the Massachusetts Assessors land uses classifications (MADOR, 2002). These categories are common to each town in the watershed. “Public service” in the MADOR system is tax-exempt properties, including lands owned by government (e.g., wellfields, schools, golf courses, open space, roads) and private groups like churches and colleges.

In the overall Centerville River/East Bay System watershed, the predominant land use based on area is residential, which accounts for 55% of the overall watershed area and 88% of the parcels in the system watershed (Figure IV-2). Single-family residences (MADOR land use code 101) are 94% of the residential parcels and single-family residences are 91% of the residential land area. In the individual subwatersheds, residential land uses vary between 51 and 64% of the subwatershed areas. After residential land use, public service is usually the second highest percentage land use, except in the Centerville River East subwatershed, where Lake Wequaquet and Long Pond push the freshwater area percentage higher than public service. Undeveloped parcels are the second highest parcel count after residential with 5 to 14% of the parcel counts in the subwatersheds. Overall, undeveloped land uses account for 7% of the entire Centerville River/East Bay watershed, while commercial properties account for approximately 1% of the watershed area.

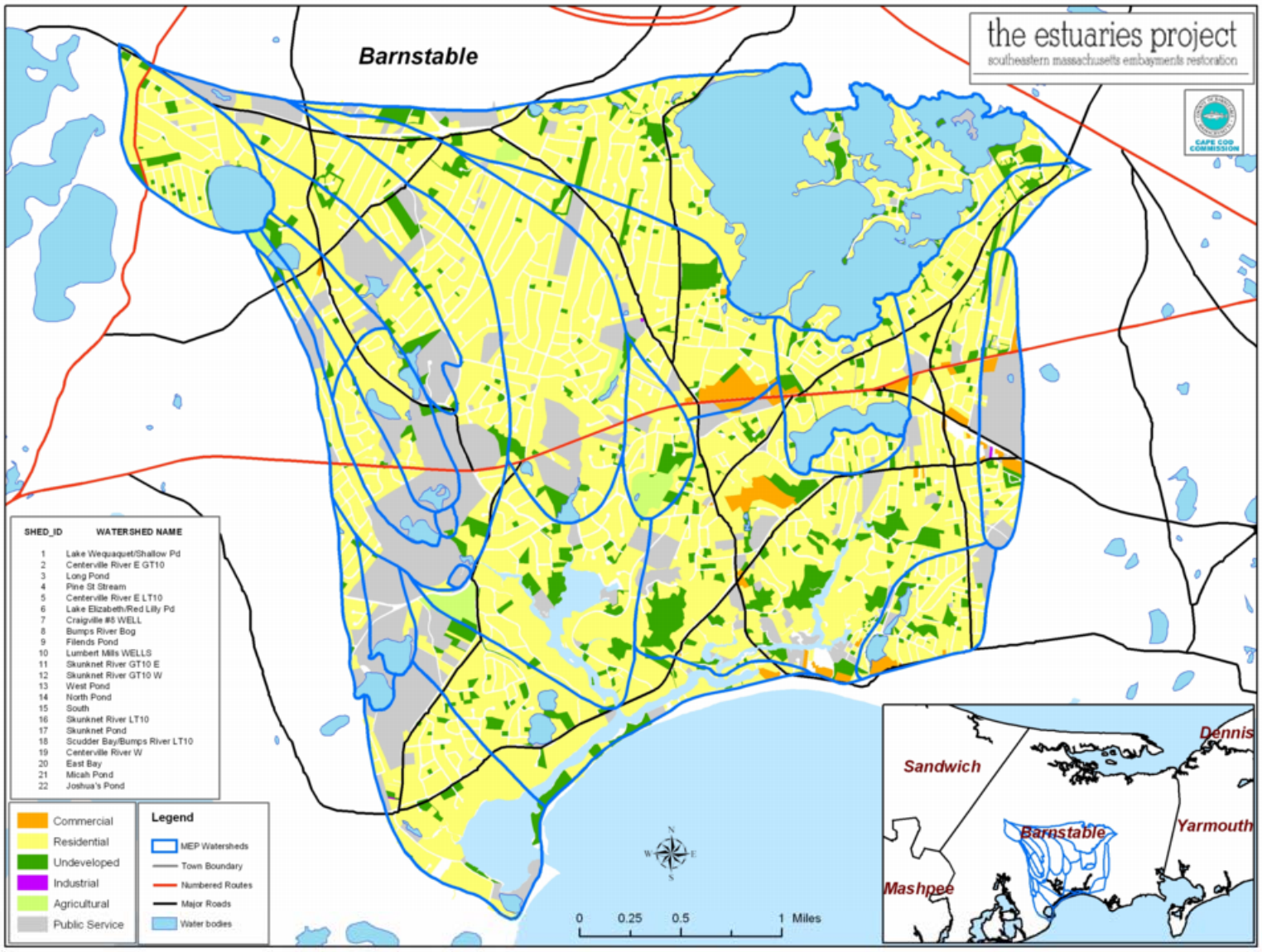


Figure IV-1. Land-use in the Centerville River/East Bay watershed. The watershed is completely contained within the Town of Barnstable. Land use classifications are based on assessors' records provided by the town.

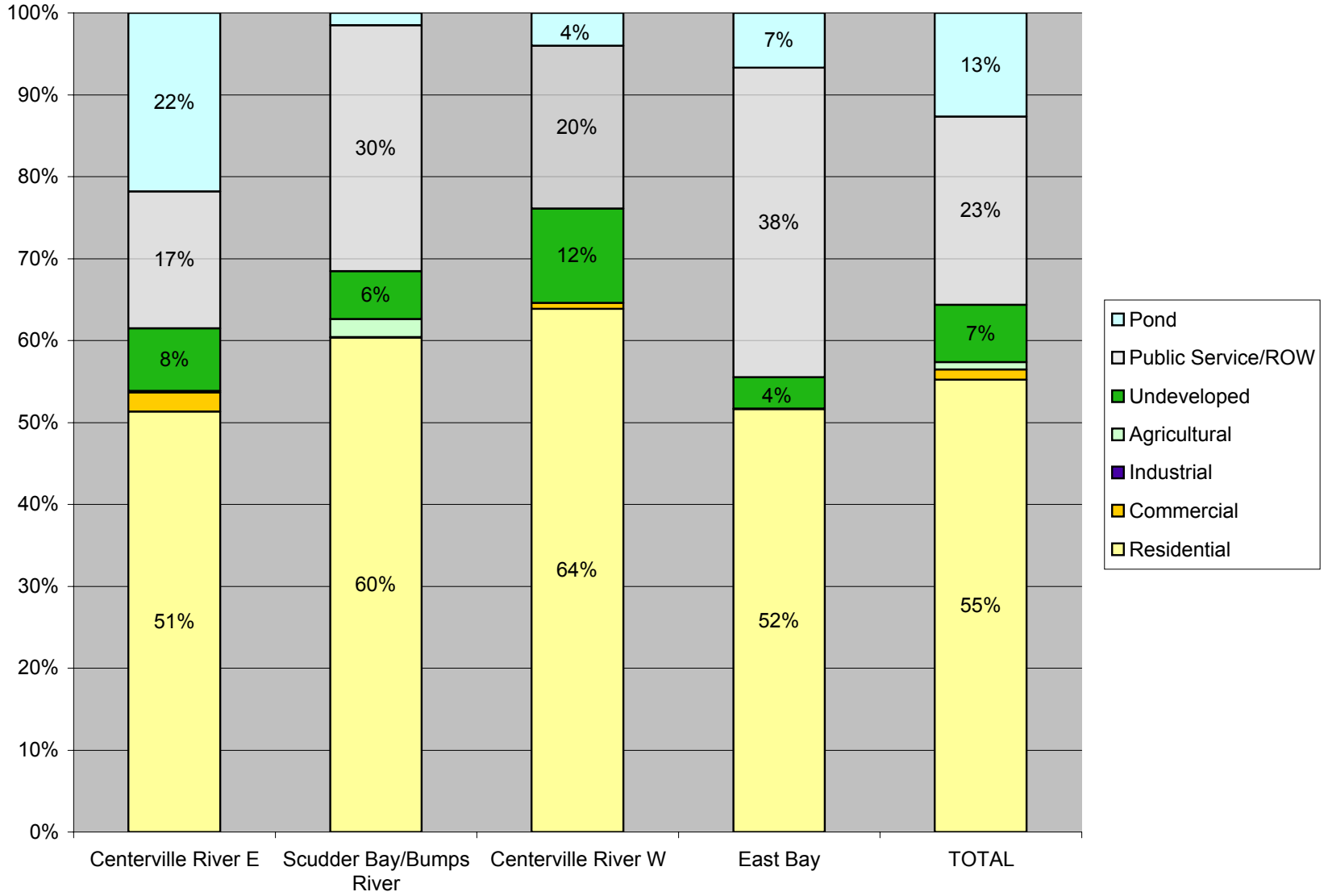


Figure IV-2. Distribution of land-uses within the major subwatersheds and whole watershed to Centerville River/East Bay. Only percentages greater than or equal to 4% are shown.

In order to estimate wastewater flows within the Centerville River/East Bay study area, the Cape Cod Commission obtained parcel-by-parcel water use information from the Town of Barnstable. The water use data includes information from the Centerville, Osterville, Marstons Mills (COMM) Water District, as well as some data from the Town of Barnstable Water Supply Division (WSD), which supplies water to properties on the easternmost edge of the watershed. The information from COMM contains water use from 2001 through 2005, MEP wastewater loads were determined by averages of the number of annual volume at each parcel. The WSD parcels presented an additional challenge; only 1993 water use is available to the Town for these parcels (personal communication, Jim Benoit, Town of Barnstable GIS Division). The town is currently working with contractors to the previous owners of the water supply system to obtain previous years' water use (personal communication, Hans Keijser, Town of Barnstable Water Supply Division). Select parcels within this service area are also connected to the municipal sewer system and the Hyannis WWTF; these parcels have zero wastewater nitrogen loads in the watershed nitrogen loading analysis. MEP staff linked water use information to the parcel and assessors data using GIS techniques. There are no municipal WWTFs in the Centerville River/East Bay watershed, but there are nine innovative/alternative septic systems (personal communication, Sue Rask, Barnstable County Department of Health and the Environment). Wastewater-based nitrogen loading from the individual parcels using on-site septic systems is based upon the measured water-use, nitrogen concentration, and consumptive loss of water before the remainder is treated in a septic system (see Section IV.1.2).

IV.1.2 Nitrogen Loading Input Factors

Wastewater/Water Use

The Massachusetts Estuaries Project septic system nitrogen loading rate is fundamentally based upon a per capita nitrogen load to the receiving aquatic system. Specifically, the MEP septic system wastewater nitrogen loading is based upon a number of studies and additional information that directly measured septic system and per capita loads on Cape Cod or in similar geologic settings (Nelson et al. 1990, Weiskel & Howes 1991, 1992, Koppelman 1978, Frimpter et al. 1990, Brawley et al. 2000, Howes and Ramsey 2001, Costa et al. 2002). Variation in per capita nitrogen load has been found to be relatively small, with average annual per capita nitrogen loads generally between 1.9 to 2.3 kg person-yr^{-1}.

However, given the seasonal shifts in occupancy and rapid population growth throughout southeastern Massachusetts, decennial census data yields accurate estimates of total population only in selected watersheds. To correct for this uncertainty and more accurately assess current nitrogen loads, the MEP employs a water-use approach. The water-use approach is applied on a parcel-by-parcel basis within a watershed, where annual water meter data is linked to assessors parcel information using GIS techniques. The parcel specific water use data is converted to septic system nitrogen discharges (to the receiving aquatic systems) by adjusting for consumptive use (e.g. irrigation) and applying a wastewater nitrogen concentration. The water use approach focuses on the nitrogen load, which reaches the aquatic receptors downgradient in the aquifer.

All nitrogen losses within the septic system are incorporated into the MEP analysis. For example, information developed at the Alternative Septic System Test Center at the Massachusetts Military Reservation on Title 5 septic systems have shown nitrogen removals between 21% and 25%. Multi-year monitoring from the Test Center has revealed that nitrogen removal within the septic tank was small (1% to 3%), with most (20 to 22%) of the removal

occurring within five feet of the soil adsorption system (Costa et al. 2001). Downgradient studies of septic system plumes indicate that further nitrogen loss during aquifer transport is negligible (Robertson et al. 1991, DeSimone and Howes 1996).

In its application of the water-use approach to septic system nitrogen loads, the MEP has ascertained for the Estuaries Project region that while the per capita septic load is well constrained by direct studies, the consumptive use and nitrogen concentration data are less certain. As a result, the MEP has derived a combined term the effective N Loading Coefficient (consumptive use multiplied by N concentration) of 23.63, to convert water (per volume) to nitrogen load (N mass). This coefficient uses a per capita nitrogen load of 2.1 kg N person-yr^{-1} and is based upon direct measurements and corrects for changes in concentration that result from per capita shifts in water-use (e.g. due to installing low plumbing fixtures or high versus low irrigation usage).

The nitrogen loads developed using this approach have been validated in a number of long and short term field studies where integrated measurements of nitrogen discharge from watersheds could be directly measured. Weiskel and Howes (1991, 1992) conducted a detailed watershed/stream tube study that monitored septic systems, leaching fields and the transport of the nitrogen in groundwater to adjacent Buttermilk Bay. This monitoring resulted in estimated annual per capita nitrogen loads of 2.17 kg (as published) to 2.04 kg (if new attenuation information is included). Modeled and measured nitrogen loads were determined for a small sub-watershed to Mashapaquit Creek in West Falmouth Harbor (Smith and Howes, manuscript in review) where measured nitrogen discharge from the aquifer was within 5% of the modeled N load. Another evaluation was conducted by surveying nitrogen discharge to the Mashpee River in reaches with swept sand channels and in winter when nitrogen attenuation is minimal. The modeled and observed loads showed a difference of less than 8%, easily attributable to the low rate of attenuation expected at that time of year in this type of ecological situation (Samimy and Howes, unpublished data).

While census based population data has limitations in the highly seasonal MEP region, part of the regular MEP analysis is to compare expected water used based on average residential occupancy to measured average water uses. This is performed as a quality assurance check to increase certainty in the final results. This comparison has shown that the larger the watershed the better the match between average water use and occupancy. For example, in the cases of the combined Great Pond, Green Pond and Bournes Pond watershed in the Town of Falmouth and the Popponesset Bay/Eastern Waquoit Bay watershed, which covers large areas and have significant year-round populations, the septic nitrogen loading based upon the census data is within 5% of that from the water use approach. This comparison matches some of the variability seen in census data itself. Census blocks, which are generally smaller areas of any given town, have shown up to a 13% difference in average occupancy form town-wide occupancy rates. These analyses provide additional support for the use of the water use approach in the MEP study region.

Overall, the MEP water use approach for determining septic system nitrogen loads has been both calibrated and validated in a variety of watershed settings. The approach: (a) is consistent with a suite of studies on per capita nitrogen loads from septic systems in sandy outwash aquifers; (b) has been validated in studies of the MEP Watershed “Module”, where there has been excellent agreement between the nitrogen load predicted and that observed in direct field measurements corrected to other MEP Nitrogen Loading Coefficients (e.g., stormwater, lawn fertilization); (c) the MEP septic nitrogen loading coefficient agrees in specific studies of consumptive water use and nitrogen attenuation between the septic tank and the

discharge site; and (d) the watershed module provides estimates of nitrogen attenuation by freshwater systems that are consistent with a variety of ecological studies. It should be noted that while points b-d support the use of the MEP Septic N Coefficient, they were not used in its development. The MEP Technical Team has developed the septic system nitrogen load over many years, and the general agreement among the number of supporting studies has greatly enhanced the certainty of this critical watershed nitrogen loading term.

The independent validation of the water quality model (Section VI) and the reasonableness of the freshwater attenuation (Section IV.2) add additional weight to the nitrogen loading coefficients used in the MEP analyses and a variety of other MEP embayments. While the MEP septic system nitrogen load is the best estimate possible, to the extent that it may underestimate the nitrogen load from this source reaching receiving waters provides a safety factor relative to other higher loads that are generally used in regulatory situations. The lower concentration results in slightly higher amounts of nitrogen mitigation (estimated at 1% to 5%)) needed to lower embayment nitrogen levels to a nitrogen target (e.g. nitrogen threshold, cf. Section VIII). The additional nitrogen removal is not proportional to the septic system nitrogen level, but is related to the how the septic system nitrogen mass compares to the nitrogen loads from all other sources that reach the estuary (i.e. attenuated loads).

In order to provide an independent validation of the average residential water use within the Centerville River/East Bay System watershed, MEP staff reviewed US Census population values for the Town of Barnstable. The state on-site wastewater regulations (*i.e.*, 310 CMR 15, Title 5) assume that two people occupy each bedroom and each bedroom has a wastewater flow of 110 gallons per day (gpd), so for the purposes of Title 5 each person generates 55 gpd of wastewater. Based on data collected during the 2000 US Census, average occupancy within Barnstable is 2.44 people per housing unit, while year-round occupancy of available housing units is 78%. Average water use for single-family residences with municipal water accounts in the Centerville River/East Bay watershed is 204 gpd. If this flow is multiplied by 0.9 to account for consumptive use, the watershed average is 183 gpd. If this flow is then divided by 55 gpd, the average estimated occupancy in the watershed is 3.3 people per household.

In most previously completed MEP studies, average population and average water use have generally agreed fairly well. Since review of water use in the Centerville River/East Bay watershed suggests that on average there is approximately one additional person per housing unit (or 30% higher than predicted), MEP staff reviewed more refined US Census information, 1990 Census information and water use information for each parcel within the watershed. Besides reviewing data on town and state levels, the US Census also develops information for smaller areas (i.e., tracts and block groups). Portions of six Census tracts are contained within the watershed to Centerville River/East Bay; year 2000 Census residential occupancy rates in the tracts range from 2.18 to 2.73 people per house. Average occupancy for these tracts reported for the 1990 Census range from 2.22 to 2.83 people per house. While these occupancies suggest that the area is given to a fairly wide range of readings, these occupancies are less than the occupancy expected based on water use.

MEP staff then reviewed the average water uses measured in the subwatersheds of the Centerville River/East Bay system. While the overall average for single-family residences (SFRs) is 202 gpd, averages in the subwatersheds varied widely with a range between 138 and 288 gpd. Review of individual SFR water uses within subwatershed ranged as high as 3,429 gpd, but even this use was consistent across five years of data. The standard deviation among

all the watershed averages is 39 gpd; the 134 gpd population estimated average is within 1.4 standard deviations of the 183 gpd measured water use mean.

At the outset of the MEP, project staff decided to utilize the water use approach for determining residential wastewater generation by septic systems because of the inherent difficulty in accurately gauging actual occupancy in areas impacted by seasonal population fluctuations such as most of Cape Cod. Estimates of summer populations on Cape Cod derived from a number of approaches (*e.g.*, traffic counts, garbage generation, sewer use) suggest average population increases from two to three times year-round residential populations measured by the US Census. While land use characteristics in the Centerville River/East Bay subwatershed may be unlikely to see summer population increases at the upper end of regional estimates, a doubling of the town occupancy for three months would be sufficient to increase the average annual water use based on Title 5 to 201 gpd, which is the same as the average measured flow in the watershed. The above analysis suggests that additional analysis of water uses within the Centerville River/East Bay watershed should be considered, but review of the water uses on the parcel, Census tract, and watershed scales do not suggest that there is any consistent inaccuracies. Given all the above analysis and the difficulty in accurately gauging seasonal population fluctuations, MEP staff decided to continue to use the Centerville River/East Bay watershed-specific water uses without any additional factors and used the average water use for the residential parcels without water use and for the 405 additional residential parcels included in the buildout analysis.

Although water use information exists for 94% of the approximately 6,936 developed parcels in the Centerville River/East Bay watershed, there are 417 parcels that are assumed to utilize private wells for drinking water. These are properties that were classified with land use codes that should be developed (e.g., 101 or 325), have been confirmed as having buildings on them through a review of aerial photographs, and do not have a listed account in the water use databases. Of the 417 parcels, 83% of them (346) are classified as single-family residences (land use code 101) and another 14% are classified as other types of residential development [e.g. 109 (multiple houses on a single property)]. The remaining 3% of the parcels are commercial and industrial properties (300s and 400s land use codes, respectively). MEP staff used current water use to develop a watershed-specific water use estimate for the residential uses that were assumed to utilize private wells (Table IV-2). Commercial and industrial properties assumed to have private wells were assigned a water use based on percentage of parcel building coverage and average water uses for commercial properties in the Three Bays and Eel Pond/Back River watersheds.

Table IV-2. Average Water Use in Centerville River/East Bay Watershed.

Land Use	State Class Codes	# of Parcels with Water Use in Watershed	Water Use (gallons per day)	
			Watershed Average	Subwatershed Average Range
Residential	101	6077	204	138 to 288
Commercial	300 to 389	43	817	21 to 9,693
Industrial	400 to 439	none	--	--

Note: All data for analysis supplied by Town of Barnstable GIS Services Department and COMM Water District.

As mentioned previously, the eastern edge of the watershed is the boundary between the COMM Water District and the Town of Barnstable Water Supply Division (WSD) public water supply systems. Available WSD water uses exist for 1993, but more up-to-date data is not currently available. MEP staff reviewed the 1993 average residential water use and found that multiplying the 1993 water use by two brought the average into the low end of the subwatershed average water use range. There are 75 parcels in subwatershed #7 (Craigville Well) and 2 parcels in subwatershed #5 (Centerville River East LT10) that utilize this adjusted 1993 water use for estimating the wastewater nitrogen load.

Nine properties within the Centerville River/East Bay watershed have innovative/alternative (I/A) septic systems that are designed to reduce the amount of nitrogen in their effluent. MEP staff obtained a list of properties in the Town of Barnstable from the Barnstable County Department of Health and the Environment (Sue Rask, personal communication). The properties in the project watershed were then identified using the Cape Cod Commission GIS. BCDHE is tracking I/A systems for a number of Cape Cod towns and, in the process, have developed an extensive database of their performance. Based on 368 samples, the average total nitrogen effluent produced by these systems following an initial startup phase is 18.4 mg/l. This concentration was adjusted to a loading factor of 16.6 mg/l based on the similar method used to determine the loading factor for standard Title 5 systems. This factor was applied to the water use for the nine properties identified as using I/A nitrogen reducing septic systems.

It should also be noted that a community septic system collects and treats wastewater around a portion of Red Lilly Pond. The system does not have enhanced treatment according to Town of Barnstable staff (personal communication, John Jacobson), but the leaching field is located in the Centerville River E LT10 subwatershed (#5). Town staff identified the parcels connected to this system and the wastewater loads were added to subwatershed #5 in the nitrogen-loading model.

Nitrogen Loading Input Factors: Fertilized Areas

The second largest source of estuary watershed nitrogen loading is usually fertilized lawns, golf courses, and cranberry bogs, with lawns being the predominant source within this category. In order to add this source to the nitrogen loading model for the Centerville River/East Bay system, MEP staff reviewed available information about residential lawn fertilizing practices and incorporated site-specific information to determine nitrogen loading from large tracks of turf in the watershed. MEP staff contacted the staff at appropriate organizations regarding the following large turf areas: the municipal Olde Barnstable Fairgrounds Golf Course, playing fields for the Barnstable Public Schools, and the horse paddocks at the Sheriff's Youth Ranch. Cranberry bog nitrogen loading was determined based on previous studies conducted in southeastern Massachusetts.

Residential lawn fertilizer use has rarely been directly measured in watershed-based nitrogen loading investigations. Instead, lawn fertilizer nitrogen loads have been estimated based upon a number of assumptions: a) each household applies fertilizer, b) cumulative annual applications are 3 pounds per 1,000 sq. ft., c) each lawn is 5000 sq. ft., and d) only 25% of the nitrogen applied reaches the groundwater (leaching rate). Because many of these assumptions had not been rigorously reviewed in over a decade, the MEP Technical Staff undertook an assessment of lawn fertilizer application rates and a review of leaching rates for inclusion in the Watershed Nitrogen Loading Sub-Model.

The initial effort in this assessment was to determine nitrogen fertilization rates for residential lawns in the Towns of Falmouth, Mashpee and Barnstable. The assessment accounted for proximity to fresh ponds and embayments. Based upon ~300 interviews and over 2,000 site surveys, a number of findings emerged: 1) average residential lawn area is ~5000 sq. ft., 2) half of the residences did not apply lawn fertilizer, and 3) the weighted average application rate was 1.44 applications per year, rather than the 4 applications per year recommended on the fertilizer bags. Integrating the average residential fertilizer application rate with a leaching rate of 20% results in a fertilizer contribution of N to groundwater of 1.08 lb N per residential lawn; these factors are used in the MEP nitrogen loading calculations. It is likely that this still represents a conservative estimate of nitrogen load from residential lawns. It should be noted that professionally maintained lawns were found to have the higher rate of fertilizer application and hence higher estimated loss to groundwater of 3 lb/lawn/yr.

MEP staff contacted Superintendent Bruce McIntyre to obtain current information for fertilizer practices at the municipal Olde Barnstable Fairgrounds Golf Course. Golf courses usually have different fertilizer application rates for different turf areas, usually higher annual application rates for tees and greens (~3-4 pounds per 1,000 square feet) and lower rates for fairways and roughs (~2-3.5 pounds per 1,000 square feet). At the Olde Barnstable Fairgrounds Golf Course average annual nitrogen application rates (lbs/1,000 ft2) for the various turf areas are: greens, 4.5; tees, 4; fairways, 3, and rough, 2. As has been done in all MEP reviews, MEP staff reviewed the layout of the Olde Barnstable Fairgrounds Golf Course, classified the turf types, and assigned these areas to the appropriate subwatersheds. The nitrogen application rates were then applied to these areas and a load was calculated. Only a portion of the golf course is located in the watershed and the entire portion in the watershed is located within subwatershed to the Skunknet River (#16).

MEP staff also contacted Lee Saarkinnen of the Barnstable Public Schools and Kathy Hill, who has a contract to run the horse program at the Sheriff's Youth Ranch. Ms. Hill indicated that the horse paddocks are not fertilized and all horse manure on the site is removed every week. Based on this, no additional nitrogen load was added to the model for these activities at the Ranch. Mr. Saarkinnen indicated that turf at the Barnstable Public Schools playing fields have an annual nitrogen application rate of 0.75 lbs per acre. These playing fields are located at the Barnstable Middle and High School (subwatersheds #5, 7) and the Marstons Mills Horace Mann School (subwatershed #12). Field areas were determined based on review of aerial photographs and loads were determined and assigned to the appropriate subwatersheds on this basis.

Cranberry bog fertilizer application rate and percent nitrogen attenuation in the bogs is based on the only annual study of nutrient cycling and loss from cranberry agriculture that has been conducted in southeastern Massachusetts (Howes and Teal, 1995). Only the bog loses measurable nitrogen, the forested upland releases only very low amounts. For the watershed nitrogen loading analysis, the areas of active bog surface are based on review of aerial photographs for properties classified as cranberry bogs in the town-supplied land use classifications.

Nitrogen Loading Input Factors: Other

The nitrogen loading factors for atmospheric deposition, impervious surfaces and natural areas are from the MEP Embayment Modeling Evaluation and Sensitivity Report (Howes and Ramsey 2001). The factors are similar to those utilized by the Cape Cod Commission's Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and Massachusetts DEP's

Nitrogen Loading Computer Model Guidance (1999). The recharge rate for natural areas and lawn areas is the same as utilized in the MEP-USGS groundwater modeling effort (Section III). Factors used in the MEP nitrogen loading analysis for the Centerville River/East Bay watershed are summarized in Table IV-3.

Table IV-3. Primary Nitrogen Loading Factors used in the Centerville River/East Bay MEP analyses. General factors are from MEP modeling evaluation (Howes & Ramsey 2001). Site-specific factors are derived from Barnstable data. *Data from MEP lawn study in Falmouth, Mashpee & Barnstable 2001.

Nitrogen Concentrations:	mg/l	Recharge Rates:	in/yr
Road Run-off	1.5	Impervious Surfaces	40
Roof Run-off	0.75	Natural and Lawn Areas	27.25
Direct Precipitation on Embayments and Ponds	1.09	Water Use/Wastewater:	
Natural Area Recharge	0.072	Existing developed residential parcels wo/water accounts and buildout residential parcels:	204 gpd
Wastewater Coefficient	23.63		
Fertilizers:			
Average Residential Lawn Size (ft^2)*	5,000		
Residential Watershed Nitrogen Rate (lbs/lawn)*	1.08	Existing developed parcels w/water accounts:	Measured annual water use
Cranberry Bogs nitrogen application (lbs/ac)	31	Commercial and industrial parcels wo/water accounts and buildout additions:	21 gpd/1,000 ft2 of building
Cranberry Bogs nitrogen attenuation	34%		
Nitrogen Fertilizer Rate for golf courses, cemeteries, and public parks determined from site-specific information		Commercial and industrial building coverage for parcels wo/water accounts and buildout additions:	28%

IV.1.3 Calculating Nitrogen Loads

Once all the land and water use information was linked to the parcel coverages, parcels were assigned to various watersheds based initially on whether at least 50% or more of the land area of each parcel was located within a respective watershed. Following the assigning of boundary parcels, all large parcels were examined individually and were split (as appropriate) in order to obtain less than a 2% difference between the total land area of each subwatershed and the sum of the area of the parcels within each subwatershed. The resulting "parcelized" watersheds to Centerville River/East Bay are shown in Figure IV-3.

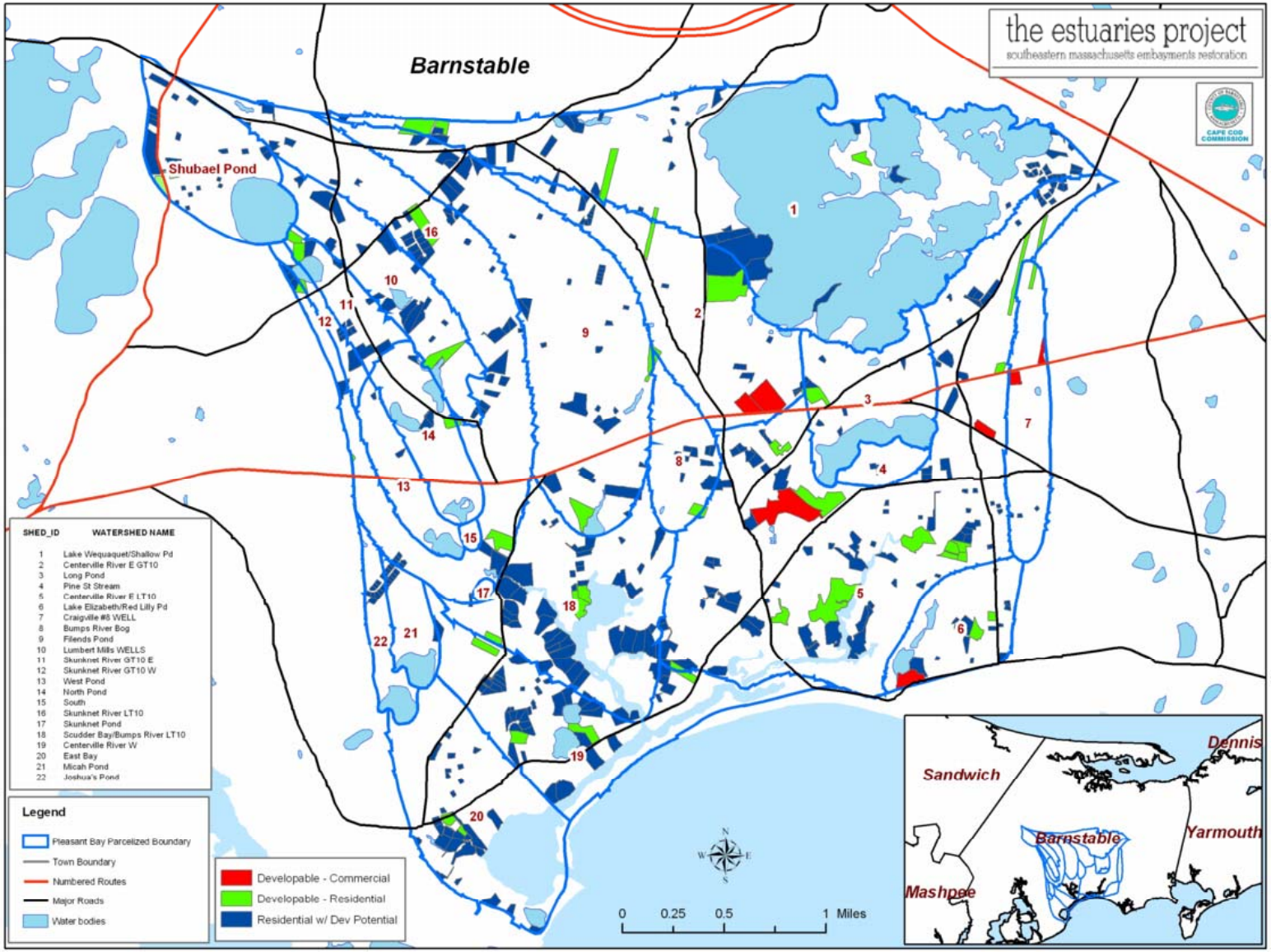


Figure IV-3. Parcels, Parcelized Watersheds, and Developable Parcels in the Centerville River/East Bay watersheds.

Table IV-4. Centerville River/East Bay Nitrogen Loads. Attenuation of Centerville River/East Bay system nitrogen loads occurs as nitrogen moves through upgradient ponds and streams during transport to the estuary. All values are kg N yr^{-1}.

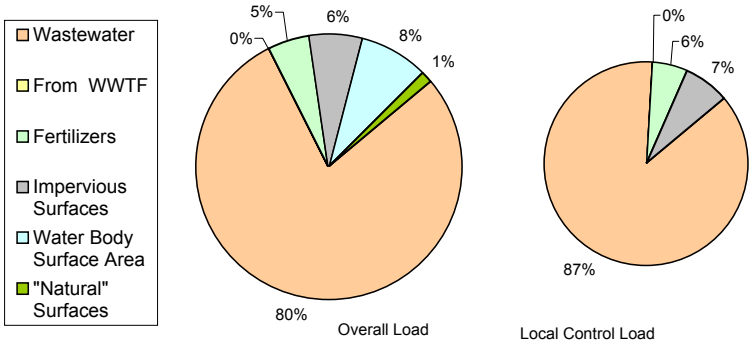
		Centerville River/East Bay N Loads by Input (kg/yr):							% of Pond Outflow	Present N Loads			Buildout N Loads		
Name	Watershed ID#	Wastewater	From WWTF	Fertilizers	Impervious Surfaces	Water Body Surface Area	"Natural" Surfaces	Buildout		UnAtten N Load	Atten %	Atten N Load	UnAtten N Load	Atten %	Atten N Load
CENTERVILLE RIVER/EAST BAY SYSTEM		**48493**	**47**	**3155**	**3972**	**5156**	**921**	**3107**		**61745**		**48277**	**64852**		**50731**
Centerville River East		**23544**	**47**	**1150**	**2006**	**3759**	**402**	**1735**		**30908**		**22466**	**32643**		**23779**
Centerville R E LT10	5	10577	47	83	841	0	186	797		11733		11733	12530		12530
Craigville #8 WELL	7	451	0	40	53	0	11	60	48%	555		555	616		616
Lake Wequaquet (LW)	LW	1905	0	163	161	1245	37	148	38%	3510	50%	1755	3658	50%	1829
Long Pond (LP)	LP	572	0	47	51	246	10	50	15%	925	50%	315	975	50%	333
Centerville R E GT10	2 + LW	4653	0	353	410	670	78	259		6164		5234	6423		5453
Pine Street Stream	4 + LP,LW	3717	0	298	326	1384	61	286		5786	20%	1882	6072	20%	1972
Lake Elizabeth/Red Lilly Pd (stream att too?)	6, 7	1669	0	167	164	50	20	135	100%	2070	60%	828	2206	60%	882
Centerville River East Estuary Surface		0	0	0	0	164	0	0		164		164	164		164
Scudder Bay		**19614**	**0**	**1699**	**1577**	**611**	**397**	**1027**		**23898**		**19208**	**24925**		**20010**
Bumps River Bog	8	1098	0	230	92	0	19	96		1440		1440	1536		1536
Filends Pond	9	6746	0	544	520	25	92	222	100%	7928	20%	6343	8150	20%	6520
Scudder Bay	18	3100	0	163	212	0	67	163		3542		3542	3704		3704
Scudder Bay Estuary Surface		0	0	0	0	250	0	0		250		250	250		250
Skunknet River		8670	0	762	752	335	218	547		10738	20%	7634	11284	20%	8000
Lumbert Mills WELLS	10 + SP	1837	0	138	128	121	53	277		2276			2553		2006
Skunknet R GT10 E	11 + SP	758	0	64	65	79	21	68		987		739	1055		784
Skunknet R GT10 W	11 + SP	383	0	35	30	51	10	47		509		333	557		364
West Pond	13	712	0	60	66	46	13	15		897	30%	628	912	30%	638
North Pond	14	569	0	45	49	34	25	15		722		722	737		737
South	15	0	0	0	0	0	2	0		2		2	2		2
Skunknet R LT10	16	4411	0	420	414	4	94	126		5343		5343	5468		5468
Skunknet Pond	17	0	0	0	0	0	1	0		1	50%	1	1	50%	1
Centerville River West		**2812**	**0**	**145**	**180**	**262**	**56**	**200**		**3454**		**3454**	**3654**		**3654**
Centerville R W	19	2812	0	145	180	0	56	200		3192		3192	3392		3392
Centerville River West Estuary Surface		0	0	0	0	262	0	0		262		262	262		262
East Bay		**2523**	**0**	**161**	**210**	**525**	**67**	**144**		**3486**		**3149**	**3630**		**3288**
East Bay	20	2117	0	129	166	0	51	133		2464		2464	2597		2597
Joshua's Pond (JP)	JP + MP	340	0	29	37	86	11	11	77%	504	50%	221	515	50%	226
Micah's Pond (MP)	MP	66	0	3	7	28	4	0	40%	107	50%	53	107	50%	53
East Bay Estuary Surface		0	0	0	0	411	0	0		411		411	411		411

The review of individual parcels straddling watershed boundaries included corresponding reviews and individualized assignment of nitrogen loads associated with lawn areas, septic systems, and impervious surfaces. Individualized information for parcels with atypical nitrogen loading (condominiums, golf courses, etc.) was also assigned at this stage. It should be noted that small shifts in nitrogen loading due to the above assignment procedure generally have a negligible effect on the total nitrogen loading to the Centerville River/East Bay estuary. The assignment effort was undertaken to better define the sub-embayment loads and enhance the use of the Linked Watershed-Embayment Model for the analysis of management alternatives.

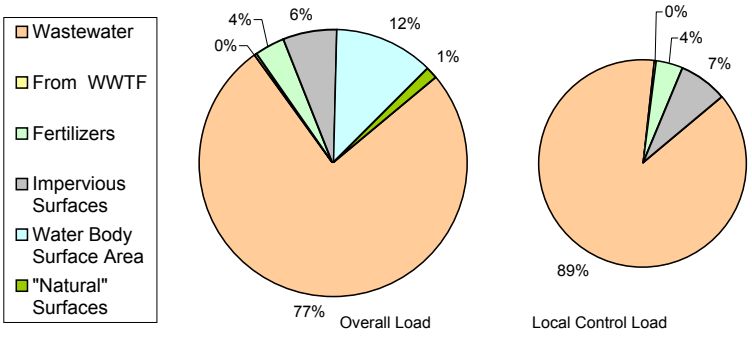
Following the assignment of all parcels, subwatershed modules were generated for each of the 22 sub-watersheds summarizing water use, parcel area, frequency, sewer connections, private wells, and road area. The individual sub-watershed modules were then integrated to create the Centerville River/East Bay Watershed Nitrogen Loading module with summaries for each of the individual subembayments. The subembayments represent the functional embayment units for the Linked Watershed-Embayment Model's water quality component.

For management purposes, the aggregated embayment watershed nitrogen loads are partitioned by the major types of nitrogen sources in order to focus development of nitrogen management alternatives. Within the Centerville River/East Bay System, the major types of nitrogen loads are: wastewater (e.g., septic systems), fertilizer, impervious surfaces, direct atmospheric deposition to water surfaces, and recharge within natural areas (Table IV-4). The output of the watershed nitrogen loading model is the annual mass (kilograms) of nitrogen added to the contributing area of component sub-embayments, by each source category (Figure IV-4 a-e). In general, the annual watershed nitrogen input to the watershed of an estuary is then adjusted for natural nitrogen attenuation during transport to the estuarine system before use in the embayment water quality sub-model.

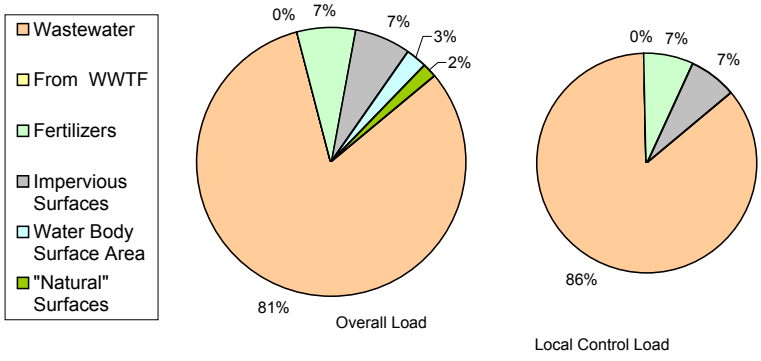
Since groundwater outflow from a pond can enter more than one downgradient sub-watershed, the length of shoreline on the downgradient side of the pond was used to apportion the pond-attenuated nitrogen load to respective downgradient watersheds. The apportionment was based on the percentage of discharging shoreline bordering each downgradient sub-watershed. So for example, Lake Wequaquet has a downgradient shoreline of 9,086 feet; 42% of that shoreline discharges into the Long Pond subwatershed (watershed 3 in Figure IV-1), 38% discharges to the Centerville River E LT10 subwatershed (watershed 6), and 20% discharges to the Centerville River E GT10 subwatershed. The attenuated nitrogen load discharging from Lake Wequaquet is divided among these subwatersheds based on these percentages of the downgradient shoreline. Using this method, 83% of the loads developed in the Three Bays MEP analysis for Shubael Pond are added to the Centerville River/East Bay subwatersheds.



a. Centerville River/East Bay System Overall

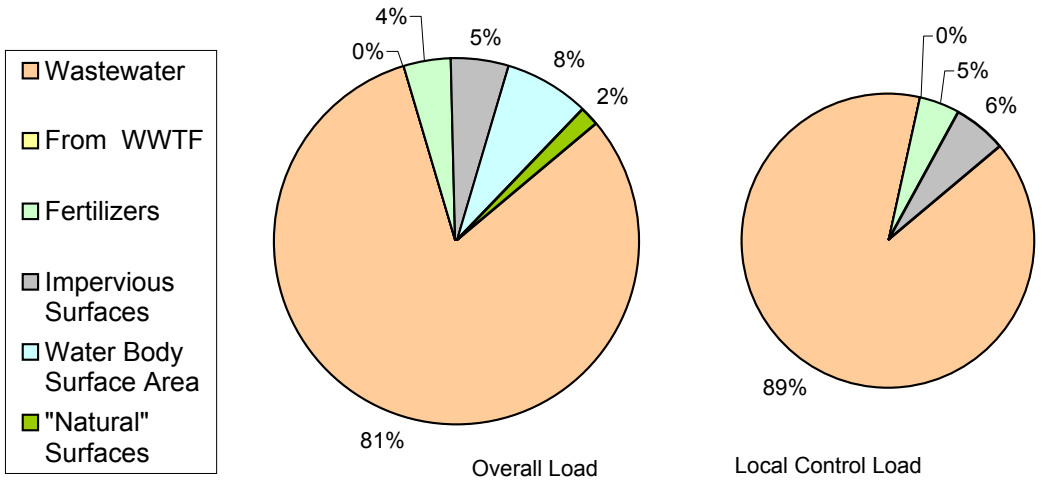


b. Centerville River East

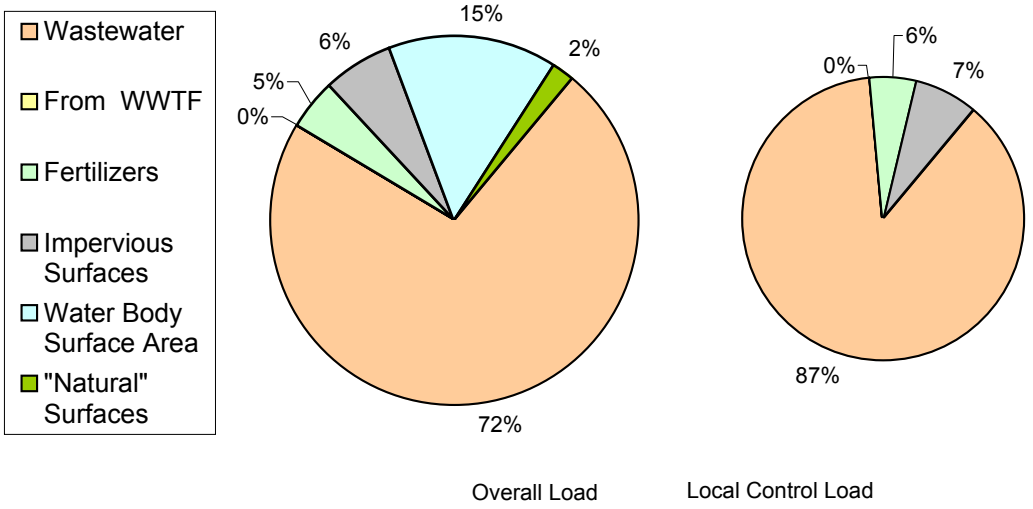


c. Scudder Bay/Bumps River

Figure IV-4 (a-c). Land use-specific unattenuated nitrogen load (by percent) to the (a) overall Centerville River/East Bay System watershed, (b) Centerville River East subwatershed, and (c) Scudder Bay/Bumps River subwatershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control.



d. Centerville River West



E. East Bay

Figure IV-4 (d-e). Land use-specific unattenuated nitrogen load (by percent) to the (d) Centerville River West subwatershed, and (e) East Bay subwatershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control.

Freshwater Pond Nitrogen Loads

Freshwater ponds on Cape Cod are generally kettle hole depressions that intercept the surrounding groundwater table revealing what some call "windows on the aquifer." Groundwater typically flows into the pond along the upgradient shoreline, then lake water flows back into the groundwater system along the downgradient shoreline. Occasionally a Cape Cod pond will also have a stream outlet or herring run that also acts as a discharge point. Since the

nitrogen loads flow into the pond with the groundwater, the relatively more productive pond ecosystems incorporate some of the nitrogen, retain some nitrogen in the sediments, and change the nitrogen among its various oxidized and reduced forms. As result of these interactions, some of the nitrogen is removed from the watershed system, mostly through burial in the sediments and denitrification that returns it to the atmosphere. Following these reductions, the remaining (reduced or attenuated) loads flow back into the groundwater system along the downgradient side of the pond or through a stream outlet and eventual discharge into the downgradient embayment. The nitrogen load summary in Table IV-4 includes both the unattenuated (nitrogen load to each subwatershed) and attenuated nitrogen loads.

Pond nitrogen attenuation in freshwater ponds has generally been found to be at least 50% in MEP analyses, so the watershed model contains a conservative attenuation rate of 50%. However, in some cases, if sufficient monitoring information is available, a pond-specific attenuation rate is incorporated into the watershed nitrogen loading modeling (Three Bays MEP Report, 2005). Detailed studies of other southeastern Massachusetts freshwater systems including Ashumet Pond (AFCEE, 2000) and Agawam/Wankinco River Nitrogen Discharges (CDM, 2000) have also supported a 50% attenuation factor. In order to estimate nitrogen attenuation in the ponds physical and chemical data for each pond is reviewed. Available bathymetric information is reviewed relative to measured pond temperature profiles to determine whether an epilimnion (*i.e.*, well mixed, homothermic, upper portion of the water column) exists in each pond. Bathymetric information is necessary to develop a residence or turnover time and complete an estimate of nitrogen attenuation. In the Centerville River/East Bay watershed, bathymetric information is available for Lake Wequaquet and the following ponds: Bearses, Joshua's, Long, Micah, Shallow, and lower Red Lilly. Of the ponds with bathymetric information, none are deep enough to develop strong temperature stratification and samples from all depths generally can be used for determining average nitrogen concentrations. Deepest samples must be checked for potential impact by sediment regeneration of nitrogen, especially if low oxygen conditions occur.

In MEP analyses, available nitrogen concentrations from individual ponds are reviewed to establish whether sediment regeneration is a significant factor in a pond and, if not, the entire volume of the pond is used to determine a turnover time. Turnover time is how long it takes the recharge from the upgradient watershed to completely exchange the water in the pond or, in the case of a thermally stratified pond, exchange just the epilimnion. The total mass of nitrogen in the pond or epilimnion is adjusted using the pond turnover time to determine the annual nitrogen load returned to the aquifer through the downgradient shoreline. This mass is then compared to the nitrogen load coming from the pond's watershed to determine the nitrogen attenuation factor for the pond. Generally, monitoring is insufficient to support use of a factor different than the standard 50% attenuation.

The standard attenuation assumption for the ponds in the Centerville River/East Bay watershed was checked through the use of pond water quality information collected from the annual Cape Cod Pond and Lake Stewardship (PALS) water quality snapshot. The PALS snapshot is a collaborative Cape Cod Commission/SMAST Program that allows trained, citizen volunteers of each of the 15 Cape Cod towns to collect pond samples in August and September using a standard protocol. Snapshot samples have been collected every year between 2001 and 2005. The standard protocol for the snapshot includes field collection of dissolved oxygen and temperature profiles, Secchi disk depth readings and water samples at various depths depending on the total depth of the pond. PALS snapshot data is available in the Centerville River/East Bay watershed for the following ponds: Bearses, Joshua, Lake Elizabeth, Long, Micah, Red Lilly, Shallow, and Lake Wequaquet. Water samples were analyzed at the SMAST

laboratory for total nitrogen, total phosphorus, chlorophyll *a*, alkalinity, and pH. Table IV-5 presents the turnover times and attenuation factors for the ponds in the Centerville River/East Bay watershed.

Table IV-6 summarizes the pond attenuation estimates calculated from land-use modeled nitrogen inflow loads and nitrogen loads recharged to the downgradient aquifer or to outflow streams from each pond based on pond characteristics and measured nitrogen levels. Nitrogen attenuation within these ponds varies between 84 and 96%. However, a caveat to these attenuation estimates is that they are based upon nitrogen outflow loads from water column samples collected at one time during the year, and are not necessarily representative of the annual nitrogen loads that are transferred downgradient.

Table IV-5. Nitrogen attenuation by Freshwater Ponds in the Centerville River/East Bay watershed based upon 2001 through 2005 Cape Cod Pond and Lakes Stewardship (PALS) program sampling. These data were collected to provide a site-specific check on nitrogen attenuation by these systems. The MEP Linked N Model for Centerville River/East Bay uses a standard value of 50% for the pond systems.

Pond	PALS ID	Area acres	Maximum Depth m	Overall turnover time Yrs	N Load Attenuation %
Bearses	BA-617	66.8	4.9	0.03	
Joshua	BA-807	14.7	7.1	0.51	96%
Lake Elizabeth	BA-795	6.3	1.1	1.00	
Long	BA-737	51.0	6.4	0.74	94%
Micah	BA-797	16.0	10.5	2.40	88%
Red Lilly	BA-782	4.5	0.8	0.78	
Shallow	BA-626	78.4	2.0	0.97	
Wequaquet complex	BA-605	596.3	8.1	2.42	84%
				Mean	91%
				std dev	6%

Data sources: all areas from CCC GIS; Max Depth from MADFW or Cape Cod PALS monitoring; Volume for turnover time calculations from MADFW bathymetric maps (www.mass.gov/dfwele/dfw/dfw_pond.htm); TN concentrations for attenuation calculation from PALS monitoring

Lake Wequaquet is listed as a "complex" in Table IV-5 because of lack of definition between Lake Wequaquet, Bearses Pond, and Shallow Pond in the original groundwater modeling completed for this project. Collected streamflow information at the Pine Street location indicates that flow from this complex must discharge through Long Pond (see Section IV.2.4), but more refined definition of groundwater flow within the complex is necessary to provide more detailed assessment of attenuation factors in the separate basins.

There are a number of "ponds" that are shown in the watershed delineation (see Figure III-1) that are not listed in Table IV-5. Although watersheds were delineated to these waters during the initial watershed modeling, review of aerial photographs has shown that many of these are either not as extensive or more closely approximate traditional wetlands. Attenuation

factors of less than 50% are assigned to these components and further discussion is provided in Section IV.2.

Buildout

Part of the regular MEP watershed nitrogen loading modeling is to prepare a buildout assessment of potential development within the study area watershed. For the Centerville River/East Bay modeling, MEP staff consulted with Town of Barnstable planners to determine the factors that would be used in the assessment (Thomas Broadrick, personal communication). MEP staff developed the buildout by reviewing the development potential of each property. The buildout procedure used in this subwatershed and generally completed by MEP staff is to evaluate town zoning to determine minimum lot sizes in each of the zoning districts, including overlay districts (*e.g.*, water resource protection districts). Larger lots are subdivided by the minimum lot size to determine the total number of new lots and existing developed properties are reviewed for additional development potential; for example, residential lots that are twice the minimum lot size, but have only one residence. MEP staff also included additional development on residential parcels that are classified as developable residential (state class land use codes 130 and 131) but are less than the minimum lot size and are greater than 5,000 square feet. These parcels are assigned one residence in the buildout; 5,000 square feet is a common minimum buildable lot size in Cape Cod town regulations. Properties classified by the Barnstable assessor as "undevelopable" (e.g., codes 132, 392, and 442) were not assigned any development at buildout. Commercially developable properties were not subdivided; the area of each parcel and the factors in Table IV-3 were used to determine a wastewater flow for these properties. All the parcels included in the buildout assessment of the Centerville River/East Bay watershed are shown in Figure IV-3.

Overall, a nitrogen load for each additional residence or business is included in the cumulative unattenuated buildout indicated in a separate column in Table IV-4. Buildout additions within the overall Centerville River/East Bay System watershed will increase the unattenuated loading rate by 5%.

IV.2 ATTENUATION OF NITROGEN IN SURFACE WATER TRANSPORT

IV.2.1 Background and Purpose

Modeling and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land or watershed. This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out, sewering analysis, enhanced flushing, pond/wetland restoration for natural attenuation, etc.) to changes in water quality and habitat health. Therefore, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems. Rates of nitrogen loading to the sub-watersheds of the Centerville River System (inclusive of Scudder Bay and Bumps River estuarine reaches) being investigated under this nutrient threshold analysis was based upon the delineated watersheds (Section III) and their land-use coverages (Section IV.1). If all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters. This condition exists in watersheds where nitrogen transport from source to estuarine waters is through groundwater flow in sandy outwash aquifers (such as the developed region of the Centerville River System watershed). The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. However, in most watersheds in southeastern

Massachusetts, nitrogen passes through a surface water ecosystem (pond, wetland, stream) on its path to the adjacent embayment. Surface water systems, unlike sandy aquifers, do support the needed conditions for nitrogen retention and denitrification. The result is that the mass of nitrogen passing through lakes, ponds, streams and marshes (fresh and salt) is diminished by natural biological processes that represent removal (not just temporary storage). However, this natural attenuation of nitrogen load is not uniformly distributed within the watershed, but is associated with ponds, streams and marshes. In the case of the Centerville River embayment system watersheds, a portion of the freshwater flow and transported nitrogen passes through several surface water systems (Skunknett River, Bumps River, stream from Long Pond, stream from Lake Elizabeth) prior to entering the estuary, producing the opportunity for significant nitrogen attenuation.

Failure to determine the attenuation of watershed derived nitrogen overestimates the nitrogen load to receiving estuarine waters. If nitrogen attenuation is significant in one portion of a watershed and insignificant in another the result is that nitrogen management would likely be more effective in achieving water quality improvements if focused on the watershed region having unattenuated nitrogen transport (other factors being equal). In addition to attenuation by freshwater ponds (see Section IV.1.3, above), attenuation in surface water flows is also important. An example of the significance of surface water nitrogen attenuation relating to embayment nitrogen management was seen in the Agawam River, where >50% of nitrogen originating within the upper watershed was attenuated prior to discharge to the Wareham River Estuary (CDM 2000). Similarly, MEP analysis of the Quashnet River indicates that in the upland watershed, which has natural attenuation predominantly associated with riverine processes, the integrated attenuation was 39% (Howes et al. 2004). In addition, a preliminary study of Great, Green and Bournes Ponds in Falmouth, measurements indicated a 30% attenuation of nitrogen during stream transport (Howes and Ramsey 2001). An example where natural attenuation played a significant role in nitrogen management can be seen relative to West Falmouth Harbor (Falmouth, MA), where ~40% of the nitrogen discharge to the Harbor originating from the groundwater effluent plume emanating from the WWTF was attenuated by a small salt marsh prior to reaching Harbor waters. Clearly, proper development and evaluation of nitrogen management options requires determination of the nitrogen loads reaching an embayment, not just loaded to the watershed.

Given the importance of determining accurate nitrogen loads to embayments for developing effective management alternatives and the potentially large errors associated with ignoring natural attenuation, direct integrated measurements of upper watershed attenuation were undertaken as part of the MEP Approach. MEP conducted long-term measurements of natural attenuation relating to surface water discharges to the head of the embayment system (e.g. Scudder Bay, estuarine reach of Bumps River) in addition to the natural attenuation measures by fresh kettle ponds, addressed above (Section IV.1). These additional site-specific studies were conducted in the 4 major surface water flow systems in the watershed to Centerville River, 1) the Skunknett River discharging to the estuarine reach of Bumps River, 2) Bumps River discharging to Scudder Bay, 3) the stream from Long Pond discharging to Centerville River and 4) the stream from Lake Elizabeth discharging to Centerville River (Figure IV-5).

Quantification of watershed based nitrogen attenuation is contingent upon being able to compare nitrogen load to the embayment system directly measured in freshwater stream flow (or in tidal marshes, net tidal outflow) to nitrogen load as derived from the detailed land use analysis (Section IV.1). Measurement of the flow and nutrient load associated with the freshwater streams discharging to the estuary provides a direct integrated measure of all of the

processes presently attenuating nitrogen in the contributing area upgradient from the various gauging sites. Flow and nitrogen load were measured at the gages in each freshwater stream site for between 15 and 26 months of record depending on the stream gaging location (Figures IV-6 to IV-9). During each study period, velocity profiles were completed on each river every month to two months. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities represent the computation of instantaneous stream flow (Q).

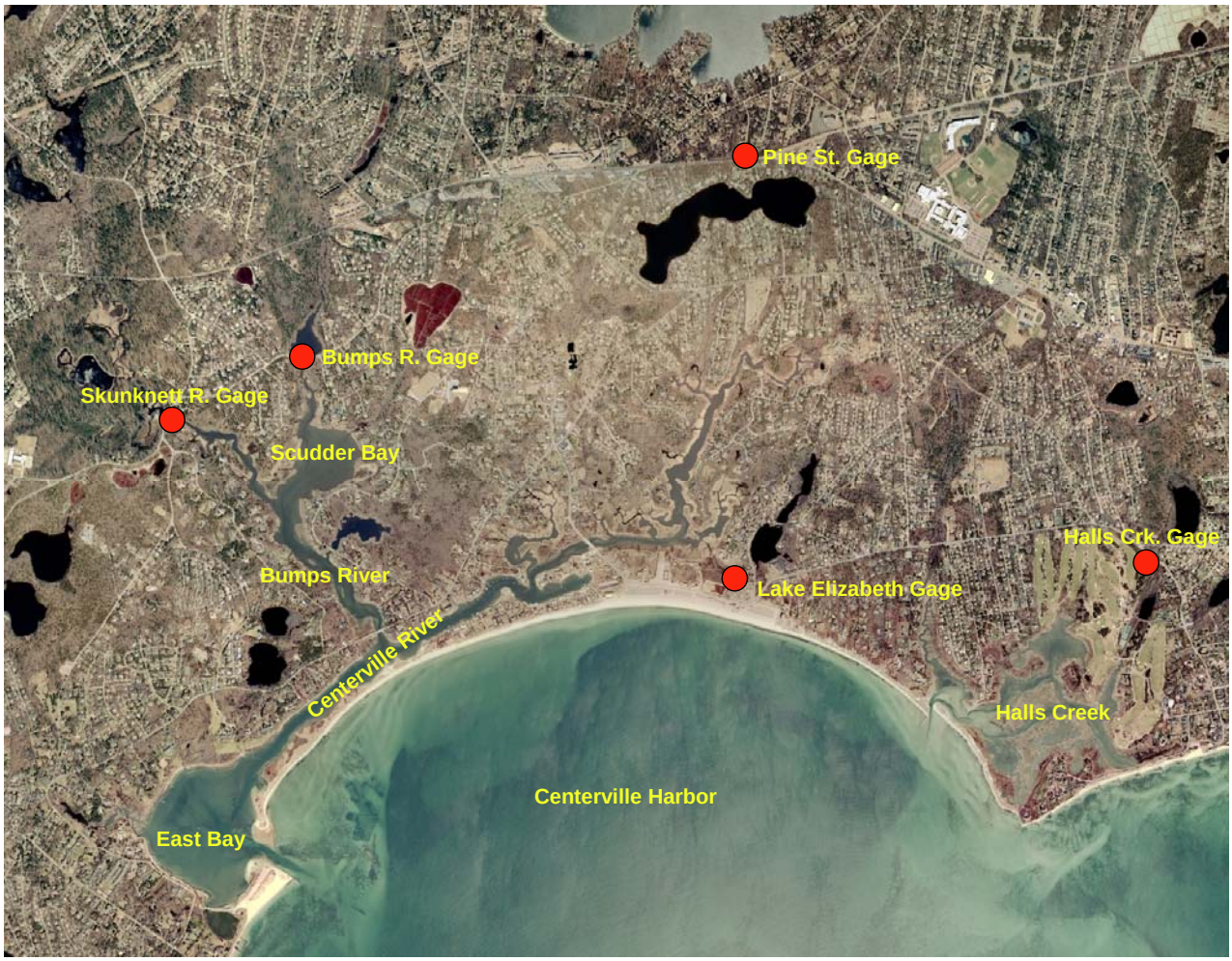


Figure IV-5. Location of Stream gage (red symbols) in the Centerville River/Harbor embayment system.

Determination of stream flow at each gage was calculated and based on the measured values obtained for stream cross sectional area and velocity. Stream discharge was represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity measurement were obtained. Velocity measurements across the entire stream cross section were not averaged and then applied to the total stream cross sectional area.

The formula that was used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma(A * V)$$

where by:

Q = Stream discharge (m^3/s)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection will have a calculated stream discharge value and the summation of all the sub-sectional stream discharge values will be the total calculated discharge for the stream.

Periodic measurement of flows over the entire stream gage deployment period allowed for the development of a stage-discharge relationship (rating curve) that could be used to obtain flow volumes from the detailed record of stage measured by the continuously recording stream gages. Water level data obtained every 10-minutes was averaged to obtain hourly stages for a given river. These hourly stages values where then entered into the stage-discharge relation to compute hourly flow. Hourly flows were summed over a period of 24 hours to obtain daily flow and further, daily flows summed to obtain annual flow. In the case of tidal influence on stream stage, the diurnal low tide stage value was extracted on a day-by-day basis in order to resolve the stage value indicative of strictly freshwater flow. The two low tide stage values for any given day were averaged and the average stage value for a given day was then entered into the stage – discharge relation in order to compute daily flow. A complete annual record of stream flow (365 days) was generated for the surface water discharges flowing into the estuarine portion of Centerville River/Harbor system.

The annual flow record for the surface water flow at each gage was merged with the nutrient data set generated through the weekly water quality sampling performed at the gage locations to determine nitrogen loading rates to the head (tidally influenced) of the Centerville River/Harbor system. Nitrogen discharge from the streams was calculated using the paired daily discharge and daily nitrogen concentration data to determine the mass flux of nitrogen through a specific gauging site. For each of the stream gage locations, weekly water samples were collected (at low tide for a tidally influenced stage) in order to determine nutrient concentrations from which nutrient load was calculated. In order to pair daily flows with daily nutrient concentrations, interpolation between weekly nutrient data points was necessary. These data are expressed as nitrogen mass per unit time (kg/d) and can be summed in order to obtain weekly, monthly, or annual nutrient load to the embayment system as appropriate. Comparing these measured nitrogen loads based on stream flow and water quality sampling to predicted loads based on the land use analysis allowed for the determination of the degree to which natural biological processes within the watershed to each pond currently reduces (percent attenuation) nitrogen loading to the embayment system.

IV.2.2 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Skunknett River to Estuarine Reach of Bumps River

North Pond, West Pond and South Pond, located upgradient of the Skunknett River gage site is a complex of small freshwater ponds and unlike many of the freshwater ponds, this network of ponds has stream outflow rather than discharging solely to the aquifer along its down-gradient shore. This stream outflow, the Skunknett River, may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetlands and streambed associated with the Skunknett River. The combined rate of nitrogen attenuation by these processes was

determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the Skunknett River above the gage site and the measured annual discharge of nitrogen to the tidal portion of the Bumps River, Figure IV-5.

At the Skunknett River gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the Skunknett River-Bumps River estuarine reach system that carries the flows and associated nitrogen load to the head of the upper portion of the estuarine reach of the Bumps River. As the Skunknett River is tidally influenced the gage was located above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to be <0.9 ppt. Therefore, the gage location was deemed acceptable for making freshwater flow measurements. Calibration of the gage was checked monthly. The gage on the Skunknett River was installed on March 27, 2003 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Stage data collection continued until September 8, 2005 for a total deployment of 26 months. Two 12-month uninterrupted records used in this analysis encompass both the summer 2004 and 2005 field season.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Skunknett River site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the estuarine portion of the Bumps River flowing to Centerville River/Harbor (Figure IV-6 and Table IV-6). In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for the Skunknett River measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from the Skunknett River was 18% above the long-term average modeled flows. Measured flow in the Skunknett River was obtained for two distinct yet consecutive hydrologic years (September 2003 to August 2004 and September 2004 to August 2005). The average flow for the two hydrologic years measured were used for the purpose of modeling the estuarine system. The average daily flow based on the MEP measured flow data was 13,925 m^3/day compared to the long term average flows determined by the USGS modeling effort (11,353 m^3/day). Additional confirmation of the MEP measured discharge for the Skunknett River was sought in comparing the MEP measured flow to measured flows for the Skunknett River which were obtained independent of the MEP effort during a study for the Town of Barnstable of the Audubon Skunknett River Wildlife Sanctuary (Hamersley, 2004). The study focused on nitrogen fluxes and mitigation strategies in the pond and river system as was conducted by SMAST/Coastal Systems Group scientists. Based on flow measurements conducted in 2002 to 2003 period, the flow from the Skunknett River at the same location as the MEP gage was determined to be 13,317 m^3/day. This flow is consistent with the MEP determined flow in the following years and it was concluded that the MEP flow for the Skunknett River was justified.

Table IV-6. Comparison of water flow and nitrogen discharges from Rivers and Streams (freshwater) discharging to estuarine reach of Centerville River. The "Stream" data is from the MEP stream gauging effort. Watershed data is based upon the MEP watershed modeling effort by USGS.

Stream Discharge Parameter	Skunknett River Discharge[a]	Bumps River Discharge[a]	Long Pond Stream Discharge[a]	Lake Elizabeth Stream Discharge[a]	Data Source
Total Days of Record	365[b]	365[b]	365[b]	365[b]	(1)
Flow Characteristics					
Stream Average Discharge (m3/day) **	13925	5679	6518	1547	(1)
Contributing Area Average Discharge (m3/day)	11353	5217	6254	1381	(2)
Discharge Stream 2002-03 vs. Long-term Discharge	18%	8%	4%	11%	
Nitrogen Characteristics					
Stream Average Nitrate + Nitrite Concentration (mg N/L)	1.113	2.027	0.199	0.937	(1)
Stream Average Total N Concentration (mg N/L)	1.495	2.978	0.530	1.470	(1)
Nitrate + Nitrite as Percent of Total N (%)	74%	68%	38%	64%	(1)
Total Nitrogen (TN) Average Measured Stream Discharge (kg/day)	20.81	16.91	3.45	2.27	(1)
TN Average Contributing UN-attenuated Load (kg/day)	29.42	21.72	10.34	5.67	(3)
Attenuation of Nitrogen in Pond/Stream (%)	29%	22%	67%	60%	(4)

(a) Flow and N load to streams discharging to Centerville includes apportionments of Pond contributing area.
(b) September 1, 2003 to August 31, 2004.
** Flow is an average of annual flow for 2003-2005

(1) MEP gage site data
(2) Calculated from MEP watershed delineations to ponds upgradient of specific gages;
the fractional flow path from each sub-watershed which contribute to the flow in the streams to Centerville River;
and the annual recharge rate.
(3) As in footnote (2), with the addition of pond and stream conservative attentuation rates.
(4) Calculated based upon the measured TN discharge from the rivers vs. the unattenuated watershed load.

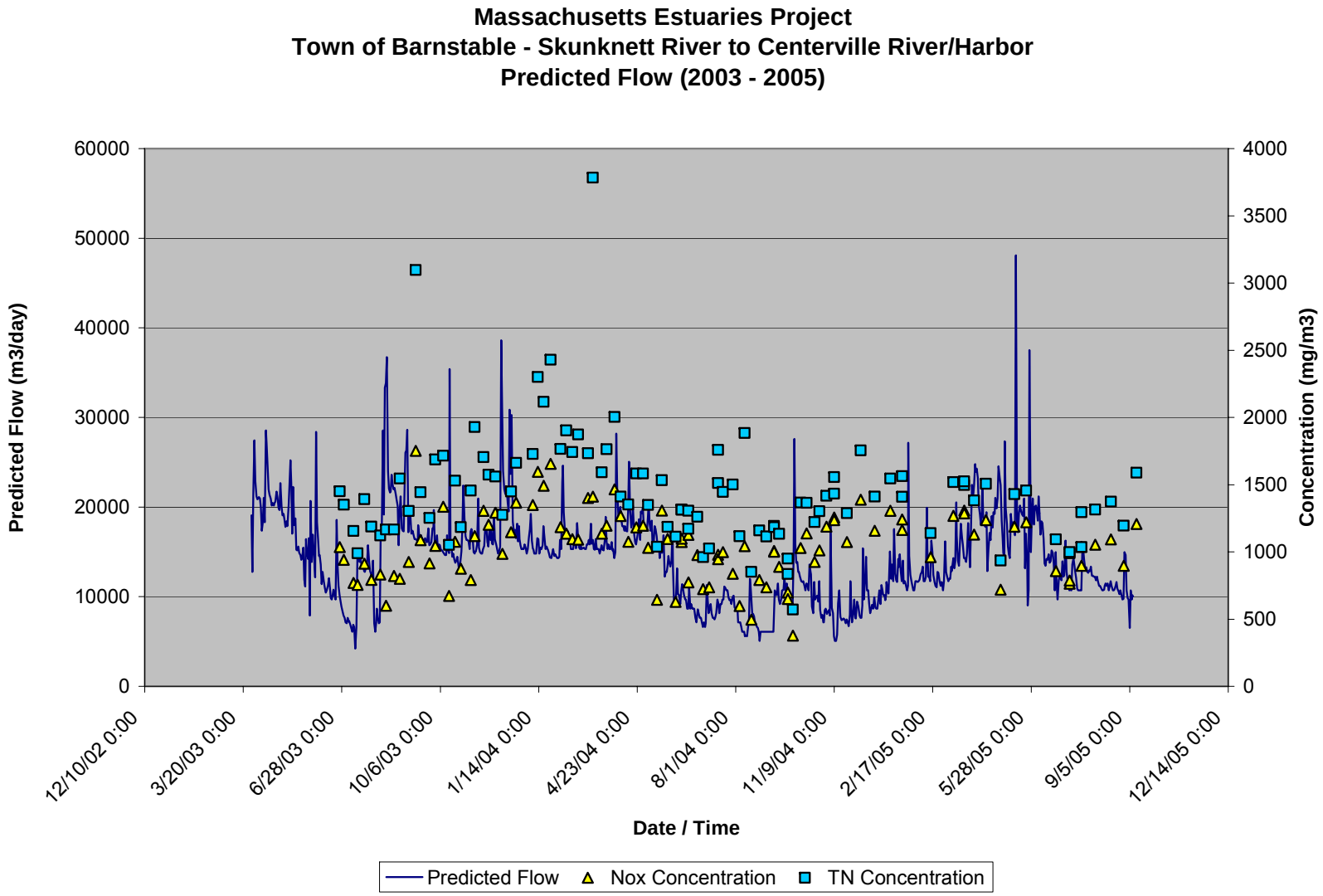


Figure IV-6. Skunknett River discharge (solid blue line), nitrate+nitrite (yellow triangle) and total nitrogen (blue box) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Scudder Bay (Table IV-7).

The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in the Skunknett River may in part be due to above average rainfall during the stream gage deployment period based on rainfall records obtained from a rain gage in the Town of Hyannis. Ten years of rainfall data (1993-2004) indicate that the average rainfall in the vicinity of the Centerville River system was 38.76 inches. By comparison, rainfall in 2003 and 2004 was 50.07 and 34.62 inches respectively. Rainfall in 2002 was 48.28 inches (above long term average). This was in contrast to rainfall amounts totaling 50.07 inches in 2003. It should be recognized that 2002 and 2003 rainfall was above average thus the water table is likely to have been higher than usual due to the 2 years of higher rainfall. This is significant relative to measured flow in the Skunknett River surface water system as it is essentially a groundwater fed feature. Based upon the rainfall and groundwater levels associated with the stream measurement (suggesting a higher flow than the long-term average) and the some what higher measured stream discharge then predicted (+18%) it appears that the stream is capturing the upgradient recharge (and loads) accurately.

Total nitrogen concentrations within the Skunknett River outflow were moderate, 1.495 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 20.81 kg/day and a measured total annual TN load of 5657 kg/yr. In the Skunknett River, nitrate was the predominant form of nitrogen (74%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the outflowing stream waters also suggests that plant production within the upgradient freshwater ecosystems is not nitrogen limited. In addition, the high nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system either within the North Pond, West Pond and South Pond network or along the freshwater reach of the Skunknett River.

From the measured nitrogen load discharged by the Skunknett River to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon lower total nitrogen load (7596 kg yr^{-1}) discharged from the freshwater Skunknett River compared to that added by the various land-uses to the associated watershed (10738 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is 29% (i.e. 29% of nitrogen input to watershed does not reach the estuary). This slightly lower level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the network of upgradient ponds which are essentially shallow flow through systems. The directly measured nitrogen loads from the river was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

IV.2.3 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Bumps River to Scudder Bay

Filends Pond located immediately upgradient of the Bumps River gage site is a small freshwater pond and unlike many of the freshwater ponds, this pond has stream outflow rather than discharging solely to the aquifer along its down-gradient shore. This stream outflow to the freshwater Bumps River may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetlands and streambed associated with the Bumps River. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the Bumps River

above the gage site and the measured annual discharge of nitrogen to the tidal portion of Scudder bay and Bumps River, Figure IV-5.

At the Bumps River gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the Bumps River that carries the flows and associated nitrogen load to the head of Scudder Bay and the estuarine reach of the Bumps River. As the Bumps River is tidally influenced the gage was located above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to be <0.1 ppt. Therefore, the gage location was deemed acceptable for making freshwater flow measurements. Calibration of the gage was checked monthly. The gage on the Bumps River was installed on March 27, 2003 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Stage data collection continued until November 8, 2004 for a total deployment of 21 months. The 12-month uninterrupted record used in this analysis encompasses the summer 2003 and 2004 field season.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Bumps River site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the estuarine portion of Scudder Bay and the Bumps River (Figure IV-7 and Table IV-6). In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for the Bumps River measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from the Bumps River was 8% above the long-term average modeled flows. Measured flow in the Bumps River was obtained for one hydrologic year (September 2003 to August 2004). The average daily flow based on the MEP measured flow data was 5,679 m^3/day compared to the long term average flows determined by the USGS modeling effort (5,217 m^3/day). The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in the Bumps River are in part be due to above average rainfall during the stream gage deployment period based on rainfall records obtained from a rain gage in the Town of Hyannis. Based on ten years of rainfall data (1993-2004) the average rainfall in the vicinity of the Centerville River system was 38.76 inches. By comparison, rainfall in 2003 and 2004 was 50.07 and 34.62 inches respectively. Rainfall in 2002 was 48.28 inches (above long term average). This was in contrast to rainfall amounts totaling 50.07 inches in 2003. It should be recognized that 2002 and 2003 rainfall was above average thus the water table is likely to have been higher than usual due to the 2 years of higher rainfall. This is significant relative to measured flow in the Bumps River surface water system as it is essentially a groundwater fed feature. Based upon the rainfall and groundwater levels associated with the stream measurement (suggesting a higher flow than the long-term average) and the some what higher measured stream discharge then predicted (+8%) it appears that the stream is capturing the upgradient recharge (and loads) accurately.

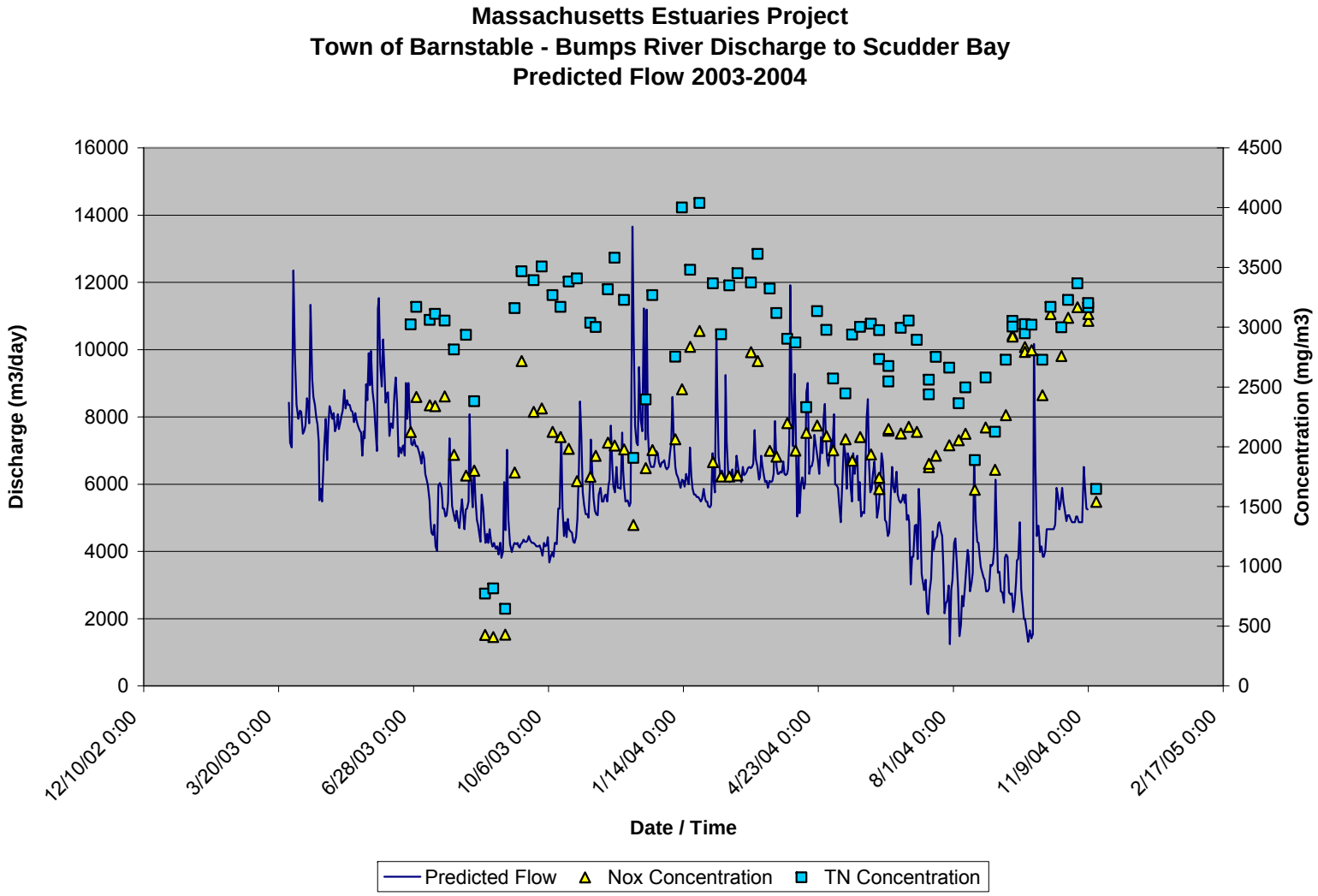


Figure IV-7. Bumps River discharge (solid blue line), nitrate+nitrite (yellow triangle) and total nitrogen (blue box) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Scudder Bay (Table IV-7).

Total nitrogen concentrations within the Bumps River outflow were high, 2.978 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 16.91 kg/day and a measured total annual TN load of 6173 kg/yr. In the Bumps River, nitrate was the predominant form of nitrogen (68%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the outflowing stream waters also suggests that plant production within the upgradient freshwater ecosystems is not nitrogen limited. In addition, the high nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system either within Filends Pond or along the freshwater reach of the Bumps River.

From the measured nitrogen load discharged by the Bumps River to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon lower nitrogen load (6173 kg yr^{-1}) discharged from the freshwater Bumps River compared to that added by the various land-uses to the associated watershed (7928 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is 22% (i.e. 22% of nitrogen input to watershed does not reach the estuary). This slightly lower level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the upgradient pond which is essentially a shallow flow through system. The directly measured nitrogen loads from the river was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

IV.2.4 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Long Pond to Centerville River

Long Pond located upgradient of the Pine Street gage site is a moderately sized freshwater pond and unlike many of the freshwater ponds, this pond has stream outflow rather than discharging solely to the aquifer along its down-gradient shore. This stream outflow, the stream from Long Pond to Centerville River, may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetlands and streambed associated with the Long Pond Stream. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the Long Pond and stream system above the gage site and the measured annual discharge of nitrogen to the tidal portion of Centerville River, Figure IV-5.

At the Pine Street gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the stream from Long Pond that carries the flows and associated nitrogen load to the estuarine reach of the Centerville River. As Centerville River is tidally influenced the gage was located above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to be <0.1 ppt. Therefore, the gage location was deemed acceptable for making freshwater flow measurements. Calibration of the gage was checked monthly. The gage on the stream from Long Pond was installed on April 22, 2004 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Stage data collection continued until November 8, 2005 for a total deployment of 18 months. The 12-month uninterrupted record used in this analysis encompasses the summer 2004 and 2005 field season.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Pine Street gage site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the estuarine portion of the Centerville River (Figure IV-8 and Table IV-6). In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for the stream from Long Pond measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from the stream from Long Pond was 4% above the long-term average modeled flows. Measured flow in the Long Pond stream was obtained for one hydrologic year (September 2004 to August 2005). The average daily flow based on the MEP measured flow data was 6,518 m^3/day compared to the long term average flows determined by the USGS modeling effort (6,254 m^3/day). The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in the Long Pond stream may in part be due to above average rainfall during the stream gage deployment period based on rainfall records obtained from a rain gage in the Town of Hyannis. Based on ten years of rainfall data (1993-2004) the average rainfall in the vicinity of the Centerville River system was 38.76 inches. By comparison, rainfall in 2003 and 2004 was 50.07 and 34.62 inches respectively. Rainfall for the period August 2004 to July 2005 was 36.50 inches, slightly below the long term average of 38.76 inches. Rainfall in 2002 was 48.28 inches (above long term average). This was in contrast to rainfall amounts totaling 50.07 inches in 2003. It should be recognized that 2002 and 2003 rainfall was above average thus the water table is likely to have been higher than usual due to the 2 years of higher rainfall. This is significant relative to measured flow in the Long Pond stream surface water system as it is essentially a groundwater fed feature. Based upon the rainfall and groundwater levels associated with the stream measurement (suggesting a slightly higher flow than the long-term average) and the some what higher measured stream discharge then predicted (+4%) it appears that the stream is capturing the upgradient recharge (and loads) accurately.

Total nitrogen concentrations within the Long Pond stream outflow were moderate, 0.530 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 3.45 kg/day and a measured total annual TN load of 1,260 kg/yr. In the Long Pond stream, nitrate was not the predominant form of nitrogen (38%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was more completely taken up by plants within the pond or stream ecosystems. The lower concentration of inorganic nitrogen in the outflowing stream waters also suggests that plant production within the upgradient freshwater ecosystems may be slightly nitrogen limited. In addition, the lower nitrate levels in outflowing waters from Long Pond suggests slightly less possibility for additional uptake by freshwater systems might be accomplished in this system either within Long Pond or along the freshwater reach of the stream from Long Pond.

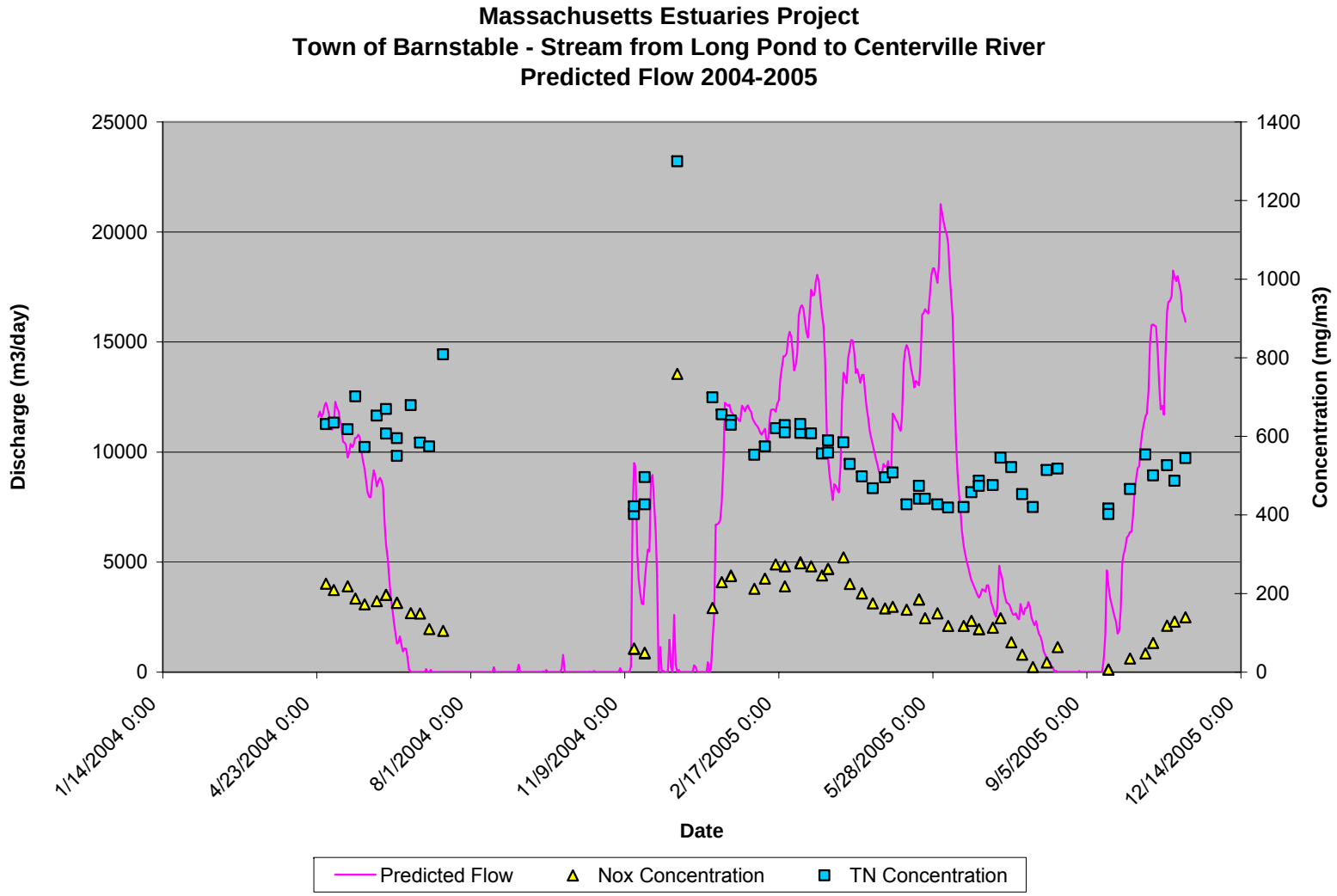


Figure IV-8. Stream discharge from Long Pond(solid pink line), nitrate+nitrite (yellow triangle) and total nitrogen (blue box) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Centerville River (Table IV-7).

From the measured nitrogen load discharged by the stream from Long Pond discharging to Centerville River and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon lower nitrogen load (1,260 kg yr^{-1}) discharged from the freshwater Back River compared to that added by the various land-uses to the associated watershed (3,773 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is 67% (i.e. 67% of nitrogen input to watershed does not reach the estuary). This level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the upgradient pond which is essentially a relatively deep kettle pond system with substantial residence time. The directly measured nitrogen loads from the stream was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

IV.2.5 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Lake Elizabeth to Centerville River

Lake Elizabeth located upgradient of the stream gage site is a small freshwater pond and unlike many of the freshwater ponds, this pond has stream outflow rather than discharging solely to the aquifer along its down-gradient shore. This stream outflow, the Lake Elizabeth stream, may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetlands and streambed associated with the lake and its outflowing stream. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the lake and stream above the gage site and the measured annual discharge of nitrogen to the tidal portion of Centerville River, Figure IV-5.

At the Lake Elizabeth stream gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the stream that carries the flows and associated nitrogen load to the estuarine reach of Centerville River. As the Lake Elizabeth stream is tidally influenced the gage was located above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to be <0.2 ppt. Therefore, the gage location was deemed acceptable for making freshwater flow measurements. Calibration of the gage was checked monthly. The gage on the stream from Lake Elizabeth was installed on May 15, 2003 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Stage data collection continued until November 8, 2004 for a total deployment of 18 months. The 12-month uninterrupted record used in this analysis encompasses the summer 2003 and 2004 field seasons.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Lake Elizabeth stream site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the estuarine portion of Centerville River (Figure IV-9 and Table IV-6). In addition, a water balance was constructed based upon the US Geological Survey

groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for the stream from Lake Elizabeth measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from the Lake Elizabeth stream was 11% above the long-term average modeled flows. Measured flow in the Lake Elizabeth stream was obtained for one hydrologic year (September 2003 to August 2004). The average daily flow based on the MEP measured flow data was 1,547 m^3/day compared to the long term average flows determined by the USGS modeling effort (1,381 m^3/day). The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in the Lake Elizabeth stream may in part be due to above average rainfall during the stream gage deployment period based on rainfall records obtained from a rain gage in the Town of Hyannis. Based on ten years of rainfall data (1993-2004) the average rainfall in the vicinity of the Centerville River system was 38.76 inches. By comparison, rainfall in 2003 and 2004 was 50.07 and 34.62 inches respectively. Rainfall in 2002 was 48.28 inches (above long term average). This was in contrast to rainfall amounts totaling 50.07 inches in 2003. It should be recognized that 2002 and 2003 rainfall was above average thus the water table is likely to have been higher than usual due to the 2 years of higher rainfall. This is significant relative to measured flow in the Lake Elizabeth surface water system as it is essentially a groundwater fed feature. Based upon the rainfall and groundwater levels associated with the stream measurement (suggesting a higher flow than the long-term average) and the some what higher measured stream discharge then predicted (+11%) it appears that the stream is capturing the upgradient recharge (and loads) accurately.

Total nitrogen concentrations within the Lake Elizabeth stream outflow were moderate, 1.470 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 2.27 kg/day and a measured total annual TN load of 830 kg/yr. In the Lake Elizabeth stream, nitrate was the predominant form of nitrogen (64%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the outflowing stream waters also suggests that plant production within the upgradient freshwater ecosystems is not nitrogen limited. In addition, the high nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system either within Lake Elizabeth or along the freshwater reach of the stream.

From the measured nitrogen load discharged by the Lake Elizabeth stream discharge to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon the lower nitrogen load (830 kg yr^{-1}) discharged from the freshwater stream compared to that added by the various land-uses to the associated watershed (2,070 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is 60% (i.e. 60% of nitrogen input to watershed does not reach the estuary). This level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the upgradient pond which is essentially a coastal kettle pond system with substantial residence time. The directly measured nitrogen loads from the river was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

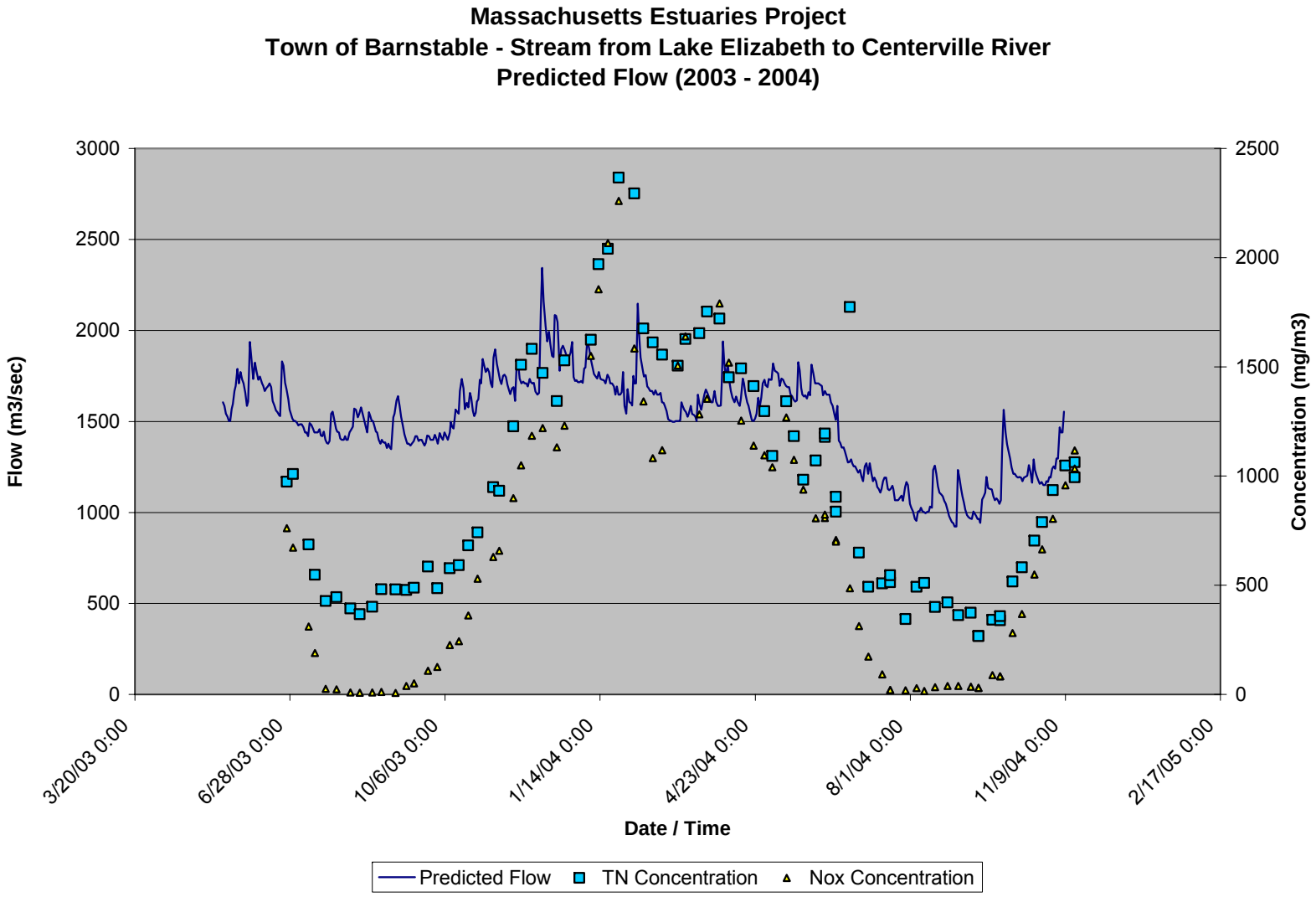


Figure IV-9. Stream discharge from Lake Elizabeth (solid blue line), nitrate+nitrite (yellow triangle) and total nitrogen (blue box) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Centerville River (Table IV-7).

Table IV-7. Summary of annual volumetric discharge and nitrogen load from the Rivers and Streams (freshwater) discharging to the Centerville River based upon the data presented in Figures IV-6 through IV-9 and Table IV-6.

EMBAYMENT SYSTEM	PERIOD OF RECORD	DISCHARGE (m3/year)	ATTENUATED LOAD (Kg/yr)	
			Nox	TN
Skunknett River (MEP)	**September 1, 2003 to August 31, 2004** **September 1, 2004 to August 31, 2005** **Average 2003 - 2005**	5391034 4774129 **5082582**	6043 5271 **5657**	8715 6477 **7596**
Skunknett River (SMAST)	**2002 - 2003**	4860705		
Skunknett River (CCC)	Based on Watershed Area and Recharge	4144021	--	--
Bumps River (Freshwater) MEP	**September 1, 2003 to August 31, 2004**	**2072872**	**4201**	**6173**
Bumps River (Freshwater) CCC	Based on Watershed Area and Recharge	1904385	--	--
Long Pond Stream Discharge (MEP)	**September 1, 2004 to August 31, 2005**	**2379169**	**473**	**1260**
Long Pond Stream Discharge (CCC)	Based on Watershed Area and Recharge	2282678	--	--
Lake Elizabeth Stream Discharge (MEP)	**September 1, 2003 to August 31, 2004**	**564615**	**529**	**830**
Lake Elizabeth Stream Discharge (CCC)	Based on Watershed Area and Recharge	503984	--	--

IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS

The overall objective of the benthic nutrient flux Surveys was to quantify the summertime exchange of nitrogen, between the sediments and overlying waters within each major basin area within the Centerville River Embayment System. The mass exchange of nitrogen between water column and sediments is a fundamental factor in controlling nitrogen levels within coastal waters. These fluxes and their associated biogeochemical pools relate directly to carbon, nutrient and oxygen dynamics and the nutrient related ecological health of these shallow marine ecosystems. In addition, these data are required for the proper modeling of nitrogen in shallow aquatic systems, both fresh and salt water.

IV.3.1 Sediment-Watercolumn Exchange of Nitrogen

As stated in above sections, nitrogen loading and resulting levels within coastal embayments are the critical factors controlling the nutrient related ecological health and habitat quality within a system. Nitrogen enters the Centerville River System predominantly in highly bioavailable forms from the surrounding upland watershed and more refractory forms in the inflowing tidal waters. If all of the nitrogen remained within the water column (once it entered), then predicting water column nitrogen levels would be simply a matter of determining the watershed loads, dispersion, and hydrodynamic flushing. However, as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bioavailable form nitrate. This nitrate and other bioavailable forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved forms into phytoplankton “particles”. Most of these “particles” remain in the water column for sufficient time to be flushed out to a down gradient larger water body (like Vineyard/Nantucket Sound). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals and deposited on the bottom. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence), a fraction of the phytoplankton with their associated nitrogen “load” become incorporated into the surficial sediments of the bays.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within enclosed tributary basins, particularly if they are deeper than the adjacent embayment. To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary.

Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic (oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter with its nitrogen content that bioavailable nitrogen is returned to the embayment water column for another round of uptake by phytoplankton. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that have been investigated by SMAST and the MEP, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. In contrast in some systems, with deep depositional basins or salt marsh tidal creeks, the sediments can be a net sink for nitrogen even during summer. These latter salt marsh channels and ponds can be seen in the Bumps River sub-system and the upper most reach of the Centerville River, which is essentially a tidal salt marsh. Failure to account for the nitrogen balance of the sediments generally results in significant errors in determination of

threshold nitrogen loadings. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

IV.3.2 Method for determining sediment-watercolumn nitrogen exchange

For the Centerville River system, in order to determine the contribution of sediment regeneration to nutrient levels during the most sensitive summer interval (July-August), sediment samples were collected and incubated under *in situ* conditions. Sediment samples were collected from 20 sites throughout the Centerville River Estuary (Figure IV-10) in August 2003. Measurements of total dissolved nitrogen, nitrate + nitrite, ammonium were made in time-series on each incubated core sample.

Rates of nitrogen release were determined using undisturbed sediment cores incubated for 24 hours in temperature-controlled baths. Sediment cores (15 cm inside diameter) were collected by SCUBA divers and cores transported by small boat to a shore side field lab. Cores were maintained from collection through incubation at *in situ* temperatures. Bottom water was collected and filtered from each core site to replace the headspace water of the flux cores prior to incubation. The number of core samples from each site (Figure IV-10) per incubation are as follows:

Centerville River Benthic Nutrient Regeneration Cores

- Station CVH-9 1 core (Lower Region)
- Station CVH-10 1 core (Lower Region)
- Station CVH-11 1 core (Lower Region)
- Station CVH-13 1 core (Lower Region)
- Station CVH-14 1 core (Lower Region)
- Station CVH-22 1 core (East Bay)
- Station CVH-23 1 core (East Bay)
- Station CVH-24 2 cores (East Bay)
- Station CVH-25 1 core (East Bay)
- Station CVH-26 1 core (East Bay)
- Station CVH-27 1 core (East Bay)
- Station CVH-28 1 core (Lower Region)
- Station CVH-29 1 core (Lower Region)

Bumps River/Scudder Bay Benthic Nutrient Regeneration Cores

- Station CVH-15 1 core (Lower Region)
- Station CVH-16 1 core (Lower Region)
- Station CVH-17 1 core (Upper Region)
- Station CVH-18/19 2 cores (Upper Region)
- Station CVH-20 1 core (Upper Region)
- Station CVH-21 1 core (Upper Region)

Note: there was no core CVH 12; cores CVH 1-4 & 5-8 were external to Centerville River.

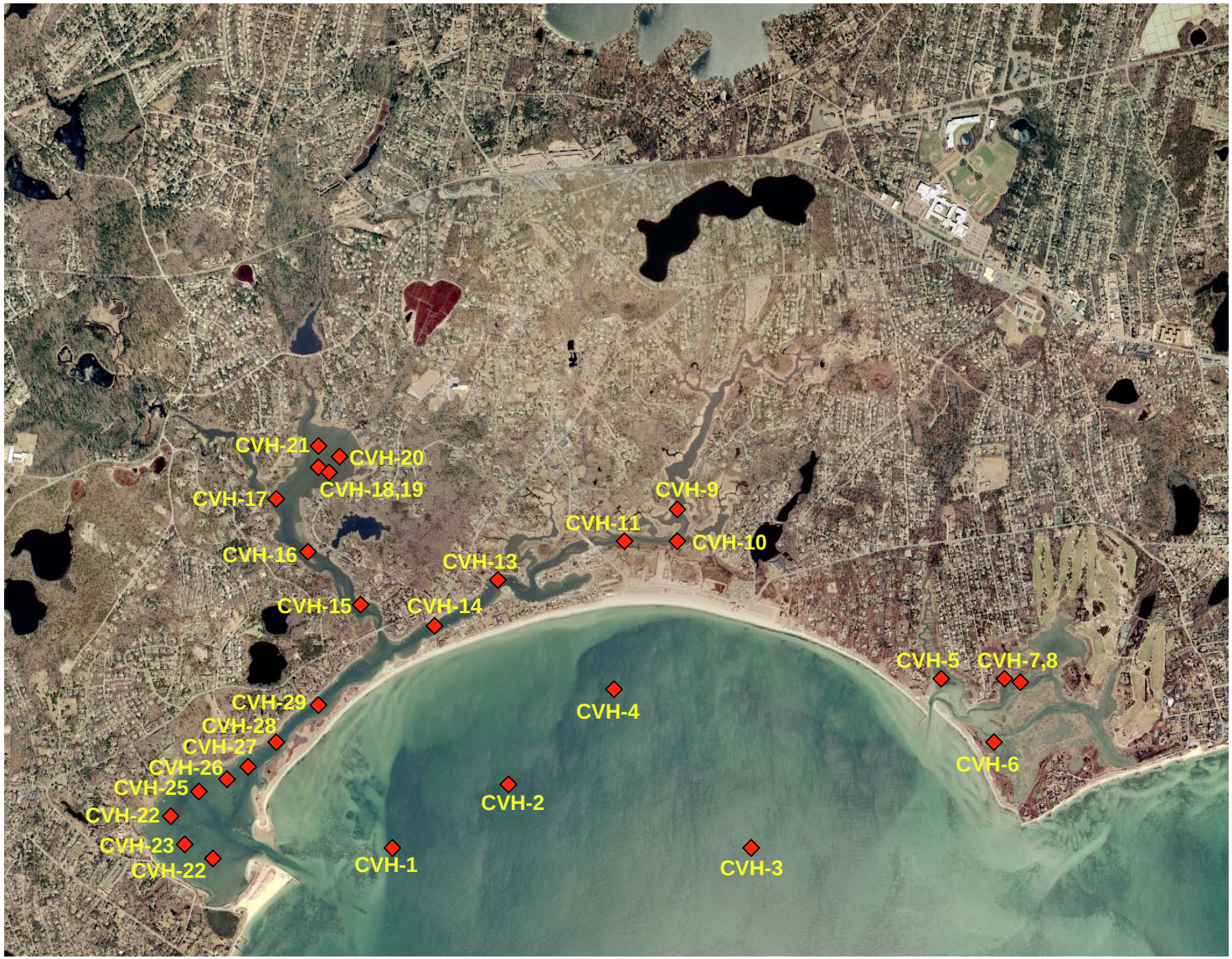


Figure IV-10. Centerville River embayment system sediment sampling sites (red symbols) for determination of nitrogen regeneration rates. Numbers are for reference to station identifications listed above.

Sampling was distributed throughout the embayment system and the results for each site combined for calculating the net nitrogen regeneration rates for the water quality modeling effort.

Sediment-water column exchange follows the methods of Jorgensen (1977), Klump and Martens (1983), and Howes *et al.* (1998) for nutrients and metabolism. Upon return to the field laboratory (Harbormasters Office) the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with filtered water), filtered into acid leached polyethylene bottles and held on ice for nutrient analysis. Ammonium (Scheiner 1976) and ortho-phosphate (Murphy and Reilly 1962) assays were conducted within 24 hours and the remaining samples frozen (-20°C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia *et al.* 1977). Rates were determined from linear regression of analyte concentrations through time.

Chemical analyses were performed by the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST) at the University of Massachusetts in New Bedford, MA. The laboratory follows standard methods for saltwater analysis and sediment geochemistry.

IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments

Water column nitrogen levels are the balance of inputs from direct sources (land, rain etc), losses (denitrification, burial), regeneration (water column and benthic), and uptake (e.g. photosynthesis). As stated above, during the warmer summer months the sediments of shallow embayments typically act as a net source of nitrogen to the overlying waters and help to stimulate eutrophication in organic rich systems. However, some sediments may be net sinks for nitrogen and some may be in "balance" (organic N particle settling = nitrogen release). Sediments may also take up dissolved nitrate directly from the water column and convert it to dinitrogen gas (termed "denitrification"), hence effectively removing it from the ecosystem. This process is typically a small component of sediment denitrification in embayment sediments, since the water column nitrogen pool is typically dominated by organic forms of nitrogen, with very low nitrate concentrations. However, this process can be very effective in removing nitrogen loads in some systems, particularly in streams, ponds and salt marshes, where overlying waters support high nitrate levels.

In addition to nitrogen cycling, there are ecological consequences to habitat quality of organic matter settling and mineralization within sediments, these relate primarily to sediment and water column oxygen status. However, for the modeling of nitrogen within an embayment it is the relative balance of nitrogen input from water column to sediment versus regeneration which is critical. Similarly, it is the net balance of nitrogen fluxes between water column and sediments during the modeling period that must be quantified. For example, a net input to the sediments represents an effective lowering of the nitrogen loading to down-gradient systems and net output from the sediments represents an additional load.

The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the organic levels within the sediment (oxic/anoxic) and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake throughout the summer months, even though organic nitrogen is being mineralized and

released to the overlying water as well. The rate of nitrate uptake, simply dominates the overall sediment nitrogen cycle.

In order to model the nitrogen distribution within an embayment it is important to be able to account for the net nitrogen flux from the sediments within each part of each system. This requires that an estimate of the particulate input and nitrate uptake be obtained for comparison to the rate of nitrogen release. Only sediments with a net release of nitrogen contribute a true additional nitrogen load to the overlying waters, while those with a net input to the sediments serve as an "in embayment" attenuation mechanism for nitrogen.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure IV-11).

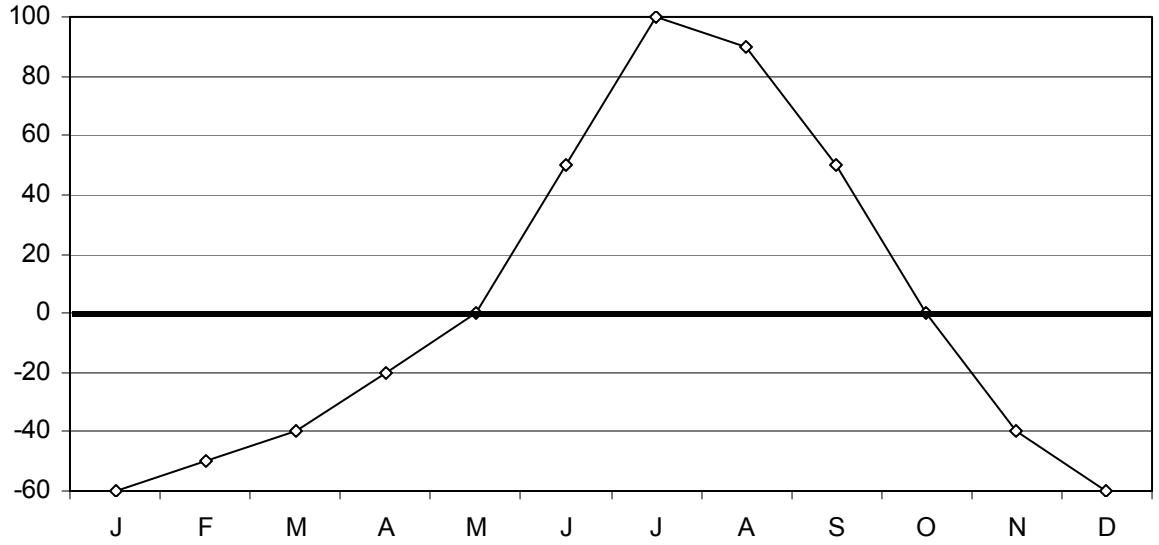


Figure IV-11. Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates.

In order to determine the net nitrogen flux between water column and sediments, all of the above factors were taken into account. The net input or release of nitrogen within a specific embayment was determined based upon the measured total dissolved nitrogen uptake or release, and estimate of particulate nitrogen input.

Sediment sampling was conducted within the Centerville River Estuary in order to obtain the nitrogen regeneration rates required for parameterization of the water quality model. The distribution of cores was established to cover gradients in sediment type, flow field and phytoplankton density. For each core the nitrogen flux rates (described in the section above) were evaluated relative to measured sediment organic carbon and nitrogen content and sediment type and an analysis of each site's tidal flow velocities. The maximum bottom water flow velocity at each coring site was determined from the hydrodynamic model. These data were then used to determine the nitrogen balance within each sub-embayment.

The magnitude of the settling of particulate organic carbon and nitrogen into the sediments was accomplished by determining the average depth of water within each sediment site, the average summer particulate carbon and nitrogen concentration within the overlying water and the tidal velocities from the hydrodynamic model (Chapter V). Two levels of settling were used. If the sediments were organic rich and fine grained, and the hydrodynamic data showed low tidal velocities, then a water column particle residence time of 8 days was used (based upon phytoplankton and particulate carbon studies of poorly flushed basins). If the sediments indicated coarse-grained sediments and low organic content and high velocities, then half this settling rate was used. Adjusting the measured sediment releases was essential in order not to over-estimate the sediment nitrogen source and to account for those sediment areas which are net nitrogen sinks for the aquatic system. This approach has been previously validated in outer Cape Cod embayments (Town of Chatham embayments) by examining the relative fraction of the sediment carbon turnover (total sediment metabolism), which would be accounted for by daily particulate carbon settling. This analysis indicated that sediment metabolism in the highly organic rich sediments of the wetlands and depositional basins is driven primarily by stored organic matter (ca. 90%). Also, in the more open lower portions of larger embayments, storage appears to be low and a large proportion of the daily carbon requirement in summer is met by particle settling (approximately 33% to 67%). This range of values and their distribution is consistent with ecological theory and field data from shallow embayments. Additional, validation has been conducted on deep enclosed basins (with little freshwater inflow), where the fluxes can be determined by multiple methods. In this case the rate of sediment regeneration determined from incubations was comparable to that determined from whole system balance.

Net nitrogen release or uptake from the sediments within the Centerville River System were comparable to other similar embayments with similar configuration and flushing rates. Overall, sediment nitrogen release was generally low or negative 36.6 to –13.2 mg N m^{-1} d^{-1}. Only the main depositional basin of East Bay showed a moderate level of net nitrogen release, 59 mg N m^{-1} d^{-1}. The rates of nitrogen release were much less than in heavily nitrogen loaded sub-embayments within the Pleasant Bay Estuary (~100 mg N m^{-1} d^{-1}), but very similar to the River (Upper Pleasant Bay) with its similar configuration (-10.9 to 34.2 mg N m^{-1} d^{-1}). The general pattern is consistent with other estuaries, with nitrogen loss from the sediments in the main depositional basin and from the Centerville River sediments, and net uptake in the shallow creeks and salt marsh basins is typical of southeastern Massachusetts estuaries. Net nitrogen uptake was observed in each of the salt marsh dominated sub-systems (-4.5 to -13.2 mg N m^{-1} d^{-1}), specifically the salt marsh areas within the Centerville River System, the upper reach of the

Centerville River which functions as a tidal salt marsh, the shallow Bumps River channel with fringing marshes, and the shallow basin of Scudder Bay which is bordered by tidal marshes and has the characteristics of a salt marsh pond. Net nitrogen uptake by estuarine basins influenced by salt marshes has been well documented within the MEP region.

Net nitrogen release rates for use in the water quality modeling effort for the component sub-basins of the Centerville River System (Chapter VI) are presented in Table IV-8. There was a clear spatial pattern of sediment nitrogen flux, with a strong gradient ranging from the more organic rich inner salt marsh basins showing uptake and the deeper lower reaches of the Centerville River showing net nitrogen release and the main depositional basin at the terminus of the River (East Bay) showing the highest rate of release. Even so, the sediments within the Centerville River System showed only a moderate range in nitrogen fluxes compared to other systems in the region and appear to be in balance with the overlying waters and the nitrogen flux rates consistent with the moderate nitrogen loading to this system and it relatively high flushing rate.

Table IV-8. Rates of net nitrogen return from sediments to the overlying waters of the Centerville River Estuarine System. These values are combined with the basin areas to determine total nitrogen mass in the water quality model (see Chapter VI). Measurements represent July -August rates.

Location	Sediment Nitrogen Flux (mg N m^{-2} d^{-1})			i.d.
	Mean	S.E.	# sites	
Centerville River				
Upper Salt Marsh Reach	-4.7	0.4	3	CVH 9,10,11
Mid River Reach	32.3	3.6	2	CVH 13,14
Lower Reach	36.6	2.0	2	CVH 28,29
East Bay				
Bay/River mouth	-8.9	0.9	2	CVH 26,27
Main Basin	59.1	3.0	4	CVH 22,23,24,25
Bumps River Sub-estuary				
Scudder Bay	-13.2	0.2	4	CVH 18,19,20,21
Bumps River	-4.5	0.8	3	CVH 15,16,17

Station numbers refer to Figures IV-7.

V. HYDRODYNAMIC MODELING

V.1 INTRODUCTION

In general, water quality studies of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. For example, the spread of pollutants may be analyzed from tidal current information developed by the numerical models.

Estuarine water quality is dependent upon nutrient and pollutant loading and the processes that help flush nutrients and pollutants from the estuary (e.g., tides and biological processes). Relatively low nutrient and pollutant loading and efficient tidal flushing are indicators of high water quality. The ability of an estuary to flush nutrients and pollutants is proportional to the volume of water exchanged with a high quality water body (i.e. Nantucket Sound). Several embayment-specific parameters influence tidal flushing and the associated residence time of water within an estuary. For the Centerville River system, the most important parameters are the tide attenuation along with the shape, length and depth of the estuary and its attached sub-systems.

Shallow coastal embayments are the initial recipients of freshwater flows (i.e., groundwater and surface water) and the nutrients they carry. An embayment's shape influences the time that nutrients are retained in them before being flushed out to adjacent open waters, and their shallow depths both decrease their ability to dilute nutrient (and pollutant) inputs and increase the secondary impacts of nutrients recycled from the sediments. Degradation of coastal waters and development are tied together through inputs of pollutants in runoff and groundwater flows, and to some extent through direct disturbance, i.e. boating, oil and chemical spills, and direct discharges from land and boats. Excess nutrients, especially nitrogen, promote phytoplankton blooms and the growth of epiphytes on eelgrass and attached algae, with adverse consequences including low oxygen, shading of submerged aquatic vegetation, and aesthetic problems.

To understand the dynamics of the Centerville River, a hydrodynamic study was performed. The system is located in the Village of Centerville along the south coast of Cape Cod, Massachusetts. A site map showing the general study area is shown in Figure V-1. The system consists of East Bay which is the entrance to the system from Nantucket Sound, Centerville River, Bumps River, which attaches to Scudder Bay, as well as numerous other smaller coves, creeks, and marshes. It is relatively shallow on average, the exceptions being deeper channel that provides a path between the Nantucket Sound and the river. The approximate tidal range within the system is 4 feet, with Nantucket Sound tidal variations providing the hydraulic forcing that drives water movement throughout the system.

Centerville River is a shallow tidal estuary, with a mean water depth of only 2.5 feet. Although Centerville River contains a larger overall area of salt marsh compared to other systems (approximately 230 acres), this marsh area only accounts for 37 percent of the estuary surface area.

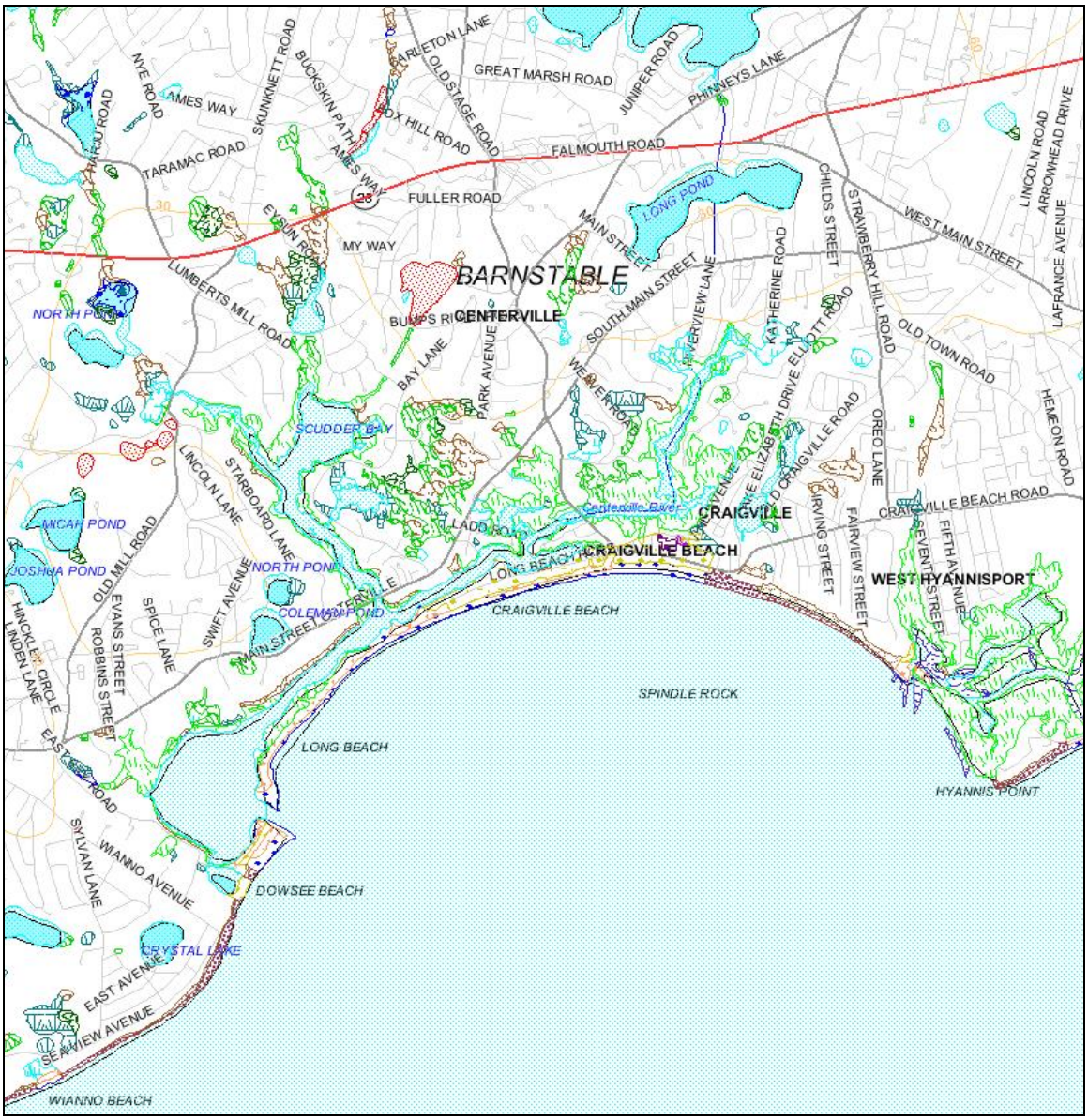


Figure V-1. Map of the Centerville River estuary (from Massachusetts Office of Geographic and Environmental Information).

Circulation in the Centerville River system is dominated by tidal exchange with Nantucket Sound. From measurements made in the course of this study, the average tide range at the entrance to Centerville River is approximately 2.66 feet. Flow restrictions caused by narrow channels, bridge abutments, and frictions losses, reduce the tide range in upper Centerville River to approximately 2.52 feet. Freshwater inflow is relatively small in comparison to tidal waters entering through the inlets, and does not have a significant impact on the hydraulic response of the system.

The hydrodynamic study consisted of two major components. In the first portion of the study, bathymetry, Acoustic Doppler Current Profile (ADCP) measurements, and tide data were collected in order to accurately characterize the physical system, and to provide data necessary for the hydrodynamic modeling portion of the study. The bathymetry survey of Centerville River

was performed to determine the variation of embayment and channel depths throughout the system. This survey addressed the previous lack of adequate bathymetry data for this area. In addition to the survey, tides were recorded for 44 days at four locations within Centerville River and at an offshore gage. This tide data were necessary to run and calibrate the hydrodynamic model of the system.

A numerical hydrodynamic model of the Centerville River system was developed in the second portion of this study. Using the bathymetry survey data, a finite element model grid was generated for use with the RMA-2 hydrodynamic code. The tide data from the offshore gage was used to define the open boundary condition that drives the circulation of the model, and data from the five locations within the system were used to calibrate and verify model performance to ensure that it accurately represents the dynamics of the real, physical system. In addition to the calibration process, the ADCP current measurements supplied the data needed as an independent verification of the hydrodynamic model results.

The calibrated computer model of the Centerville River system was used to compute the flushing rates of each of the sub-embayments of the system. Though water quality in an embayment cannot be directly inferred by use of the computed flushing rate alone, it can serve as a useful indicator of an embayments flushing performance relative to other similar systems. The ultimate utility of this hydrodynamic model is as input into a constituent transport model, where water quality constituents like nitrogen are modeled to determine the water quality dynamics of a system.

For this system, the final calibrated model offers an understanding of water movement through the estuary, and provides the first step towards evaluating the water quality of these estuarine systems, as well as understanding nitrogen loading “thresholds” for each system. Tidal flushing information will be utilized as the basis for a quantitative evaluation of water quality. Nutrient loading data combined with measured environmental parameters within the various sub-embayments become the basis for an advanced water quality model based on total nitrogen concentrations. This type of model provides a tool for evaluating existing estuarine water quality, as well as determining the likely positive impacts of various alternatives for improving overall estuarine health, enabling the bordering towns to understand how pollutant loadings into the estuary will affect the biochemical environment and its ability to sustain a healthy marine habitat.

V.2 GEOMORPHIC AND ANTHROPOGENIC EFFECTS TO THE ESTUARINE SYSTEM

The southern coast of Cape Cod in the vicinity of Centerville River is a relatively quiescent region (Figure V-2). The only exposure to waves directly from the Atlantic Ocean is through the 4 mile wide opening of Vineyard Sound to the southwest, the 10 mile wide Nantucket Sound opening to the east (between Monomoy Point and Nantucket Island) and the 7 mile gap of Muskeget Channel to the south. As a result of this sheltering, the study area is mostly limited to exposure to short period waves which are locally generated. Although natural wave and tidal forces continue to reshape the shoreline, day-to-day conditions have limited impact on the shoreline migration and/or inlet stability. For typical wave conditions, longshore transport of sand is from west-to-east along the south coast of Barnstable, due primarily to the local wind-driven waves. Tidal currents within Nantucket Sound flood to the northeast and ebb to the southwest.



Figure V-2. Aerial photograph of the Centerville River.

In contrast to the mild day-to-day conditions, infrequent hurricane events such as the hurricanes of 1938, 1944, and 1954, as well as Hurricane Bob in 1991, all caused significant overwash and transport of beach sediments. The 1944 hurricane broke through the beach opposite the entrance to Bumps River. This breach closed naturally over a two year period. (USACE, 1977) In addition to the hurricane events in the region, northeast storm events (causing waves to approach the shoreline from the east and southeast) create a sediment transport reversal from typical conditions, where the longshore sediment transport is generally from east-to-west for a short time.

The single most dominant factor for shoreline change in the study area is the construction of the 400 foot long stone jetty which defines the western edge of the entrance to East Bay and also serves as the eastern edge of Dowses Beach. The history of the jetty construction is unclear, although shoreline maps from the U.S. Coast and Geodetic Survey show that the jetty was constructed sometime between 1893 and 1939 (Figure V-3). The accretion of Dowses Beach and accompanying offset of Long Beach clearly reveal that the construction of the west jetty occurred at some point after the first map but before the second.

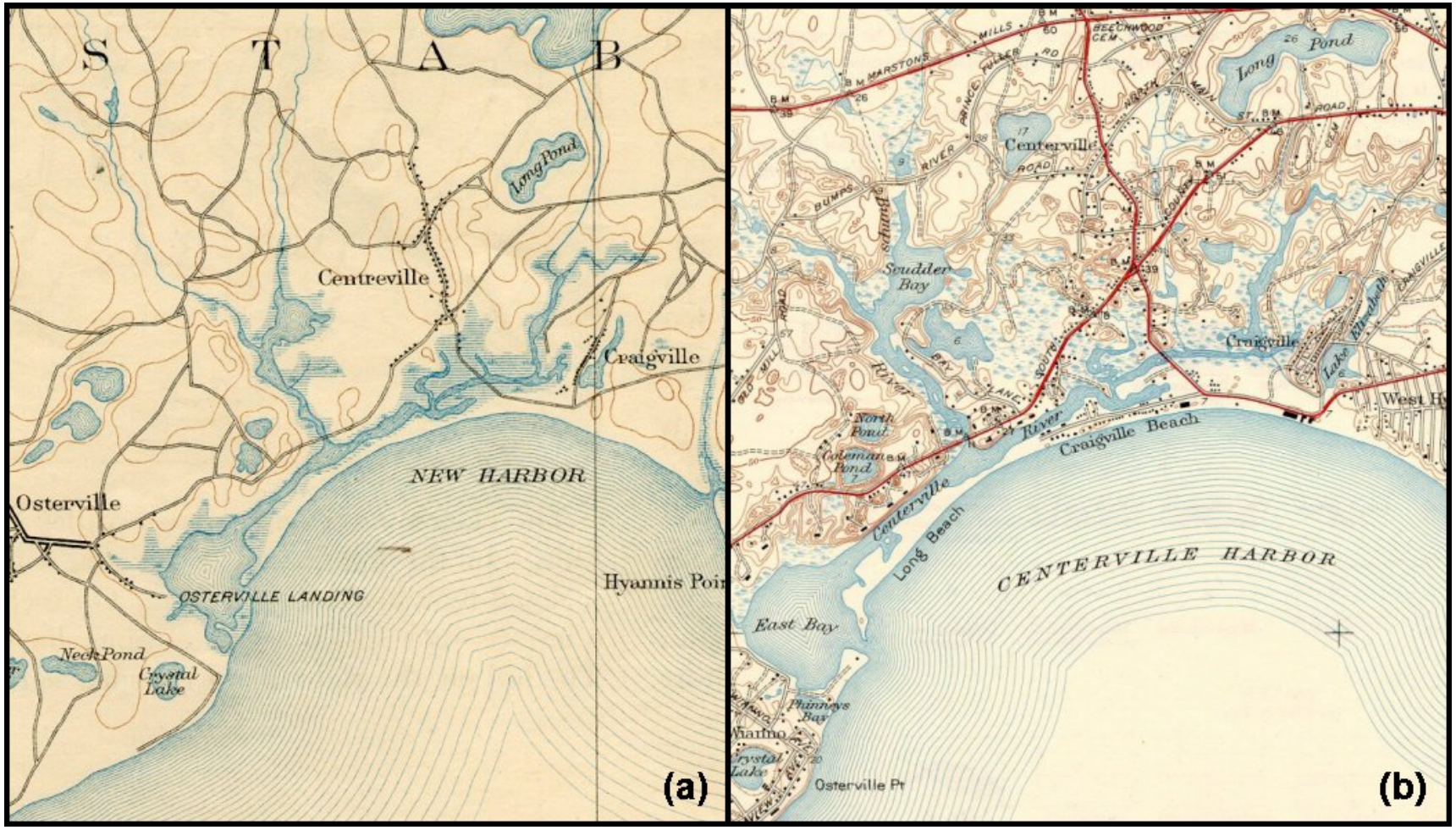


Figure V-3. Historical maps of the Centerville River study area from (a) 1893 and (b) 1939.

The new jetty served to impound a majority of the sand which would normally have continued to the east onto Long Beach. This trapping of sand by the jetty, and to a lesser extent the inlet itself, starved the downdrift section of shoreline, leading to the erosion and retreat of Long Beach. Dowses Beach is shown in Figure V-4, both in 1971 and 2005. The position of the shoreline with respect to the jetty looks to have advanced only a small bit seaward, suggesting that the jetty was close to being filled to impoundment in 1971. In this condition, sediment is no longer interrupted by the structure itself, but is bypassed into the inlet and carried to the flood shoals inside East Bay or offshore. Some of this sand continues to Long Beach, while some is likely lost to deep water and not returned to the nearshore system.

The entrance channel to East Bay was dredged in 1971 and about 30,000 cubic yards of the material was placed on the west end of Dowses Beach where there had been erosion issues. About 20,000 cubic yards of material 1971 dredging was placed on Long Beach to the east. This small amount of sand likely provided only a small benefit to Long Beach, which has experienced a retreat of well over 100 feet from its pre-jetty location. In addition to nourishment related to navigational dredging, residents have nourished Long Beach using private funds.

V.3 FIELD DATA COLLECTION AND ANALYSIS

Accurate modeling of system hydrodynamics is dependent upon measured conditions within the estuary for two important reasons. To accurately define the system geometry and boundary conditions for the numerical model and to provide 'real' observations of hydrodynamic behavior to calibrate and verify the model results.

To support hydrodynamic and future water quality modeling efforts in Centerville River, bathymetry, tidal currents, and water elevation variations of the embayments were measured. Cross-channel current measurements were surveyed through a complete tidal cycle at two locations in Centerville River.

The system geometry was defined using the bathymetry data collected and aerial photographs. The bathymetric data collection effort was focused on areas of flow constrictions, near inlets, channels, and narrow sections of the estuaries. The bathymetric information was utilized to develop the computational grid of the system geometry for the hydrodynamic modeling effort. Tidal elevation measurements within the embayment were used for both forcing conditions and to evaluate tidal attenuation through the estuarine system.

V.3.1 Data Acquisition

V.3.1.1 Water Elevation

Changes in water surface elevation were measured using internal recording tide gages. These tide gages were installed on fixed platforms (such as pier pilings or screw anchors secured to the seabed) to record changes in water pressure over time. Variations in the water surface can be due to tides, wind set-up, or other low frequency oscillations of the sea surface. The tide gages were installed in 5 locations in Centerville River estuary (Figure V-5) in April 2004 and recovered mid-May 2004. Data records span at least 29 days to yield an adequate time period for resolving the primary tidal constituents.

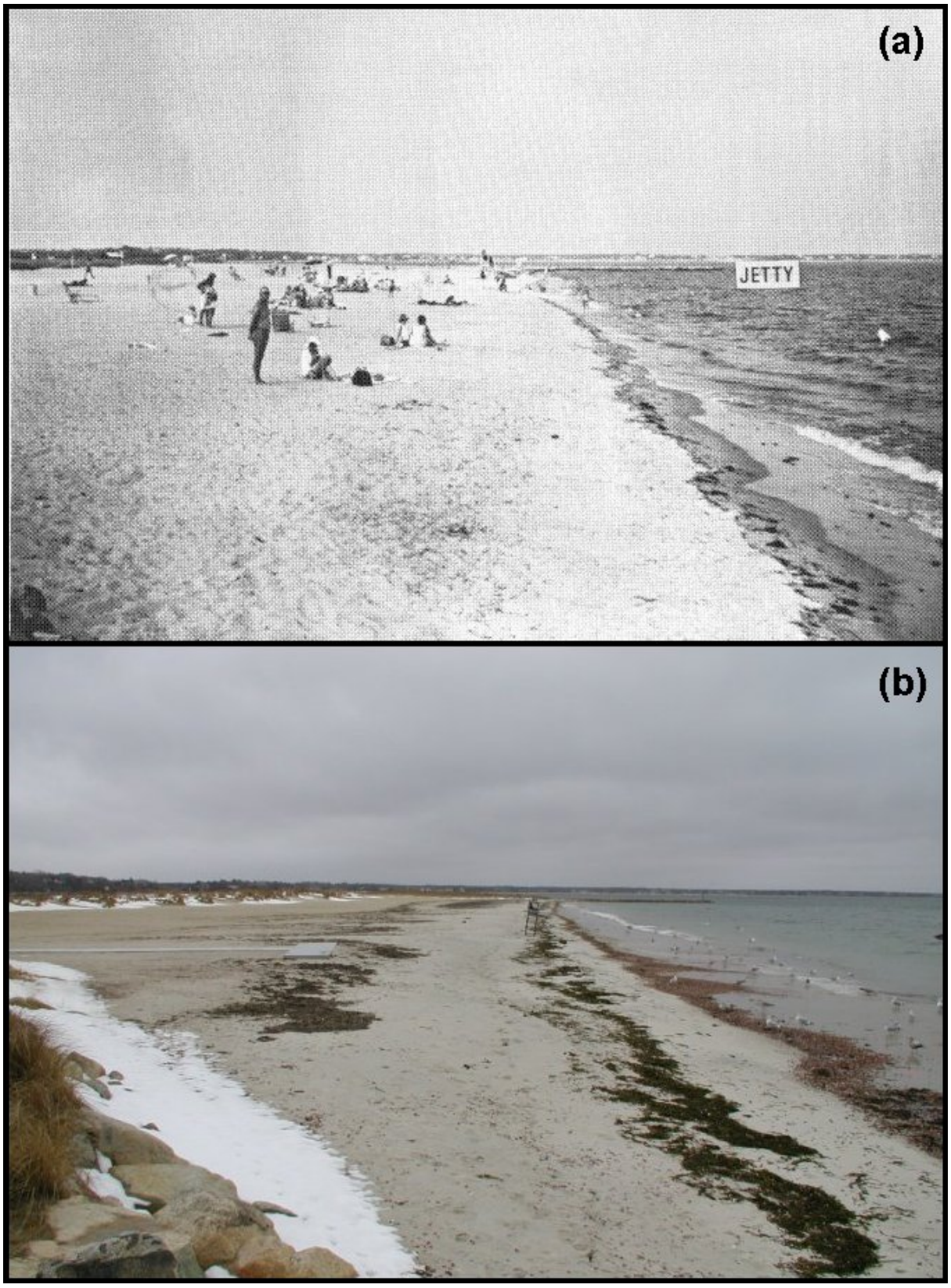


Figure V-4. Photographs of Dowses Beach looking to the east towards the jetty in (a) 1971 and (b) 2005.

The tide gages used for the study were Brancker XR-420 instruments. Data collections parameters were set for 10-minute intervals, with each 10-minute observation resulting from a 16-second burst of measurements that are averaged for each observation. Each of these instruments use strain gage transducers to sense variations in pressure, with resolution of 0.001% full scale and a pressure accuracy of 0.01% full scale. Each gage was calibrated prior to installation to assure accuracy.

Once the data were downloaded from each instrument, the water pressure readings were corrected for variations in atmospheric pressure. Hourly atmospheric readings were obtained from the NOAA buoy in Buzzards Bay (site BUZM3), interpolated to 10-minute intervals, and subtracted from the pressure readings, resulting in water pressure above the instrument. Further, a (constant) water density value of 1025 kg/m^3 was applied to the readings to convert from pressure units (psi) to head units (i.e., feet of water above the tide gage). Several of the sensors were surveyed into local benchmarks to provide vertical rectification of the water level; these survey values were used to adjust the water surface to a known vertical datum. The result from each gage is a time series representing the variations in water surface elevation relative to NAVD88. Figure V-6 present the water levels at each gage location.

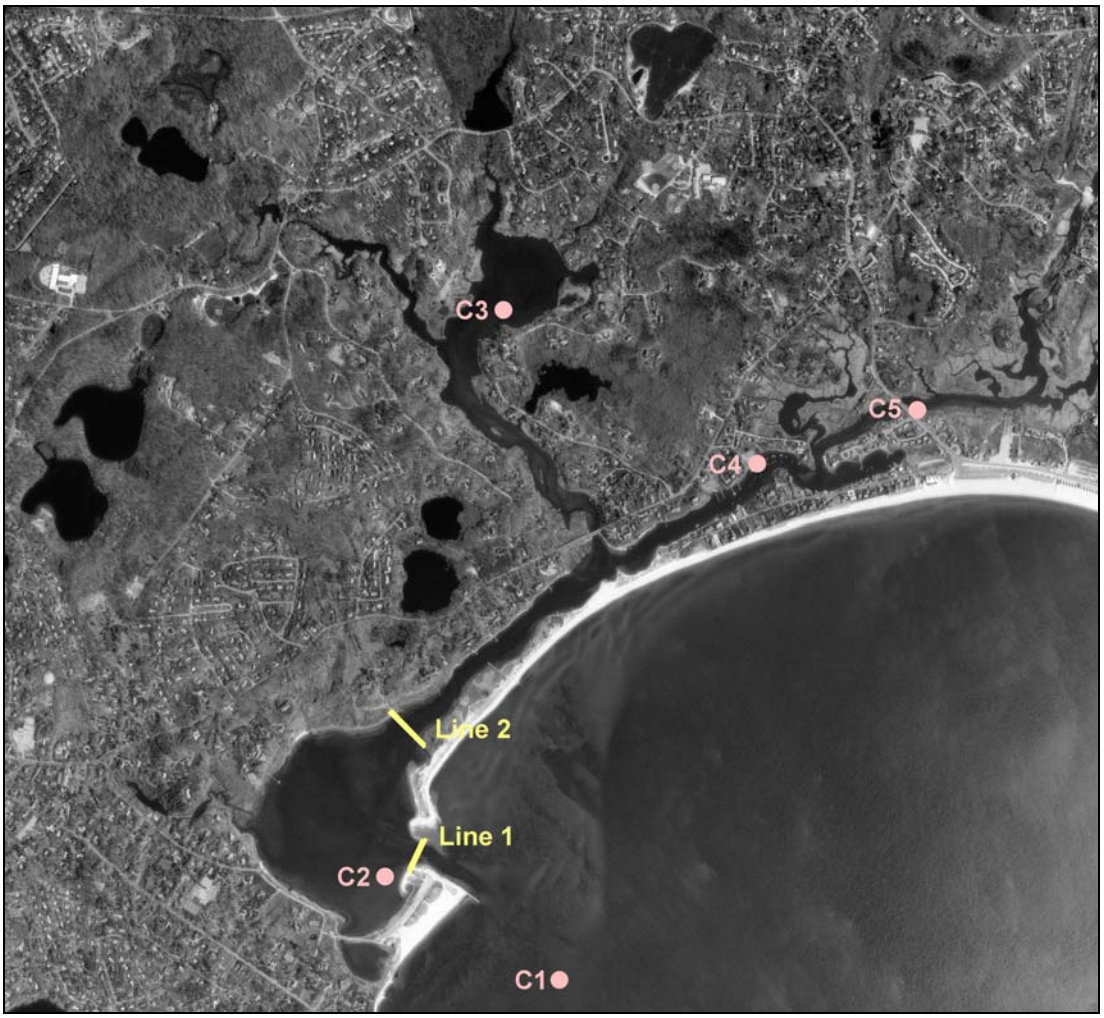


Figure V-5. Tide gage and ADCP transect locations in Centerville River C1 to C5 are tide gage locations. Yellow lines 1 and 2 are ADCP transect locations.

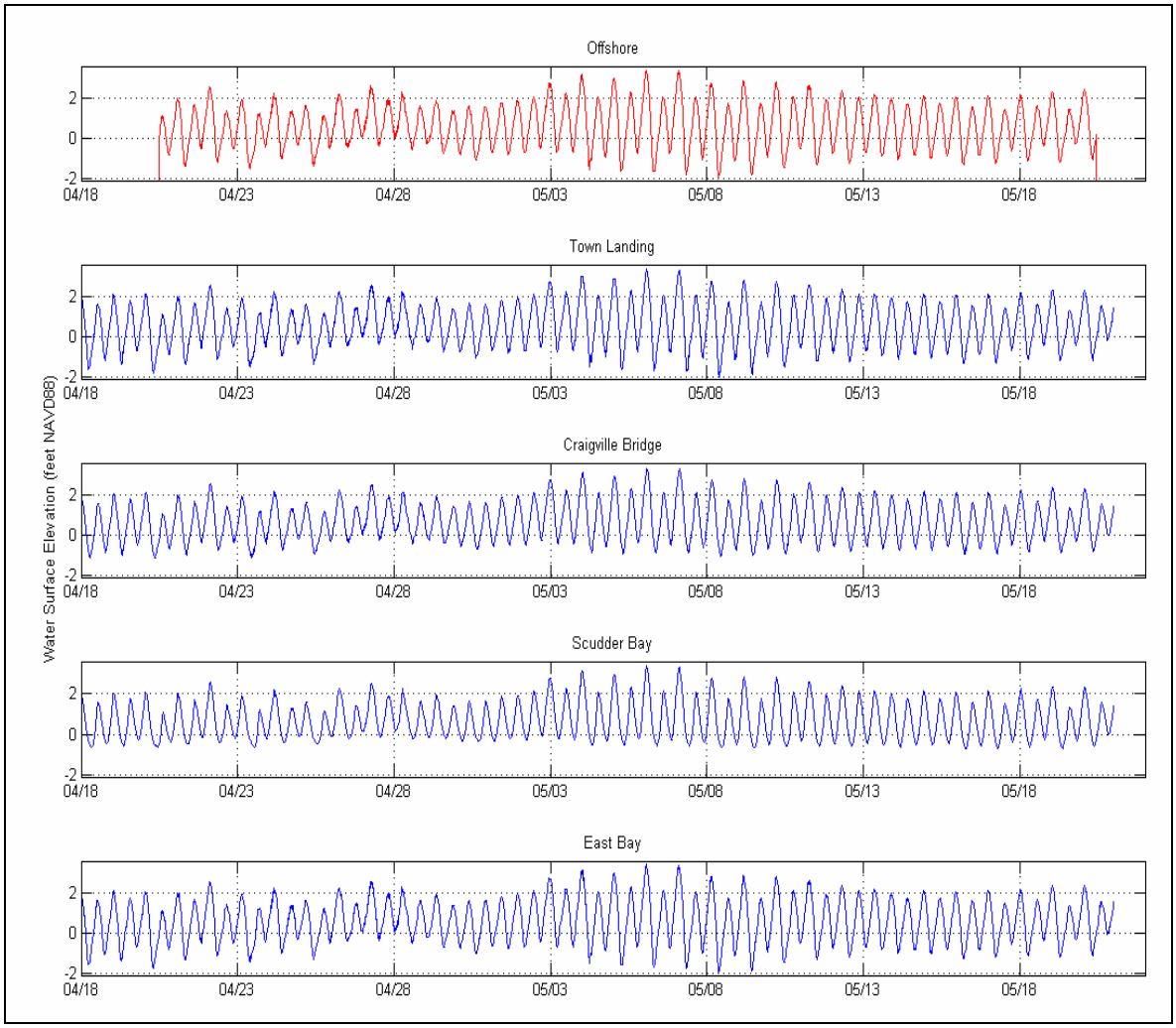


Figure V-6. Tidal elevation observations for Nantucket Sound (C1 of Figure V-5), Town Landing (location C4), Craigville Beach Bridge (location C5), Scudder Bay (location C3), and East Bay (location C2).

V.3.1.2 Bathymetry

The bathymetric, or depth, survey of Centerville River was conducted by Applied Coastal in October 2003. The surveys were completed using a small vessel equipped with a precision fathometer interfaced to a differential GPS receiver. The fathometer has a depth resolution of approximately 0.1 foot and the differential GPS provides x-y position measurements accurate to approximately 1-3 feet. Digital data output from both the echo sounder and GPS were logged to a laptop computer in Hypack.

GPS positions and echo sounder measurements were merged to produce data sets consisting of water depth as a function of x-y horizontal position (in Massachusetts Mainland State Plane, 1983). The data were combined with water surface elevations to obtain the vertical elevation of the bottom (z) relative to the NAVD 1988 vertical datum (NAVD88). The resulting xyz files (Figure V-7) were input to mapping software to calculate depth contours for the system shown in Figure V-8.

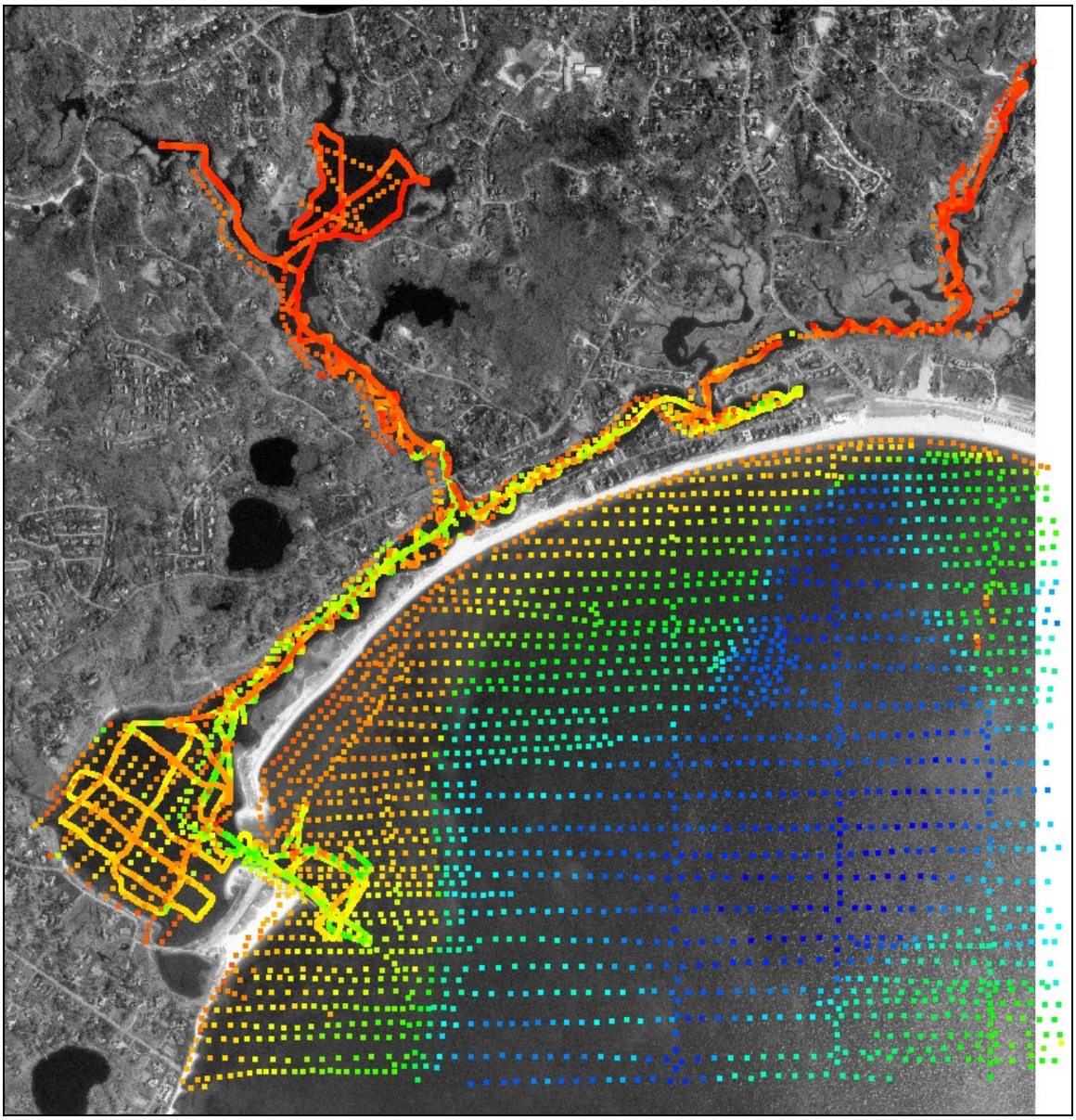


Figure V-7. Bathymetry points collected within Centerville River. Color indicates water depth relative to the NAVD88 vertical datum.

V.3.1.3 Current Measurements

The measurements were collected using an Acoustic Doppler Current Profiler (ADCP) mounted aboard a small survey vessel. The boat repeatedly navigated a pre-defined set of transect lines through the area, approximately every 30 minutes, with the ADCP continuously collecting current profiles. This pattern was repeated for approximately 10-hours to ensure measurements over the entire tidal cycle. The results of the data collection effort are high-resolution observations of the spatial and temporal variations in tidal current patterns throughout the survey area.

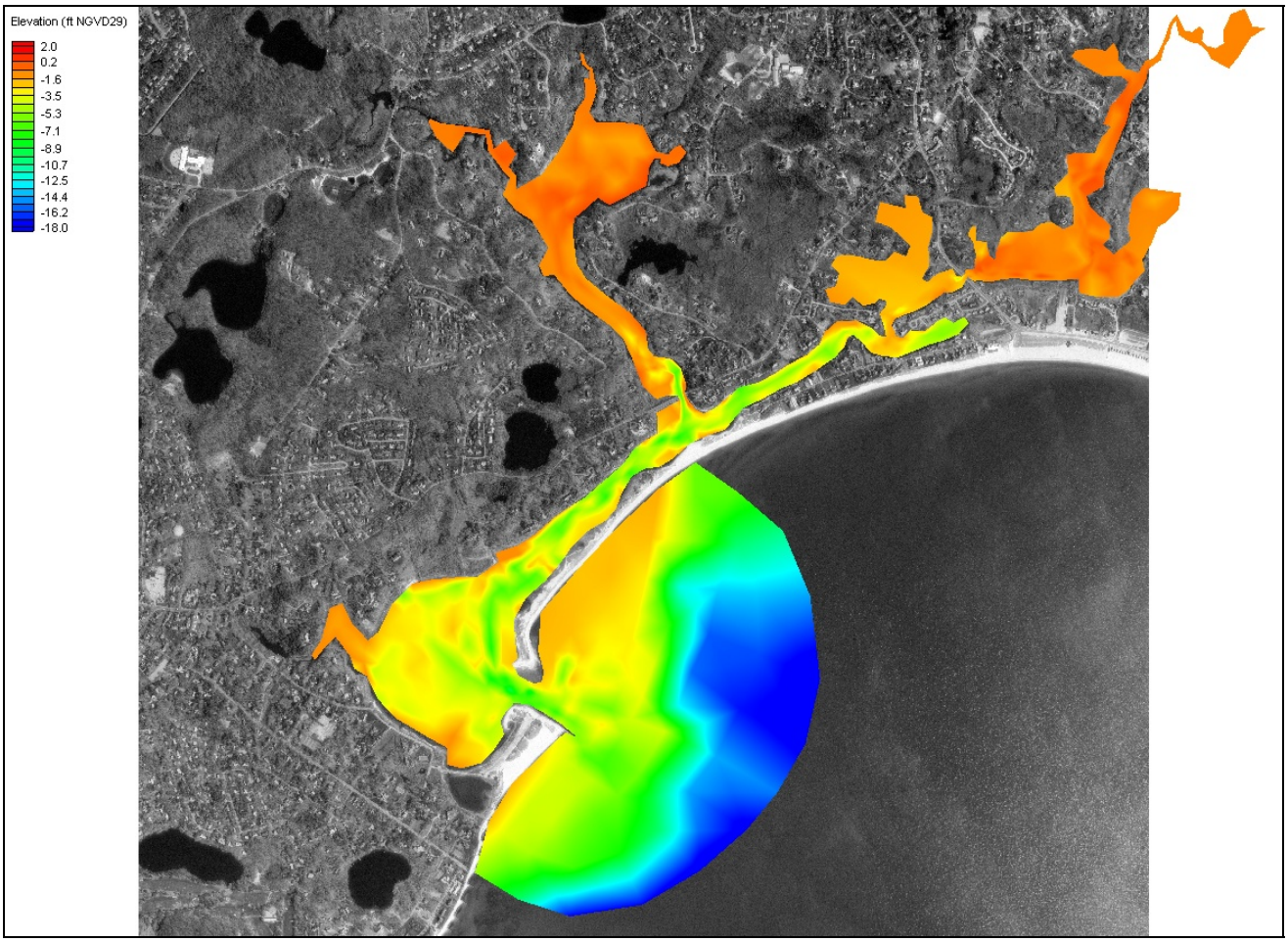


Figure V-8. Bathymetric map of Centerville River. Color indicates water depth relative to the NAVD88 vertical datum.

Measurements were obtained with a BroadBand 1200 kHz Acoustic Doppler Current Profiler (ADCP) manufactured by RD Instruments (RDI) of San Diego, CA. The ADCP was mounted to a specially constructed mast, which was rigidly attached to the rail of the survey vessel. The ADCP was oriented to look downward into the water column, with the sensors located approximately 1 foot below the water surface. The mounting technique assured no flow disturbance due to vessel wake.

The ADCP emits individual acoustic pulses from four angled transducers (at 20° from the vertical) in the instrument. The instrument then listens to the backscattered echoes from discrete depth layers in the water column. The difference in time between the emitted pulses and the returned echoes, reflected from ambient particles (plankton, debris, sediment, etc.), is the time delay. BroadBand ADCPs measure the change in travel times from successive pulses. As particles move further away from the transducers sound takes longer to travel back and forth. The change in travel time, or propagation delay, corresponds to a change in distance between the transducer and the sound scatter, due to a Doppler shift. The propagation delay, the time lag between emitted pulses, and the speed of sound in water are used to compute the velocity of the particle relative to the transducer. By combining the velocity components for at least three of the four directional beams, the current velocities are transformed using the unit's

internal compass readings to an orthogonal earth coordinate system in terms of east, north, and vertical components of current velocity.

Vertical structure of the currents is obtained using a technique called 'range-gating'. Received echoes are divided into successive segments (gates) based on discrete time intervals of pulse emissions. The velocity measurements for each gate are averaged over a specified depth range to produce a single velocity at the specified depth interval ('bin'). A velocity profile is composed of measurements in successive vertical bins.

The collection of accurate current data with an ADCP requires the removal of the speed of the transducer (mounted to the vessel) from the estimates of current velocity. 'Bottom tracking' is the strongest echo return from the emission of an additional, longer pulse to simultaneously measure the velocity of the transducer relative to the bottom. Bottom tracking allows the ADCP to record absolute versus relative velocities beneath the transducer. In addition, the accuracy of the current measurements can be compromised by random errors (or noise) inherent to this technique. Improvements in the accuracy of the measurement for each bin are achieved by averaging several velocity measurements together in time. These averaged results are termed 'ensembles'; the more pings used in the average, the lower the standard deviation of the random error.

For this study, the standard deviation (or accuracy) of current estimates (resulting from an ensemble average of 8 individual pulses) was approximately 0.30 ft/sec. Each ensemble took approximately 5-6 seconds to collect. Averaging parameters resulted in a horizontal resolution of approximately 10 feet along the transect line. For example, ADCP transect 1 (Figure V-5) at the inlet to Centerville River was approximately 250 feet across, resulting in approximately 20 to 25 independent velocity profiles per transect. The vertical resolution was set to 0.79 ft, or one velocity observation per every 9.48 inches of water depth. The first measurement bin was centered 1.77 feet from the surface, allowing for the transducer draft as well as an appropriate blanking distance between the transducer and the first measurement.

Position information was collected by Hypack, an integrated navigation software package running on a PC computer, linked to a differential GPS. The position data were read from the device in the WGS-84 coordinate system, and transformed to NAD 1983 Massachusetts Mainland State Plane coordinates. Position updates were available every 1 second. Clock synchronization between the GPS and ADCP laptop computers allowed each ADCP ensemble to be assigned an accurate GPS position during post-processing.

Current measurements were collected by the ADCP as the vessel navigated repeatedly a series of two (2) pre-defined transect lines in Centerville River (Figure V-5). The line-cycles were repeated every half-hour throughout the survey. The first cycle was begun at 07:29 hours (Eastern Daylight Time, EDT) and the final cycle was completed at 17:36 hours (EDT), for a survey duration of approximately 10 hours on October 24, 2003.

The transect lines 1 and 2 were run in ascending order. These lines were designed to measure as accurately as possible the volume flux through the constrictions during a complete tidal cycle. Line 1 ran across the throat of Centerville River Inlet in a west-to-east direction. Line 2 ran south-to-north across inlet to East Bay along Centerville River along the eastern shore of East Bay.

V.3.2 ADCP Data Processing Techniques

Data processing consisted of the following:

- Convert raw ADCP (binary) files to ASCII data
- Merge ADCP vertical profile data with GPS position data
- QA/QC procedures to verify the accuracy of both ADCP and position data
- Manipulate the ADCP data to calculate spatial averages and cross section discharge values

The data files were converted from raw binary format to ASCII values using RDI's BBLIST conversion program. The command set for this conversion process is described in greater detail in the RDI ADCP manual, and consists of developing a user-defined output file format, through which all conversions are defined.

The output data file from this procedure consists of multiple ensemble data 'packets'. The ensemble 'packet' consists of a single line containing the time of the profile, the ensemble number, and the measured water temperature (measured by the ADCP's internal temperature sensor) followed by consecutive rows and columns of the profile data. Each row of profile data corresponds to one bin, or depth layer, with succeeding columns representing east and north components of velocity, error velocity, speed, direction, echo amplitudes (for 4 beams), and correlation magnitudes (for 4 beams). Each ensemble, collected approximately every 5-6 seconds, has 30 rows corresponding to each discrete depth layer, starting at 1.77 feet. A single data file consists of multiple ensembles, as few as 25-30 to as many as 100. A single data file was recorded for each transect.

The next step in the processing was the assignment of an accurate x-y position pair to each ensemble. This was accomplished using the time stamp of both the ADCP data file and the position data file. Prior to the survey, the clocks used for each system were synchronized to assure this operation was valid. The procedure finds the time of each ADCP ensemble, then searches the position data file for the nearest corresponding time. When the nearest time is found, subject to a 'neighborhood' limit of 1 second, the x-y pair for that time is assigned to the ADCP ensemble. This method produces some inaccuracies; however for this survey the error in position definition was less than approximately 3.5 feet (calculated as vessel speed of 2 knots times the neighborhood value of 1 second for this survey). If no time is found within 1 second of the ADCP time, then a position is calculated using the ADCP bottom track velocity for that ensemble, and the time interval between ensembles.

Once each ensemble was assigned a valid x-y position, the data were reduced to calculate vertical averages as well as total discharge. A mean value of each east and north component of velocity is calculated for each vertical profile. These component mean values are then used to determine the mean speed and mean direction.

The total discharge time series represents the total volumetric flow through a waterway cross-section over the duration of the tidal cycle. Discharge calculations were performed on velocity components normal and tangential to the transect azimuth, which in most cases was perpendicular to the channel axis. To determine accurately the discharge normal to the channel cross-section (i.e. along-stream), the east and north velocity components were rotated into normal (along-stream) and tangential (cross-stream) components. Only the along-stream component was used to calculate total discharge.

The discharge through a cross section, Q_t, is the product of the upstream velocity, $V_{upstream}$, multiplied by the cross sectional area, A_{cs}, or

$$\Sigma Q_t = \Sigma_{i=1...N} (V_{upstream} * A_{cs})$$

where the cross sectional area is the water depth times the lateral (cross-stream) distance from the previous ensemble profile. The summation occurs over i, where i represents each individual ensemble profile from 1 to N, with 1 representing the top (surface) bin and N representing the deepest (near-bottom) bin.

Data recorded for the bottom-most bins in the water column can be contaminated by side lobe reflections from the transducer. At times, the measurements can be invalid. Validity of the bottom bin measurements is determined by comparing the standard deviation of bottom values to the standard deviation of mid-column measurements. If the standard deviation at the bottom was more than twice the standard deviation of mid-column measurements, the bottom bin was discarded from the discharge calculation. If the bottom value was within the limits defined by adjacent measurements, the value was included in the calculation.

The total discharge calculations assume a linear extrapolation of velocity from the surface to the first measurement bin. Since the ADCP cannot directly measure the surface velocity, it is assumed the surface layer discharge is equivalent to the discharge in the first depth layer. The same linear assumption was applied to bottom bins when the bin measurement was declared invalid; that is, the bottom bin value was assumed equivalent to the overlying bin velocity value.

V.3.3 Discussion of Results

V.3.3.1 Tidal Harmonic Analysis

Analyses of the tide and bathymetric data provided insight into the hydrodynamic characteristics of the Centerville River system. Harmonic analysis of the tidal time series produced tidal amplitude and phase of the major tidal constituents, and provided assessments of hydrodynamic 'efficiency' of each system in terms of tidal attenuation. This analysis also yielded an assessment of the relative influence of non-tidal, or residual, processes (such as wind forcing) on the hydrodynamic characteristics of each system.

Figure V-6 shows the tidal elevation for the period April 18 through May 21, 2004 at five locations in Centerville River: Offshore Centerville River in Nantucket Sound (Location C1), East Bay (Location C2), Scudder Bay (location C3), Centerville River at the town landing (Location C4), and Centerville River on the eastern side of Craigville Beach Bridge (Location C5). The curves have a predominant 12.42-hour variation around the lunar semi-diurnal (twice-a-day), or M_2, tidal constituent. There was also a strong modulation of the lunar and solar tides, resulting in the familiar spring-neap fortnightly cycle. The spring (maximum) tide range was approximately 4.5 feet, and occurred on April 26. The neap (or minimum) tide range was 1.9 feet, occurring May 5.

To better quantify the changes to the tide from the inlet to inside the system, the standard tide datums were computed from the 29-day records. These datums are presented in Table V-1. For most NOAA tide stations, these datums are computed using 19 years of tide data, the definition of a tidal epoch. For this study, a significantly shorter time span of data was available; however, these datums still provide a useful comparison of tidal dynamics within the system. The Mean Higher High Water(MHHW) and Mean Lower Low Water(MLLW) levels represent the

mean of the daily highest and lowest water levels. The Mean High Water (MHW) and Mean Low Water (MLW) levels represent the mean of all the high and low tides of a record, respectively. The Mean Tide Level (MTL) is simply the average of the MHW and MLW.

Table V-1. Tide datums computed from 29-day records collected in Centerville River in April/May 2004. Datum elevations are given relative to NAVD 88.

Tide Datum	Offshore (feet)	East Bay (feet)	Scudder Bay (feet)	Centerville River-Town Landing (feet)	Centerville River-Craigville Beach (feet)
Maximum Tide	3.379	3.427	3.379	3.355	3.325
MHHW	2.376	2.396	2.375	2.371	2.373
MHW	1.931	2.012	1.996	1.989	2.012
MTL	0.600	0.604	0.829	0.586	0.750
MLW	-0.732	-0.803	-0.338	-0.817	-0.512
MLLW	-1.194	-1.169	-0.500	-1.201	-0.799
Minimum Tide	-1.952	-1.939	-0.734	-1.987	-1.103

Harmonic analyses were performed on the time series from each gage location. Harmonic analysis is a mathematical procedure that fits sinusoidal functions of known frequency to the measured signal. The amplitudes and phase of 23 known tidal constituents result from this procedure. Table V-2 presents the amplitudes of the eight largest tidal constituents. The M_2, or the familiar twice-a-day lunar semi-diurnal, tide is the strongest contributor to the signal with an amplitude of 1.6 feet in Nantucket Sound. The range of the M_2 tide is twice the amplitude, or 3.2 feet. The diurnal tides, K_1 and O_1, possess amplitudes of approximately 0.3 feet and 0.2 feet respectively, throughout the Centerville River system. Other semi-diurnal tides strongly contribute to the observed tide; the S_2 (12.00 hour period) and N_2 (12.66-hour period) tides both have amplitudes of 0.4 feet offshore of Centerville River.

The observed astronomical tide is therefore the sum of several individual tidal constituents, with a particular amplitude and frequency. For demonstration purposes a graphical example of how these constituents add together is shown in Figure V-9.

Table V-2 also shows how the constituents vary as the tide propagates into the upper reaches of the two tidal rivers. Note the reduction in the M_2 amplitude from Nantucket Sound to the inlets, and the further reduction at the upper portions of Centerville and Little Rivers. The amplitude reduction is greatest at the upper reaches of Little River, where the M_2 amplitude is 0.33 feet smaller than offshore. The decrease in the amplitude of M_2 constituent is evidence of frictional damping. Usually, a portion of the energy lost from the M_2 tide is transferred to higher harmonics (i.e., the M_4 and M_6), and is observed as an increase in amplitude of these constituents over the length of an estuary. This effect is observed in the analysis of the Centerville River tides, where a maximum 0.1 ft increase occurs in the M_4.

Table V-3 presents the phase delay of the M_2 tide at all tide gage locations compared to the offshore gage in Nantucket Sound. Phase delay is another indication of tidal damping, and results with a later high tide at inland locations. The greater the frictional effects, the longer the delay between locations.

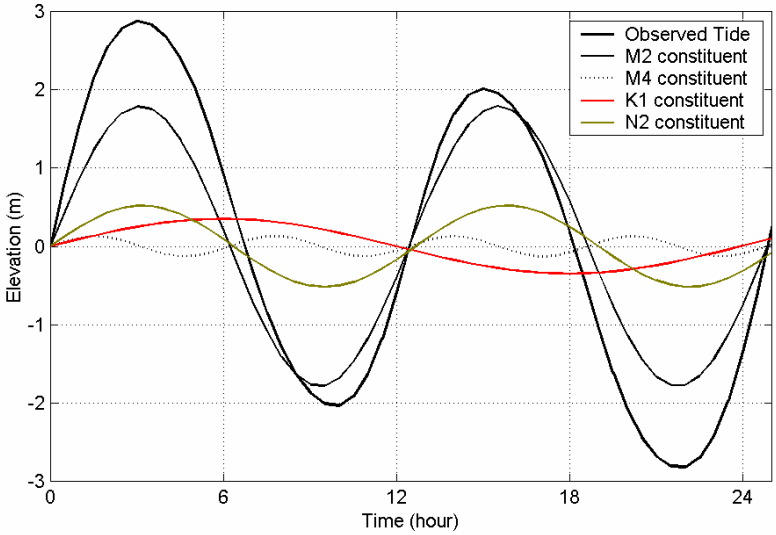


Figure V-9. Example of an observed astronomical tide as the sum of its primary constituents.

Table V-2. Tidal Constituents, Centerville River, April-May 2004.

	AMPLITUDE (feet)							
	M2	M4	M6	S2	N2	K1	O1	Msf
Period (hours)	12.42	6.21	4.14	12.00	12.66	23.93	25.82	354.61
Offshore	1.59	0.18	0.01	0.41	0.44	0.24	0.18	0.07
East Bay	1.48	0.20	0.02	0.35	0.41	0.25	0.17	0.04
Scudder Bay	1.34	0.28	0.03	0.28	0.39	0.24	0.16	0.12
Centerville River-Town Landing	1.47	0.24	0.02	0.35	0.40	0.25	0.17	0.09
Centerville River-Craigville Beach	1.26	0.26	0.03	0.27	0.36	0.25	0.15	0.14

Table V-3. M_2 Tidal Attenuation, Centerville River, April-May 2004 (Delay in minutes relative to Offshore).

Location	Delay (minutes)
Offshore	--
East Bay	21.45
Scudder Bay	30.80
Centerville River -Town Landing	38.73
Centerville River -Craigville Beach	56.74

In addition to the tidal analysis, the data were further evaluated to determine the importance of tidal versus non-tidal processes to changes in water surface elevation. These other processes include wind forcing (set-up or set-down) within the estuary, as well as sub-tidal oscillations of the sea surface. Variations in water surface elevation can also be affected by freshwater discharge into the system, if these volumes are relatively large. This analysis calculated the energy (or variance) of the original water elevation time series, and compared these energy values to that of the purely tidal signal (re-created by summing the contributions from the 23 known harmonic constituents). Subtracting the tidal signal from the original elevation time series resulted with the non-tidal, or residual, portion of the water elevation changes. The energy of this non-tidal signal is compared to the tidal signal, and yields a quantitative measure of how important these non-tidal physical processes can be to hydrodynamic circulation within the estuary. The results of this analysis for the Centerville River region are posted in Table V-4.

Table V-4. Percentages of Tidal versus Non-Tidal Energy, Centerville River, April to May 2004.

	Total Variance ($ft^2 \cdot sec$)	Tidal (%)	Non-tidal (%)
Offshore	1.55	92.4	7.6
East Bay	1.36	91.8	8.2
Scudder Bay	1.14	90.9	9.1
Centerville River - Town Landing	1.37	91.0	9.0
Centerville River - Craigville Beach	1.04	89.3	10.7

Table V-4 shows that the percentage of tidal energy was largest in the offshore signal in Nantucket Sound; as should be expected given the tidal attenuation through the system. In general, the energy of the signal decreases with distance from the offshore gage, with the lowest energy found in upper regions of the estuarine systems. The analysis also shows that tides are responsible for approximately 90% of the water level changes in Centerville River. Meteorological effects in this data set were significant (approximately 10%) contributors to the total observed water level changes. However, the change in the non-tidal variance from offshore to the systems' upper reaches (approximately 3%) indicates that the offshore tide is adequate for use as the forcing time series of the computer hydrodynamic model of these systems. This relative increase in non-tidal energy within this system is likely due to the decrease in tidal energy as a result of frictional forces rather than actual growth of residual forces. The damping can be seen in Figure V-10.

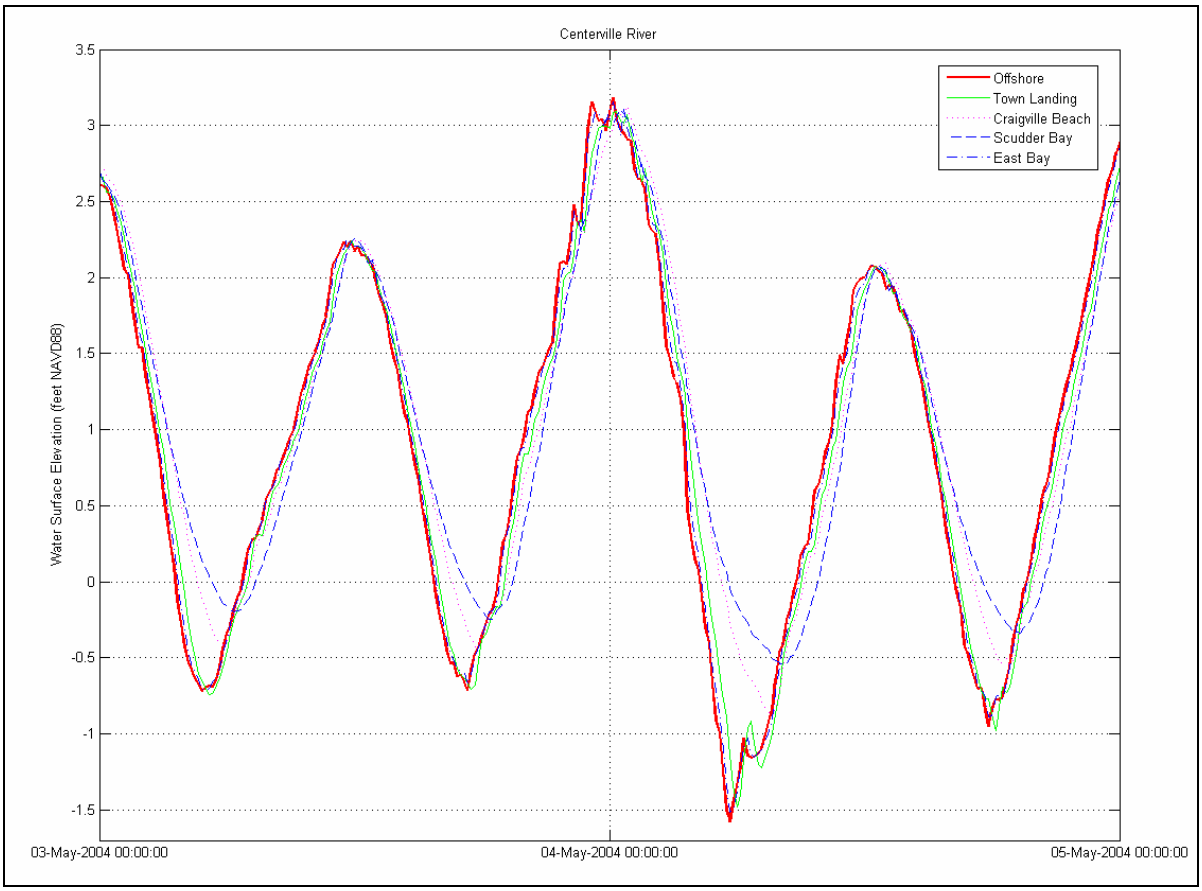


Figure V-10. Water elevation variations for a 2-day period in the Centerville River estuary. Notice the reduced amplitude as well as the delay in times of high- and low- tide relative to offshore (Nantucket Sound) due to frictional damping through the estuary.

V.3.3.2 Current Measurements

Current measurements in Centerville River, surveyed on October 24, 2003, provided observation of the temporal and spatial variability of the flow regime during a tidal cycle. The survey was designed to observe tidal flow through the Centerville River inlet, and attenuation by frictional damping through upstream constrictions at hourly intervals. The current measurements observed during the flood and ebb tides at each constriction can be seen in Figures V-11 through V-14. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. For example, at the Centerville River inlet (line A1), positive along-channel is in the direction of northwest, and positive cross-channel is in the direction of northeast. In the lower left panel of the figures, the mean current or average currents across the channel are shown relative to the shoreline. The lower right panel indicates the stage of the tide during the transect illustrated (shown by a vertical line through the water elevation curve).

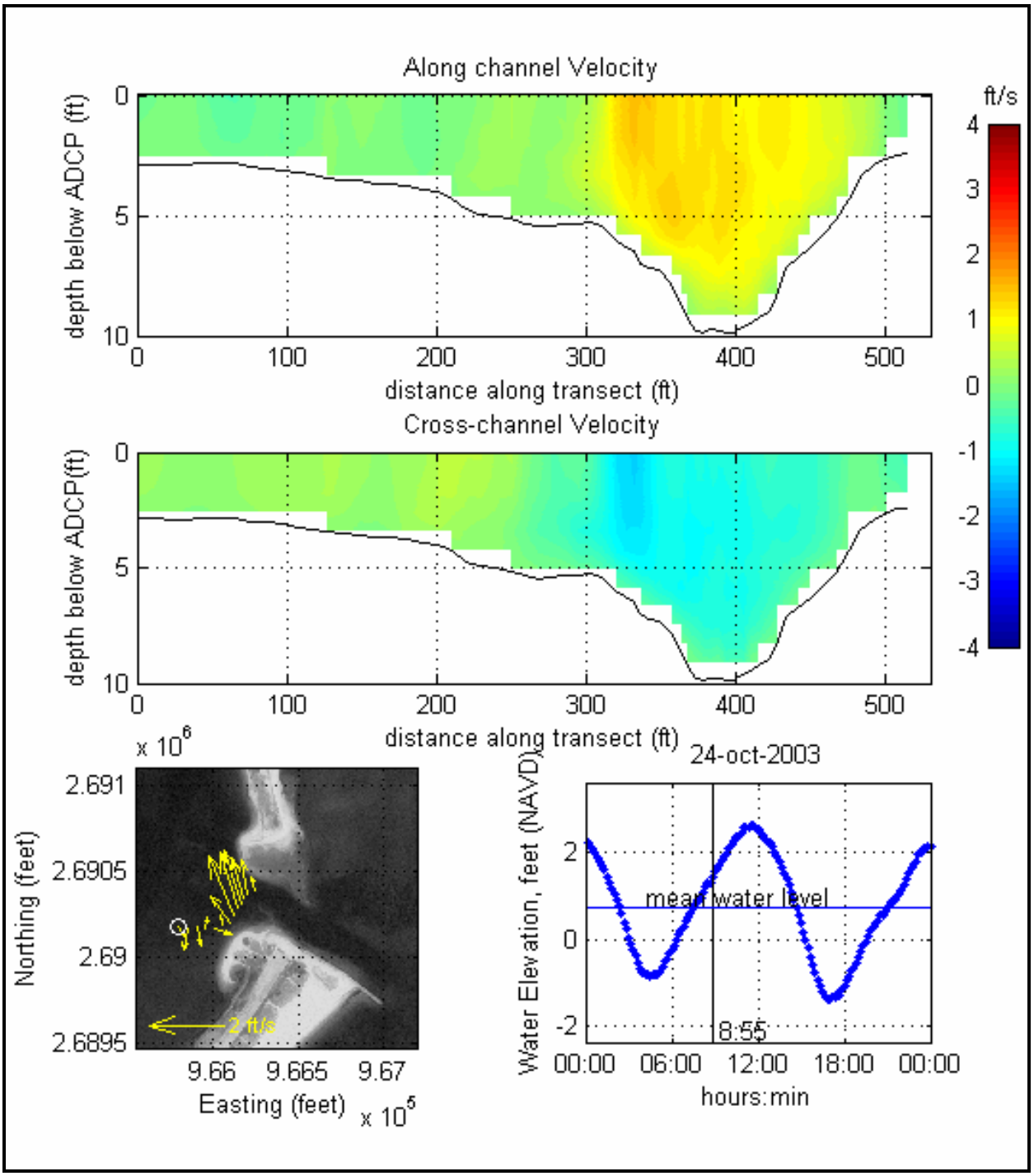


Figure V-11. Color contour plots of along-channel and cross-channel velocity components for transect line A1 across the Centerville River inlet measured at 8:55 on October 24, 2003 during the flood tide. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel.

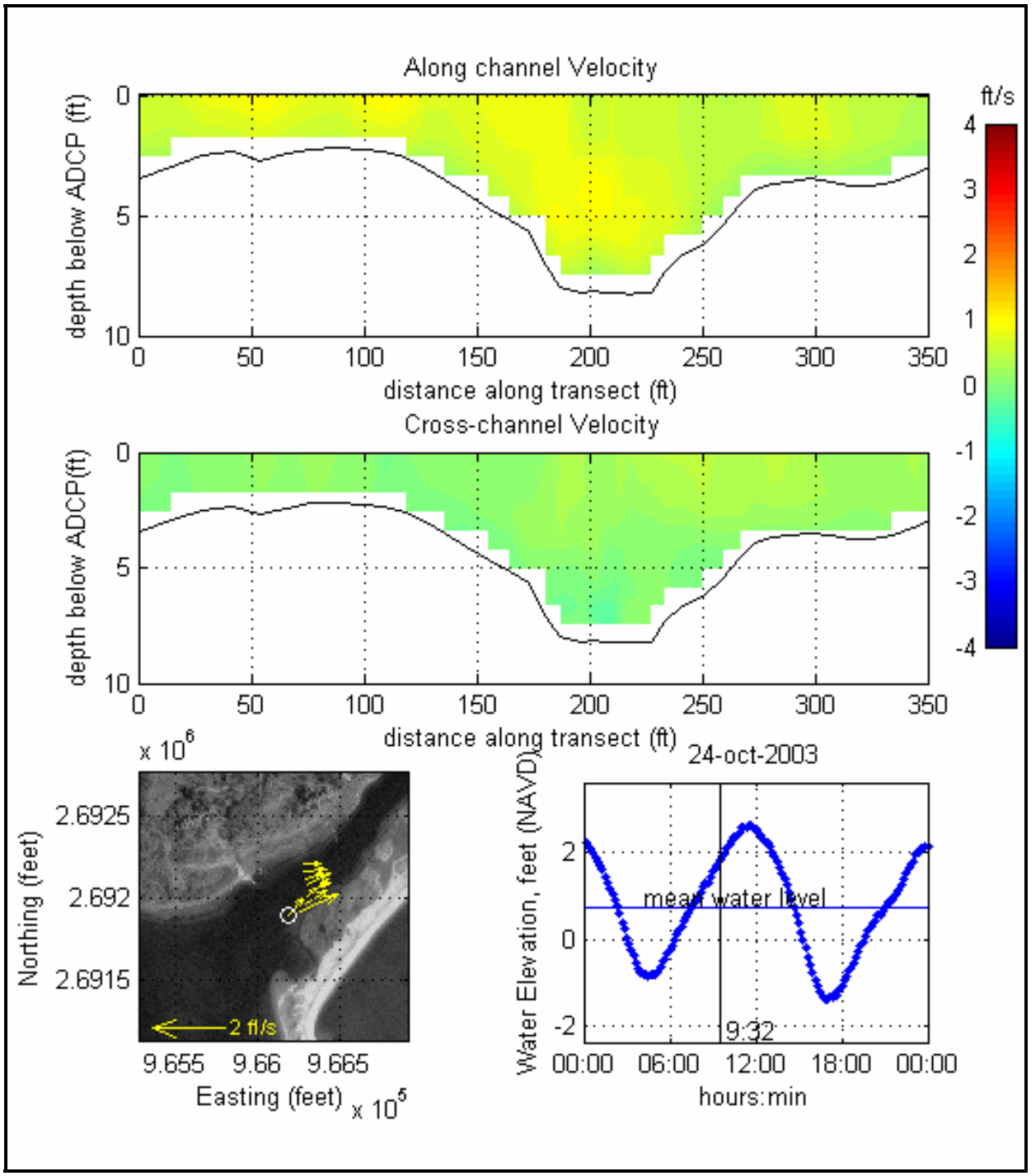


Figure V-12. Color contour plots of along-channel and cross-channel velocity components for transect line A2 across Centerville River measured at 9:32 on October 24, 2003 during the flood tide. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel.

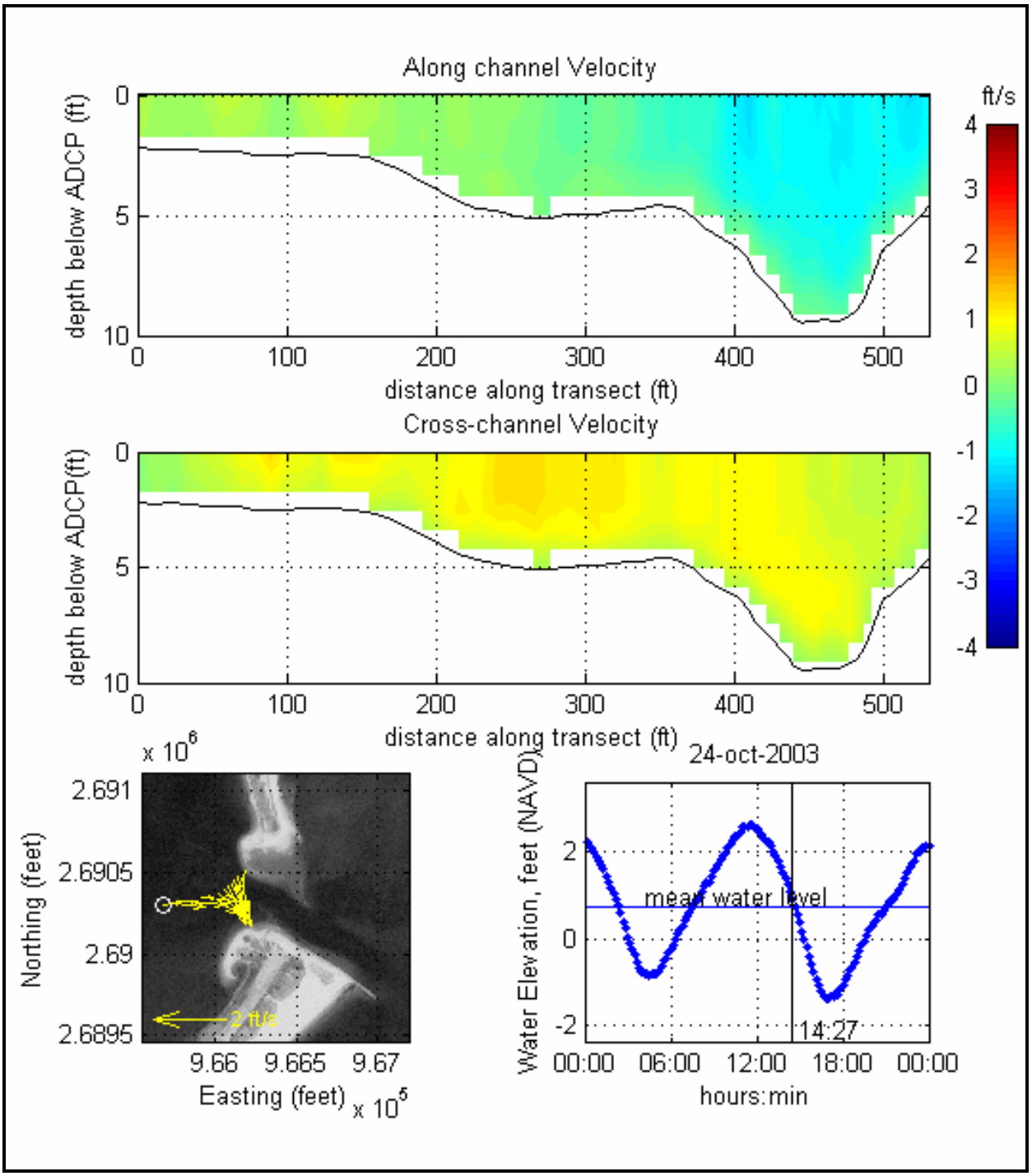


Figure V-13. Color contour plots of along-channel and cross-channel velocity components for transect line A1 across Centerville River inlet measured at 14:27 on October 24, 2003 during the ebb tide. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel.

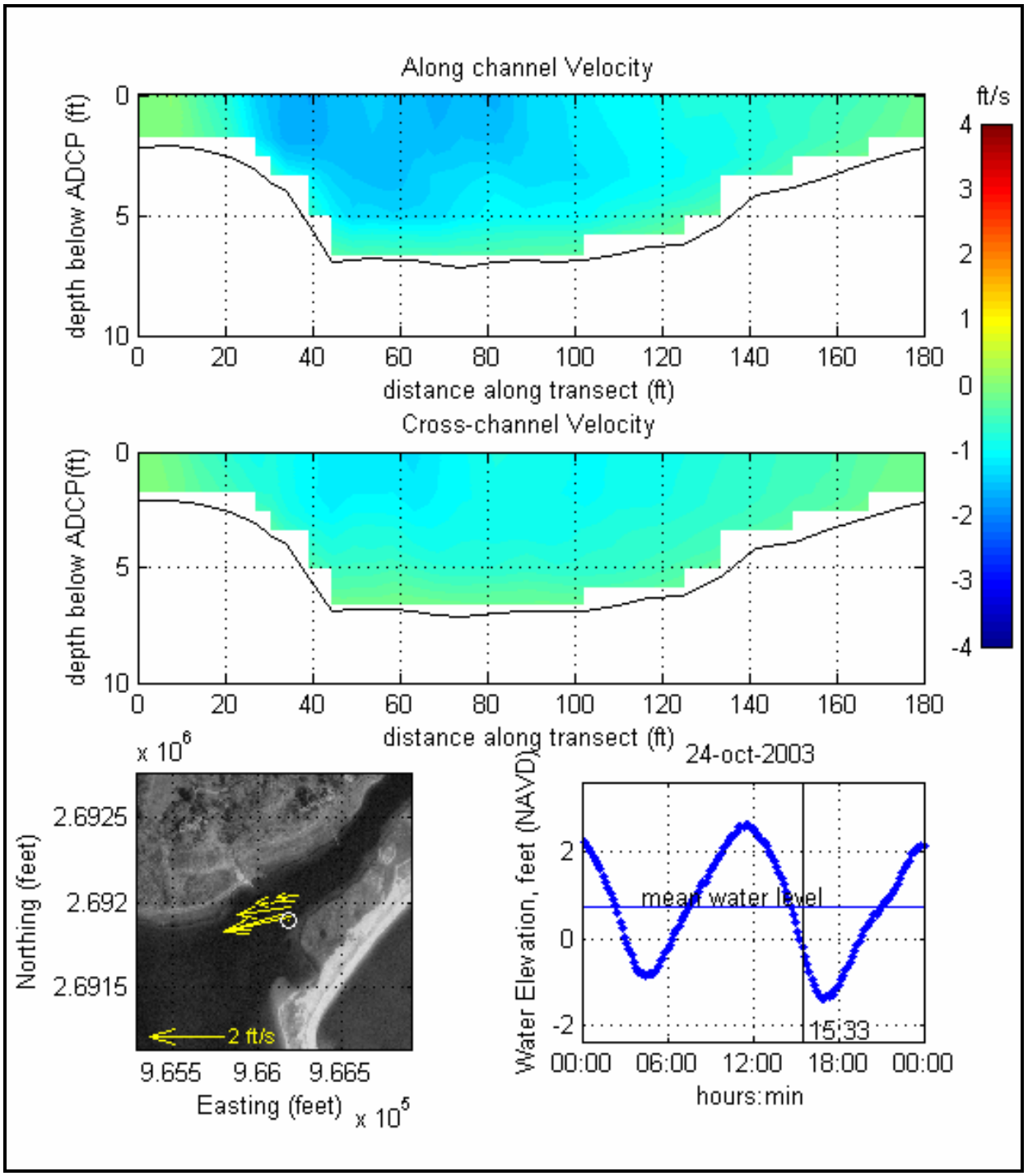


Figure V-14. Color contour plots of along-channel and cross-channel velocity components for transect line A2 across Centerville River measured at 15:33 on October 24, 2003 during the ebb tide. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel.

The inlet to Centerville River is relatively unimpeded by large shoals, although the almost 90° turn from the inlet to Centerville River does decrease the hydraulic efficiency of the opening. Tidal currents through Centerville River inlet (line A1) reached maximum speeds of approximately 2 ft/sec on the flood tide. During periods of maximum currents (flood and ebb) the inlet tidal flows are strongest through the main channel (Figures V-11 and V-13). During slack-water periods, currents were vertically coherent, with negligible stratification in the water column. Maximum volume flux through the Centerville River inlet during flood tide was 2,050 ft^3/sec, while the maximum flux during ebb conditions was slightly higher, at -2,360 ft^3/sec.

ADCP Survey line A2, was measured upstream of Centerville inlet entrance, at the mouth of Centerville River. Measured currents across this transect reached maximum speeds of approximately 2.0 ft/sec on the ebb tide (Figure V-14). During flood tide, the volume flow rate was 1,185 ft^3/sec across line A2, and –1,220 ft^3/sec during ebb tide.

V.4 HYDRODYNAMIC MODELING

For the modeling of the Centerville River system, Applied Coastal utilized a state-of-the-art computer model to evaluate tidal circulation and flushing in these systems. The particular model employed was the RMA-2 model developed by Resource Management Associates (King, 1990). It is a two-dimensional, depth-averaged finite element model, capable of simulating transient hydrodynamics. The model is widely accepted and tested for analyses of estuaries or rivers.

V.4.1 Model Theory

In its original form, RMA-2 was developed by William Norton and Ian King under contract with the U.S. Army Corps of Engineers (Norton et al., 1973). Further development included the introduction of one-dimensional elements, state-of-the-art pre- and post-processing data programs, and the use of elements with curved borders. Recently, the graphic pre- and post-processing routines were updated by a Brigham Young University through a package called the Surface water Modeling System or SMS (BYU, 1998). Graphics generated in support of this report primarily were generated within the SMS modeling package.

RMA-2 is a finite element model designed for simulating one- and two-dimensional depth-averaged hydrodynamic systems. The dependent variables are velocity and water depth, and the equations solved are the depth-averaged Navier Stokes equations. Reynolds assumptions are incorporated as an eddy viscosity effect to represent turbulent energy losses. Other terms in the governing equations permit friction losses (approximated either by a Chezy or Manning formulation), Coriolis effects, and surface wind stresses. All the coefficients associated with these terms may vary from element to element. The model utilizes quadrilaterals and triangles to represent the prototype system. Element boundaries may either be curved or straight.

The time dependence of the governing equations is incorporated within the solution technique needed to solve the set of simultaneous equations. This technique is implicit; therefore, unconditionally stable. Once the equations are solved, corrections to the initial estimate of velocity and water elevation are employed, and the equations are re-solved until the convergence criteria is met.

V.4.2 Model Setup

There are three main steps required to implement RMA-2:

- Grid generation

- Boundary condition specification
- Calibration

The extent of each finite element grid was generated using 1994 digital aerial photographs from the MassGIS online orthophoto database. A time-varying water surface elevation boundary condition (measured tide) was specified on the southern boundary of the grid within Nantucket Sound, based on the tide gage data collected offshore of Centerville River within Nantucket Sound (see Figure V-5 for gage location). Once the grid and boundary conditions were set, the model was calibrated to ensure accurate predictions of tidal flushing. Various friction and eddy viscosity coefficients were adjusted, through several model calibration simulations for the system, to obtain agreement between measured and modeled tides. The calibrated model provides the requisite hydrodynamic information for future detailed water quality modeling.

V.4.2.1 Grid Generation

The grid generation process was aided by the use of the SMS package. A 1994 digital aerial orthophoto and the bathymetry survey data were imported to SMS, and a finite element grid was generated to represent the embayments and waterways within the estuary. The aerial photograph was used to determine the land boundary of the system, as well as determine the surface coverage of salt marsh. The bathymetry data was interpolated to the developed finite element mesh of the system. The completed grid consists of 3,224 nodes, which describe 1,127 total 2-dimensional (depth averaged) quadratic elements. The maximum nodal depth was -19.85 ft (NAVD88), along the open boundary to Nantucket Sound. The maximum modeled marsh plain elevation was +0.71 ft. In the model grid, an average marsh plain elevation of +0.0 ft was used, based on spot surveys across the marsh. The model marsh topography was varied to provide a monotonically sloping surface, in order to enhance the stability of the hydrodynamic model. The completed grid mesh of the Centerville River system is shown in Figure V-15.

The finite element grid for the system provided the detail necessary to evaluate accurately the variation in hydrodynamic properties of the system. Areas of marsh were included in the model because they represent a large portion of the total area of this system, and have a significant effect on system hydrodynamics. Fine resolution was required to simulate the numerous channel constrictions that significantly impact the estuarine hydrodynamics, such as the bridge abutments, as well as the marsh creeks. The SMS grid generation program was used to develop quadrilateral and triangular two-dimensional elements throughout the estuary.

Grid resolution was governed by two factors: 1) expected flow patterns, and 2) the bathymetric variability of the system. Relatively fine grid resolution was employed where complex flow patterns were expected. For example, smaller node spacing in marsh creeks and channels was designed to provide a more detailed analysis in these regions of rapidly varying flow. Widely spaced nodes were often employed in areas where flow patterns are not likely to change dramatically, such as in outer portion of the bay, along the channels, and on the marsh plain. Appropriate implementation of wider node spacing and larger elements reduced computer run time with no sacrifice of accuracy.

V.4.2.2 Boundary Condition Specification

Two types of boundary conditions were employed for the RMA-2 model of the Centerville River system: 1) "slip" boundaries, and 2) tidal elevation boundaries. All of the elements with land borders have "slip" boundary conditions, where the direction of flow was constrained shore-parallel. The model generated all internal boundary conditions from the governing conservation

equations. A tidal boundary condition was specified at the offshore boundary of the sound. TDR measurements provided the required data. The rise and fall of the tide in Nantucket Sound is the primary driving force for estuarine circulation in this system. Dynamic (time-varying) model simulations specified a new water surface elevation at the boundary to the bay every model time step (10 minutes). Although freshwater enters Centerville Rivers via groundwater, the rate of inflow can be considered negligible relative to the tidal flow that dominates the hydrodynamic processes.

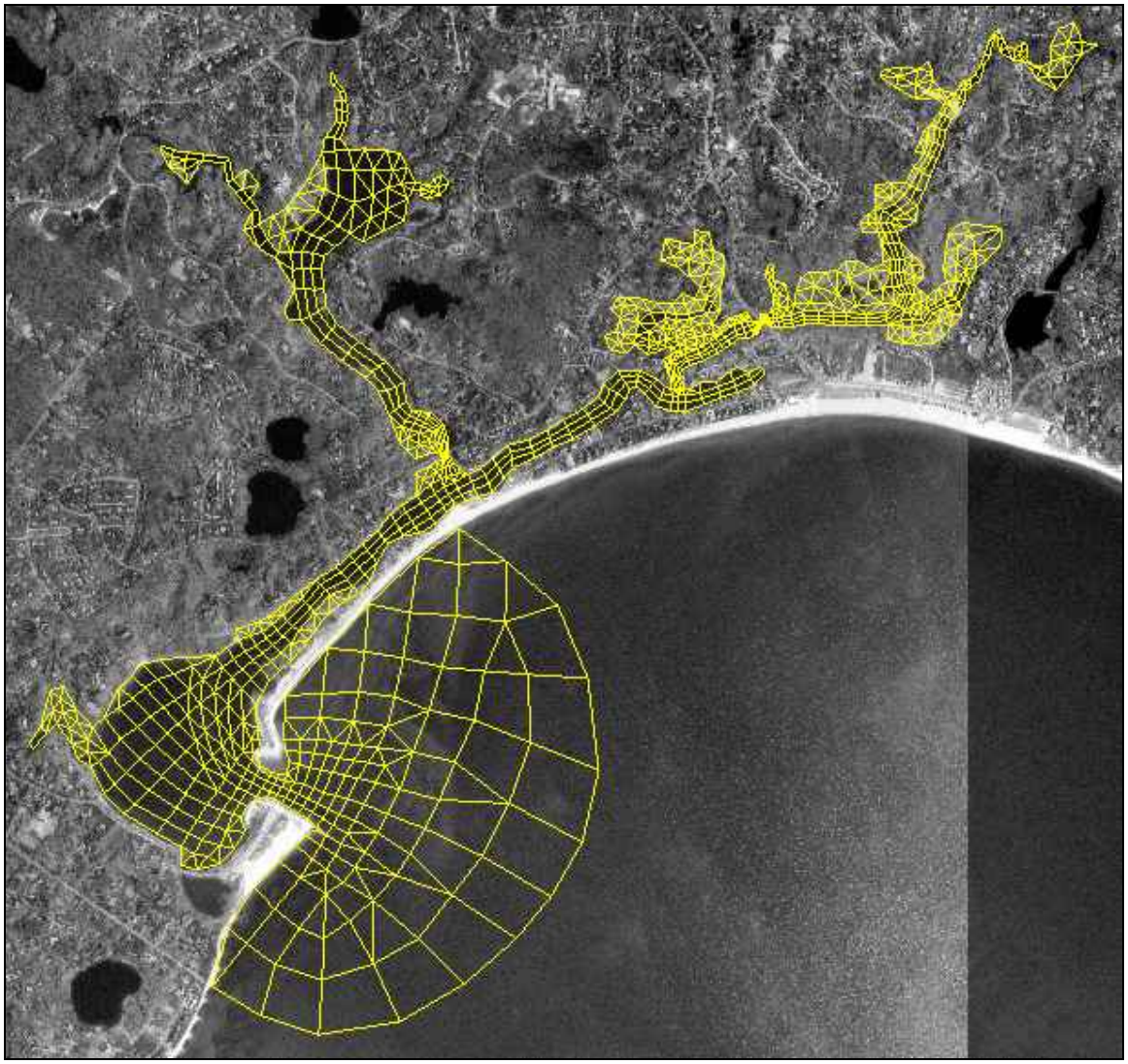


Figure V-15. Plot of hydrodynamic model finite element mesh for the Centerville River system.

V.4.2.3 Calibration

After developing the finite element grid, and specifying boundary conditions, the model for the Centerville River system was calibrated. The calibration procedure ensures that the model predicts accurately what was observed in nature during the field measurement program. Numerous model simulations are required for an estuary model, specifying a range of friction and eddy viscosity coefficients, to calibrate the model.

Calibration of the hydrodynamic model required a close match between the modeled and measured tides in each of the sub-embayments where tides were measured (i.e., from the TDR deployments). Initially, the model was calibrated to obtain visual agreement between modeled and measured tides. Once visual agreement was achieved, an approximately seven-day period (14 tide cycles) was modeled to calibrate the model based on dominant tidal constituents discussed in Section V.3.3.1. The seven-day period was extracted from a longer simulation to avoid effects of model spin-up, and to focus on average tidal conditions. Modeled tides for the calibration time period were evaluated for time (phase) lag and height damping of dominant tidal constituents

The calibration was performed for a seven-day period beginning May 1, 2004. This time period represents the transition from neap to spring tide conditions, or a period of average tidal conditions for forcing conditions for use in model verification and flushing analysis.

The calibrated model was used to analyze existing detailed flow patterns and compute residence times. The ability to model a range of flow conditions is a primary advantage of a numerical tidal flushing model. For instance, average residence times were computed over the entire seven-day simulation. Other methods, such as dye and salinity studies, evaluate tidal flushing over relatively short time periods (less than one day). These short-term measurement techniques may not be representative of average conditions due to the influence of unique, short-lived atmospheric events.

V.4.2.3.1 Friction Coefficients

Friction inhibits flow along the bottom of estuary channels or other flow regions where velocities are relatively high. Friction is a measure of the channel roughness, and can cause both significant amplitude damping and phase delay of tidal signals. Friction is approximated in RMA-2 as a Manning coefficient, and is applied to grid areas by user specified material types. Initially, Manning's friction coefficients between 0.023 and 0.045 were specified for all element material types. These values correspond to typical Manning's coefficients determined experimentally in smooth earth-lined channels with no weeds (low friction) to winding channels and marsh plains with higher friction (Henderson, 1966).

To improve model accuracy, friction coefficients were varied throughout the model domain. First, the Manning’s coefficients were matched to bottom type. For example, lower friction coefficients were specified for the smooth sandy channels found in the lower portions of the Centerville River, versus the heavily vegetated marsh plains in upper Centerville River, which provide greater flow resistance. Final model calibration runs incorporated various specific values for Manning's friction coefficients, depending upon flow damping characteristics of separate regions within each estuary. Manning's values for different bottom types were initially selected based ranges provided by the Civil Engineering Reference Manual (Lindeburg, 1992), and values were incrementally changed when necessary to obtain a close match between measured and modeled tides. Final calibrated friction coefficients are summarized in the Table V-5.

Table V-5. Manning's Roughness coefficients used in model simulations. These delineations correspond to the material type areas shown in Figure V-16.

System Embayment	Bottom Friction
Offshore	0.025
East Bay	0.025
East Bay Marsh Plain	0.045
Bumps River and Scudder Bay	0.025
Bumps River and Scudder Bay Marsh Plain	0.045
Centerville River	0.025
Centerville River Marsh Plain	0.045
Upper Centerville River	0.023
Upper Centerville River Marsh Plain	0.040

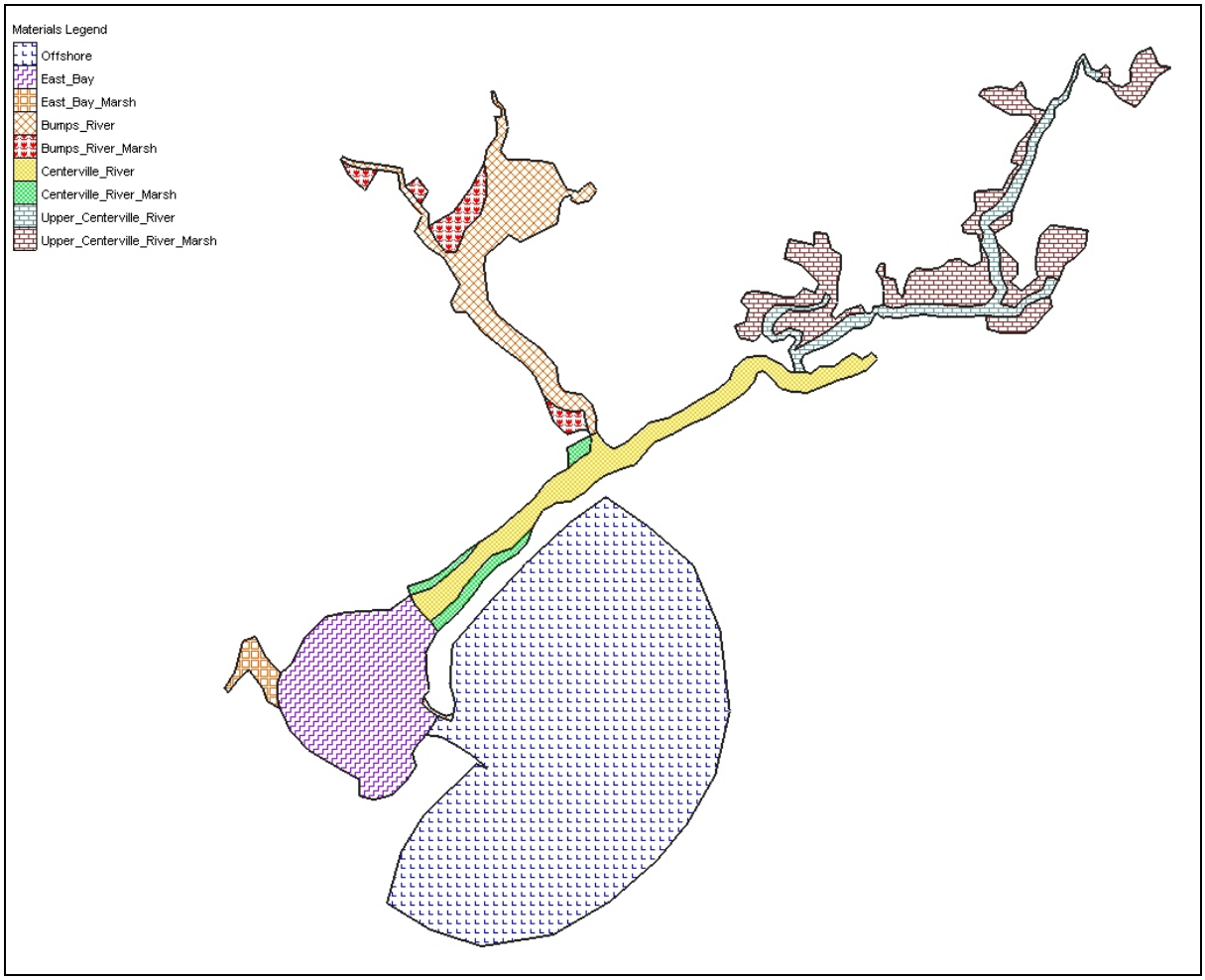


Figure V-16. Hydrodynamic model grid material properties. Color patterns designate the different model material types used to vary model calibration parameters and compute flushing rates.

V.4.2.3.2 Turbulent Exchange Coefficients

Turbulent exchange coefficients approximate energy losses due to internal friction between fluid particles. The significance of turbulent energy losses increases where flow is swifter, such as inlets and bridge constrictions. According to King (1990), these values are proportional to element dimensions (numerical effects) and flow velocities (physics). In most cases, the modeled systems were relatively insensitive to turbulent exchange coefficients because there were no regions of strong turbulent flow. Typically, model turbulence coefficients were set between 40 and 60 lb-sec/ft^2. Higher values (up to 70 lb-sec/ft^2) were used on the marsh plain, to ensure solution stability.

V.4.2.3.3 Marsh Porosity Processes

Modeled hydrodynamics were complicated by wetting/drying cycles on the marsh plain included in the model within Centerville River. Cyclically wet/dry areas of the marsh will tend to store waters as the tide begins to ebb and then slowly release water as the water level drops within the creeks and channels. This store-and-release characteristic of these marsh regions was partially responsible for the distortion of the tidal signal, and the elongation of the ebb phase of the tide. On the flood phase, water rises within the channels and creeks initially until water surface elevation reaches the marsh plain, when at this point the water level remains nearly constant as water 'fans' out over the marsh surface. The rapid flooding of the marsh surface corresponds to a flattening out of the tide curve approaching high water. Marsh porosity is a feature of the RMA-2 model that permits the modeling of hydrodynamics in marshes. This model feature essentially simulates the store-and-release capability of the marsh plain by allowing grid elements to transition gradually between wet and dry states. This technique allows RMA-2 to vary the ability of an element to hold water, like squeezing a sponge. The marsh porosity feature of RMA-2 is typically utilized in estuarine systems where the marsh plain has a significant impact on the hydrodynamics of a system.

V.4.2.3.4 Comparison of Modeled Tides and Measured Tide Data

A best-fit of model predictions for the first TDR deployment was achieved using the aforementioned values for friction and turbulent exchange. Figures V-17 though V-20 illustrate the seven-day calibration simulation along with 72-hour sub-section, for East Bay, Scudder Bay, Centerville River at the Town Landing, and Centerville River at the Craigville Beach Bridge. Modeled (dashed line) and measured (solid line) tides are illustrated at each model location with a corresponding TDR.

Although visual calibration achieved reasonable modeled tidal hydrodynamics, further tidal constituent calibration was required to quantify the accuracy of the models. Calibration of M_2 was the highest priority since M_2 accounted for a majority of the forcing tide energy in the modeled systems. Due to the duration of the model runs, four dominant tidal constituents were selected for constituent comparison: K_1, M_2, M_4, and M_6. Measured tidal constituent heights (H) and time lags (ϕ_{lag}) shown in Table V-6 for the calibration period differ from those in Table V-2 because constituents were computed for only the seven-day section of the 29-days represented in Table V-2. Table V-6 compares tidal constituent height and time lag for modeled and measured tides at the TDR locations.

The constituent calibration resulted in excellent agreement between modeled and measured tides. The largest errors associated with tidal constituent amplitude were on the

order of 0.1 ft, or just greater than one inch. Time lag errors were typically less than the time increment resolved by the model (0.1667 hours or 10 minutes), indicating good agreement between the model and data. The largest errors were in Centerville River at Craigville Beach Bridge, but the model still very closely agrees with the TDR measurement, see Figure V-20.

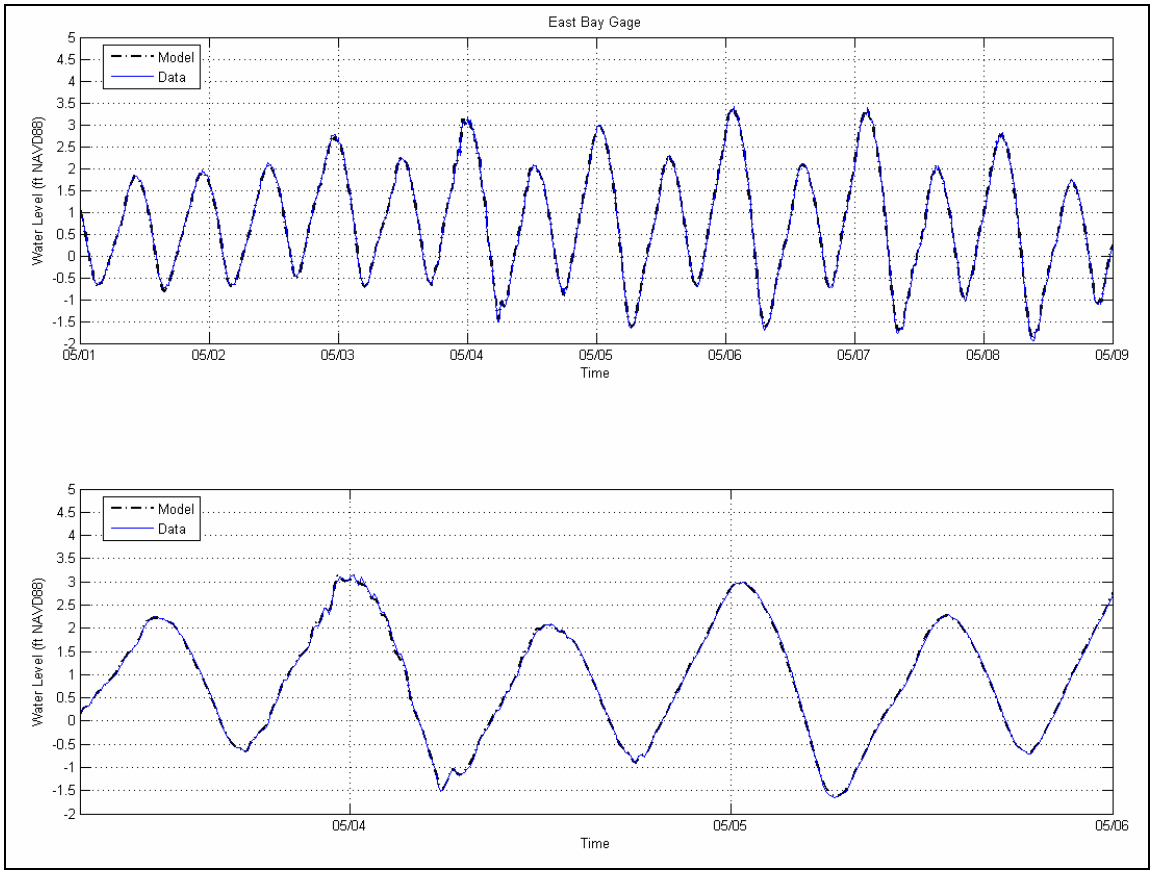


Figure V-17. Comparison of model output and measured tides for the TDR location in East Bay. The bottom plot is a 72-hour sub-section of the total modeled time period, shown in the top plot.

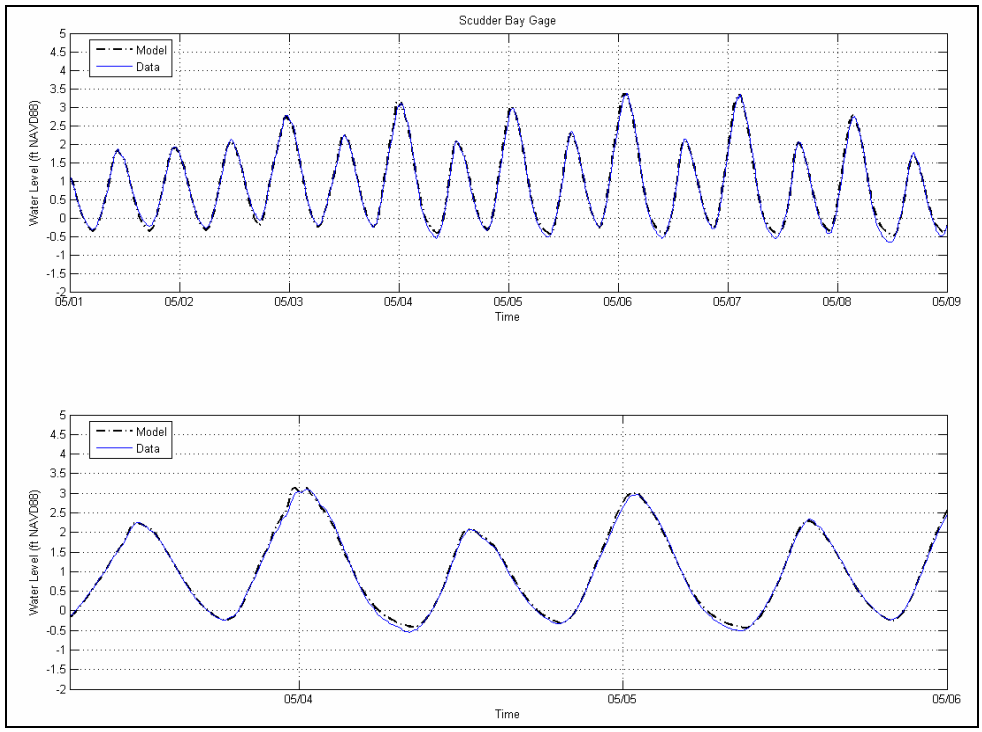


Figure V-18. Comparison of model output and measured tides for the TDR location in Scudder Bay. The bottom plot is a 72-hour sub-section of the total modeled time period, shown in the top plot.

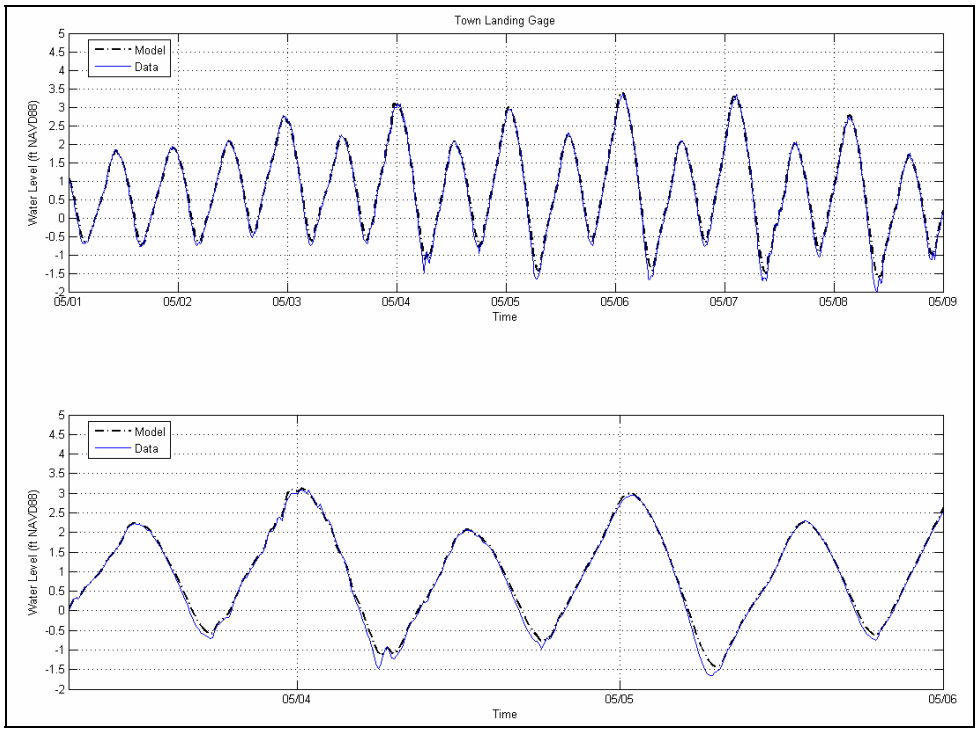


Figure V-19. Comparison of model output and measured tides for the TDR location at the Town Landing in Centerville River. The bottom plot is a 72-hour sub-section of the total modeled time period, shown in the top plot.

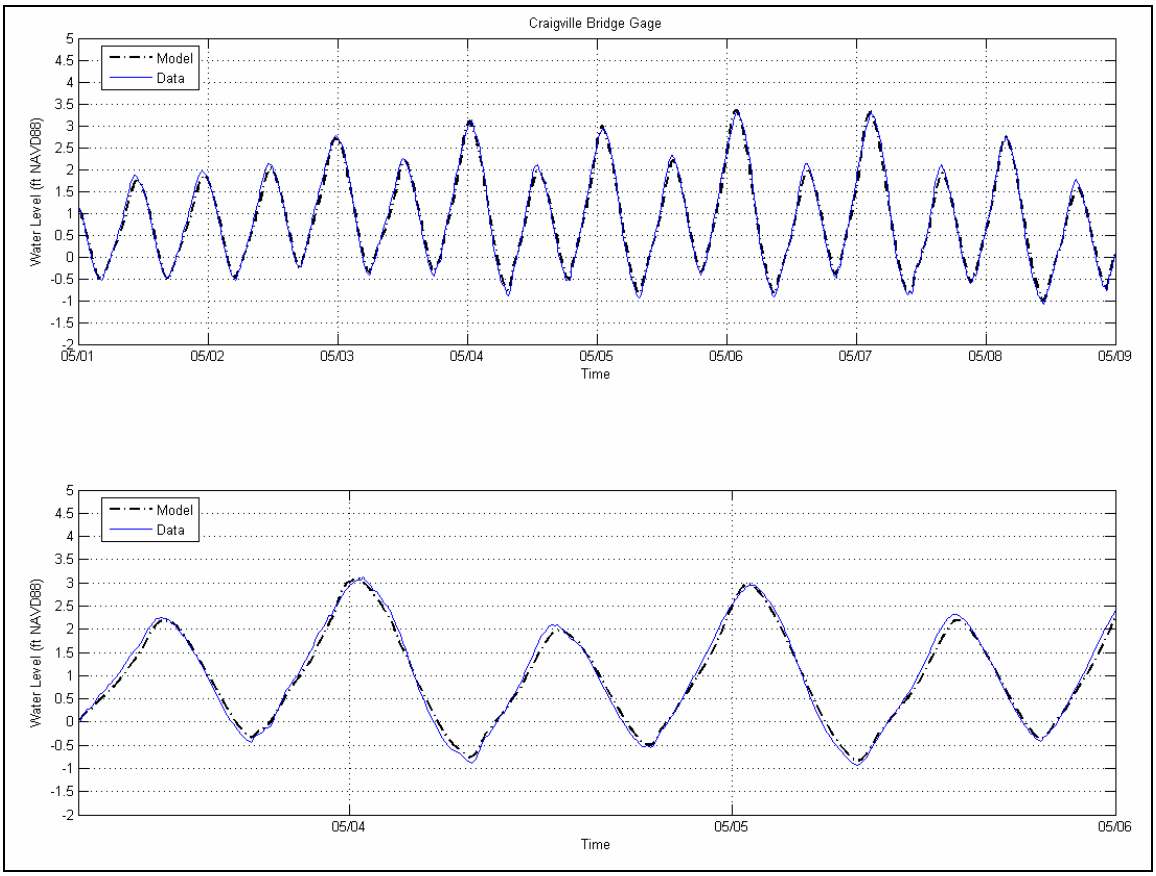


Figure V-20. Comparison of model output and measured tides for the TDR location at the Craigville Beach Bridge in Centerville River. The bottom plot is a 72-hour sub-section of the total modeled time period, shown in the top plot.

V.4.2.4 Model Verification

A verification of the model was then conducted for the period of October 21, 2003 to October 29, 2003 to simulate the time period when the ADCP measurements were taken (October 24, 2003). The verification compared the measured and modeled tide and compared flow rates computed from ADCP measurements to flow rates extracted from the hydrodynamic model. Flow measurements were extracted from the model along two lines in Centerville River which corresponds to the ADCP measurement transects (see Figure V-5 for transect locations).

Comparisons of the modeled and measured flow rates for the ADCP transects are shown in Figures V-21 and V-22. The graphs show that the model follows the trends and characteristics of the ADCP data. However, the model slightly over-predicts the volume of water flow across the transect lines. To quantify the error, an R square error analysis was performed on the results. The results, shown in Table V-7, indicate that the error in the flows rates was small with R-squared values above 0.9.

Table V-6. Tidal constituents for measured water level data and calibrated model output for Centerville River.

Model calibration run						
Location	Constituent Amplitude (ft)				Phase (rad)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Offshore	1.64	0.22	0.09	0.49	-1.31	-0.79
East Bay	1.63	0.21	0.09	0.49	-1.27	-0.72
Scudder Bay	1.33	0.14	0.03	0.43	-0.93	-2.12
Centerville River-Town Landing	1.54	0.15	0.10	0.47	-1.14	-0.53
Centerville River-Craigville Beach	1.33	0.10	0.09	0.42	-0.93	-0.75
Measured tide during calibration period						
Location	Constituent Amplitude (ft)				Phase (rad)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Offshore	1.64	0.22	0.09	0.49	-1.31	-0.79
East Bay	1.63	0.22	0.09	0.49	-1.26	-0.71
Scudder Bay	1.34	0.13	0.04	0.42	-0.93	-1.97
Centerville River-Town Landing	1.61	0.20	0.10	0.48	-1.17	-0.55
Centerville River-Craigville Beach	1.43	0.10	0.07	0.43	-0.99	-0.66
Error						
Location	Error Amplitude (ft)				Phase error (min)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Offshore	0.00	0.00	0.00	0.00	0.07	-0.04
East Bay	0.01	0.01	0.00	0.00	1.50	1.00
Scudder Bay	0.02	-0.01	0.01	-0.01	0.73	9.30
Centerville River-Town Landing	0.06	0.05	0.00	0.01	-3.36	-1.39
Centerville River-Craigville Beach	0.09	0.00	+0.02	0.01	-7.40	5.37

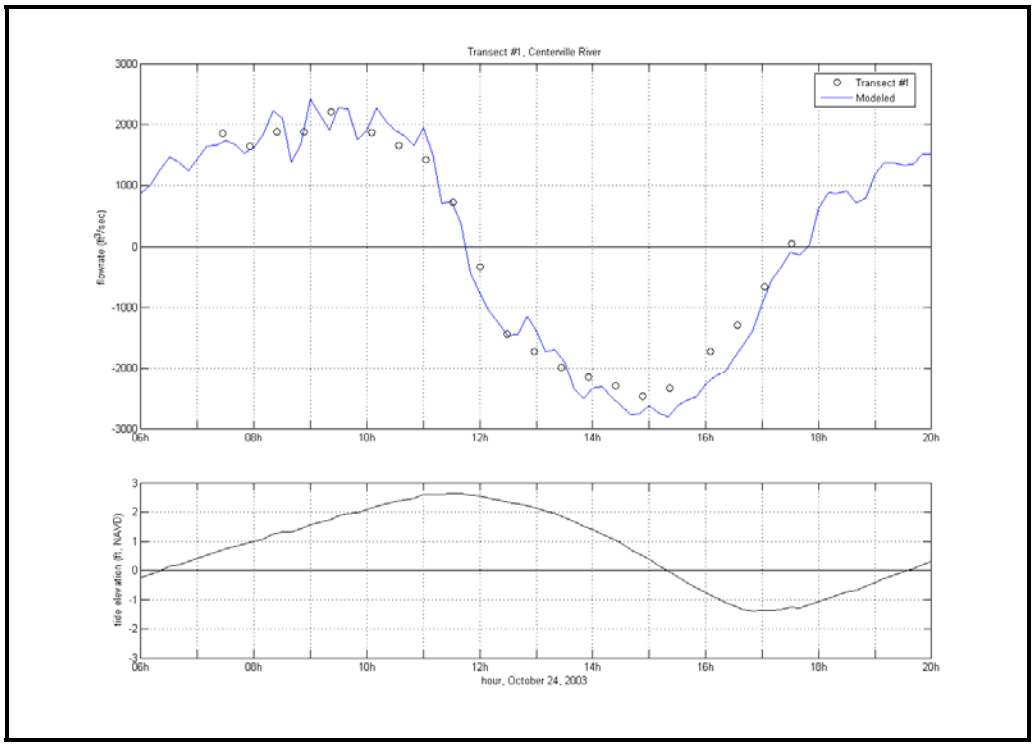


Figure V-21. Comparison of computed flow rates to ADCP Transect 1 across the entrance of East Bay. Model period shown corresponds to transition from high to low tide. Positive flow indicated flooding tide, while negative flow indicates ebbing tide.

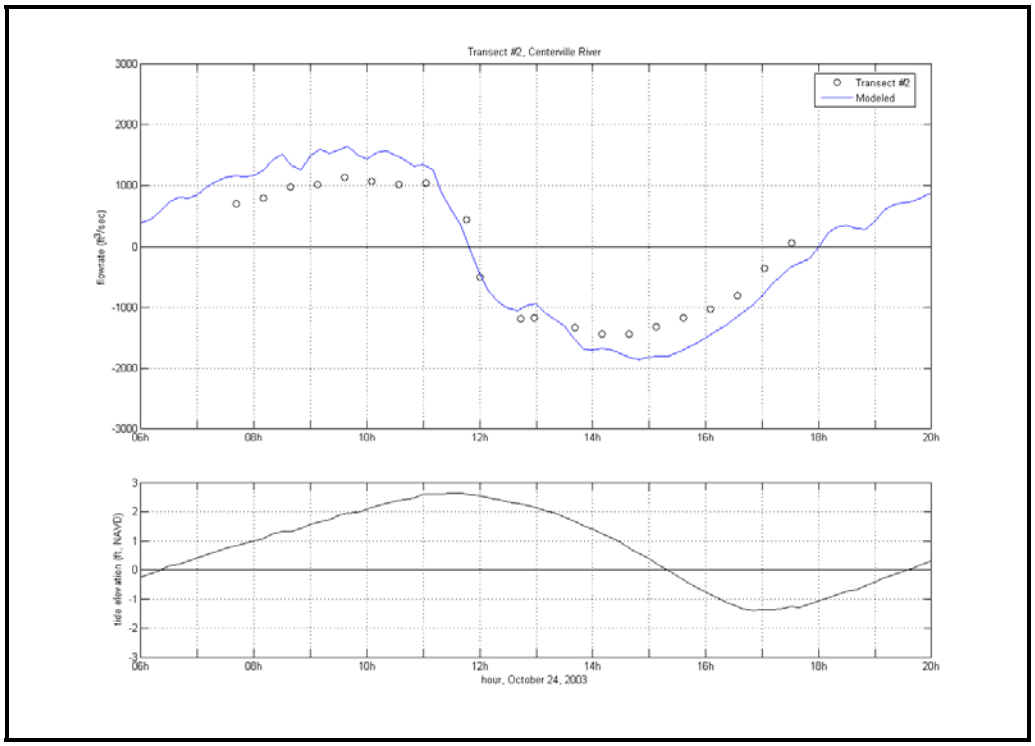


Figure V-22. Comparison of computed flow rates to the ADCP transect at Transect 2. Model period shown corresponds to transition from high to low tide. Positive flow indicated flooding tide, while negative flow indicates ebbing tide.

There are several possible reasons for the model over-predicting the flow measurements. The primary limitation of the ADCP measurements was the inability to capture the outer edges of the channel as a result of depth limitations with the boat and the ADCP. The size of this gap was dependent of the side slopes of the channel. For Transect 1 this ranged between 8 to 12 feet and 15 to 20 feet for Transect 2; therefore, the measurements do not account for the flow along the outer most edges of the channels. Thus, the measured flow rates are assumed to be 10 to 15 percent lower than actual flow rates. Secondly, the ADCP is unable to measure velocities in the first 1 to 2 feet of the water column, due to the ADCP transducer being suspended below the water surface and signal blanking across the first measurement cell. The ADCP cannot take measurements across the first measurement cell since a time gap is required between the transmission and receipt of the acoustic signal (this allows measurement of the Doppler shift). To account for the unmeasured portion of the water column, velocities from second measurement cell were used to represent the portion of water column above. This resulted in a slight under prediction in surface currents and thus adds to the under-prediction of flow rates. Although the measured flow rates were approximately 15 percent less than the modeled flows, the current measurement limitations (primarily the loss of data near the shallow channel edges) provide a reasonable explanation for this magnitude of error. Therefore, the ADCP measurements within Centerville River provided adequate measurements to verify the results of the hydrodynamic model.

Table V-7. Least square error results on the flow analysis for Centerville River.

Transect	R Squared	R Square Error (ft^3/s)
Transect 1	0.978	421
Transect 2	0.913	385

V.4.2.5 Model Circulation Characteristics

The final calibrated and validated model serves as a useful tool in investigating the circulation characteristics of the Centerville River system. Using model inputs of bathymetry and tide data, current velocities and flow rates can be determined at any point in the model domain. This is a very useful feature of a hydrodynamic model, where a limited amount of collected data can be expanded to determine the physical attributes of the system in areas where no physical data record exists.

Examining the results from the model run shows ebb velocities in the entrance and lower channels are slightly larger than velocities during maximum flood. The highest velocities occur at the bridge constrictions at Craigville Beach Road on the Centerville River, where the channel width is constrained between the bridge abutments. Similar velocity magnitudes occur along the Centerville River and at the entrance to East Bay. In areas with wider channels, the peak velocities are slightly lower. The maximum velocities in the entrance to East Bay peaks at approximately 2.7 feet/sec during the ebb tide, while maximum ebb velocities are about 1.8 feet/sec. A close-up of the model output is presented in Figure V-23, showing contours of velocity magnitude, along with velocity vectors that indicate the magnitude and direction of flow, for a single model time-step, at the portion of the tide cycle where maximum ebb velocities occur at the entrance to East Bay.

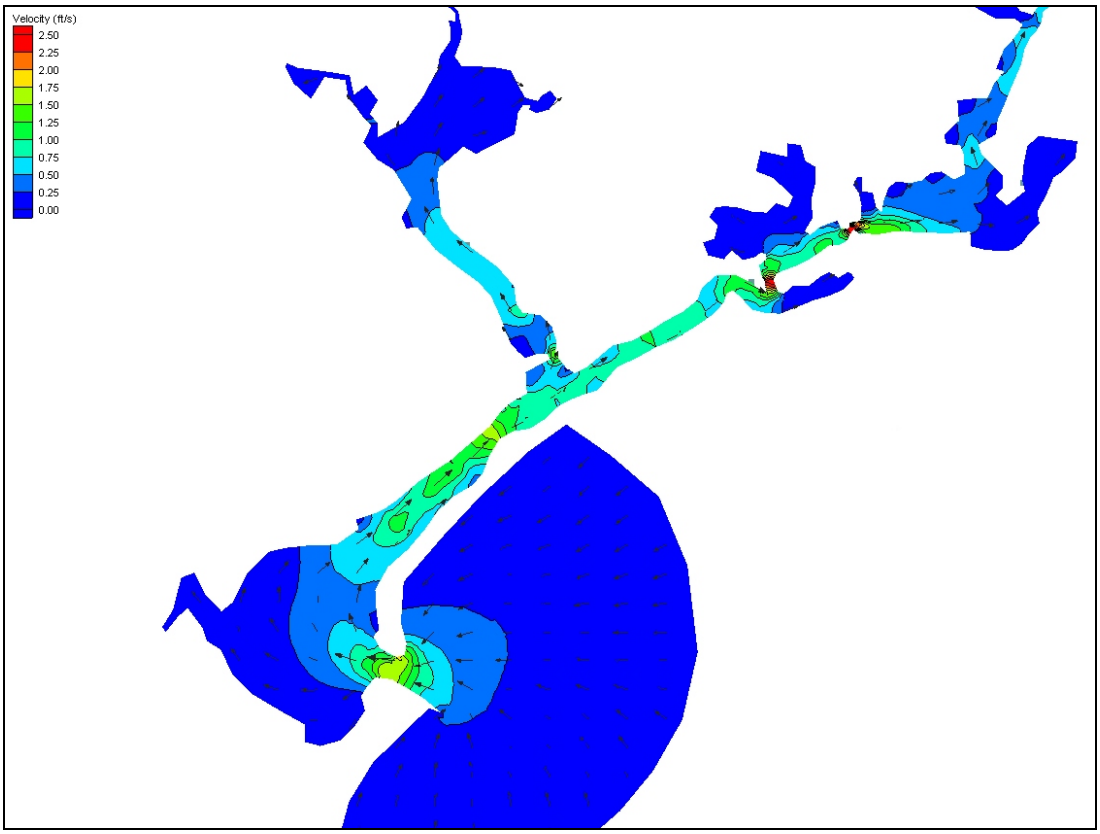


Figure V-23. Example of hydrodynamic model output for a single time step where maximum flood velocities occur for this tide cycle. Color contours indicate velocity magnitude, and vectors indicate the direction of flow.

V.4 FLUSHING CHARACTERISTICS

Since the magnitude of freshwater inflow is much smaller in comparison to the tidal exchange through each inlet, the primary mechanism controlling estuarine water quality within the modeled Centerville River system is tidal exchange. A rising tide offshore in Nantucket Sound creates a slope in water surface from the ocean into the modeled systems. Consequently, water flows into (floods) the system. Similarly, each estuary drains into the open waters of Nantucket Sound on an ebbing tide. This exchange of water between each system and the ocean is defined as tidal flushing. The calibrated hydrodynamic model is a tool to evaluate quantitatively tidal flushing of each system, and was used to compute flushing rates (residence times) and tidal circulation patterns.

Flushing rate, or residence time, is defined as the average time required for a parcel of water to migrate out of an estuary from points within the system. For this study, **system residence times** were computed as the average time required for a water parcel to migrate from a point within the each embayment to the entrance of the system. System residence times are computed as follows:

$$T_{system} = \frac{V_{system}}{P} t_{cycle}$$

where T_{system} denotes the residence time for the system, V_{system} represents volume of the (entire) system at mean tide level, P equals the tidal prism (or volume entering the system through a single tidal cycle), and t_{cycle} the period of the tidal cycle, typically 12.42 hours (or 0.52 days). To compute system residence time for a sub-embayment, the tidal prism of the sub-embayment replaces the total system tidal prism value in the above equation.

In addition to system residence times, a second residence, the **local residence time**, was defined as the average time required for a water parcel to migrate from a location within a sub-embayment to a point outside the sub-embayment. Using Scudder Bay as an example, the **system residence time** is the average time required for water to migrate from Scudder Bay and Bumps River, through Centerville River, into East Bay, and into Nantucket Sound, where the **local residence time** is the average time required for water to migrate from Scudder Bay to just Centerville River (not all the way to the sound). Local residence times for each sub-embayment are computed as:

$$T_{local} = \frac{V_{local}}{P} t_{cycle}$$

where T_{local} denotes the residence time for the local sub-embayment, V_{local} represents the volume of the sub-embayment at mean tide level, P equals the tidal prism (or volume entering the local sub-embayment through a single tidal cycle), and t_{cycle} the period of the tidal cycle (again, 0.52 days).

Residence times are provided as a first order evaluation of estuarine water quality. Lower residence times generally correspond to higher water quality; however, residence times may be misleading depending upon pollutant/nutrient loading rates and the overall quality of the receiving waters. As a qualitative guide, **system residence times** are applicable for systems where the water quality within the entire estuary is degraded and higher quality waters provide the only means of reducing the high nutrient levels. For the Centerville River system this approach is applicable, since it assumes the main system has relatively low quality water relative to Nantucket Sound.

The rate of pollutant/nutrient loading and the quality of water outside the estuary both must be evaluated in conjunction with residence times to obtain a clear picture of water quality. Efficient tidal flushing (low residence time) is not an indication of high water quality if pollutants and nutrients are loaded into the estuary faster than the tidal circulation can flush the system. Neither are low residence times an indicator of high water quality if the water flushed into the estuary is of poor quality. Advanced understanding of water quality will be obtained from the calibrated hydrodynamic model by extending the model to include pollutant/nutrient dispersion. The water quality model will provide a valuable tool to evaluate the complex mechanisms governing estuarine water quality in the Centerville River system.

Since the calibrated RMA-2 model simulated accurate two-dimensional hydrodynamics in the system, model results were used to compute residence times. Residence times were computed for the entire estuary, as well the two main sub-embayments within the system. In addition, **system** and **local residence times** were computed to indicate the range of conditions possible for the system. Residence times were calculated as the volume of water (based on the mean volumes computed for the simulation period) in the entire system divided by the average volume of water exchanged with each sub-embayment over a flood tidal cycle (tidal prism). Units then were converted to days. The volume of the entire estuary was computed as cubic

feet. Sub-embayment mean volumes and average tide prisms computer for the Centerville River system are presented in Table V-8.

Residence times were averaged for the tidal cycles comprising a representative 7.25 day period (14 tide cycles), and are listed in Table V-9. The modeled time period used to compute the flushing rates was different from the modeled calibration period, and included the transition from neap to spring tide conditions. Model divisions used to define the system sub-embayments include 1) East Bay, 2) Lower Centerville River, (3) Upper Centerville River, and 4) Scudder Bay and Bumps River (corresponds to divisions shown in Figure V-16). The model calculated flow crossing specified grid lines for each sub-embayment to compute the tidal prism volume. Since the 7.25-day period used to compute the flushing rates of the system represent average tidal conditions, the measurements provide the most appropriate method for determining mean flushing rates for the system sub-embayments.

Computed flushing rates for the Centerville River system show that as a whole, the system flushes well. A flushing time of 0.51 days for the entire estuary shows that on average, water is resident in the system for approximately a half of a day. This is also evident by the fact that the tidal prism of the whole estuary is approximately equal to its mean volume. Scudder Bay and Bumps River have the greatest system residence time. However the local residence time for Scudder Bay and Bumps River is less than a day. As a whole the system flushes well due to shallow basin depths and relatively large forcing tide.

Table V-8. Embayment mean volumes and average tidal prism during simulation period.

Embayment	Mean Volume (ft^3)	Tide Prism Volume (ft^3)
Centerville River (whole system)	39,774,950	39,337,036
East Bay	15,481,617	13,749,703
Centerville River (Lower)	10,511,886	7,966,521
Scudder Bay and Bumps River	5,645,965	8,135,937
Centerville River (Upper)	7,715,137	10,348,940

Table V-9. Computed System and Local residence times for embayments in the Centerville River system.

Embayment	System Residence Time (days)	Local Residence Time (days)
Centerville River (whole system)	0.53	0.53
East Bay	1.50	0.59
Centerville River (Lower)	1.98	0.69
Scudder Bay and Bumps River	3.66	0.36
Centerville River (Upper)	2.68	0.39

Possible errors in computed residence times can generally be linked to two sources: the bathymetry information and simplifications employed to calculate residence time. In this study, the most significant errors associated with the bathymetry data result from the process of interpolating the data to the finite element mesh, which was the basis for all the flushing

volumes used in the analysis. In addition, limited topographic measurements were available on the extensive marsh plains. Minor errors may be introduced in residence time calculations by simplifying assumptions. Flushing rate calculations assume that water exiting an estuary or sub-embayment does not return on the following tidal cycle. For regions where a strong littoral drift exists, this assumption is valid. However, water exiting a small sub-embayment on a relatively calm day may not completely mix with estuarine waters. In this case, the "strong littoral drift" assumption would lead to an under-prediction of residence time. Since littoral drift in Nantucket Sound is typically strong because of the effects of local winds induce tidal mixing and alongshore drift within the sound, the "strong littoral drift" assumption only will cause minor errors in residence time calculations. Based on our knowledge of estuarine processes, we estimate that the combined errors due to bathymetric inaccuracies represented in the model grid and the "strong littoral drift" assumption are within 10% to 15% of "true" residence times.

VI. WATER QUALITY MODELING

VI.1 DATA SOURCES FOR THE MODEL

Several different data types and calculations are required to support the water quality modeling effort for the Centerville River System. These include the output from the hydrodynamics model, calculations of external nitrogen loads from the watersheds, measurements of internal nitrogen loads from the sediment (benthic flux), and measurements of nitrogen in the water column.

VI.1.1 Hydrodynamics and Tidal Flushing in the Embayment

Extensive field measurements and hydrodynamic modeling of the embayment were an essential preparatory step to the development of the water quality model. The result of this work, among other things, was a calibrated model output representing the transport of water within the system embayment. Files of node locations and node connectivity for the RMA-2V model grid were transferred to the RMA-4 water quality model; therefore, the computational grid for the hydrodynamic model also was the computational grid for the water quality model. The period of hydrodynamic output for the water quality model calibration was a 11-tidal cycle period in May 2004. Each modeled scenario (e.g., present conditions, build-out) required the model be run for a 28-day spin-up period, to enable the model to reach a dynamic “steady state”, and ensure that model spin-up would not affect the final model output.

VI.1.2 Nitrogen Loading to the Embayment

Three primary nitrogen loads to embayment are recognized in this modeling study: external loads from the watersheds, nitrogen load from direct rainfall on the embayment surface, and internal loads from the sediments. Additionally, there is a fourth load to the Centerville River System, consisting of the background concentrations of total nitrogen in the waters entering from Nantucket Sound. This load is represented as a constant concentration along the seaward boundary of the model grid.

VI.1.3 Measured Nitrogen Concentrations in the Embayment

In order to create a model that realistically simulates the total nitrogen concentrations in a system in response to the existing flushing conditions and loadings, it is necessary to calibrate the model to actual measurements of water column nitrogen concentrations. The refined and approved data for each monitoring station used in the water quality modeling effort are presented in Table VI-1. Station locations are indicated in Figure VI-1. The multi-year averages present the “best” comparison to the water quality model output, since factors of tide, temperature and rainfall may exert short-term influences on the individual sampling dates and even cause inter-annual differences. Three years of baseline field data is the minimum required to provide a baseline for MEP analysis. Five years of data (collected between 2001 and 2005) were available for stations monitored by SMAST in the Centerville River System.

Table VI-1. Pond-Watcher measured data, and modeled Nitrogen concentrations for the Centerville River System used in the model calibration plots of Figure VI-2. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means.

Sub-Embayment	Scudder Bay	Bumps River	Centerville River	Centerville River	Centerville River	Centerville River	East Bay
Monitoring station	BC-3	BC-4	BC-5	BC-7	BC-8	BC-9	BC-10
2001 mean	0.593	0.325	0.697	0.484	0.423	0.332	0.330
2002 mean	0.628	0.505	0.759	0.618	0.513	0.460	0.466
2003 mean	0.661	0.542	0.793	0.589	0.588	0.433	0.413
2004 mean	0.569	0.485	0.710	0.536	0.552	0.453	0.390
2005 mean	0.610	0.423	0.720	0.467	0.474	0.399	0.382
mean	0.619	0.481	0.745	0.551	0.526	0.430	0.408
s.d. all data	0.105	0.113	0.147	0.117	0.125	0.112	0.086
N	28	28	29	29	57	55	57
model min	0.386	0.333	0.457	0.385	0.335	0.316	0.310
model max	0.695	0.616	0.749	0.670	0.584	0.514	0.442
model average	0.524	0.451	0.609	0.526	0.454	0.389	0.349

VI.2 MODEL DESCRIPTION AND APPLICATION

A two-dimensional finite element water quality model, RMA-4 (King, 1990), was employed to study the effects of nitrogen loading in the Centerville River System. The RMA-4 model has the capability for the simulation of advection-diffusion processes in aquatic environments. It is the constituent transport model counterpart of the RMA-2 hydrodynamic model used to simulate the fluid dynamics of the Centerville River System. Like RMA-2 numerical code, RMA-4 is a two-dimensional, depth averaged finite element model capable of simulating time-dependent constituent transport. The RMA-4 model was developed with support from the US Army Corps of Engineers (USACE) Waterways Experiment Station (WES), and is widely accepted and tested. Members of the MEP Technical Team have utilized this model in water quality studies of other Cape Cod embayments, including systems in Falmouth (Ramsey *et al*., 2000); Mashpee, MA (Howes *et al*., 2004) and Chatham, MA (Howes *et al*., 2003).

The overall approach involves modeling total nitrogen as a non-conservative constituent, where bottom sediments act as a source or sink of nitrogen, based on local biochemical characteristics. This modeling represents summertime conditions, when algal growth is at its maximum. Total nitrogen modeling is based upon various data collection efforts and analyses presented in previous sections of this report. Nitrogen loading information was derived from the Cape Cod Commission watershed loading analysis (based on the USGS watersheds), as well as the measured bottom sediment nitrogen fluxes. Water column nitrogen measurements were utilized as model boundaries and as calibration data. Hydrodynamic model output (discussed in Section V) provided the remaining information (tides, currents, and bathymetry) needed to parameterize the water quality model of the system.

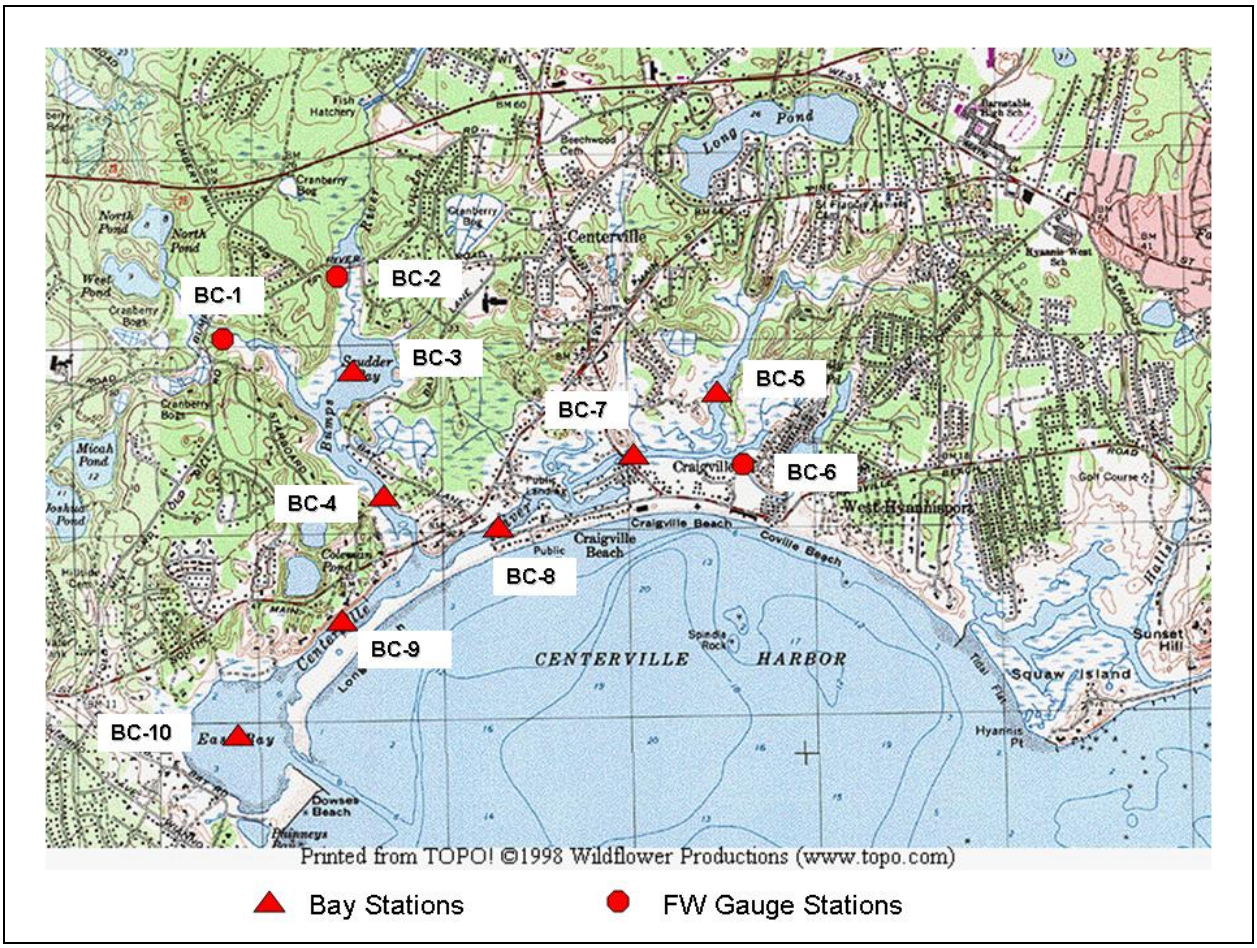


Figure VI-1. Estuarine water quality monitoring station locations in the Centerville River System. Station labels correspond to those provided in Table VI-1.

VI.2.1 Model Formulation

The formulation of the model is for two-dimensional depth-averaged systems in which concentration in the vertical direction is assumed uniform. The depth-averaged assumption is justified since vertical mixing by wind and tidal processes prevent significant stratification in the modeled sub-embayments. The governing equation of the RMA-4 constituent model can be most simply expressed as a form of the transport equation, in two dimensions:

$$\left(\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y}\right) = \left(\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x} + \frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y} + \sigma\right)$$

where c in the water quality constituent concentration; t is time; u and v are the velocities in the x and y directions, respectively; D_x and D_y are the model dispersion coefficients in the x and y directions; and σ is the constituent source/sink term. Since the model utilizes input from the RMA-2 model, a similar implicit solution technique is employed for the RMA-4 model.

The model is therefore used to compute spatially and temporally varying concentrations c of the modeled constituent (i.e., total nitrogen), based on model inputs of 1) water depth and velocity computed using the RMA-2 hydrodynamic model; 2) mass loading input of the modeled constituent; and 3) user selected values of the model dispersion coefficients. Dispersion

coefficients used for each system sub-embayment were developed during the calibration process. During the calibration procedure, the dispersion coefficients were incrementally changed until model concentration outputs matched measured data.

The RMA-4 model can be utilized to predict both spatial and temporal variations in total for a given embayment system. At each time step, the model computes constituent concentrations over the entire finite element grid and utilizes a continuity of mass equation to check these results. Similar to the hydrodynamic model, the water quality model evaluates model parameters at every element at 10-minute time intervals throughout the grid system. For this application, the RMA-4 model was used to predict tidally averaged total nitrogen concentrations throughout Centerville River System.

VI.2.2 Water Quality Model Setup

Required inputs to the RMA-4 model include a computational mesh, computed water elevations and velocities at all nodes of the mesh, constituent mass loading, and spatially varying values of the dispersion coefficient. Because the RMA-4 model is part of a suite of integrated computer models, the finite-element meshes and the resulting hydrodynamic simulations previously developed for the Centerville River System was used for the water quality constituent modeling portion of this study.

Based on measured flow rates from SMAST and groundwater recharge rates from the USGS, the hydrodynamic model was set-up to include the latest estimate of surface water flows from Pine Street stream, Lake Elizabeth/Red Lilly Pond stream, Bumps River, and Skunknet River along with ground water flowing into the system from watersheds. The Pine Street stream has a measured flow rate of 2.66 ft^3/sec (6,518 m^3/day), Lake Elizabeth/Red Lilly Pond stream has a measured flow rate of 0.63 ft^3/sec (1,547 m^3/day), Bumps River has a measured flow rate of 2.39 ft^3/sec (5,847 m^3/day), and Skunknet River has a measured flow rate of 5.69 ft^3/sec (13,925 m^3/day). The overall groundwater flow rate into the system is 22.26 ft^3/sec (54,449 m^3/day) distributed amongst the watersheds.

For the model, an initial total N concentration equal to the concentration at the open boundary was applied to the entire model domain. The model was then run for a simulated month-long (28 day) spin-up period. At the end of the spin-up period, the model was run for an additional 5 tidal-day (125 hour) period. Model results were recorded only after the initial spin-up period. The time step used for the water quality computations was 10 minutes, which corresponds to the time step of the hydrodynamics input for the Centerville River System.

VI.2.3 Boundary Condition Specification

Mass loading of nitrogen into each model included 1) sources developed from the results of the watershed analysis, 2) estimates of direct atmospheric deposition, 3) summer benthic regeneration, and 4) point source input developed from measurements of the Pine Street stream, Lake Elizabeth/Red Lilly Pond stream, Bumps River, and Skunknet River. Nitrogen loads from each separate sub-embayment watershed were distributed across the sub-embayment. For example, the combined watershed direct atmospheric deposition load for Scudder Bay was evenly distributed at grid cells that formed the perimeter of the embayment. Benthic regeneration load was distributed among another sub-set of grid cells which are in the interior portion of each basin.

The loadings used to model present conditions in Centerville River System are given in Table VI-2. Watershed and depositional loads were taken from the results of the analysis of Section IV. Summertime benthic flux loads were computed based on the analysis of sediment cores in Section IV. The area rate (g/sec/m^2) of nitrogen flux from that analysis was applied to the surface area coverage computed for each sub-embayment (excluding marsh coverages, when present), resulting in a total flux for each embayment (as listed in Table VI-2). Due to the highly variable nature of bottom sediments and other estuarine characteristics of coastal embayments in general, the measured benthic flux for existing conditions also is variable. For present conditions, some sub-embayments have almost twice the loading rate from benthic regeneration as from watershed loads. For other sub-embayments, the benthic flux is relatively low or negative indicating a net uptake of nitrogen in the bottom sediments.

In addition to mass loading boundary conditions set within the model domain, concentrations along the model open boundary were specified. The model uses concentrations at the open boundary during the flooding tide periods of the model simulations. TN concentrations of the incoming water are set at the value designated for the open boundary. The boundary concentration in Nantucket Sound was set at 0.33 mg/L, based on SMAST data from the Sound. The open boundary total nitrogen concentration represents long-term average summer concentrations found within Nantucket Sound.

Table VI-2. Sub-embayment loads used for total nitrogen modeling of the Centerville River System, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent **present loading conditions.**

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Centerville River East	55.737	0.449	5.394
Scudder Bay	14.452	0.685	-2.125
Centerville River West	9.463	0.718	3.497
East Bay	8.627	1.126	12.694
Surface Water Sources			
Pine Street Stream	3.452	-	-
Lake Elizabeth Stream	2.274	-	-
Bumps River	16.912	-	-
Skunknet River	21.260	-	-

VI.2.4 Model Calibration

Calibration of the total nitrogen model proceeded by changing model dispersion coefficients so that model output of nitrogen concentrations matched measured data. Generally, several model runs of each system were required to match the water column measurements. Dispersion coefficient (*E*) values were varied through the modeled system by setting different values of *E* for each grid material type, as designated in Figure VI-2. Observed values of *E* (Fischer, *et al.*, 1979) vary between order 10 and order 1000 m^2/sec for riverine estuary systems characterized by relatively wide channels (compared to channel depth) with moderate currents (from tides or atmospheric forcing). Generally, the relatively quiescent areas of Centerville River require values of *E* that are lower compared to the riverine estuary systems evaluated by Fischer, *et al.*, (1979). Observed values of *E* in these calmer areas typically range

between order 10 and order 0.001 m^2/sec (USACE, 2001). The final values of *E* used in each sub-embayment of the modeled systems are presented in Table VI-3. These values were used to develop the "best-fit" total nitrogen model calibration. For the case of TN modeling, "best fit" can be defined as minimizing the error between the model and data at all sampling locations, utilizing reasonable ranges of dispersion coefficients within each sub-embayment.

Table VI-3. Values of longitudinal dispersion coefficient, E, used in calibrated RMA4 model runs of salinity and nitrogen concentration for Centerville River System.

Embayment Division	E m^2/sec
Offshore	50.0
East Bay	100.0
East Bay Marsh	1.0
Scudder Bay	1.5
Bumps River/ Scudder Bay Marsh	0.9
Centerville River	45.0
Centerville River Marsh	1.0
Upper Centerville River	4.0
Upper Centerville River Marsh	0.7
Centerville River West	100.0
Stream Inputs	0.4
Bumps River	25.0
Centerville River East	15.0
Centerville River East Marsh	7.0

Comparisons between model output and measured nitrogen concentrations are shown in plots presented in Figure VI-3. In these plots, means of the water column data and a range of two standard deviations of the annual means at each individual station are plotted against the modeled maximum, mean, and minimum concentrations output from the model at locations which corresponds to the SMAST monitoring stations.

For model calibration, the mid-point between maximum modeled TN and average modeled TN was compared to mean measured TN data values, at each Pond-Watcher water-quality monitoring station. The calibration target would fall between the modeled mean and maximum TN because the monitoring data are collected, as a rule, during mid ebb tide.

Also presented in this figure are unity plot comparisons of measured data verses modeled target values for the system. The model fit is exceptional for the Centerville River System, with rms error of 0.04 mg/L and an R^2 correlation coefficient of 0.88.

A contour plot of calibrated model output is shown in Figure VI-4 for Centerville River System. In the figure, color contours indicate nitrogen concentrations throughout the model domain. The output in the figure show average total nitrogen concentrations, computed using the full 5-tidal-day model simulation output period.

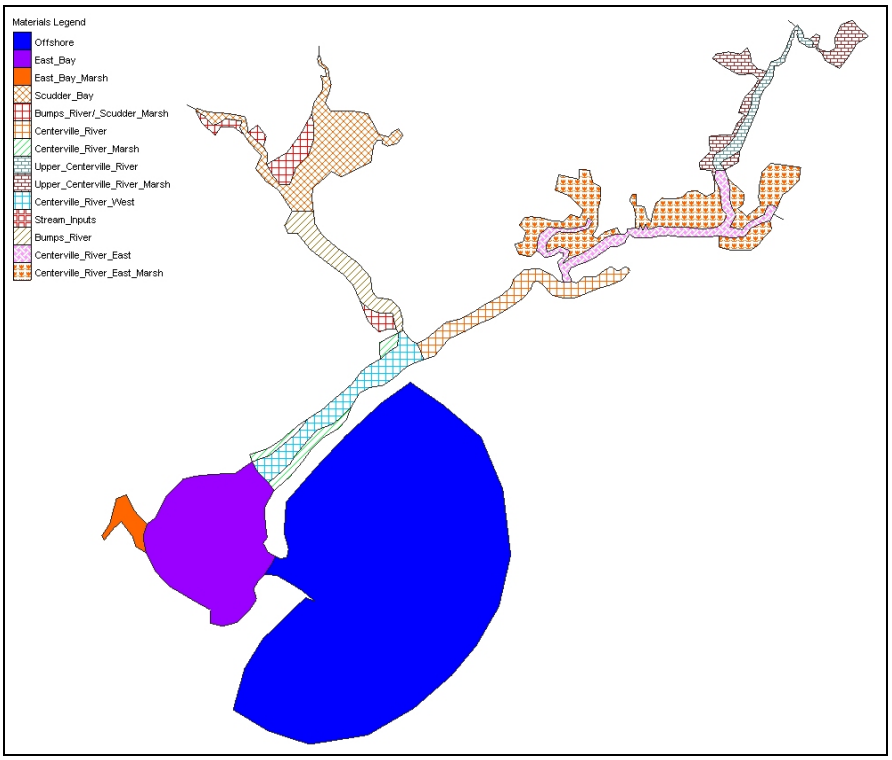


Figure VI-2. Map of Centerville River water quality model longitudinal dispersion coefficients. Color patterns designate the different areas used to vary model dispersion coefficient values.

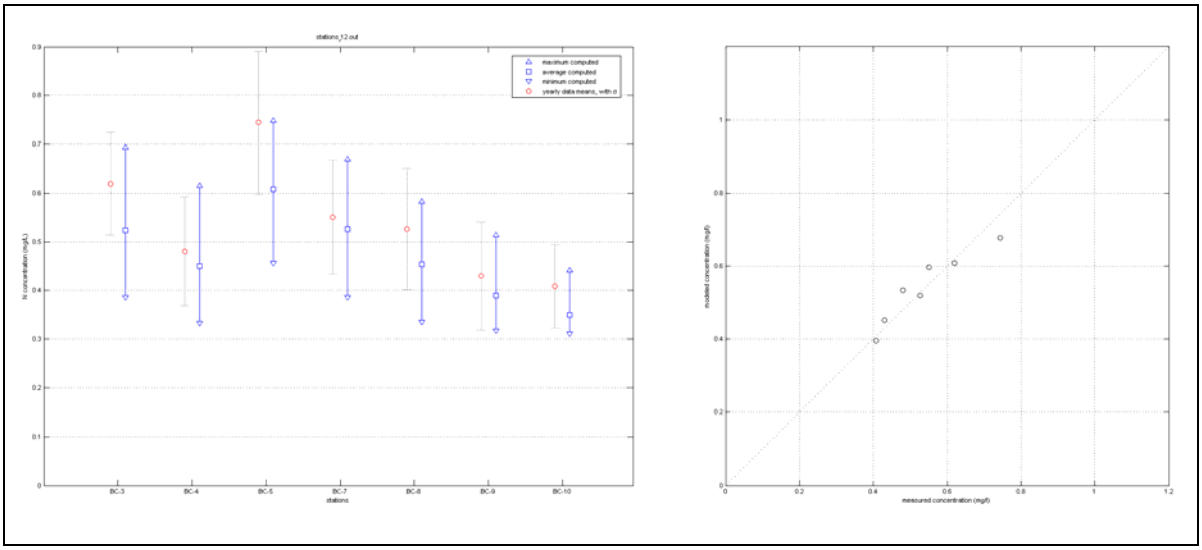


Figure VI-3. Comparison of measured total nitrogen concentrations and calibrated model output at stations in Centerville River System. For the left plot, station labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed concentration for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset. For the plots to the right, model calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for each model are also presented.

VI.2.5 Model Salinity Verification

In addition to the model calibration based on nitrogen loading and water column measurements, numerical water quality model performance is typically verified by modeling salinity. This step was performed for the Centerville River System using salinity data collected at the same stations as the nitrogen data. The only required inputs into the RMA4 salinity model of each system, in addition to the RMA2 hydrodynamic model output, were salinities at the model open boundary, and groundwater inputs. The open boundary salinity was set at 30.2 ppt. For groundwater inputs salinities were set at 0 ppt. Groundwater input used for the model was 22.26 ft^3/sec (54,449 m^3/day) distributed amongst the watersheds. Groundwater flows were distributed evenly in each model through the use of several 1-D element input points positioned along each model's land boundary.

Comparisons of modeled and measured salinities are presented in Figure VI-5, with contour plots of model output shown in Figure VI-6. Though model dispersion coefficients were not changed from those values selected through the nitrogen model calibration process, the model skillfully represents salinity gradients in Centerville River System. The rms error of the models was 1.44 ppt, and correlation coefficient was 0.72. The salinity verification provides a further independent confirmation that model dispersion coefficients and represented freshwater inputs to the model correctly simulate the real physical systems.

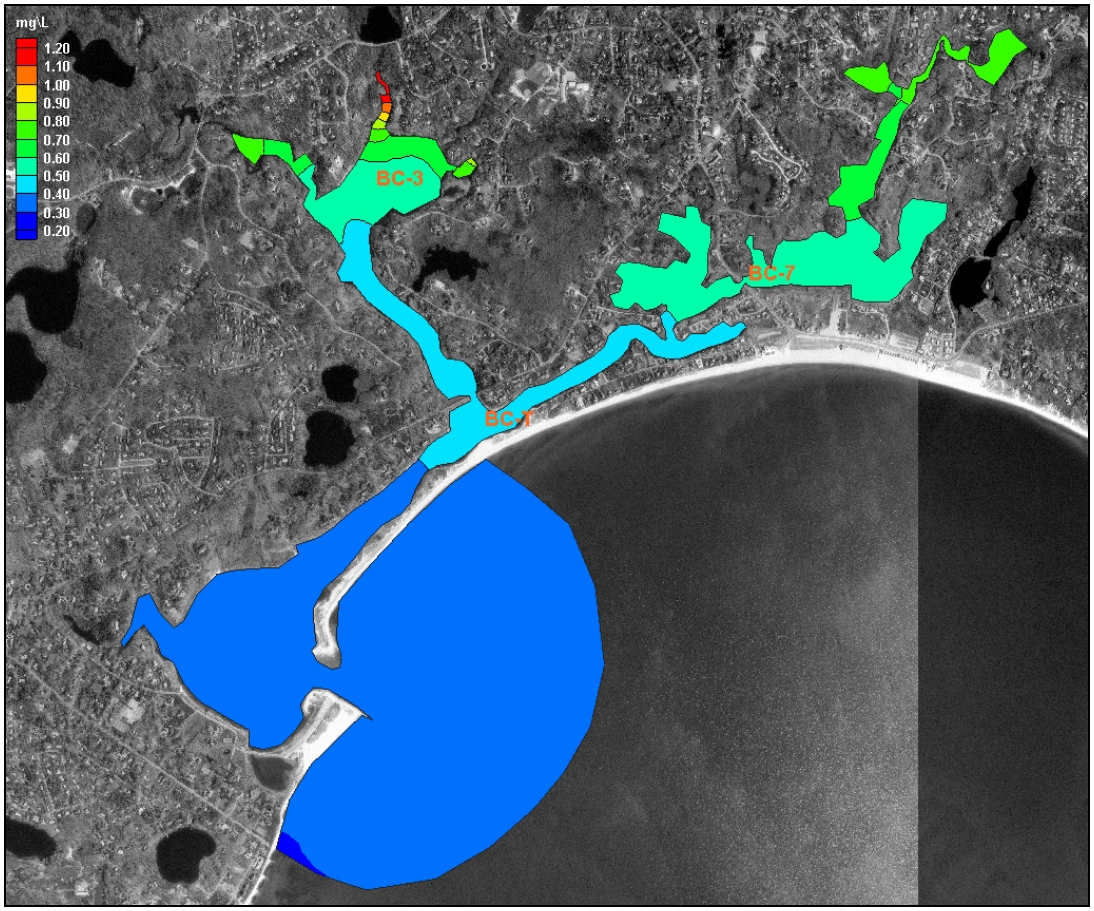


Figure VI-4. Contour plots of average total nitrogen concentrations from results of the present conditions loading scenario, for Centerville River System. The approximate location of the sentinel threshold station for Centerville River System (BC-T) is shown.

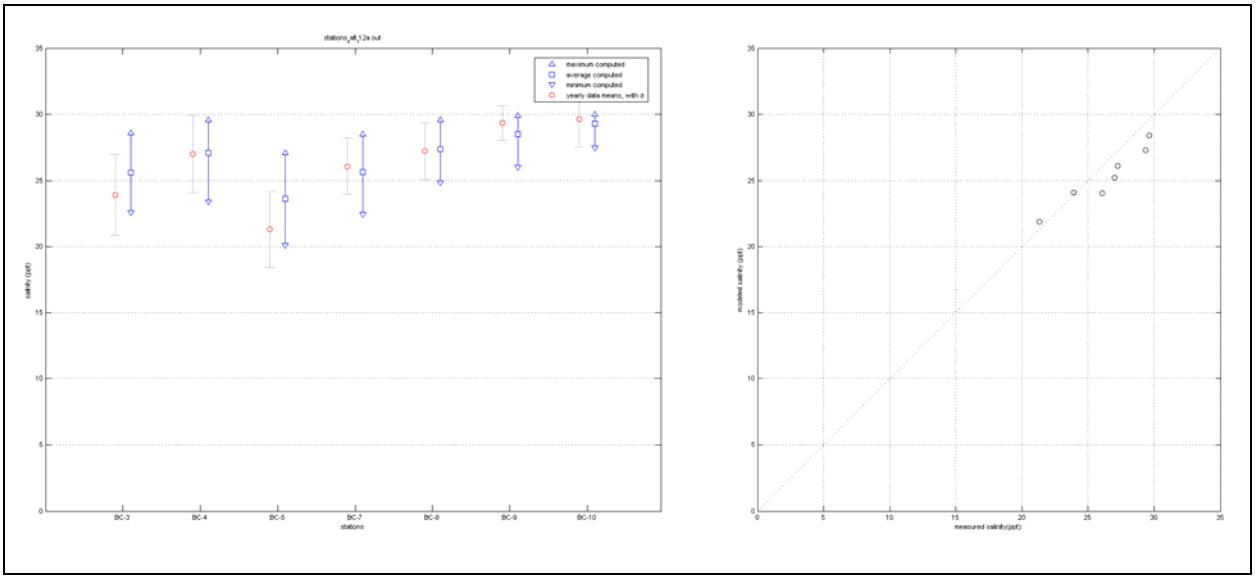


Figure VI-5. Comparison of measured and calibrated model output at stations in Centerville River System. For the left plots, stations labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed salinity for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset. For the plots to the right, model calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for each model are also presented.

VI.2.6 Build-Out and No Anthropogenic Load Scenarios

To assess the influence of nitrogen loading on total nitrogen concentrations within the embayment system, two standard water quality modeling scenarios were run: a "build-out" scenario based on potential development (described in more detail in Section IV) and a "no anthropogenic load" or "no load" scenario assuming only atmospheric deposition on the watershed and sub-embayment, as well as a natural forest within each watershed. Comparisons of the alternate watershed loading analyses are shown in Table VI-4. Loads are presented in kilograms per day (kg/day) in this Section, since it is inappropriate to show benthic flux loads in kilograms per year due to seasonal variability.

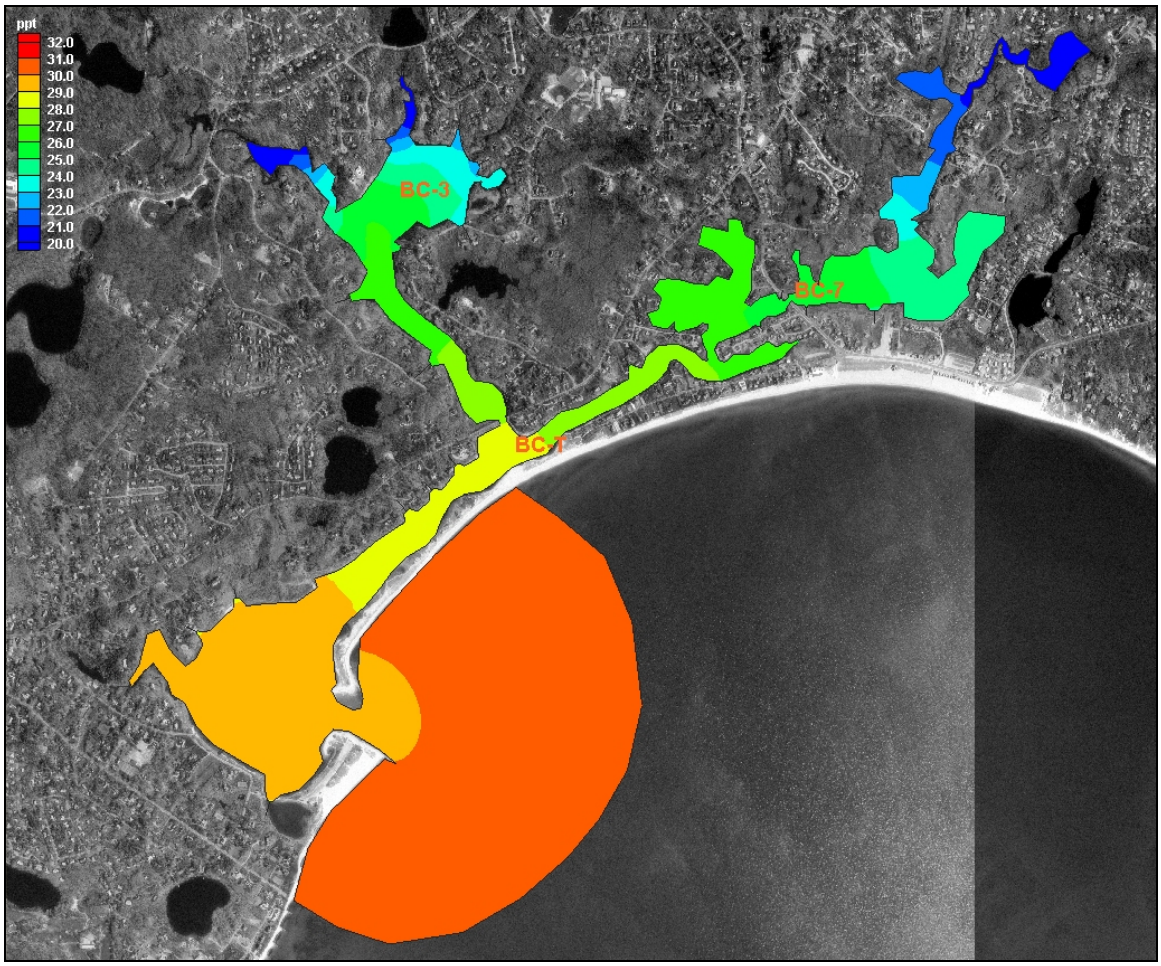


Figure VI-6. Contour plots of modeled salinity (ppt) in Centerville River System.

Table VI-4. Comparison of sub-embayment watershed loads used for modeling of present, build-out, and no-anthropogenic ("no-load") loading scenarios of the Centerville River System. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	build out (kg/day)	build out % change	no load (kg/day)	no load % change
Centerville River East	55.737	58.907	+5.7%	4.551	-91.8%
Scudder Bay	14.452	15.041	+4.1%	1.025	-92.9%
Centerville River West	9.463	10.011	+5.8%	0.907	-90.4%
East Bay	8.627	9.008	+4.4%	1.458	-83.1%
Surface Water Sources					
Pine Street Stream	3.452	3.742	+8.4%	0.597	-82.7%
Lake Elizabeth Stream	2.274	2.252	-0.0	0.093	-95.9%
Bumps River	16.912	17.863	+5.6%	0.364	-97.8%
Skunknet River	21.260	21.918	+3.1%	1.044	-95.1%

VI.2.6.1 Build-Out

In general, certain sub-embayments would be impacted more than others. The build-out scenario indicates that there would be more than a 6% increase in watershed nitrogen load to the western end of Centerville River as a result of potential future development. Other watershed areas would experience similar load increases, for example the loads to East Bay would increase 4% from the present day loading levels. For the no load scenarios, a majority of the load entering the watershed is removed; therefore, the load is generally lower than existing conditions by over 80% overall and 90% in most areas.

For the build-out scenario, a breakdown of the total nitrogen load entering the Centerville River System sub-embayments is shown in Table VI-5. The benthic flux for the build-out scenarios is assumed to vary proportional to the watershed load, where an increase in watershed load will result in an increase in benthic flux (i.e., a positive change in the absolute value of the flux), and *vise versa*.

Projected benthic fluxes (for both the build-out and no load scenarios) are based upon projected PON concentrations and watershed loads, determined as:

$$(Projected\ N\ flux) = (Present\ N\ flux) * [PON_{projected}]/[PON_{present}]$$

where the projected PON concentration is calculated by,

$$[PON_{projected}] = R_{load} * \Delta PON + [PON_{(present\ offshore)}],$$

using the watershed load ratio,

$$R_{load} = (Projected\ N\ load) / (Present\ N\ load),$$

and the present PON concentration above background,

$$\Delta PON = [PON_{(present\ flux\ core)}] - [PON_{(present\ offshore)}].$$

Table VI-5. Build-out sub-embayment and surface water loads used for total nitrogen modeling of the Centerville River System, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Centerville River East	58.907	0.449	5.469
Scudder Bay	15.041	0.685	-2.170
Centerville River West	10.011	0.718	3.526
East Bay	9.008	1.126	12.799
Surface Water Sources			
Pine Street Stream	3.742	-	-
Lake Elizabeth Stream	2.252	-	-
Bumps River	17.863	-	-
Skunknet River	21.918	-	-

Following development of the nitrogen loading estimates for the build-out scenario, the water quality model of Centerville River System was run to determine nitrogen concentrations within each sub-embayment (Table VI-6). Total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios. Total

N concentrations increased the most in the upper portion of the system, with the largest change at the upper portion of Centerville River (2.8%) and the least change occurred in East Bay (0.6%) which exchanges directly with Nantucket Sound. Color contours of model output for the build-out scenario are present in Figure VI-7. The range of nitrogen concentrations shown are the same as for the plot of present conditions in Figure VI-4, which allows direct comparison of nitrogen concentrations between loading scenarios.

Table VI-6. Comparison of model average total N concentrations from present loading and the build-out scenario, with percent change, for the Centerville River System. Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	build-out (mg/L)	% change
Scudder Bay	**BC-3**	**0.524**	**0.536**	**+2.1%**
Bumps River	BC-4	0.451	0.458	+1.6%
Centerville River	BC-5	0.609	0.626	+2.8%
Centerville River	**BC-7**	**0.526**	**0.538**	**+2.2%**
Centerville River	BC-8	0.454	0.462	+1.7%
Centerville River	BC-9	0.389	0.394	+1.1%
East Bay	BC-10	0.349	0.351	+0.6%
Confluence of Bumps River and Centerville River	**BC-T**	**0.412**	**0.418**	**+1.4%**

VI.2.6.2 No Anthropogenic Load

A breakdown of the total nitrogen load entering each sub-embayment for the no anthropogenic load ("no load") scenario is shown in Table VI-7. The benthic flux input to each embayment was reduced (toward zero) based on the reduction in the watershed load (as discussed in §VI.2.6.1). Compared to the modeled present conditions and build-out scenario, atmospheric deposition directly to each sub-embayment becomes a greater percentage of the total nitrogen load as the watershed load and related benthic flux decrease.

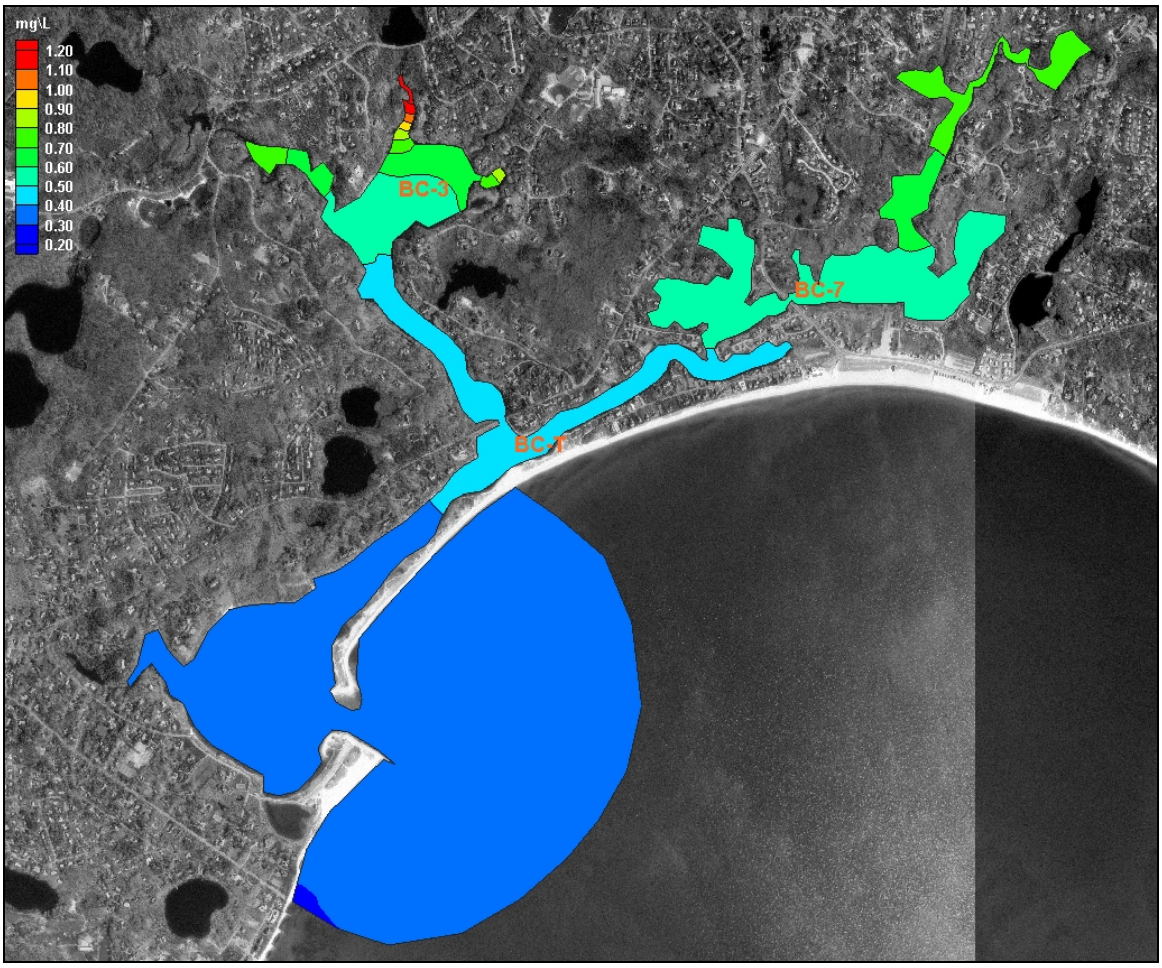


Figure VI-7. Contour plots of modeled total nitrogen concentrations (mg/L) in Centerville River System, for projected build-out loading conditions, and bathymetry. The approximate location of the sentinel threshold station for Centerville River System (BC-T) is shown.

Table VI-7. "No anthropogenic loading" ("no load") sub-embayment and surface water loads used for total nitrogen modeling of Centerville River System, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Centerville River East	4.551	0.449	3.847
Scudder Bay	1.025	0.685	-1.432
Centerville River West	0.907	0.718	3.038
East Bay	1.458	1.126	11.125
Surface Water Sources			
Pine Street Stream	0.597	-	-
Lake Elizabeth Stream	0.093	-	-
Bumps River	0.364	-	-
Skunknet River	1.044	-	-

Following development of the nitrogen loading estimates for the no load scenario, the water quality model was run to determine nitrogen concentrations within each sub-embayment. Again, total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios. The relative change in total nitrogen concentrations resulting from "no load" was significant as shown in Table VI-8, with reductions greater than 40% occurring in Scudder Bay and the upper portions of Centerville River. Results for each system are shown pictorially in Figure VI-8.

Table VI-8. Comparison of model average total N concentrations from present loading and the no anthropogenic ("no load") scenario, with percent change, for the Centerville River System. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	no-load (mg/L)	% change
Scudder Bay	**BC-3**	**0.524**	**0.312**	**-40.5%**
Bumps River	BC-4	0.451	0.311	-30.9%
Centerville River	BC-5	0.609	0.328	-46.2%
Centerville River	**BC-7**	**0.526**	**0.326**	**-38.1%**
Centerville River	BC-8	0.454	0.320	-29.5%
Centerville River	BC-9	0.389	0.312	-19.8%
East Bay	BC-10	0.349	0.309	-11.6%
Confluence of Bumps River and Centerville River	**BC-T**	**0.412**	**0.314**	**-23.7%**

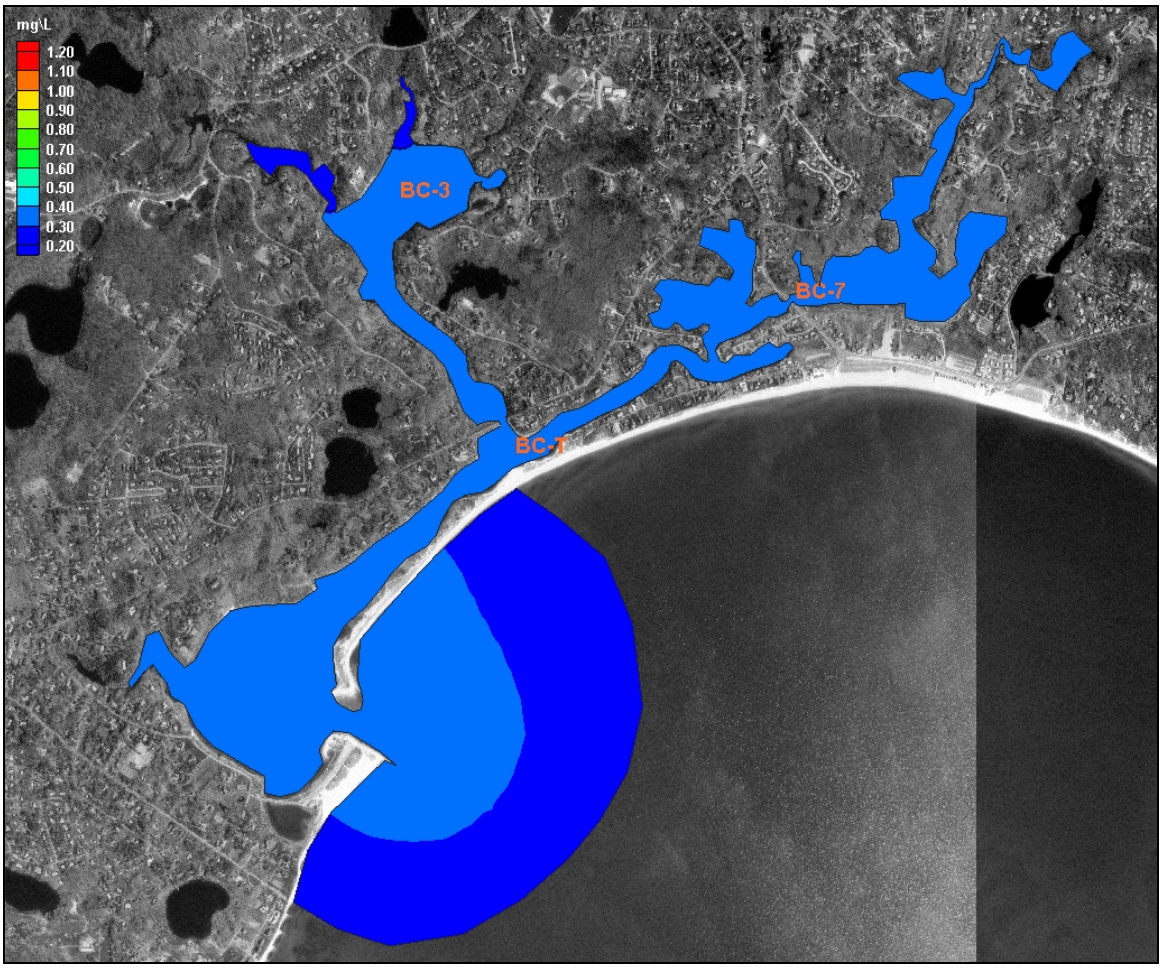


Figure VI-8. Contour plots of modeled total nitrogen concentrations (mg/L) in Centerville River System, for no anthropogenic loading conditions, and bathymetry. The approximate location of the sentinel threshold station for Centerville River System (BC-T) is shown.

VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll, and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (fish, shellfish, infauna) which it supports. For the Centerville River embayment system, the MEP assessment is based upon data from the water quality monitoring database and MEP surveys of eelgrass distribution, benthic animal communities and sediment characteristics, and dissolved oxygen records conducted during the summer of 2003. These data form the basis of an assessment of this system's present health, and when coupled with a full water quality synthesis and projections of future conditions based upon the water quality modeling effort, will support complete nitrogen threshold development for these systems (Chapter VIII).

VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS

There are a variety of indicators that can be used in concert with water quality monitoring data for evaluating the ecological health of embayment systems. The best biological indicators are those species which are non-mobile and which persist over relatively long periods, if environmental conditions remain constant. The concept is to use species, which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

As a basis for a nitrogen thresholds determination, MEP focused on major habitat quality indicators: (1) bottom water dissolved oxygen and chlorophyll a (Section VII.2), (2) eelgrass distribution over time (Section VII.3) and (3) benthic animal communities (Section VII.4). Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate cause being nitrogen loading). However, oxygen conditions can change rapidly and frequently show strong tidal and diurnal patterns. Even severe levels of oxygen depletion may occur only infrequently, yet have important effects on system health. To capture this variation, the MEP Technical Team deployed dissolved oxygen sensors within the upper portion of the Centerville River System, Scudder Bay, as well as closer to the inlet to the Centerville River system in East Bay and at the Town Landing in the mid River reach to record the frequency and duration of low oxygen conditions during the critical summer period. This work was conducted in 2003 in association with the Town of Barnstable.

The MEP habitat analysis uses eelgrass as a sentinel species for indicating nitrogen over-loading to coastal embayments. Eelgrass is a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. Mapping of the eelgrass beds within the Centerville River System was conducted for comparison to historic records (DEP Eelgrass Mapping Program, C. Costello). Temporal trends in the distribution of eelgrass beds are used by the MEP to assess the stability of the habitat and to determine trends potentially related to nutrient related water quality. Eelgrass beds can decrease within embayments in response to a variety of causes, but throughout almost all of the embayments within southeastern Massachusetts, the primary cause appears to be related to increases in embayment nitrogen levels. Within the Centerville River System, temporal changes in eelgrass distribution provides a strong basis for evaluating recent increases (nitrogen loading) or decreases (increased flushing-new inlet) in nutrient enrichment.

In areas that do not naturally support eelgrass beds, benthic animal indicators were used to assess the level of habitat health from "healthy" (low organic matter loading, high D.O.) to "highly stressed" (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment samples were identified and the environments ranked based upon the fraction of healthy, transitional, and stressed indicator species. The analysis is based upon life-history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes *et al.* 1997). These data are coupled with the level of diversity (H') and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

VII.2 BOTTOM WATER DISSOLVED OXYGEN

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 3.8 mg L^{-1}. Massachusetts State Water Quality Classification indicates that SA (high quality) waters maintain oxygen levels above 6 mg L^{-1}. The tidal waters of the Centerville River System are currently listed under this Classification as SA. It should be noted that the Classification system represents the water quality that the embayment should support, not the existing level of water quality. It is through the MEP and TMDL processes that management actions are developed and implemented to keep or bring the existing conditions in line with the Classification.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates in summer than winter (Figure VII-1). It is not surprising that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute levels (mg L^{-1}) are found during the summer in southeastern Massachusetts embayments when water column respiration rates are greatest. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen conditions within shallow embayments (Taylor and Howes, 1994). To more accurately capture the degree of bottom water dissolved oxygen depletion during the critical summer period, autonomously recording oxygen sensors were moored 30 cm above the embayment bottom within key regions of the Centerville River System (Figure VII-2). The sensors (YSI 6600) were first calibrated in the laboratory and then checked with standard oxygen mixtures at the time of initial instrument mooring deployment. In addition periodic calibration samples were collected at the sensor depth and assayed by Winkler titration (potentiometric analysis, Radiometer) during each deployment. Each instrument mooring was serviced and calibration samples collected at least biweekly and sometimes weekly during a minimum deployment of 30 days within the interval from July through mid-September. All of the mooring data from the Centerville River embayment system was collected during the summer of 2003, specifically within the July to mid September period.

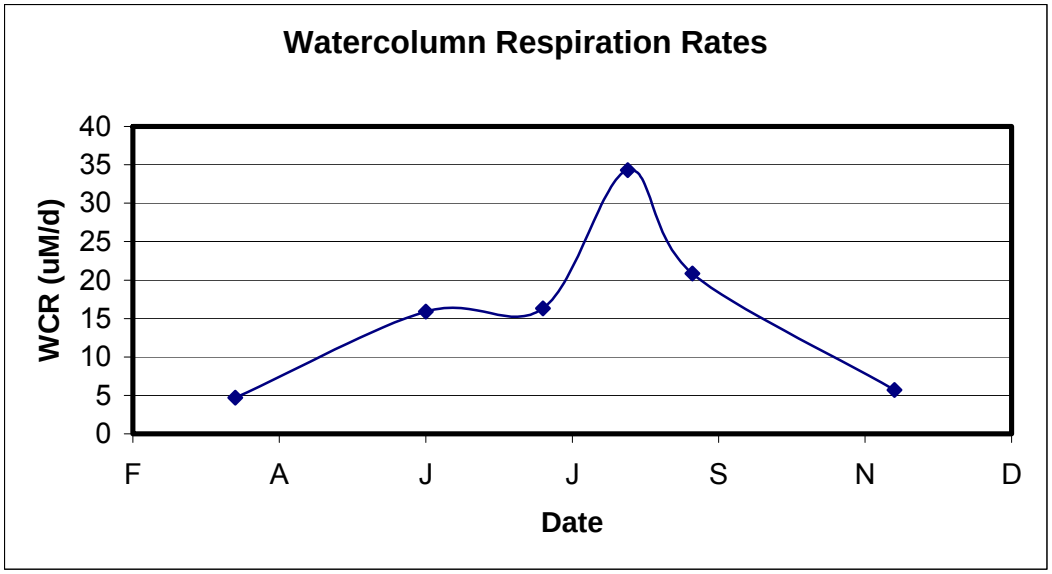


Figure VII-1. Average watercolumn respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System (Schlezinger and Howes, unpublished data). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Dissolved oxygen moorings were deployed in the Centerville River estuary (Figure VII-2) during 2003 to assess summertime fluctuations. Similar to other embayments in southeastern Massachusetts, the Centerville River System evaluated in this assessment showed high frequency variation, apparently related to diurnal and sometimes tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site, underscores the need for continuous monitoring within these systems.

Dissolved oxygen and chlorophyll a records were examined both for temporal trends and to determine the percent of the 37-40 day deployment period that these parameters were below/above various benchmark concentrations (Tables VII-1, VII-2). These data indicate both the temporal pattern of minimum or maximum levels of these critical nutrient related constituents, as well as the intensity of the oxygen depletion events and phytoplankton blooms. However, it should be noted that the frequency of oxygen depletion needs to be integrated with the actual temporal pattern of oxygen levels, specifically as it relates to daily oxygen excursions.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate nitrogen enriched conditions and some habitat quality impairment at each of the mooring sites within the estuary (Figures VII-3 through VII-5). The oxygen data throughout the estuary is consistent with elevated organic matter loads from phytoplankton production (chlorophyll a levels) indicative of nitrogen enrichment and eutrophication of estuarine systems



Figure VII-2. Aerial Photograph of the Centerville River embayment system in the Town of Barnstable showing locations of Dissolved Oxygen mooring deployments conducted in the summer of 2003.

Table VII-1a. Number of days during deployment of in situ sensors that bottomwater oxygen was below various benchmark levels.

Mooring ID.	Start Date	End Date	Total Deployment (Days)	<6 mg/L Duration (Days)	<5 mg/L Duration (Days)	<4 mg/L Duration (Days)	<3 mg/L Duration (Days)
Centerville Town Landing	8/9/2003	9/18/2003	39.9	14.20	6.57	3.02	1.01
			Mean	0.24	0.15	0.16	0.10
			Min	0.01	0.01	0.01	0.01
			Max	1.70	0.84	0.39	0.18
			S.D.	0.29	0.18	0.12	0.05
Centerville Scudder Bay	8/9/2003	9/18/2003	40.0	7.56	2.82	0.48	0.10
			Mean	0.18	0.11	0.12	0.05
			Min	0.01	0.01	0.02	0.02
			Max	0.74	0.40	0.32	0.08
			S.D.	0.14	0.09	0.14	0.04
Centerville East Bay	8/9/2003	9/15/2003	36.8	20.21	6.67	0.14	0.00
			Mean	0.47	0.17	0.03	N/A
			Min	0.01	0.01	0.01	0.00
			Max	1.92	0.74	0.06	0.00
			S.D.	0.50	0.14	0.02	N/A

Table VII-1b. Frequency distribution from Water Quality Monitoring grab sampling of bottom water oxygen. Number represent the number of field dates that oxygen was observed within the noted range (<2 mg L^{-1}, 2-3 mg L^{-1}, etc.).

Location		Range of Measured Bottomwater DO Levels (mg L^{-1})							
		<2	2-3	3-4	4-5	5-6	>6	total	Min
Scudder Bay	BC-3	0	0	2	7	12	8	29	3.4
Bumps River Estuary	BC-4	0	0	0	3	11	14	28	4.5
Upper N Centerville River	BC-5	0	1	10	9	4	5	29	2.7
Upper Centerville River	BC-7	0	0	0	2	16	12	30	4.8
Mid Centerville River	BC-8	0	0	0	4	8	13	25	4.5
Lower Centerville River	BC-9	0	0	0	0	5	25	30	5.2
East Bay	BC-10	0	0	0	0	6	25	31	5.7
Centerville Harbor	BC-11	0	0	0	0	0	32	32	6.2

Table VII-2. Duration (number of days during deployment period) that chlorophyll a levels exceed various benchmark levels within the embayment system. "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST. The mean in the final column is the average level over the deployment.

Mooring Id.	Start Date	End Date	Total Deployment (Days)	>5 ug/L Duration (Days)	>10 ug/L Duration (Days)	>15 ug/L Duration (Days)	>20 ug/L Duration (Days)	>25 ug/L Duration (Days)
Centerville Town Landing	8/9/2003	9/18/2003	31.7	30.79	22.50	16.00	12.92	11.17
Mean Chl Value = 22.0 ug/L			Mean	2.20	0.51	0.33	0.30	0.27
			Min	0.04	0.04	0.04	0.04	0.04
			Max	14.25	7.96	4.54	3.17	2.58
			S.D.	4.28	1.17	0.72	0.61	0.50
Centerville Scudder Bay	8/9/2003	9/18/2003	32.2	32.04	22.67	14.38	9.92	6.88
Mean Chl Value = 18.02 ug/L			Mean	8.01	0.45	0.28	0.20	0.17
			Min	0.04	0.04	0.04	0.04	0.04
			Max	17.71	7.42	3.29	0.63	0.54
			S.D.	7.63	1.05	0.46	0.17	0.15
Centerville East Bay	8/9/2003	9/18/2003	39.3	16.71	3.79	1.08	0.00	0.00
Mean Chl Value = 5.10 ug/L			Mean	0.19	0.29	0.08	N/A	N/A
			Min	0.04	0.04	0.04	0.00	0.00
			Max	0.71	0.54	0.25	0.00	0.00
			S.D.	0.16	0.16	0.06	N/A	N/A

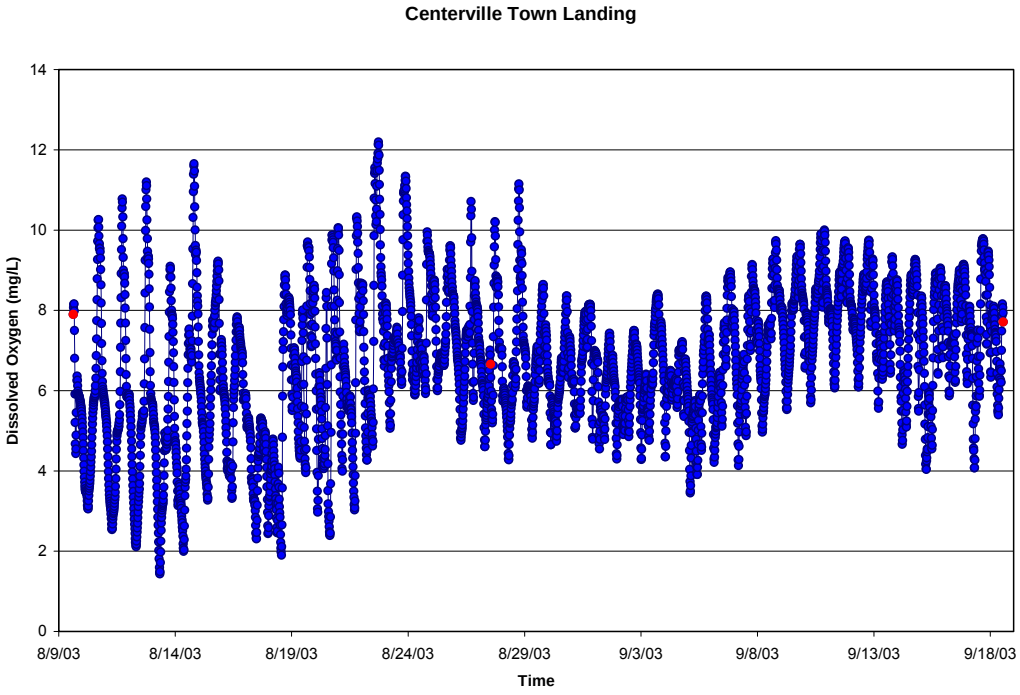


Figure VII-3. Bottom water record of dissolved oxygen at the Centerville Town Landing station, summer 2003. Calibration samples represented as red dots.

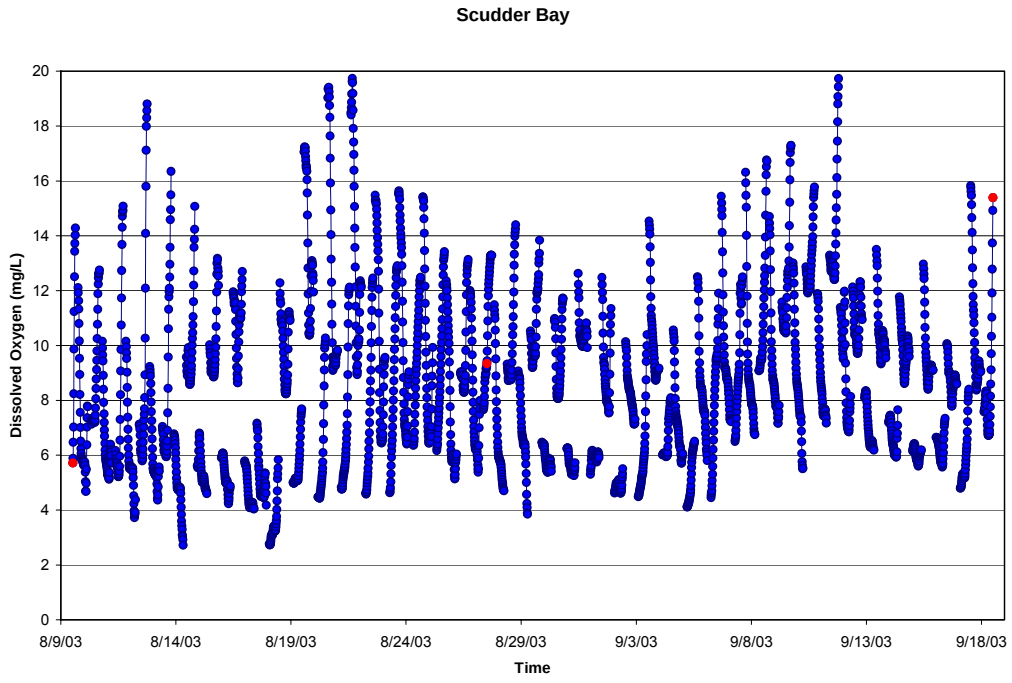


Figure VII-4. Bottom water record of dissolved oxygen in the Scudder Bay station, summer 2003. Calibration samples represented as red dots.

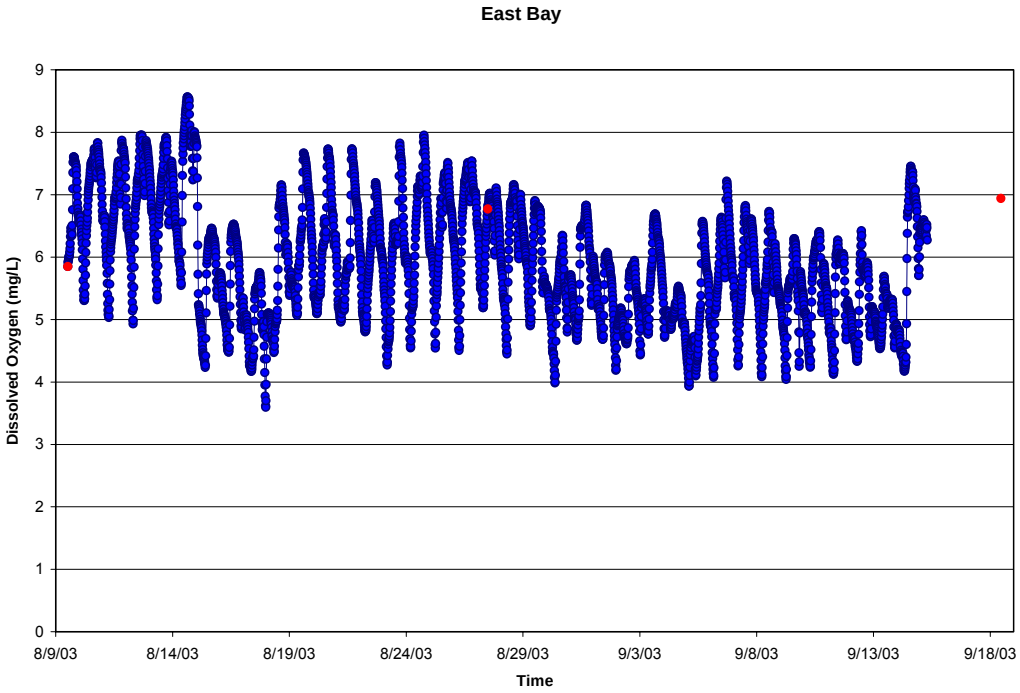


Figure VII-5. Bottom water record of dissolved oxygen in the East Bay station, summer 2003. Calibration samples represented as red dots.

There is a clear gradient in the extent of oxygen depletion from the upper to the lower portions of the system, as shown in both the mooring and Water Quality Monitoring data (Table VII-1). The lowest oxygen levels were seen in the upper Centerville River salt marsh and in Scudder Bay and oxygen levels increased moving seaward to the lower reach of the Centerville River and East Bay. However, the oxygen levels within the Centerville River System had daily minima lower than the offshore basin of Centerville Harbor which had a minimum recorded bottom water oxygen level of 6.2 mg L^{-1} over 22 sampling dates. This latter comparison is added support for the contention that the Centerville Estuary is nitrogen enriched over offshore waters.

Overall, oxygen depletion was observed at each of the mooring sites (Table VII-1a), but the degree of depletion varied between sites. East Bay generally maintained oxygen levels above 4 mg L-1, but with frequent excursions below 5 mg L^{-1}. These oxygen conditions represent a moderate level of impairment to benthic infaunal communities associated with embayments. Oxygen levels in the upper reach of the Centerville River showed even lower levels periodically into the 2-3 mg L^{-1} range, although generally with daily minima above 4 mg L^{-1}. The central region of Scudder Bay was clearly nitrogen enriched, but generally maintained daily oxygen minima above 4 mg L^{-1} and typically above 5 mg L^{-1}. This basin showed its enrichment mainly through the large daily excursions with daily maxima typically >11 mg L^{-1}.

The use of only the duration of oxygen below, for example 4 mg L^{-1}, can underestimate the level of habitat impairment in these locations. The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). This pattern was seen in both of the upper system

sites, further supporting the contention that the upper basins are currently nitrogen enriched. The upper tidal reaches of each estuary have the largest daily oxygen excursion, with daily excursions in excess of 6 mg L^{-1} common, whereas the in the lower system, East Bay, showed more modest excursions of ~3 mg L^{-1} . This further supports the assessment of nitrogen enrichment.

The observations by the continuously recording oxygen sensors were supported by the more spatially distributed grab sample data collected by the Town of Barnstable Water Quality Monitoring Program (Table VII-1b). These data support general observation that oxygen levels throughout the embayment basins of the Centerville River System are generally >4 mg L^{-1} and typically >5 mg L^{-1}, during the summer months. In contrast the salt marsh influenced sites of upper Centerville River and Scudder Bay showed greater depletions, with levels in the 3-4 mg L^{-1} range on 34% and 7% of the dates (N=29), respectively.

The spatial pattern of oxygen depletion within the Estuary was consistent with the measured chlorophyll a levels (Table VII-2, Figures VII-6 to VII-8). The level of oxygen depletion was directly related to the amount of chlorophyll a in the watercolumn. This is consistent with nitrogen enrichment resulting in increased phytoplankton biomass and subsequent organic matter deposition and decay being the process controlling oxygen level in the Centerville River System. Chlorophyll a levels in East Bay were indicative of a relatively healthy to moderately enriched basin. In East Bay chlorophyll a averaged 5.1 ug L^{-1} and was almost always <10 ug L^{-1}. The upper reach of the Centerville River and Scudder Bay supported higher phytoplankton biomass with average levels ~20 ug L^{-1} and blooms producing consistent levels of 30 ugL^{-1}.

It is important to evaluate the level of oxygen excursion and depletion relative to the functional habitats involved. In the upper Centerville River the tidal river serves as the central salt marsh creek to a rather large and healthy salt marsh which is just upgradient of the upper river oxygen mooring. In addition, there is a smaller separate salt marsh adjacent the mooring at this specific location. Dissolved oxygen levels recorded by this mooring reflect the oxygen conditions of the ebbing tidal waters from these wetlands areas. The low oxygen levels are consistent with a salt marsh tidal creek, where the organic matter enriched sediments support high levels of oxygen uptake at night and deplete the overlying waters. While oxygen depletion to 3 mg/L would indicate impairment in an embayment like the East Bay basin, it is consistent with the organically enriched nature of smaller salt marsh creeks.

The results of the summer oxygen and chlorophyll a studies are consistent with the absence of eelgrass throughout the Centerville River/Harbor System and the spatial distribution of infaunal community types and quality of habitat.

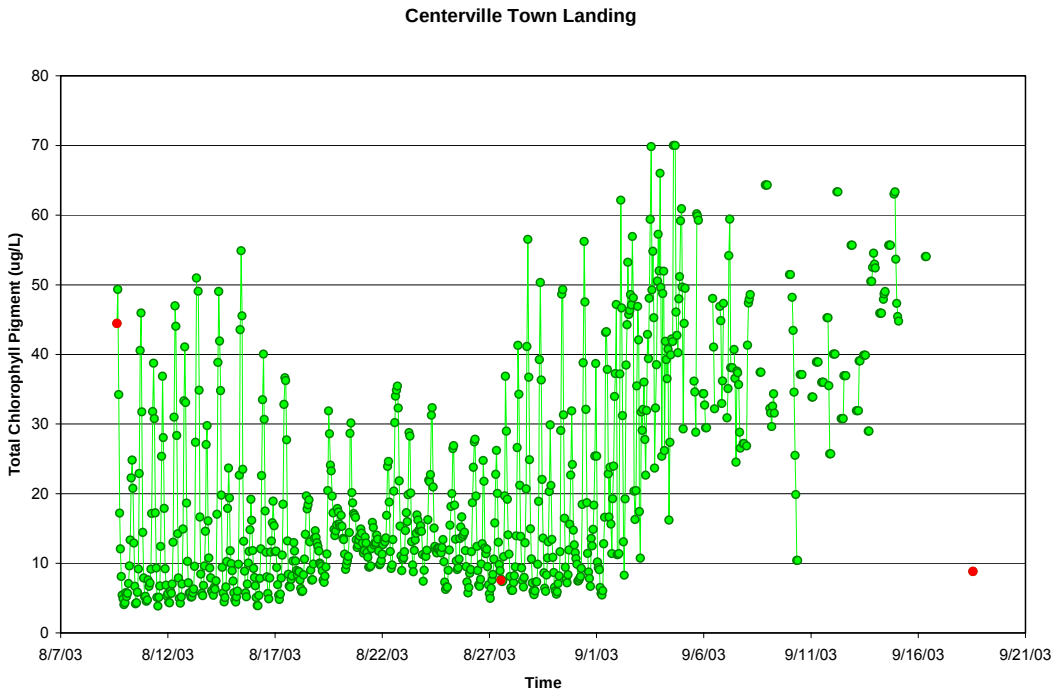


Figure VII-6. Bottom water record of Chlorophyll-a in the Centerville Town Landing station, summer 2003. Calibration samples represented as red dots.

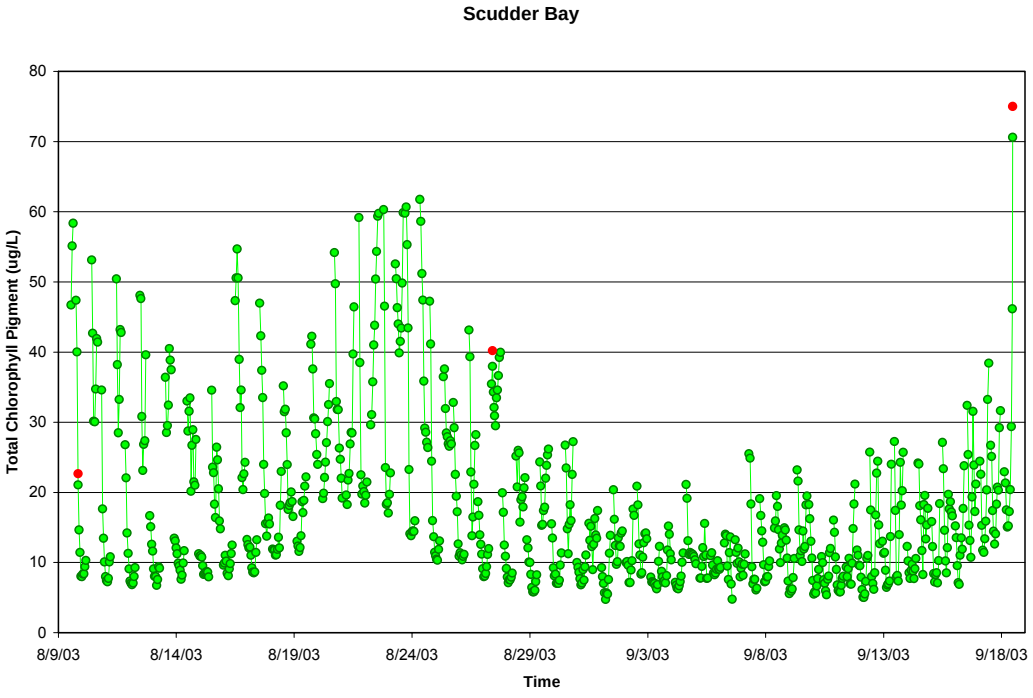


Figure VII-7. Bottom water record of Chlorophyll-a in the Scudder Bay station, summer 2003. Calibration samples represented as red dots.

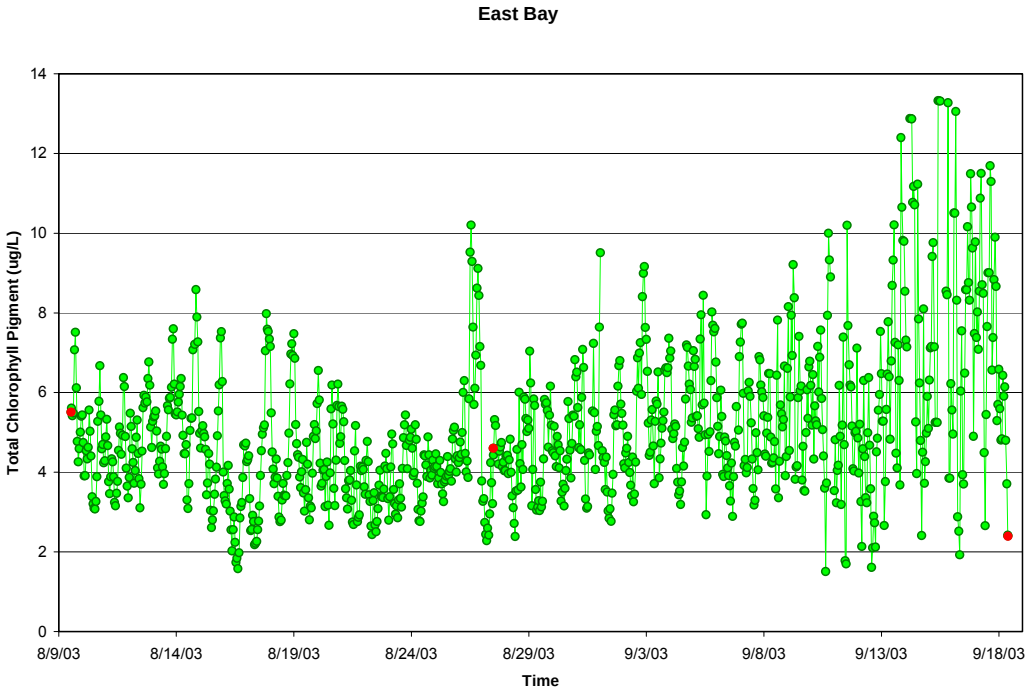


Figure VII-8. Bottom water record of Chlorophyll-*a* at the East Bay station, summer 2003. Calibration samples represented as red dots.

VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS

Eelgrass surveys and analysis of historical data was conducted for the Centerville River System by the DEP Eelgrass Mapping Program as part of the MEP Technical Team. Surveys were conducted in 1995 and 2001, as part of this program. Additional analysis of available aerial photos from 1951 was used to reconstruct the eelgrass distribution prior to any substantial development of the watershed. The 1951 data were only anecdotally validated, while the 1995 and 2001 maps were field validated. The primary use of the data is to indicate (a) if eelgrass once or currently colonizes a basin and (b) if large-scale system-wide shifts have occurred or are presently underway. Integration of these data sets provides a view of temporal trends in eelgrass distribution from 1951 to 1995 to 2001 (Figure VII-9 and VII-10); the period in which watershed nitrogen loading significantly increased to its present level. This temporal information can be used to determine the stability of the eelgrass community.

At present, eelgrass beds are not present within the Centerville River System. In addition, to the DEP mapping, this has been confirmed by the multiple MEP staff conducting the infaunal and sediment sampling and the mooring studies and by the Town of Barnstable Shellfish Department. It should be noted that although the eelgrass beds present in Centerville River as observed in the 1951 aerial photography are no longer apparent, there does appear to be eelgrass remaining just outside the inlet to Centerville River at the discharge point to the Harbor. The current lack of eelgrass beds in Centerville River is expected given the high chlorophyll a and low dissolved oxygen levels and water column nitrogen concentrations within this system. However, it appears that the lower portions of the Centerville Harbor system (principally Centerville River) had water quality conditions capable of supporting eelgrass (except in the deeper channels and basin depths) in 1951. It is important to note that very stable eelgrass

beds were observed in each survey (1951, 1995, and 2001) outside the tidal inlet to the east and west.

The present absence of eelgrass throughout the Centerville River System is consistent with the observed oxygen depletions in each basin and the chlorophyll levels as well as functional basin types. Eelgrass in the upper reaches is unlikely as these areas are strongly influenced by surrounding wetlands that do not typically support eelgrass habitat. However, basins like the Centerville River channel (from the Town Landing to East Bay) and especially subembayments like East Bay do generally support eelgrass habitat under low to moderate nitrogen loading conditions. The distribution of eelgrass in 1951 is fully consistent with this functional analysis. It appears that the eelgrass beds which have persisted just outside of the tidal inlet extended into East Bay and up the Centerville River to the mouth of Bumps River in 1951. This is consistent with the lower nitrogen loading at that time and the resultant higher sustained oxygen levels and lower chlorophyll levels (high light penetration) that should have existed at that time based upon population data. Note that nitrogen loads originating in the Bumps River sub-watershed and in the Centerville River east of the mouth of Bumps River also affect the lower reach of the River and East Bay on the ebbing tide. As a result, the entire watershed of the Centerville River system affects conditions in East Bay.

The presence of eelgrass beds just outside of the tidal inlet in each of the DEP assessments supports the presence of eelgrass beds within East Bay at earlier and lower nitrogen levels. The beds just outside of the inlet and much of East Bay have the same water depth and same tidal range, so the major environmental differences between the sites are related to nitrogen enrichment. It appears from the eelgrass and water quality information that eelgrass beds within East Bay and the lower Centerville River should be the target for restoration and that this habitat should be recovered with appropriate nitrogen management.

Other factors which influence eelgrass bed loss in embayments can also be at play in the Centerville River System, though the recent loss seems completely in-line with nitrogen enrichment. Nevertheless, a brief listing of non-nitrogen related factors is useful. Eelgrass bed loss does not seem to be directly related to mooring density, as loss in East Bay was from both mooring and non-mooring areas and the lower Centerville River is not a boat mooring area. Similarly, pier construction and boating pressure may be adding additional stress in nutrient enriched areas, but do not seem to be the overarching factor. It is not possible at this time to determine the potential effect of shellfishing on eelgrass bed distribution, although it should be noted that the System has been an important shellfish area. At present the Centerville River System (Centerville River Segment MA96-04_2004; Bumps River Segment MA96-02_2004) are listed on the MassDEP 2004 Integrated List of waters impaired by pathogens), which typically reduces shellfishing pressure on an embayment.

However, the lack of eelgrass within the main tidal channel into East Bay is certainly associated with the periodic maintenance dredging for navigation. Dredging was recently performed, however, this represents a small region within the much larger area that has lost eelgrass and some dredging will likely always be required to maintain the tidal flushing of this system at its highest level to maintain healthy habitat quality, even after nitrogen management strategies have been implemented. Under present conditions, a reduction in tidal flushing will result in magnifying the eutrophic conditions of the entire system.

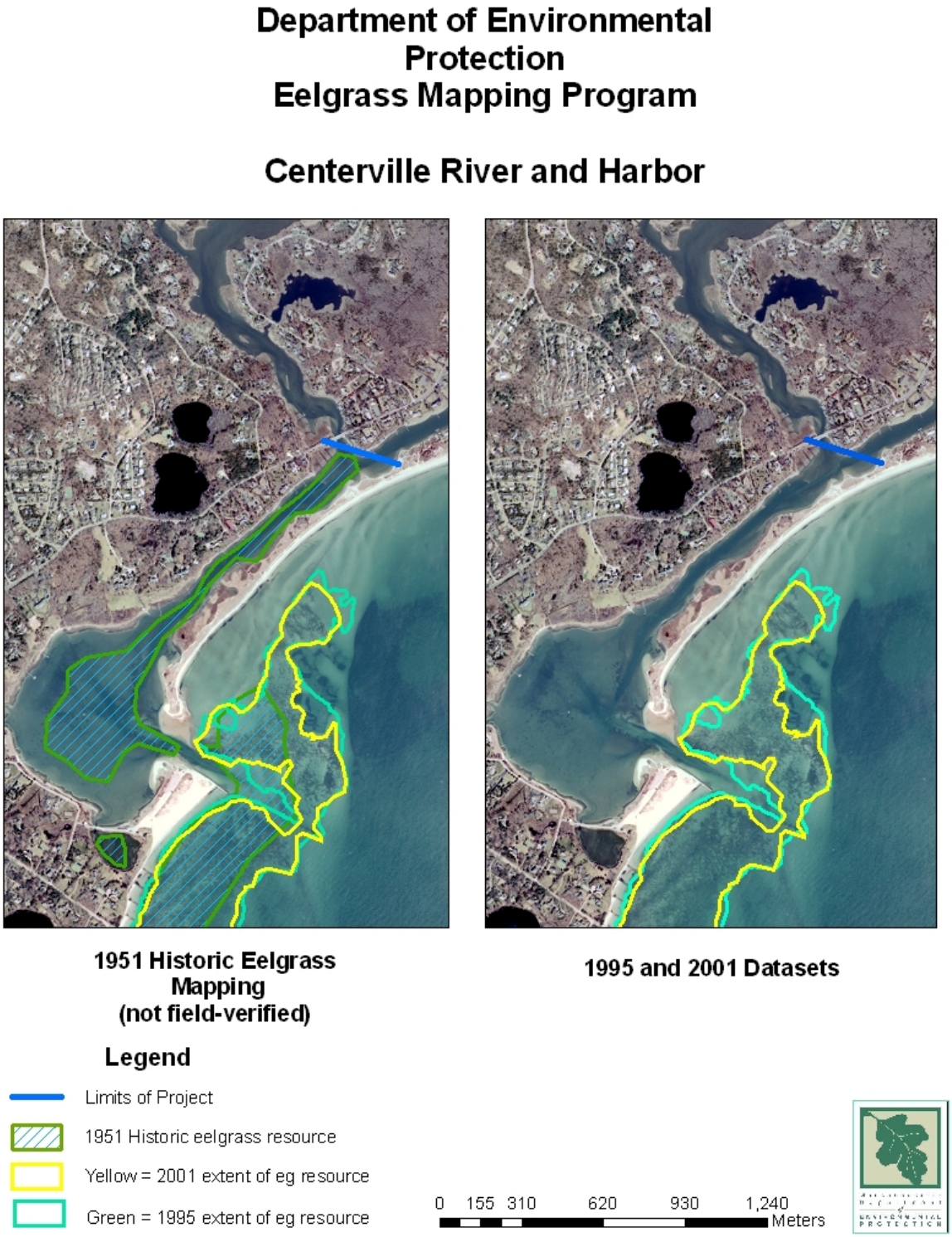


Figure VII-9. Eelgrass bed distribution within the Centerville Harbor System. The 1951 coverage is depicted by the green thatched outline inside of which circumscribes the eelgrass beds. The green (1995) and yellow (2001) areas were mapped by DEP. All data was provided by the DEP Eelgrass Mapping Program.

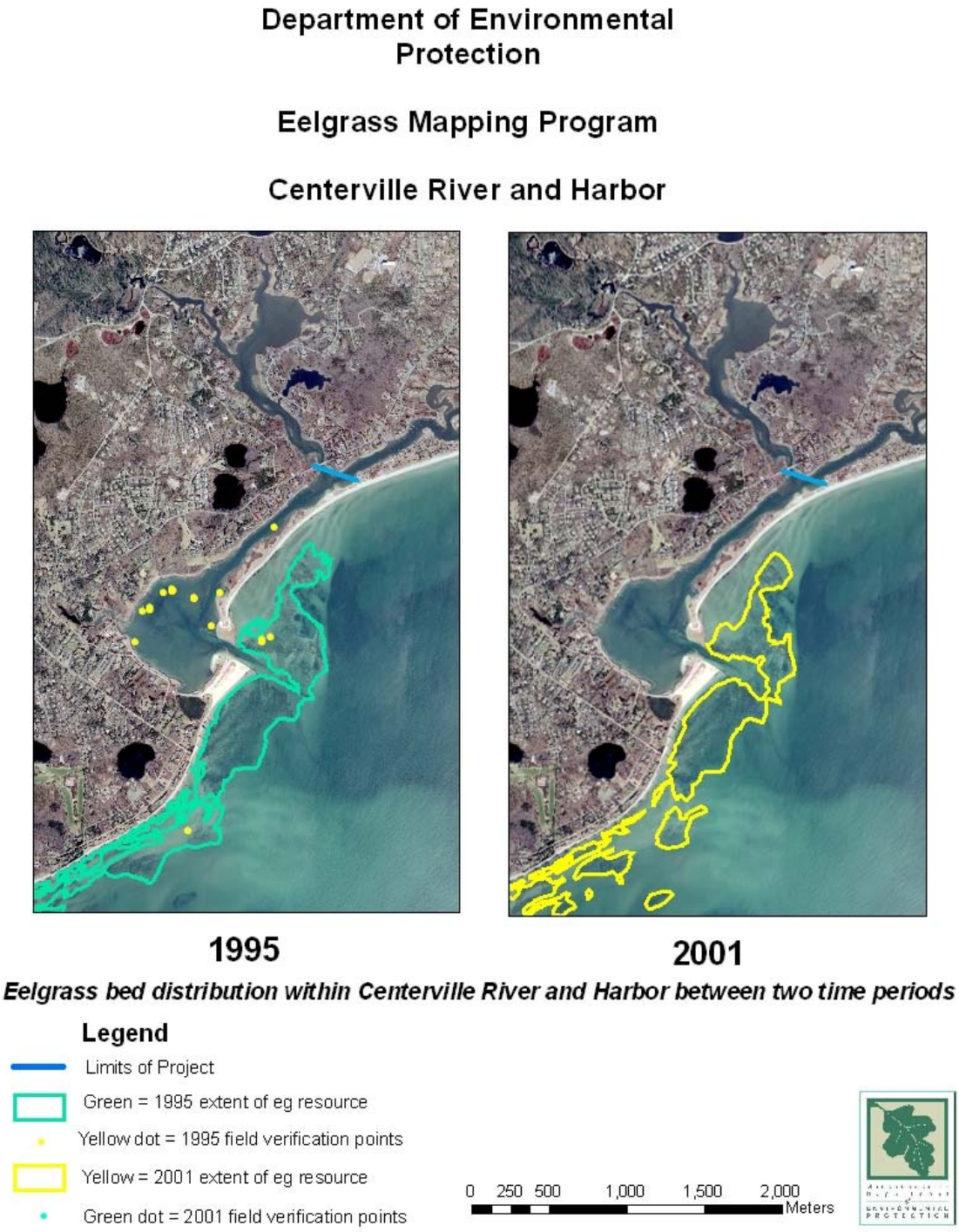


Figure VII-10. Eelgrass bed distribution within the Centerville Harbor System in addition to field verification points. The 1995 and 2001 coverage is depicted by the green and yellow thatched outlines inside of which circumscribes the eelgrass beds. The green (1995) and yellow (2001) areas were mapped by DEP. All data was provided by the DEP Eelgrass Mapping Program.

It is not possible to determine a general idea of short- and long-term rates of change in eelgrass coverage from the mapping data, since there is only limited temporal data with no eelgrass found in the recent surveys. However, it is possible to utilize the 1951 coverage data as an indication that a minimum eelgrass bed area that might be recovered, on the order of 52 acres, if nitrogen management alternatives were implemented (Table VII-3). Note that restoration of this habitat will necessarily result in restoration of other resources throughout the Centerville River/Harbor System and in the region of Scudder Bay and the Town Landing located low in the system, but distant from the inlet and influence of strong tidal flushing. Since East Bay is influenced by waters ebbing from both branches of the entire up-gradient basins, its nitrogen management will de facto result in a lowering of nitrogen enrichment throughout the Centerville River System and therefore an improvement of infaunal habitats in Scudder Bay and the upper Centerville River, which have traditionally only supported infaunal habitat, will support eelgrass after restoration, given its distance from the inlet and limited circulation,

The relative pattern of these data is consistent with the results of the oxygen and chlorophyll a patterns described in the previous section and the benthic infauna analysis, below.

Table VII-3. Changes in eelgrass coverage in the Centerville River portion of the Centerville Harbor system within the Town of Barnstable over the past half century (C. Costello).

EMBAYMENT	1951 (acres)	1995 (acres)	2001 (acres)	% Difference (1951 to 2001)
Centerville River	52.18	0.00	0.00	100%
There is presently no eelgrass in the Centerville River portion of the Centerville Harbor system.				

VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling was conducted at 21 locations throughout the Centerville River System (Figure VII-11). In some cases multiple assays were conducted. In all areas and particularly those that do not support eelgrass beds, benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity and evenness of the community. It should be noted that, given the loss of eelgrass beds, portions of the Centerville River System are clearly impaired by nutrient overloading. However, to the extent that it can still support healthy infaunal communities, the benthic infauna analysis is important for determining the level of impairment (moderately impaired→significantly impaired→severely degraded). This assessment is also important for the establishment of site-specific nitrogen thresholds (Chapter VIII).

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas, as shown by the oxygen and chlorophyll records , have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5. However, the number of species and individuals must also be taken into account as a high diversity can be achieved in a population decimated by organic loading. Also, as stated above, the specific species must also be examined as a large number of stress indicator species (e.g. Capitellids) or intermediate quality species (*Amplesca*) would be indicative of a significantly or moderately impaired environment, respectively, even if the number of individuals and species is relatively high.

The Infauna Study indicated that most of the infaunal habitat within the Centerville River System is either presently either healthy or only moderately impaired, when evaluated based upon the function type of the basins (i.e. embayment versus salt marsh creek/pond) Table VII-4).

The Bumps River estuarine reach and the lower Centerville River currently support healthy infaunal animal habitat for a coastal embayment/tidal river on Cape Cod. These areas support large numbers of individuals (generally >500) and species (up to 32/sample), with very high Diversity (H' 3.2-4.3) and Eveness (>0.75). The basin of East Bay, which is depositional and receives the ebb tidal waters from the entire estuarine system, is presently showing moderate impairment. This moderate impairment is seen primarily in the dominance of amphipod mats throughout the central basin (*Amplesca*). While the community is supportive of generally high numbers of individuals, the number of species, diversity and Eveness are reduced. Amphipod mats represent a valuable and productive resource, but are indicative of a habitat transitioning from healthy to stressful conditions, particularly as relates to organic matter loading from nitrogen enrichment. The upper Centerville River and the associated mid reach of the Centerville River are dominated by salt marsh conditions. Under these conditions the number of individuals and species is high and the Diversity and Eveness approximates healthy conditions even for an embayment. The species present are typical of salt marsh creeks, which generally have organic matter tolerant species (e.g. *Streblospio*) and crustaceans and mollusks. The upper reaches of the Centerville River appear to be currently supporting healthy infaunal habitat. Similarly, Scudder Bay exhibits infauna habitat quality indicative of organic matter enrichment. However, this basin supports salt marsh areas around its margins and a shallow central basin. It appears that this basin is functioning at least partially as a salt marsh pond and was evaluated as such by the MEP Technical Team. Therefore, this basin appears to be presently moderately impaired, based upon its moderate-low number of species and moderate-low (100) numbers of individuals. The nutrient enriched conditions within this basin appear to be beyond the accommodation of the infaunal community and nitrogen management will be needed to restore this benthic resource.

The MEP Surveys did detect a small localized area of degraded infaunal habitat within the Centerville River System, a small lagoon altered for boats directly inland of the western stretch of Craigville Beach. This small basin contains a shallow sill across its entrance to the River and a "deep" basin (Figure V-6). The basin configuration and sill create a localized depositional area with localized bottom water hypoxia. The result is a significantly degraded yet small altered basin, which requires a local rather than system-wide solution (restoring proper basin configuration and flow). In advance of completion of the MEP analysis, the information regarding the specifics of this sill and associated impacts to the associated deep basin were communicated to the Town of Barnstable by the MEP Technical Team. In a proactive fashion,

the Town of Barnstable subsequently invoked the necessary process to dredge the area of concern in order to restore a proper basin configuration and restore effective exchange of tidal waters. Dredging of the sill was completed in the winter of 2005 going into 2006 (December – January timeframe).

The infaunal study indicated an overall system supporting generally healthy to moderately impaired infaunal habitat relative to the ecosystem types represented. The Centerville River System is a complex estuary composed of 4 functional types of component basins: an embayment (East Bay, a salt marsh pond/embayment (Scudder Bay), a tidal salt marsh (upper Centerville River) and a tidal river (mid-lower Centerville River). Each of these 4 functional components has different natural sensitivities to nitrogen enrichment and organic matter loading. Evaluation of infaunal habitat quality must consider the natural structure of each system and the types of infaunal communities that they support.

These results of the MEP benthic analysis are integrated into the assessment of habitat quality throughout the Centerville River System relative to nitrogen levels and thresholds presented in Chapter VIII.

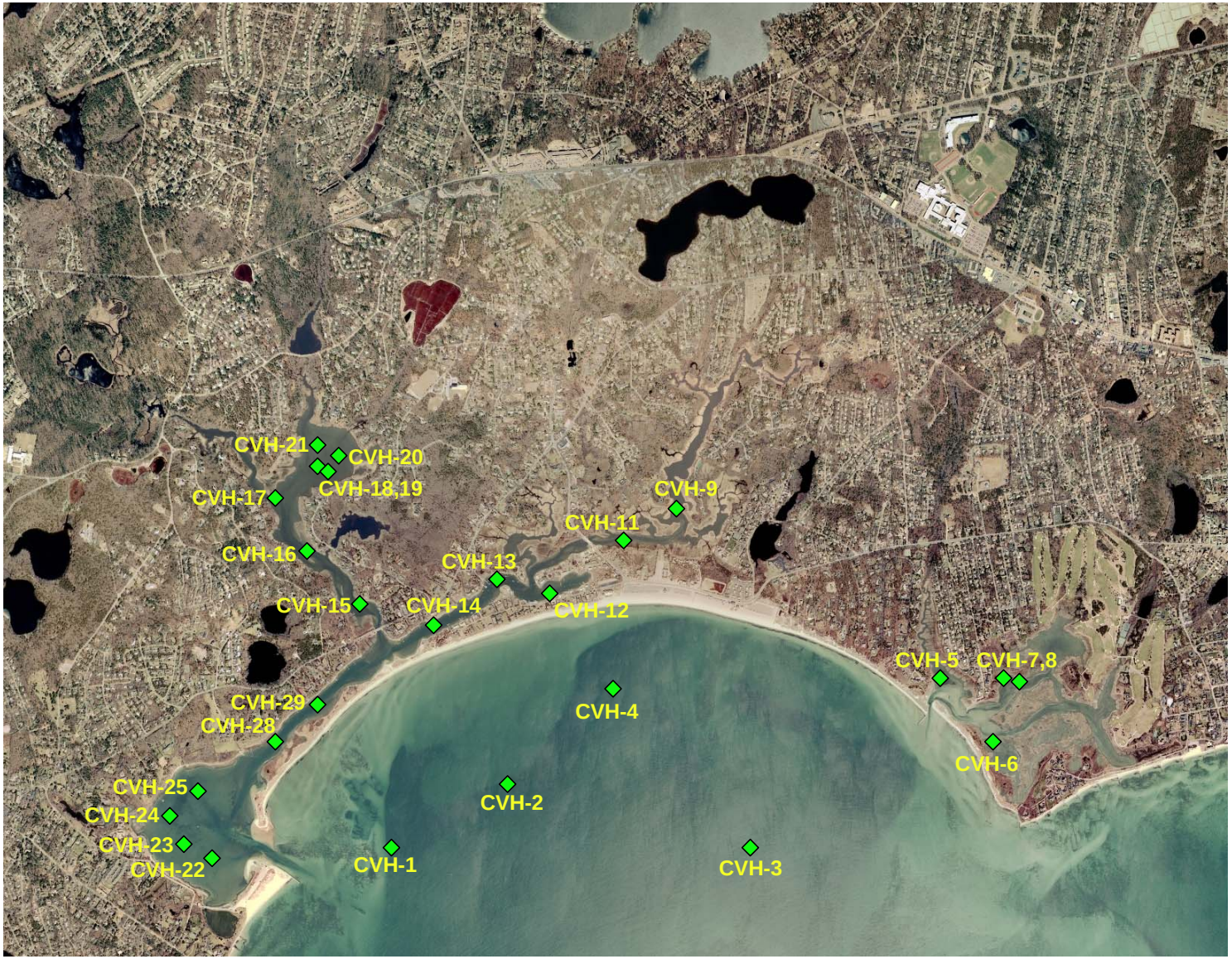


Figure VII-11. Aerial photograph of the Centerville River embayment system showing location of benthic infaunal sampling stations (green symbol).

Table VII-4. Benthic infaunal community data for the Centerville River Estuarine System. Estimates of the number of species adjusted to the number of individuals and community diversity (H') and Evenness (E) to allow comparison between locations (sample surface area, 0.0625 m^2). Station ID.'s with a "D" represent a second grab sample from the same general location.

Sub-Embayment	Sta I.D.	Total Actual Species	Total Actual Individuals	Species Calculated @ 75 Indiv.	Weiner Diversity (H')	Evenness (E)
Centerville River-East Bay/Bumps River-Scudder Bay System						
Scudder Bay	Sta. 18	6	104	6	2.51	0.97
	Sta.18D	4	72	N/A	1.66	0.83
	Sta. 20	5	144	5	1.68	0.72
	Sta. 21	3	88	3	1.24	0.78
Bumps River Main River	Sta. 15	30	682	18	3.79	0.77
Main River	Sta. 16	32	727	21	4.28	0.86
Confluence with Scudder B.	Sta. 17	14	720	13	3.17	0.83
Upper Centerville River Marsh	Sta. 9	17	815	11	2.70	0.66
	Sta. 9D	14	641	12	3.19	0.84
	Sta. 11	17	1643	12	2.33	0.57
	Sta. 11D	12	412	9	2.14	0.60
East River lagoon*	Sta. 12	10	39	N/A	2.80	0.84
	Sta. 12D	8	33	N/A	2.41	0.80
Mid Centerville River	Sta. 13	8	184	8	2.66	0.89
	Sta. 14	11	256	11	2.58	0.75
	Sta. 14D	17	174	14	2.99	0.73
Lower Centerville River	Sta. 28	32	457	22	4.30	0.86
	Sta. 29	31	708	18	3.70	0.75
	Sta. 29D	20	325	15	3.44	0.80
East Bay	Sta. 22	9	144	9	2.91	0.92
	Sta. 23	6	264	6	1.34	0.52
	Sta. 24	5	944	4	1.27	0.55
	Sta. 25	4	256	4	1.55	0.77
	Sta. 25D	5	112	5	2.13	0.92

* Dredged lagoon deep basin and sill at entrance, structurally depositional with organic rich sediments and depleted

VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS

VIII.1. ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires integration of key habitat parameters (infauna and eelgrass), sediment characteristics, and nutrient related water quality information (particularly dissolved oxygen and chlorophyll) a). Additional information on temporal changes within each sub-embayment and its associated watershed nitrogen load further strengthen the analysis. These data were collected to support threshold development for the Centerville River System by MEP Team and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels from the baseline Town of Barnstable Water Quality Monitoring Program, conducted with assistance from Three Bays Preservation and technical support from the Coastal Systems Program at SMAST.

The Centerville River System is a complex estuary composed of 4 functional types of component basins: an embayment (East Bay), a salt marsh pond/embayment (Scudder Bay), a tidal salt marsh (upper Centerville River) and a tidal river (mid-lower Centerville River). Each of these 4 functional components has different natural sensitivities to nitrogen enrichment and organic matter loading. Evaluation of eelgrass and infaunal habitat quality must consider the natural structure of each system and the ability to support eelgrass beds and the types of infaunal communities that they support. At present, the Centerville River System is showing variations in nitrogen enrichment and habitat quality among its various component basins. In general the system is showing healthy to moderately impaired benthic habitat. However, the lower basins (e.g. lower Centerville River, East Bay) are clearly significantly impaired based on eelgrass criteria, as historical eelgrass beds have been lost and eelgrass is no longer present within the System.

Eelgrass: The present lack of eelgrass throughout the Centerville River System is consistent with the observed oxygen depletions in each basin and the chlorophyll levels and functional basin types comprising this estuary. The upper estuarine reaches, which are strongly influenced by surrounding wetlands, do not typically support eelgrass habitat, due to their naturally nutrient enriched shallow waters and salt marsh function. However, basins like the Centerville River channel (from the Town Landing to East Bay), and especially the sub-embayment of East Bay, typically do support eelgrass habitat under low to moderate nitrogen loading conditions. The distribution of eelgrass in 1951 is fully consistent with this functional analysis and the conclusion that the lower region of this Estuary (e.g. downstream of Bumps River mouth) is currently over its nitrogen threshold level that supports healthy eelgrass habitat.

Analysis of the eelgrass beds which have persisted just outside of the tidal inlet and extended in 1951 into East Bay and up the Centerville River to the mouth of Bumps River, supports the contention that the recent loss of eelgrass is the result of nitrogen enrichment, as the well flushed outer beds have been extremely stable over the past half century. These beds are at similar water depths and have the same tidal excursion as the historical bed areas within the lower estuary. Therefore, the major environmental differences between the sites appear to be directly related to nitrogen enrichment. The recent loss of beds from within the Centerville River System is also consistent with the lower nitrogen loading and the resultant higher sustained oxygen levels and lower chlorophyll levels (high light penetration) that should have existed at that time, based upon population data.

It appears from the eelgrass and water quality information that eelgrass beds within East Bay and the lower Centerville River should be the target for restoration and that this habitat should be recovered with appropriate nitrogen management. From the historical analysis, it appears that on the order of 52 acres of eelgrass habitat could be recovered, if nitrogen management alternatives were implemented. Note that restoration of this habitat will necessarily result in restoration of other resources throughout the Centerville River/Harbor System and in the region of Scudder Bay and the Town Landing located low in the system, but distant from the inlet and influence of strong tidal flushing. Since East Bay is influenced by waters ebbing from both branches of the entire up-gradient basins, its nitrogen management will de facto result in a lowering of nitrogen levels throughout the Centerville River System and therefore an improvement of infaunal habitats in Scudder Bay and the upper Centerville River, which have traditionally only supported infaunal habitat. Based upon the above analysis, eelgrass habitat should be the primary nitrogen management goal for the lower Centerville River System and infaunal habitat quality the management target for the upper reaches. These goals are the focus of the MEP management alternatives analysis presented in Chapter IX.

Water Quality: Overall, the oxygen levels within the major sub-basins to the Centerville River System are indicative of relatively healthy or only moderately impaired conditions, since the upper reaches are defined as infaunal habitats (e.g. historically have not supported eelgrass) and when their physical structure and natural biogeochemical cycling is considered. Similar to other embayments in southeastern Massachusetts, the upper Centerville River, Scudder Bay and East Bay basins of the Centerville River System evaluated in this assessment showed high frequency variation, apparently related to diurnal and sometimes tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site, underscores the need for continuous monitoring within these systems.

Overall, oxygen depletion was observed at each of the mooring sites (Table VII-1a), but the degree of depletion varied between sites. East Bay generally maintained oxygen levels above 4 mg L-1, but with frequent excursions below 5 mg L^{-1}. These oxygen conditions represent a moderate level of impairment to benthic infaunal communities associated with embayments. Oxygen levels in the upper reach of the Centerville River showed even lower levels periodically into the 2-3 mg L^{-1} range, although generally with daily minima above 4 mg L^{-1}. The central region of Scudder Bay was clearly nitrogen enriched, but generally maintained daily oxygen minima above 4 mg L^{-1} and typically above 5 mg L^{-1}. This basin showed its enrichment mainly through the large daily excursions with daily maxima typically >11 mg L^{-1}.

The observations obtained by the continuously recording oxygen sensors were supported by the more spatially distributed grab sample data collected by the Town of Barnstable Water Quality Monitoring Program (Table VII-1b). These data support general observation that oxygen levels throughout the embayment basins of the Centerville River System are generally >4 mg L^{-1} and typically >5 mg L^{-1}, during the summer months. In contrast the salt marsh influenced sites of upper Centerville River and Scudder Bay showed greater depletions, with levels in the 3-4 mg L^{-1} range on 34% and 7% of the dates, respectively.

The spatial pattern of oxygen depletion within the Estuary was consistent with the measured chlorophyll a levels (Table VII-2, Figures VII-6 –VII-8). The level of oxygen depletion was directly related to the amount of chlorophyll a in the watercolumn. This is consistent with nitrogen enrichment resulting in increased phytoplankton biomass and subsequent organic matter deposition and decay being the process controlling oxygen level in the Centerville River

System. Chlorophyll a levels in East Bay were indicative of a relatively healthy to moderately enriched basin. In East Bay chlorophyll a averaged on 5.1 ug L^{-1} and was almost always <10 ug L^{-1}. The upper reach of the Centerville River and Scudder Bay supported higher phytoplankton biomass with average levels ~20 ug L^{-1} and blooms producing consistent levels of 30 ugL^{-1}.

Tidally averaged total nitrogen (TN) levels showed a similar pattern, consistent with the extent of oxygen depletion at each site and the chlorophyll a levels. Tidally averaged TN (Chapter VI) showed moderate enrichment in uppermost Bumps River (i.e. Scudder Bay, 0.53 mg N L^{-1}) and the salt marshes of upper Centerville River (0.63 mg N L^{-1}) and decline to levels <0.4 mg N L^{-1} in the lower Centerville River/East Bay portion of the system.

It is important to evaluate the level of oxygen excursion and depletion relative to the functional habitats involved. In the upper Centerville River the tidal river serves as the central salt marsh creek to a rather large and healthy salt marsh. Dissolved oxygen levels (and infaunal habitat quality) is consistent with a salt marsh tidal creek, where the organic matter enriched sediments support high levels of oxygen uptake at night and deplete the overlying waters. While oxygen depletion to 3 mg/L would indicate impairment in an embayment like the East Bay basin, it is consistent with the organically enriched nature of smaller salt marsh creeks.

The results of the summer oxygen and chlorophyll a studies are consistent with the absence of eelgrass (Section VII-3) throughout the Centerville River/Harbor System and the spatial distribution of infaunal community types and quality of habitat (Section VII-4).

Infaunal Communities: The infaunal study indicated an overall system supporting generally healthy to only moderately impaired infaunal habitat relative to the ecosystem types represented (i.e. embayment versus salt marsh creek/pond).

The Bumps River estuarine reach and the lower Centerville River currently support healthy infaunal animal habitat for a coastal embayment/tidal river on Cape Cod. These areas support large numbers of individuals (generally >500) and species (up to 32/sample), with very high diversity (H' 3.2-4.3) and Eveness (>0.75). The basin of East Bay, which is depositional and receives the ebb tidal waters from the entire Estuarine System, is presently showing moderate impairment. This moderate impairment is seen primarily in the dominance of amphipod mats throughout the central basin (*Amplesca*). While the community is supportive of generally high numbers of individuals the number of species, diversity and Eveness are reduced. Amphipod mats represent a valuable and productive resource, but transitional between healthy and stressful conditions, particularly as relates to organic matter loading from nitrogen enrichment. The upper Centerville River and the associated mid reach of the Centerville River are dominated by salt marsh conditions. Under these conditions the number of individuals and species is high and the diversity and Eveness approximates healthy conditions even for an embayment. The species present are typical of salt marsh creeks, which generally have organic matter tolerant species (e.g. *Streblospio*) and crustaceans and mollusks. The upper reaches of the Centerville River appear to be currently supporting healthy infaunal habitat. Similarly, Scudder Bay exhibits infauna habitat quality indicative of organic matter enrichment. However, this basin supports salt marsh areas around its margins and a shallow central basin. It appears that this basin is functioning at least partially as a salt marsh pond and was evaluated as such by the MEP Technical Team. Therefore, this basin appears to be presently moderately impaired, based upon its moderate-low number of species and moderate-low (100) numbers of individuals. The nutrient enriched conditions within this basin appear to

be beyond the accommodation of the infaunal community and nitrogen management will be needed to restore this benthic resource.

The MEP Surveys did detect a small localized area of degraded infaunal habitat within the Centerville River System, a small lagoon altered for boats directly inland of the western stretch of Craigville Beach. This small basin contains a shallow sill across its entrance to the River and a "deep" basin (Figure V-6). The basin configuration and sill create a localized depositional area with localized bottom water hypoxia. The result is a significantly degraded small altered basin, which will require a local solution (restoring proper basin configuration and flow) in addition to the system-wide effort which is the focus of the present analysis.

The overall results indicate a system generally supportive of diverse healthy communities appropriate to each of the 4 component functional basin types as shown in Table VIII-1. The infaunal habitat quality within each of the basins of the Centerville River System is fully consistent with the oxygen and chlorophyll measurements, temporal trend in eelgrass (i.e. loss from lower estuary) and relatively tidally averaged total nitrogen concentration for each basin. The healthy infauna habitats within the Bumps River, Lower Centerville River at TN levels <0.46 are also consistent with other systems. Similarly, the moderately impaired infaunal habitat in East Bay reflects the basins' depositional nature and depth, indicating a sensitivity of this basin to the negative effects of nitrogen enrichment. The healthy habitat within the upper Centerville marshes at 0.63 mg N L-1, also reflects the tolerance of salt marsh communities to nitrogen enrichment (e.g. Cockle Cove Salt Marsh, Chatham).

VIII.2. THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout and embayment system, is to first identify a sentinel location within the embayment and second to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality. The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level are determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

Determination of the critical nitrogen threshold for maintaining high quality habitat within Centerville River Estuarine System is based primarily upon the nutrient and oxygen levels, temporal trends in eelgrass distribution and current benthic community indicators. Given the database available for this threshold analysis, it is possible to develop a site-specific threshold which is a refinement upon general threshold analysis frequently employed.

The Centerville River System is presently supportive of infaunal habitat throughout its 4 component basins. However, there is a moderate level of infaunal habitat impairment within Scudder Bay and the mid region of the Centerville River, requiring nitrogen management for restoration. The primary habitat issue within the Centerville River System relates to the loss of eelgrass from the lower estuary, specifically from the Centerville River west of the entrance to Bumps River and in East Bay. This loss of eelgrass classifies these areas as "significantly impaired", although they presently support healthy to moderately healthy infaunal communities. Further impairment to both the infaunal habitat in Scudder Bay and the eelgrass habitat in the lower estuary are supported by the variety of other indicators which support the conclusion that these impairments are the result of nitrogen enrichment, primarily from watershed nitrogen loading.

Table VIII-1. Summary of Nutrient Related Habitat Health within the Centerville River Estuary on Nantucket Sound within the Town of Barnstable, MA., based upon assessment data presented in Chapter VII. The upper estuarine reach of the Centerville River is presently a tidal salt marsh. The Centerville River mid reach (from the bridge at Craigville Beach to the mouth Bumps River) and lower reach (Bumps River mouth to East Bay) and East Bay are sub-embayments, while the Bumps River and Scudder Bay support significant salt marsh areas.

Health Indicator	Centerville River Embayment System					
	Centerville River Reach			East Bay	Bumps River	Scudder Bay
	Upper	Mid	Lower			
Dissolved Oxygen	H[1]	MI[3]	H/MI[4]	MI[2]	MI[3]	MI[12]
Chlorophyll	MI[6]	--[13]	H[5]	H[5]	--[13]	MI[6]
Macroalgae	--[8]	--[8]	--[7]	--[7]	--[7]	--[8]
Eelgrass	--[10]	--[10]	SI[9]	SI[9]	--[10]	--[10]
Infaunal Animals	H[17]	H/ MI[16]	H[11]	MI[14]	H[11]	MI[15]
Overall:	**H**	**H/MI**	**H[10]-SI[8]**	**MI[14]-SI[8]**	**H**	**MI**

1 – salt marsh tidal creek, periodic oxygen depletions to 3-4 mg/L.
2 – oxygen depletions frequently to 4-5 mg/L., levels generally >5 mg/L.
3 – Monitoring Program grab sample data, periodically 4.5-5 mg DO/L generally >5 mg DO/L.
4 -- Monitoring Program grab sample data, >5 mg DO/L, but may follow East Bay time-series.
5 – modest chlorophyll a levels generally 4-8 ug/L , average 5 ug/L.
6 – elevated chlorophyll levels, mean 18-20 ug/L.
7 – very sparse or absence of drift algae, no surficial microphyte mat
8-- no drift algae, but benthic algae forming a surficial mat, microphytes
9-- MassDEP (C. Costello) indicates that eelgrass lost from this system between 1951-2000.
10 – no evidence this basin is supportive of eelgrass.
11 -- infauna: high numbers of individuals and species, high diversity and Eveness.
12 -- basin supports fringing salt marsh areas.
13 -- insufficient data
14 -- Infauna: moderate numbers of individuals, moderate-low species, dense amphipod mat.
15 -- Infauna: moderate numbers of individuals, moderate-low species, organic enrichment indicator species typical of salt marsh ponds.
16 -- moderate numbers of individuals and species, high diversity and Eveness, with polychaetes, mollusks and crustaceans, estuarine reach is transitional between saltmarsh creek and tidal river..
17 -- high numbers of individuals and moderate numbers of species. High diversity and eveness. Indicators of organic matter enrichment typical of salt marsh sediments.

H = healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment; SD = Severe Degradation; -- = not applicable to this estuarine reach

The present lack of eelgrass throughout the Centerville River System is consistent with the observed oxygen depletions in each basin and the chlorophyll levels and functional basin types comprising this estuary. The basins like the Centerville River channel (from the Town Landing to East Bay), and especially sub-embayment of East Bay typically, do support eelgrass habitat in other embayments with low to moderate nitrogen levels. These basins supported eelgrass in the 1951 analysis. The earlier presence of beds from within the lower reaches of the Centerville River System is consistent with the lower nitrogen loading and the resultant higher sustained oxygen levels and lower chlorophyll levels (high light penetration) that should have existed at that time, based upon population data.

The eelgrass and water quality information supports the conclusion that eelgrass beds within East Bay and the lower Centerville River should be the target for restoration of the Centerville River Estuary and that restoration requires appropriate nitrogen management. From the historical analysis, it appears that on the order of 52 acres of eelgrass habitat could be recovered, if nitrogen management alternatives are implemented. Therefore the sentinel station (BC-T) for the Centerville River System was placed just seaward of the mouth of the Bumps River within the Centerville River and upgradient from the Town of Barnstable Water Quality Monitoring Station BC-9. The station was located at within the uppermost extent of the known previous eelgrass coverage in this System.

The target nitrogen concentration (tidally averaged TN) for restoration of eelgrass at the sentinel location within the lower reach of the Centerville River (region seaward of the mouth of the Bumps River) was determined to be 0.37 mg TN L^{-1}. This nitrogen level is based upon the absence of eelgrass in the Lower Centerville River at a tidally averaged TN of 0.395 mg N l^{-1} and comparison to a stable eelgrass system in a similarly configured basin, the lower Oyster River (Chatham) at 0.37 mg N L^{-1}. Note that this level is only slightly lower than that determined by the MEP Technical Team for nearby Popponesset Bay (0.38 mg N L^{-1}). This difference relates to the much shallower water in Popponesset Bay then in the Centerville River. Water depth is important as the same phytoplankton concentration that results in shading of eelgrass in deep water, will allow sufficient light to support eelgrass in shallow water. The need for a lower threshold in deeper versus shallower water was seen in the MEP eelgrass habitat assessment for Bournes Pond, Falmouth.

The threshold nitrogen level at the sentinel station within the Centerville River System is within the range found for other complex systems such as 0.38 mg N L^{-1} for Stage Harbor, 0.38 N/L^{-1} for Bournes Pond and nearby Popponesset Bay and 0.35 mg N L^{-1} for West Falmouth Harbor and Phinneys Harbor. The sentinel station under present loading conditions supports a tidally corrected average concentration of 0.395 mg TN L^{-1}, so watershed nitrogen management will be required for restoration of the estuarine habitats within this system.

Note that achieving the nitrogen threshold at the sentinel station will necessarily result in restoration of other resources throughout the Centerville River/Harbor System distant from the inlet and the influence of strong tidal flushing. Since East Bay is influenced by waters ebbing from both branches of the entire up-gradient basins, its nitrogen management will de facto require a lowering of nitrogen levels throughout the Centerville River System and therefore an improvement of infaunal habitats in Scudder Bay and the middle reach of the Centerville River, which have traditionally only supported infaunal habitat. Based upon the above analysis, eelgrass habitat should be the primary nitrogen management goal for the lower Centerville River System and infaunal habitat quality the management target for the upper reaches. These goals are the focus of the MEP management threshold loading analysis (Section VIII.3) and alternatives analysis presented (Chapter IX).

Although the nitrogen management target is restoration of eelgrass habitat (and associated water clarity, shellfish and fisheries resources), benthic infaunal habitat quality must also be supported as a secondary condition. At present, in the regions with impaired infaunal habitat, the tidally averaged total nitrogen (TN) level under existing conditions is 0.526 mg N L^{-1} in Scudder Bay and between 0.543-0.465 mg N L^{-1} in the middle reach of the Centerville River (bridge to Bumps River). The observed moderate impairment at these sites is consistent with observations by the MEP Technical Team in other enclosed basins along Nantucket Sound (e.g. Perch Pond, Bournes Pond, Popponesset Bay) where levels <0.5 mg N L^{-1} were found to be supportive of healthy infaunal habitat and in deeper enclosed basins in Buzzards Bay (e.g. Eel Pond in Bourne) where healthy infaunal habitat had a slightly lower threshold level, 0.45 mg N L^{-1}, due to those being a "deep" depositional basin. The higher TN levels observed in the upper Centerville River salt marshes are within the nitrogen threshold to support the observed healthy infaunal habitat in this estuarine reach. To ensure that meeting the nitrogen threshold at the sentinel station (BC-T, just seaward of the mouth of the Bumps River within the Centerville River, upgradient from BC-9) results in restoration of the moderately impaired infaunal habitats in Scudder Bay and the middle reach of the Centerville River, nitrogen criteria for secondary infaunal "check" stations were developed by the MEP Technical Team. Based upon the Centerville River system showing moderate impairment at tidally averaged TN levels of 0.526 mg N L^{-1} in Scudder Bay (BC-3) and 0.543 at the inland end of the middle reach of the Centerville River (BC-7) and the results from nearby embayments to Nantucket Sound (noted above), it was concluded that an upper limit of 0.50 mg N L-1 tidally averaged TN would support healthy infaunal habitat in these inner regions.

It must be stressed that the nitrogen threshold for the Centerville River Estuarine System is at the sentinel location. The secondary criteria (infaunal habitat) should be met when the threshold is met at the sentinel station used for setting the nitrogen threshold and serve as a “check”. The nitrogen loads associated with the threshold concentration at the sentinel location and secondary infaunal check stations are discussed in Section VIII.3, below.

VIII.3. DEVELOPMENT OF TARGET NITROGEN LOADS

The nitrogen thresholds developed in the previous section were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Centerville River estuary system. Tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel stations chosen for Centerville River and at the secondary stations in Scudder Bay and Centerville River East. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

As shown in Table VIII-2, the nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations required 80% removal of septic load (associated with direct groundwater discharge to the embayment) for the Centerville River East watershed. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

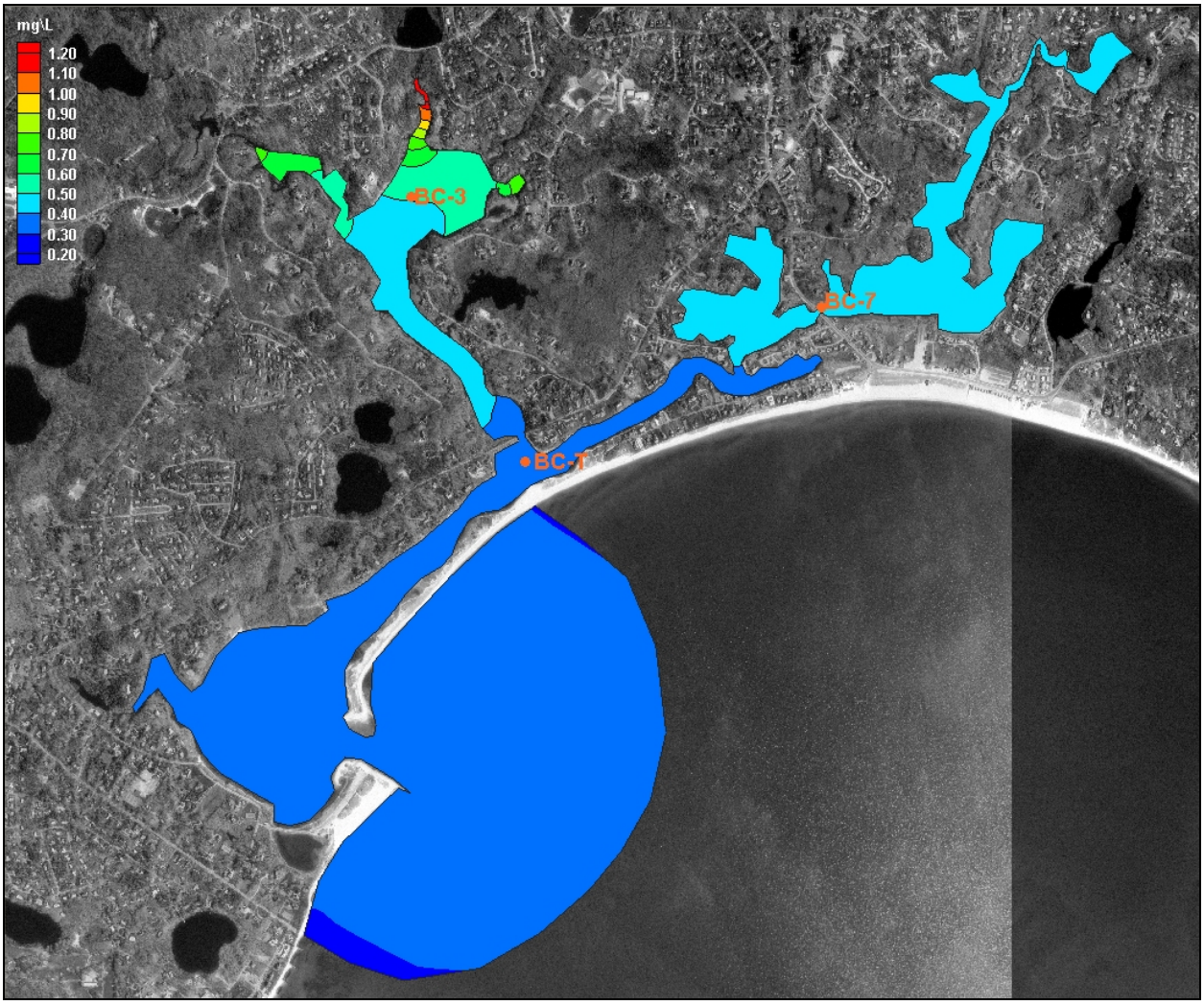


Figure VIII-1. Contour plot of modeled average total nitrogen concentrations (mg/L) in the Centerville River estuary system, for threshold conditions (0.37 mg/L at water quality monitoring station BC-T, and 0.4-0.5 at water quality monitoring stations BC-3 and BC-7). The approximate location of the sentinel threshold station for Centerville River (BC-T) is shown.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Centerville River estuary system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Centerville River East	45.929	9.184	-80.0%
Scudder Bay	11.619	11.619	+0.0%
Centerville River West	7.704	7.704	+0.0%
East Bay	6.301	6.301	+0.0%
Surface Water Sources			
Pine Street Stream	2.512	2.512	+0.0%
Lake Elizabeth Stream	1.836	1.836	+0.0%
Bumps River	14.321	14.321	+0.0%
Skunknett River	17.337	17.337	+0.0%

Tables VIII-3 and VIII-4 provide additional loading information associated with the thresholds analysis. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. Removal of 80% of the septic load from the Centerville River East watershed results in a 66% reduction in total nitrogen load. Table VIII-4 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-4, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound.

Table VIII-3. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Centerville River estuary system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Centerville River East	55.737	18.992	-65.9%
Scudder Bay	14.452	14.452	+0.0%
Centerville River West	9.463	9.463	+0.0%
East Bay	8.627	8.627	+0.0%
Surface Water Sources			
Pine Street Stream	3.452	3.452	+0.0%
Lake Elizabeth Stream	2.274	2.274	+0.0%
Bumps River	16.912	16.912	+0.0%
Skunknett River	21.260	21.260	+0.0%

Table VIII-4. Threshold sub-embayment loads and attenuated surface water loads used for total nitrogen modeling of the Centerville River estuary system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Centerville River East	18.992	0.449	4.284
Scudder Bay	14.452	0.685	-2.125
Centerville River West	9.463	0.718	3.497
East Bay	8.627	1.126	12.694
Surface Water Sources			
Pine Street Stream	3.452	-	-
Lake Elizabeth Stream	2.274	-	-
Bumps River	16.912	-	-
Skunknett River	21.260	-	-

Comparison of model results between existing loading conditions and the selected loading scenario to achieve the target TN concentrations at the sentinel station is shown in Table VIII-5. To achieve the threshold nitrogen concentrations at the sentinel station, a reduction in TN concentration of approximately 10% is required at station BC-T. The meet secondary threshold requirement for stations BC-3 and BC-7, a reduction in TN concentration of approximately 8% and 21% were required, respectively.

The basis for the watershed nitrogen removal strategy utilized to achieve the embayment thresholds may have merit, since this example nitrogen remediation effort is focused on watersheds where groundwater is flowing directly into the estuary. For nutrient loads entering the systems through surface flow, natural attenuation in freshwater bodies (i.e., streams and ponds) can significantly reduce the load that finally reaches the estuary. Presently, this attenuation is occurring due to natural ecosystem processes and the extent of attenuation being determined by the mass of nitrogen which discharges to these systems. The nitrogen reaching these systems is currently “unplanned”, resulting primarily from the widely distributed non-point nitrogen sources (e.g. septic systems, lawns, etc.). Future nitrogen management should take advantage of natural nitrogen attenuation, where possible, to ensure the most cost-effective nitrogen reduction strategies. However, “planned” use of natural systems has to be done carefully and with the full analysis to ensure that degradation of these systems will not occur. One clear finding of the MEP has been the need for analysis of the potential associated with restored wetlands or ecologically engineered ponds/wetlands to enhance nitrogen attenuation. Attenuation by ponds in agricultural systems has also been found to work in some cranberry bog systems, as well. Cranberry bogs, other freshwater wetland resources, and freshwater ponds provide opportunities for enhancing natural attenuation of their nitrogen loads. Restoration or enhancement of wetlands and ponds associated with the lower ends of rivers and/or streams discharging to estuaries are seen as providing a dual service of lowering infrastructure costs associated with wastewater management and increasing aquatic resources associated within the watershed and upper estuarine reaches.

Table VIII-5. Comparison of model average total N concentrations from present loading and the modeled threshold scenario, with percent change, for the Centerville River estuary system. Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Scudder Bay	**BC-3**	**0.524**	**0.480**	**-8.4%**
Bumps River	BC-4	0.451	0.415	-7.9%
Centerville River	BC-5	0.609	0.449	-26.3%
Centerville River	**BC-7**	**0.526**	**0.417**	**-20.8%**
Centerville River	BC-8	0.454	0.386	-15.0%
Centerville River	BC-9	0.389	0.358	-8.0%
East Bay	BC-10	0.349	0.333	-4.6%
Confluence of Bumps River-Centerville River	**BC-T**	**0.412**	**0.372**	**-9.8%**

Although the above modeling results provide one manner of achieving the selected threshold level for the sentinel site within the estuarine system, the specific example does not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment.

IX. ALTERNATIVES TO IMPROVE WATER QUALITY

IX.1 PRESENT LOADING WITH SEWERING PORTIONS OF CENTERVILLE RIVER EAST WATERSHED AND INCREASING THE NATURAL NITROGEN ATTENUATION ALONG SKUNKNET RIVER

The Centerville River East watershed contributes the largest amount of Nitrogen to the Centerville River System relative to the other watersheds. Therefore sewering within watershed will have the greatest impact upon the Nitrogen levels entering the system. However the possibility exists to combine sewering with measures to naturally increase Nitrogen attenuation along surface water tributaries within the system. For this alternative the natural Nitrogen attenuation along Skunknet River will be increased by 20-percent to evaluate the magnitude of impact it will have upon reducing the amount of sewering required. To demonstrate this, an alternative was developed to assess impact of removing 75-percent of the septic load from the Centerville River East watershed, which is a 5-percent reduction compared to the threshold analysis in Chapter VIII, along with increasing the natural Nitrogen attenuation along Skunknet River by 20-percent. The present loading conditions will be used for the rest of the system. Table IX-1 and Table IX-2 illustrate the overall change to septic and watershed loads resulting from this alternative. Septic removal from Centerville River East watershed results in significant reductions in the watershed loads in the sub-embayment. Based on the assumptions developed for this alternative, Table IX-3 presents the various components of nitrogen loading for the Centerville River system.

Table IX-1. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions with a 75-percent of the septic load removed from the Centerville River East watersheds and 20% increase to natural Nitrogen attenuation along Skunknet River. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Centerville River East	45.929	11.479	-75.0%
Scudder Bay	11.619	11.619	+0.0%
Centerville River West	7.704	7.704	+0.0%
East Bay	6.301	6.301	+0.0%
Surface Water Sources			
Pine Street Stream	2.512	2.512	+0.0%
Lake Elizabeth Stream	1.836	1.836	+0.0%
Bumps River	14.321	14.321	+0.0%
Skunknet River	17.337	11.762	-32.2%

Table IX-2. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions in Centerville River with present loading conditions with a 75-percent of the septic load removed from the Centerville River East watersheds and 20% increase to natural Nitrogen attenuation along Skunknet River. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Centerville River East	55.737	21.288	-61.8%
Scudder Bay	14.452	14.452	+0.0%
Centerville River West	9.463	9.463	+0.0%
East Bay	8.627	8.627	+0.0%
Surface Water Sources			
Pine Street Stream	3.452	3.452	+0.0%
Lake Elizabeth Stream	2.274	2.274	+0.0%
Bumps River	16.912	16.912	+0.0%
Skunknet River	21.260	15.685	-26.2%

Table IX -3. Sub-embayment loads used for total nitrogen modeling of the Centerville River system for present loading scenario with present loading conditions with a 75-percent of the septic load removed from the Centerville River East watersheds and 20% increase to natural Nitrogen attenuation along Skunknet River, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Centerville River East	21.288	0.449	4.353
Scudder Bay	14.452	0.685	-2.125
Centerville River West	9.463	0.718	3.497
East Bay	8.627	1.126	12.694
Surface Water Sources			
Pine Street Stream	3.452	-	-
Lake Elizabeth Stream	2.274	-	-
Bumps River	16.912	-	-
Skunknet River	15.685	-	-

Total nitrogen modeling results for existing conditions with the reduced septic loads for Centerville River East watershed and increase in natural attenuation to Skunknet River indicate that the Centerville River would meet the nitrogen threshold target at Station BC-T (Table IX-4 and Figure IX-1), along with meeting the secondary goals at Stations BC-3 and BC-7. It results in reductions in nitrogen concentration in all of the sub-embayments. Nitrogen concentration reductions range from approximately 4% in East Bay to 25% in upper reaches of Centerville River. Overall, this scenario indicates that to reduce the overall nitrogen load effectively, removing septic loads from the Centerville River East watershed is necessary, but that measures to increase natural attenuation are an important component to controlling the percentage of septic removal that will be necessary in the upper watershed.

Table IX-4. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads Centerville River East watershed and 20% increase to natural Nitrogen attenuation along Skunknet River), with percent change, for the Centerville River system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Scudder Bay	**BC-3**	**0.524**	**0.478**	**-8.8%**
Bumps River	BC-4	0.451	0.412	-8.5%
Centerville River	BC-5	0.609	0.457	-25.0%
Centerville River	**BC-7**	**0.526**	**0.422**	**-19.9%**
Centerville River	BC-8	0.454	0.389	-14.4%
Centerville River	BC-9	0.389	0.359	-7.9%
East Bay	BC-10	0.349	0.333	-4.4%
Confluence of Bumps River and Centerville River	**BC-T**	**0.412**	**0.373**	**-9.6%**

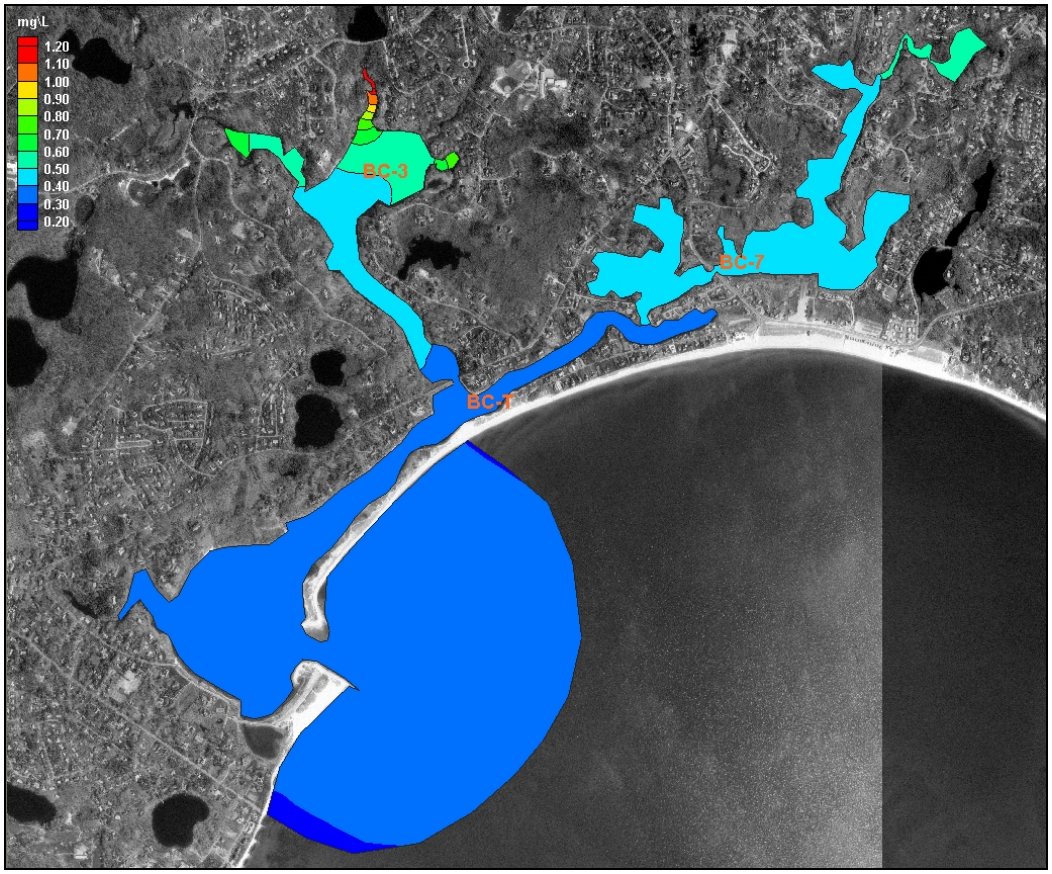


Figure IX-1. Contour plot of modeled total nitrogen concentrations (mg/L) in the Phinney's Harbor system, for present loading conditions with a 75-percent of the septic load removed from the Centerville River East watersheds and 20% increase to natural Nitrogen attenuation along Skunknet River.

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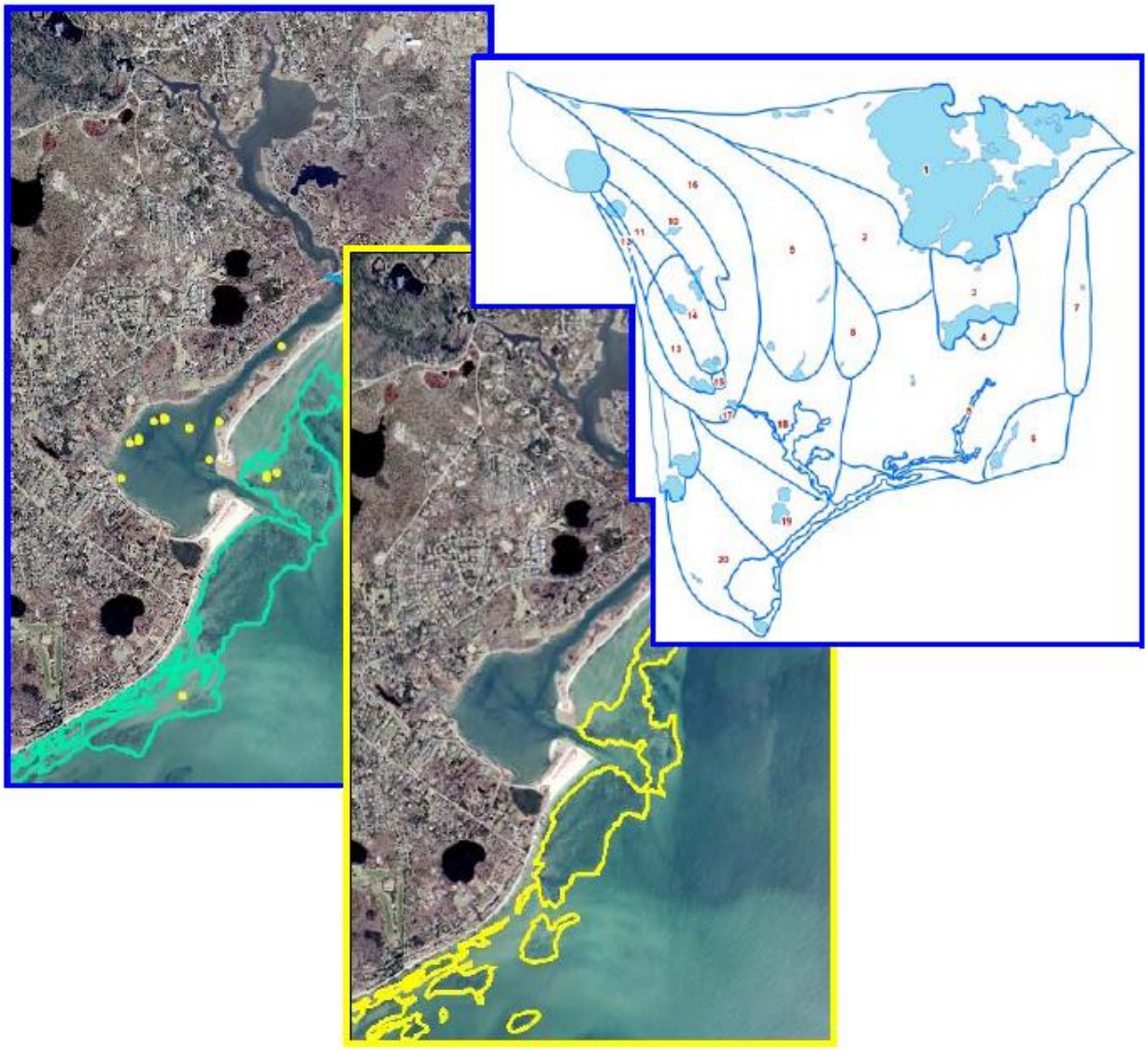
Appendix Z

MassDEP TMDL Report for Centerville River System; MassDEP, January 29, 2008.

FINAL
Centerville River - East Bay System
Total Maximum Daily Loads
For Total Nitrogen

(Report # 96-TMDL-14 Control #248.0)



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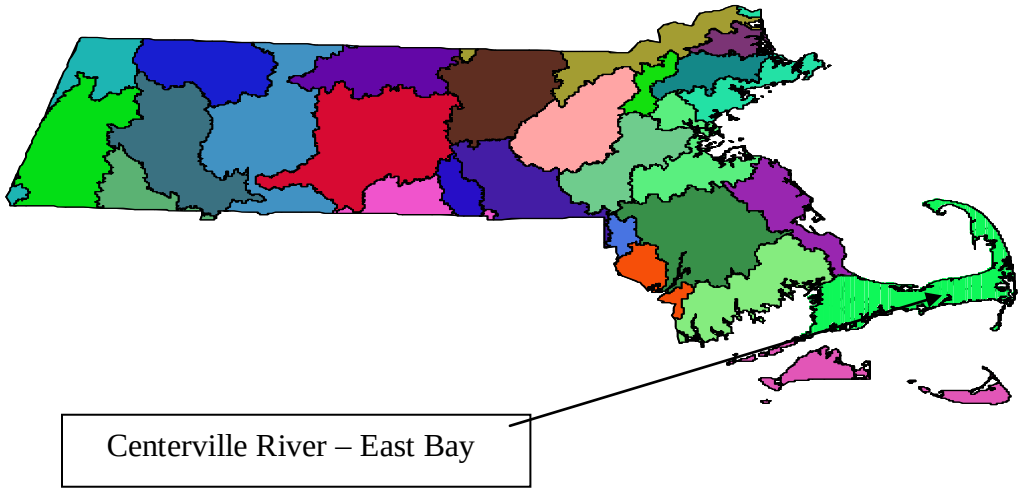
January 29, 2008

Centerville River - East Bay
Total Maximum Daily Loads
For Total Nitrogen



Key Feature: Total Nitrogen TMDL for Centerville River – East Bay
Location: EPA Region 1
Land Type: New England Coastal
303d Listing:
The waterbody segments impaired and on the Category 5 list include Centerville River.

Data Sources: University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Cape Cod Commission, Town of Barnstable.
Data Mechanism: Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model
Monitoring Plan: Town of Barnstable monitoring program (possible assistance from SMAST)
Control Measures: Sewering, Storm Water Management, Attenuation by Impoundments and Wetlands, Fertilizer Use By-laws

EXECUTIVE SUMMARY

Problem Statement

Excessive nitrogen (N) originating primarily from on-site wastewater disposal (both conventional septic systems and innovative/alternative systems) has led to significant decreases in the environmental quality of coastal rivers, ponds, and harbors in many communities in southeastern Massachusetts. In the Town of Barnstable the problems in coastal waters include:

- Loss of eelgrass beds, which are critical habitats for macroinvertebrates and fish
- Undesirable increases in macro algae, which are much less beneficial than eelgrass
- Periodic extreme decreases in dissolved oxygen concentrations that threaten aquatic life
- Reductions in the diversity of benthic animal populations
- Periodic algae blooms

With proper management of nitrogen inputs these trends can be reversed. Without proper management more severe problems might develop, including:

- Periodic fish kills
- Unpleasant odors and scum
- Benthic communities reduced to the most stress-tolerant species, or in the worst cases, near loss of the benthic animal communities

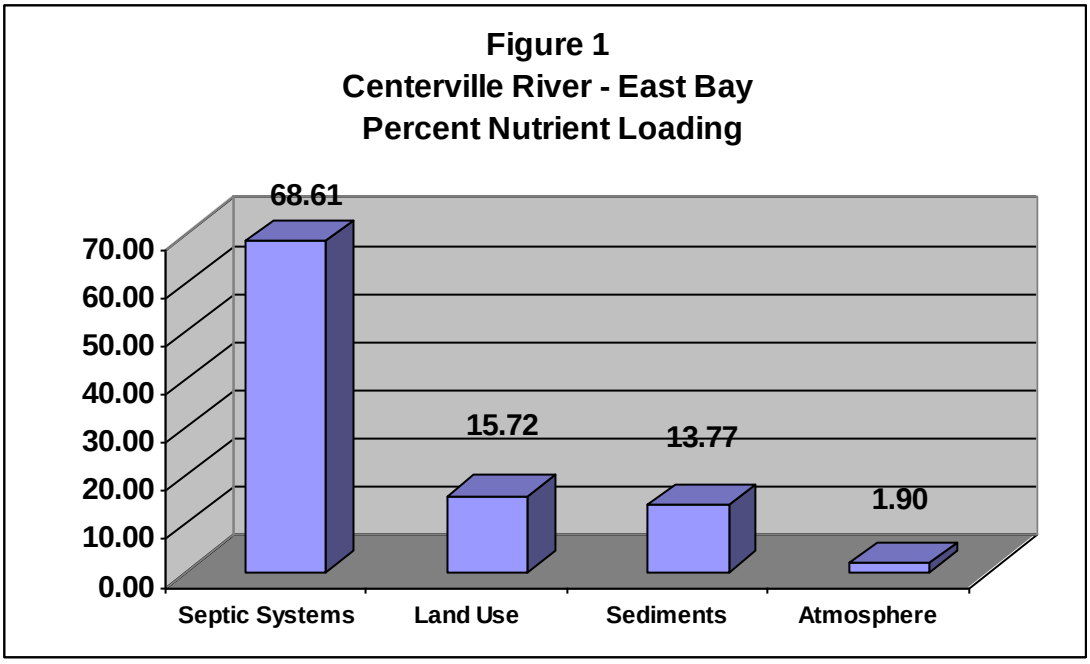
Coastal communities, including Barnstable; rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings may result in complete replacement of eelgrass by macro-algae, a higher frequency of extreme decreases in dissolved oxygen concentrations and fish kills, widespread occurrence of unpleasant odors and visible scum, and a complete loss of benthic macroinvertebrates throughout most of the embayments. As a result of these environmental impacts, commercial and recreational uses of Centerville River - East Bay System coastal waters will be greatly reduced, and could cease altogether.

Sources of nitrogen

Nitrogen enters the waters of coastal embayments from the following sources:

- The watershed
    - On-site subsurface wastewater disposal systems
    - Natural background
    - Runoff
    - Fertilizers
    - Wastewater treatment facilities
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments

Most of the present controllable N load originates from individual subsurface wastewater disposal (septic) systems, primarily serving individual residences, as seen in the following figure.



Target Threshold Nitrogen Concentrations and Loadings

The N loadings (the quantity of nitrogen) to this embayment system ranges from 22.46 kg/day in East Bay, to 81.01 kg/day in Centerville River. The resultant concentrations of N in these subembayments range from 0.33 mg/L (milligrams per liter of nitrogen) in Bumps River to 0.79 mg/L in Centerville River.

In order to restore and protect this system, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below the threshold concentrations that cause the observed environmental impacts. This concentration will be referred to as the target threshold N concentration. It is the goal of the TMDL to reach this target threshold N concentration, as it has been determined for each impaired waterbody segment. The Massachusetts Estuaries Project (MEP) has determined that, for this embayment system, N concentration of 0.37 mg/L is protective. The mechanism for achieving these target threshold N concentrations is to reduce the N loadings to the embayments. The Massachusetts Estuaries Project (MEP) has determined that the Total Maximum Daily Loads (TMDL) of N that will meet the target thresholds range from 22 to 53 kg/day. This document presents the TMDLs for each impaired water body segment and provides guidance to the affected town on possible ways to reduce the nitrogen loadings to within the recommended TMDL, and protect the waters for these waterbodies.

Implementation

The primary goal of implementation will be lowering the concentrations of N by greatly reducing the loadings from on-site subsurface wastewater disposal systems through a variety of centralized or decentralized methods such as sewering and treatment with nitrogen removal technology, advanced treatment of septage, upgrade/repairs of failed on-site systems, and/or installation of N-reducing on-site systems.

These strategies, plus ways to reduce N loadings from stormwater runoff and fertilizers, are explained in detail in the "MEP Embayment Restoration Guidance for Implementation Strategies", that is available on the MassDEP website at (http://www.mass.gov/dep/water/resources/restore.htm). The appropriateness of any of the alternatives will depend on local conditions, and will have to be determined on a case-by-case basis, using an adaptive management approach.

Finally, growth within the communities of Barnstable that would exacerbate the problems associated with N loadings, should be guided by considerations of water quality-associated impacts.

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Introduction

Section 303(d) of the Federal Clean Water Act requires each state (1) to identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. The TMDL allocation establishes the maximum loadings (of pollutants of concern), from all contributing sources, that a water body may receive and still meet and maintain its water quality standards and designated uses, including compliance with numeric and narrative standards. The TMDL development process may be described in four steps, as follows:

1. Determination and documentation of whether or not a water body is presently meeting its water quality standards and designated uses.

2. Assessment of present water quality conditions in the water body, including estimation of present loadings of pollutants of concern from both point sources (discernable, confined, and concrete sources such as pipes) and non-point sources (diffuse sources that carry pollutants to surface waters through runoff or groundwater).

3. Determination of the loading capacity of the water body. EPA regulations define the loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. If the water body is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings.

4. Specification of load allocations, based on the loading capacity determination, for non-point sources and point sources, which will ensure that the water body will not violate water quality standards.

After public comment and final approval by the EPA, the TMDL will serve as a guide for future implementation activities. The MassDEP will work with the Towns to develop specific implementation strategies to reduce N loadings, and will assist in developing a monitoring plan for assessing the success of the nutrient reduction strategies.

In the Centerville River - East Bay System, the pollutant of concern for these TMDLs (based on observations of eutrophication), is the nutrient N. Nitrogen is the limiting nutrient in coastal and marine waters, which means that as its concentration is increased, so is the amount of plant matter. This leads to nuisance populations of macro-algae and increased concentrations of phytoplankton and epiphyton that impair eelgrass beds and imperil the healthy ecology of the affected water bodies.

The TMDLs for N in the Centerville River - East Bay System are based primarily on data collected, compiled, and analyzed by University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Cape Cod Commission, and others, as part of the Massachusetts Estuaries Project (MEP). The data were collected over a study period from 2001 to 2005. This study period will be referred to as the "Present Conditions" in the TMDL since it contains the most recent data available. The accompanying MEP Technical Report can be found at http://www.oceanscience.net/estuaries/reports.htm. This report presents the results of the

analyses of this coastal embayment system using the MEP Linked Watershed-Embayment Nitrogen Management Model (Linked Model). The analyses were performed to assist the Towns with decisions on current and future wastewater planning, wetland restoration, anadromous fish runs, shellfisheries, open-space, and harbor maintenance programs. A critical element of this approach is the assessment of water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure that was conducted on each embayment. These assessments served as the basis for generating N loading thresholds for use as goals for watershed N management. The TMDLs are based on the site specific thresholds generated for each embayment. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision making process in the Towns of Barnstable.

Description of Water Bodies and Priority Ranking

The Centerville River - East Bay System in Barnstable Massachusetts, at the southeastern edge of Cape Cod, faces Nantucket Sound to the south, and consists of a number of subembayments of varying size and hydraulic complexity, characterized by limited rates of flushing, shallow depths and heavily developed watersheds (see Figures 2 and 3 below). This system constitutes an important component of the Town's natural and cultural resources. The nature of enclosed embayments in populous regions brings two opposing elements to bear: 1) as protected marine shoreline they are popular regions for boating, recreation, and land development and 2) as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the subembayments within the Centerville River - East Bay System are at risk of further eutrophication from high nutrient loads in the groundwater and runoff from their watersheds. Waterbody segments within this system are already listed as waters requiring TMDLs (Category 5) in the MA 2006 Integrated List of Waters, as summarized in Table 1A. Although not presently listed for nutrient impairment, recent data collected as part of the MEP overall effort indicates that the Centerville River and Scudder Bay are moderately impaired due to nutrients and as such need to be addressed in this TMDL.

Table 1A. The Centerville River - East Bay System Waterbody Segments in Category 5 of the Massachusetts 2006 Integrated List[1]

NAME	WATERBODY SEGMENT	DESCRIPTION	SIZE	POLLUTANT LISTED
Centerville River - East Bay System				
Centerville River	MA96-04_2006	From headwaters in wetland west of Strawberry Hill Road to confluence with Centerville Harbor, including East Bay, Barnstable.	0.25 sq mi	-Pathogens
Bumps River	MA96-02_2006	From outlet of pond at Bumps River Road through Scudder Bay to South Main Street bridge (confluence with Centerville River), Barnstable	0.07 sq mi	-Pathogens

A complete description of this embayment system is presented in Chapters I and IV of the MEP Technical Report, which is available at http://www.oceanscience.net/estuaries/reports.htm. A majority of the information on this embayment system is drawn from this report. Chapters VI and VII of the MEP Technical Report provide assessment data that show that the Centerville River - East Bay embayment system is impaired because of excess nutrients, loss of eelgrass, low dissolved oxygen levels, elevated chlorophyll *a* levels, and benthic fauna habitat degradation. Please note that pathogens are listed in Tables 1A for completeness. Further discussion of pathogens is beyond the scope of this TMDL.

The embayment addressed by this document is determined to be a high priority based on three significant factors: (1) the initiative that the Town has taken to assess the conditions of the entire embayment system, (2) the commitment made by the Town to restore and preserve the embayment, and (3) the extent of impairment in the embayment. In particular, this embayment is at risk of further degradation from increased N loads entering through groundwater and surface water from their increasingly developed watersheds. In both marine and freshwater systems, an excess of nutrients results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources. The general conditions related to the major indicators of habitat impairment, due to excess nutrient loading, are summarized and tabulated in Table 1B. Observations are summarized in the Problem Assessment section below, and detailed in Chapter VII, Assessment of Embayment Nutrient Related Ecological Health, of the MEP Technical Report.

Figure 2 Overview of Centerville River - East Bay, Barnstable



Table 1B. General summary of conditions related to the major indicators of habitat impairment observed in the Centerville River - East Bay embayment systems.

Centerville River - East Bay System	Eelgrass Loss[1]	Dissolved Oxygen Depletion	Chlorophyll *a*[2]	Macro -algae	Benthic Fauna[3]
Centerville River	SI	<6 mg/L up to 36% of time <4 mg/L up to 8% of time GF-MI	>10 ug/L up to 71% of time >20 ug/L up to 41% of time GF-MI	GF-MI	GF-MI
East Bay	SI	<6 mg/L up to 55% of time MI	>5 ug/L up to 43% of time >10 ug/L up to 10% of time GF	GF	MI
Bumps River	NS	MI	Insufficient Data	GF	GF
Scudder Bay	NS	<6 mg/L up to 19% of time <4 mg/L up to 1% of time MI	>10 ug/L up to 70% of time >20 ug/L up to 31% of time MI	MI	MI

1 Based on comparison of present conditions to 1951 Survey data.
2 Algal blooms are consistent with chlorophyll *a* levels above 20ug/L
3 Based on observations of the types of species, number of species, and number of individuals

GF – Good to Fair – little or no change from normal conditions*
MI – Moderately Impaired – slight to reasonable change from normal conditions*
SI – Significantly Impaired- considerably and appreciably changed from normal conditions*
SD – Severe Degraded – critically or harshly changed from normal conditions*
NS - Non-supportive habitat. No eelgrass was present in 1951 Survey data.
* - These terms are more fully described in MEP report "Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators"
December 22, 2003 http://www.mass.gov/dep/water/resources/coastalr.htm.

Problem Assessment

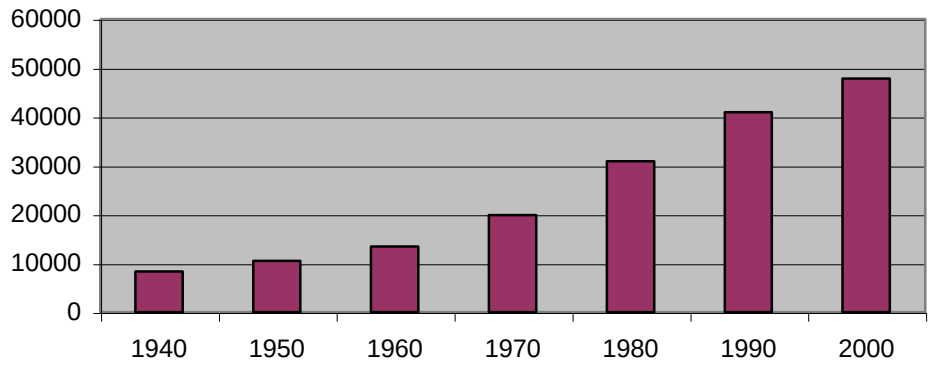
The watershed of Centerville River - East Bay embayment has had rapid and extensive development of single-family homes and the conversion of seasonal into full time residences. This is reflected in a substantial transformation of land from forest to suburban use between the years 1950 to 2000. Water quality problems associated with this development result primarily from on-site wastewater treatment systems, and to a lesser extent, from runoff - including fertilizers - from these developed areas.

On-site subsurface wastewater disposal system effluents discharge to the ground, enter the groundwater system and eventually enter the surface water bodies. In the sandy soils of Cape Cod, effluent that has entered the groundwater travel towards the coastal waters at an average rate of one foot per day. The nutrient load to the groundwater system is directly related to the number of subsurface wastewater disposal systems, which in turn are related to the population. The population of Barnstable, as with all of Cape Cod, has increased markedly since 1950. In the period from 1950 to 2000 the number of year round residents has almost quadrupled. In addition, summertime residents and visitors swell the population of the entire Cape by about 300% according to the Cape Cod Commission http://www.capecodcommission.org/data/trends98.htm#population).

Prior to the 1950's there were few homes and many of those were seasonal. During these times water quality was not a problem and eelgrass beds were plentiful. Dramatic declines in water quality, and the quality of the estuarine habitats, throughout Cape Cod, have paralleled its population growth since these times. The problems in these particular sub-embayments generally include periodic decreases of dissolved oxygen, decreased diversity and quantity of benthic animals, and periodic algal blooms. Eelgrass beds, which are critical habitat for macroinvertebrates and fish, have completely disappeared from these waters. Furthermore, the eelgrass was replaced by macroalgae, which are undesirable, because they do not provide high quality habitat for fish and invertebrates. In the most severe cases habitat degradation could lead to periodic fish kills, unpleasant odors and scums, and near loss of the benthic community and/or presence of only the most stress-tolerant species of benthic animals.

Coastal communities, including Barnstable, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as commercial fin fishing and shellfishing. The continued degradation of these coastal sub-embayments, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources. The increase in year round residents is illustrated in the following figure:

Figure 3
Barnstable Year Round Residents



Habitat and water quality assessments were conducted on this embayment system based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The embayment system in this study displays a range of habitat quality. In general, the habitat quality is highest near the tidal inlet on Nantucket Sound and poorest in the inland-most tidal reaches. This is indicated by gradients of the various indicators. Nitrogen concentrations are high throughout with a slight decrease in the central section. All eelgrass has been lost since the original 1951 survey. The dissolved oxygen records showed slight to moderate, but significant decreases in dissolved oxygen throughout the system, accompanied by above atmospheric equilibrium levels of dissolved oxygen in Scudder Bay. Elevated levels of chlorophyll *a* (5-10 ug/L) were relatively common and followed the pattern of the oxygen depletion. The benthic infauna study showed that most of the Centerville River - East Bay basins are healthy to moderately impaired.

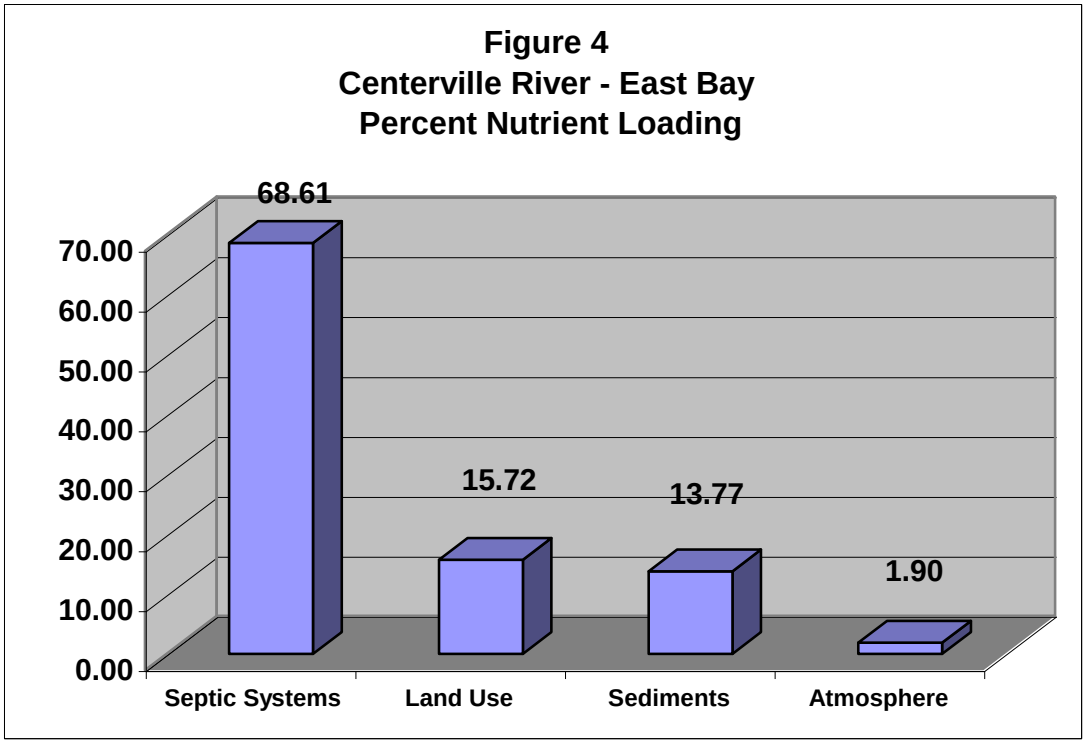
Pollutant of Concern, Sources, and Controllability

In the coastal embayments of the Town of Barnstable, as in most marine and coastal waters, the limiting nutrient is nitrogen. Nitrogen concentrations beyond those expected naturally contribute to undesirable conditions, including the severe impacts described above, through the promotion of excessive growth of plants and algae, including nuisance vegetation.

The embayment covered in this TMDL has had extensive data collected and analyzed through the Massachusetts Estuaries Program (MEP) and with the cooperation and assistance from the Town of Barnstable, the USGS, and the Cape Cod Commission. Data collection included both water quality and hydrodynamics as described in Chapters I, IV, V, and VII of the MEP Technical Report.

These investigations revealed that loadings of nutrients, especially N, are much larger than they would be under natural conditions, and as a result the water quality has deteriorated. A principal indicator of decline in water quality is the disappearance of eelgrass from its natural habitat in this embayment. This is a result of nutrient loads causing excessive growth of algae in the water (phytoplankton) and algae growing on eelgrass (epiphyton), both of which result in the loss of eelgrass through the reduction of available light levels.

As is illustrated by Figure 4, most of the N affecting this embayment system originates from on-site subsurface wastewater disposal systems (septic systems), with a lower level coming from land use, sediments, and atmospheric deposition.



The level of "controllability" of each source, however, varies widely:

Atmospheric nitrogen cannot be adequately controlled locally – it is only through region- and nation-wide air pollution control initiatives that reductions are feasible;

Sediment nitrogen control by such measures as dredging is not feasible on a large scale. However, the concentrations of N in sediments, and thus the loadings from the sediments, will decline over time if sources in the watershed are removed, or reduced to the target levels discussed later in this document. Increased dissolved oxygen will help keep nitrogen from fluxing;

Fertilizer related nitrogen loadings can be reduced through bylaws and public education;

Stormwater sources of N can be controlled by best management practices (BMPs), bylaws and stormwater infrastructure improvements;

Septic system sources of nitrogen are the largest controllable sources. These can be controlled by a variety of case-specific methods including: sewering and treatment at centralized or decentralized locations, upgrading/repairing failed systems, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing nitrogen-reducing on-site wastewater treatment systems.

Natural Background is the background load as if the entire watershed was still forested and contains no anthropogenic sources. It cannot be controlled locally.

Cost/benefit analyses will have to be conducted on all of the possible N loading reduction methodologies in order to select the optimal control strategies, priorities, and schedules.

Description of the Applicable Water Quality Standards

Water quality standards of particular interest to the issues of cultural eutrophication are dissolved oxygen, nutrients, aesthetics, excess plant biomass, and nuisance vegetation. The Massachusetts water quality standards (314 CMR 4.0) contain numeric criteria for dissolved oxygen, but have only narrative standards that relate to the other variables, as described below:

314 CMR 4.05(5)(a) states "Aesthetics – All surface waters shall be free from pollutants in concentrations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances, produce objectionable odor, color, taste, or turbidity, or produce undesirable or nuisance species of aquatic life."

314 CMR 4.05(5)(c) states, "Nutrients – Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication".

314 CMR 4.05(b) 1:

(a) Class SA

1. Dissolved Oxygen -
a. Shall not be less than 6.0 mg/l unless background conditions are lower;
b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 75% of saturation due to a discharge; and
c. site-specific criteria may apply where background conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

(b) Class SB

1. Dissolved Oxygen -
a. Shall not be less than 5.0 mg/L unless background conditions are lower;
b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 60% of saturation due to a discharge; and
c. site-specific criteria may apply where background conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

Thus, the assessment of eutrophication is based on site-specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is recommended by the US Environmental Protection Agency in their draft Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (EPA-822-B-01-003, Oct 2001). The Guidance Manual notes that lakes, reservoirs, streams, and rivers may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management. However, individual estuarine and coastal marine waters have unique characteristics, and development of individual water body criteria is typically required.

It is this framework, coupled with an extensive outreach effort that the Department, and technical support of SMAST, that MassDEP is employing to develop nutrient TMDLs for coastal waters.

Methodology - Linking Water Quality and Pollutant Sources

Extensive data collection and analyses have been described in detail in the MEP Technical Report. Those data were used by SMAST to assess the loading capacity of each sub-embayment. Physical (Chapter V), chemical, and biological (Chapters IV, VII, and VIII**)** data were collected and evaluated. The primary water quality objective was represented by conditions that:

1) restore the natural distribution of eelgrass because it provides valuable habitat for shellfish and finfish
2) prevent algal blooms
3) protect benthic communities from impairment or loss
4) maintain dissolved oxygen concentrations that are protective of the estuarine communities.

The details of the data collection, modeling and evaluation are presented and discussed in Chapters IV, V, VI, VII and VIII of the MEP Technical Report. The main aspects of the data evaluation and modeling approach are summarized below, taken from pages 4 through 9 of that report.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. It fully links watershed inputs with embayment circulation and N characteristics, and is characterized as follows:

- requires site-specific measurements within the watershed and each sub-embayment;
- uses realistic "best-estimates" of N loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed N loading to the embayment;
- accounts for N attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes N regenerated within the embayment;
- is validated by both independent hydrodynamic, N concentration, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied previously to watershed N management in over 15 embayments throughout Southeastern Massachusetts. In these applications it became clear that the model can be calibrated and validated, and has use as a management tool for evaluating watershed N management options.

The Linked Model, when properly calibrated and validated for a given embayment, becomes a N management-planning tool as described in the model overview below. The model can assess solutions for the protection or restoration of nutrient-related water quality and allows testing of management scenarios to support cost/benefit evaluations. In addition, once a model is fully functional it can be refined for changes in land-use or embayment characteristics at minimal cost. In addition, since the Linked Model uses a holistic approach that incorporates the entire watershed, embayment, and tidal source waters, it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

The Linked Model provides a quantitative approach for determining an embayment's: (1) N sensitivity, (2) N threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-3 of the MEP Technical Report). This methodology integrates a variety of field data and models, specifically:

• Monitoring - multi-year embayment nutrient sampling

• Hydrodynamics -

- embayment bathymetry (depth contours throughout the embayment)
- site-specific tidal record (timing and height of tides)
- water velocity records (in complex systems only)
- hydrodynamic model

• Watershed Nitrogen Loading

- watershed delineation
- stream flow (Q) and N load
- land-use analysis (GIS)
- watershed N model

• Embayment TMDL - Synthesis

- linked Watershed-Embayment Nitrogen Model
- salinity surveys (for linked model validation)
- rate of N recycling within embayment
- dissolved oxygen record
- macrophyte survey
- infaunal survey (in complex systems)

Application of the Linked Watershed-Embayment Model

The approach developed by the MEP for applying the linked model to specific sub-embayments, for the purpose of developing target N loading rates, includes:

1) selecting one or two sub-embayments within the embayment system, located close to the inland-most reach or reaches, which typically has the poorest water quality within the system. These are called "sentinel" stations;

2) using site-specific information and a minimum of three years of sub-embayment-specific data to select target threshold N concentrations for each sub-embayment. This is done by refining the draft threshold N concentrations that were developed as the initial step of the MEP process. The target concentrations that were selected generally occur in higher quality waters near the mouth of the embayment system;

3) running the calibrated water quality model using different watershed N loading rates, to determine the loading rate, which will achieve the target N concentration at the sentinel station. Differences between the modeled N load required to achieve the target N concentration, and the present watershed N load, represent N management goals for restoration and protection of the embayment system as a whole.

Previous sampling and data analyses, and the modeling activities described above, resulted in four major outputs that were critical to the development of the TMDL. Two outputs are related to N **concentration**:

- the present N concentrations in the sub-embayments
- site-specific target threshold N concentrations

and, two outputs are related to N **loadings:**

- the present N loads to the sub-embayments
- load reductions necessary to meet the site specific target threshold N concentrations

In summary: meeting the water quality standards by reducing the nitrogen concentration (and thus the nitrogen load) at the sentinel station, the water quality goals will be met throughout the entire system.

A brief overview of each of the outputs follows:
Nitrogen concentrations in the sub-embayments

a) Observed "present" conditions:
Table 2 presents the average concentration of N measured in this embayment from five years of data collection (during the period 2001 through 2005).). Concentrations of N are the highest at the most upstream end of Centerville River 0.79 mg/L (Station BC-5). Nitrogen at the other stations in the embayment ranges in concentration from 0.33 to 0.66 mg/L, resulting in overall ecological habitat quality that is significantly impaired. The overall means and standard deviations of the averages are presented in Appendix A (reprinted from Table VI-1 of the accompanying Tech Report).

b) Modeled site-specific target threshold nitrogen concentrations:
A major component of TMDL development is the determination of the maximum concentrations of N (based on field data) that can occur without causing unacceptable impacts to the aquatic environment. Prior to conducting the analytical and modeling activities described above, SMAST selected appropriate nutrient-related environmental indicators and tested the qualitative and quantitative relationship between those indicators and N concentrations. The Linked Model was then used to determine site-specific threshold N concentrations by using the specific physical, chemical, and biological characteristics of each sub-embayment.

As listed in Table 2, the site-specific target (threshold) N concentration is 0.37 mg/L.
The findings of the analytical and modeling investigations for this embayment system are discussed and explained below:

The threshold N level for an embayment represents the average water column concentration of N that will support the habitat quality being sought. The water column N level is ultimately controlled by the integration of the watershed N load, the N concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column N concentration is modified by the extent of sediment uptake and/or regeneration and by direct atmospheric deposition.

Table 2. Observed present nitrogen concentrations and sentinel station threshold nitrogen target concentrations derived for the Centerville River - East Bay embayment system

Centerville River - East Bay (Station I.D.)	Embayment Observed Nitrogen Concentration [1] (mg/L)	Sentinel Station Threshold Nitrogen Target Concentrations (mg/L)
Centerville River (BC-5,7,8,9)	0.43-0.75[2]	0.50[3]
East Bay (BC-10)	0.41	
Bumps River (BC-4)	0.48	
Scudder Bay (BC-3)	0.62	0.50[3]
Sentinel Station (BC-T)	No data	0.37
Nantucket Sound (Boundary Condition)	0.33	

[1] calculated as the average of the separate yearly means of 2001-2005 data. Overall means and standard deviations of the average are presented in Tables A-1 Appendix A.
[2] listed as a range since it was sampled as several segments (see Table A-1, Appendix A).
[3] The threshold value of 0.50 mg/l applies to the Centerville River @ station BC-7, and Scudder Bay @station BC-3 for the protection of benthic habitat.

Threshold N levels for each of the embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. In these systems, high habitat quality was defined as supportive of eelgrass, diverse benthic animal communities, and dissolved oxygen levels that would support Class SA waters. Chlorophyll *a* was also considered in the assessment.

Watershed nitrogen loads (Tables ES-1 and ES-2 from the MEP Technical Report) for Centerville River - East Bay embayment system was comprised primarily of wastewater nitrogen. Analysis of the data indicates that of the controllable load the septic systems contribute 81%, and land use contributes 19%.

A major finding of the MEP clearly indicates that a single total nitrogen threshold can not be applied to Massachusetts' estuaries, based upon the results of the Great, Green, and Bournes Pond Systems; Popponesset Bay System; the Hamblin / Jehu Pond / Quashnet River analysis in eastern Waquoit Bay; and the Pleasant Bay and Nantucket Sound embayments associated with the Town of Chatham. This is almost certainly going to be true for the other embayments within the MEP area, as well.

The threshold nitrogen levels for the Centerville River embayment system in Barnstable were determined as follows:

Centerville River – East Bay Threshold Nitrogen Concentrations

Following the MEP protocol, the restoration target for the Centerville River system should reflect both recent pre-degradation habitat quality and be reasonably achievable. Based upon the assessment data (Chapter VII), the Centerville River System is presently supportive of infaunal habitat throughout its component basins. However, there is a moderate level of infaunal habitat impairment within Scudder Bay and the mid region of the Centerville River, requiring nitrogen management for restoration. The primary habitat issue within the Centerville River System relates to the loss of eelgrass from the lower estuary, specifically from the Centerville River west of the entrance to Bumps River and in East Bay. This loss of eelgrass classifies these areas as "significantly impaired", although they presently support healthy to moderately healthy infaunal communities. Further impairment to both the infaunal habitat in Scudder Bay and the eelgrass habitat in the lower estuary are supported by the variety of other indicators, which support the conclusion that these impairments are the result of nitrogen enrichment, primarily from watershed nitrogen loading.

The target nitrogen concentration (tidally averaged TN) for restoration of eelgrass at the sentinel location within the lower reach of the Centerville River (region seaward of the mouth of the Bumps River) was determined to be 0.37 mg/L N. This nitrogen level is based upon the absence of eelgrass in the Lower Centerville River at a tidally averaged TN of 0.40 mg/L N and comparison to a stable eelgrass system in a similarly configured basin, the lower Oyster River (Chatham) at 0.37 mg/L N. Note: that this level is only slightly lower than that determined by the MEP Technical Team for nearby Popponesset Bay (0.38 mg/L N). This difference relates to the much shallower water in Popponesset Bay then in the Centerville River. Water depth is important as the same phytoplankton concentration that results in shading of eelgrass in deep water, will allow sufficient light to support eelgrass in shallow water. The need for a lower threshold in deeper versus shallower water was seen in the MEP eelgrass habitat assessment for Bournes Pond, Falmouth.

The threshold nitrogen level at the sentinel station within the Centerville River System is within the range found for other complex systems such as 0.38 mg/L N for Stage Harbor, 0.38 mg/L N for Bournes Pond and nearby Popponesset Bay and 0.35 mg/L N for West Falmouth Harbor and Phinneys Harbor. The sentinel station under present loading conditions supports a tidally corrected average concentration of 0.40 mg/L N, so watershed nitrogen management will be required for restoration of the estuarine habitats within this system.

Although the nitrogen management target is restoration of eelgrass habitat (and

associated water clarity, shellfish and fisheries resources), benthic infaunal habitat quality must also be supported as a secondary condition. At present, in the regions with impaired infaunal habitat, the tidally averaged total nitrogen (TN) level under existing conditions is 0.53 mg/L N in Scudder Bay and between 0.54-0.47 mg/L N in the middle reach of the Centerville River (bridge to Bumps River). The observed moderate impairment at these sites is consistent with observations by the MEP Technical Team in other enclosed basins along Nantucket Sound (e.g. Perch Pond, Bournes Pond, Popponesset Bay) where levels <0.5 mg/L N were found to be supportive of healthy infaunal habitat and in deeper enclosed basins in Buzzards Bay (e.g. Eel Pond in Bourne) where healthy infaunal habitat had a slightly lower threshold level, 0.45 mg/L N, due to those being a "deep" depositional basin. The higher TN levels observed in the upper Centerville River salt marshes are within the nitrogen threshold to support the observed healthy infaunal habitat in this estuarine reach. To ensure that meeting the nitrogen threshold at the sentinel station (BC-T, just seaward of the mouth of the Bumps River within the Centerville River, upgradient from BC-9) results in restoration of the moderately impaired infaunal habitats in Scudder Bay and the middle reach of the Centerville River, nitrogen criteria for secondary infaunal "check" stations were developed by the MEP Technical Team. Based upon the Centerville River system showing moderate impairment at tidally averaged TN levels of 0.53 mg/L N in Scudder Bay (BC-3) and 0.54 at the inland end of the middle reach of the Centerville River (BC-7)and the results from nearby embayments to Nantucket Sound (noted above), it was concluded that an upper limit of 0.50 mg/L N tidally averaged TN would support healthy infaunal habitat in these inner regions.

It is important to note that the analysis of future nitrogen loading to the Centerville River estuarine system focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round usage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine nitrogen management must include management approaches to prevent increased nitrogen loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The conclusion of the MEP analysis of the Centerville River estuarine system is that restoration will necessitate reduction in the present (2005) nitrogen inputs and management options to negate additional future nitrogen inputs.

Nitrogen loadings to the embayment

a) Present loading rates:

In the Centerville River - East Bay embayment system overall, the highest N loading from controllable sources is from septic systems. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) is significant in this embayment.

As discussed previously, however, the direct control of N from sediments is not considered feasible. However, the magnitude of the benthic contribution is related to the watershed load. Therefore, reducing the incoming load should reduce the benthic flux over time. The total N loading from all sources was 156.79 kg/day across Centerville River - East Bay embayment. A further breakdown of N loading, by source, is presented in Table 3. The data on which Table 3 is based can be found in Table ES-1 of the MEP Technical Report.

Table 3. Nitrogen loading to Centerville River - East Bay System

Centerville River - East Bay Embayment	Present Land Use Load [1] (kg/day)	Present Septic System Load (kg/day)	Benthic Input[2] (kg/day)	Present Atmospheric Deposition (kg/day)	Total nitrogen load from all sources (kg/day)
Centerville River	12.97	57.98	8.89	1.17	81.01
East Bay	2.33	6.30	12.69	1.13	22.46
Scudder Bay	9.35	43.28	0	0.69	53.32

[1] composed of fertilizer, runoff, and atmospheric deposition to lakes
[2] negative benthic flux has been set to zero as it is not a load

As previously indicated, the present N loadings to Centerville River - East Bay embayment system must be reduced in order to restore conditions and to avoid further nutrient-related adverse environmental impacts. The critical final step in the development of the TMDL is modeling and analysis to determine the loadings required to achieve the target N concentrations.

b) Nitrogen loads necessary for meeting the site-specific target nitrogen concentrations.

Table 4 lists the present controllable watershed N loadings from Centerville River - East Bay embayment system. The last two columns indicate one scenario of the reduced loads and percentage reductions that could achieve the target concentrations in the sentinel system (see following section). It is very important to note that load reductions can be produced through reduction of any or all sources of N, potentially increasing the natural attenuation of nitrogen within the freshwater systems to the embayment, and/or modifying the tidal flushing through inlet reconfiguration (where appropriate). The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the communities involved. This presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of these N impaired embayments.

As previously noted, the loadings presented in Table 4 represent one, but not the only, loading reduction scenario that can meet the TMDL goal. Other alternatives may also achieve the desired threshold concentration as well and can be explored using the MEP modeling approach. In the scenario presented, the percentage reductions in N loadings to meet the target threshold concentrations range from 0% in East Bay and Scudder Bay to 52 % in Centerville River. Table VIII-2 of the MEP Technical Report (and rewritten as Appendix B of this document) summarizes the present loadings from on-site subsurface wastewater disposal systems and the reduced loads that would be necessary to achieve the threshold N concentrations in the Centerville River - East Bay embayment system, under the scenario modeled here. In this scenario only the on-site subsurface wastewater disposal system loads were reduced to the level of the target threshold watershed load. It should be emphasized once again that this is only one scenario that will meet the target N concentrations in the sentinel systems, which is the ultimate goal of the TMDL. There can be variations depending on the chosen sub-watershed and which controllable source is

selected for reduction. Alternate scenarios will result in different amounts of nitrogen being reduced in different sub-watersheds. For example, taking out additional nitrogen upstream will impact how much nitrogen has to be taken out downstream. The town of Barnstable should take any reasonable effort to reduce the controllable nitrogen sources.

Table 4. Present Controllable Watershed nitrogen loading rate, calculated loading rate that is necessary to achieve target threshold nitrogen concentration, and the percent reduction of the existing load necessary to achieve the target threshold load.

Embayments	Present controllable watershed load [1] (kg/day)	Target threshold watershed load[2] (kg/day)	Percent controllable watershed load reductions needed to achieve threshold loads
Centerville River	70.95	34.18	52%
East Bay	8.63	8.63	0%
Scudder Bay	52.63	52.63	0%

[1] Composed of combined land use, and septic system loadings
[2] Target threshold watershed load is the load from the watershed needed to meet the embayment threshold N concentrations identified in Table 2 above

Total Maximum Daily Loads

As described in EPA guidance, a total maximum daily load (TMDL) identifies the loading capacity of a water body for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. The TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass, the leading indicator of ecological health, thus meeting water quality goals for aquatic life support. Because there are no "numerical" water quality standards for N, the TMDLs for the Centerville River - East Bay embayment system is aimed at determining the loads that would correspond to specific N concentrations determined to be protective of the water quality and ecosystems.

The effort includes detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time), for each sub-embayment. The results of the mathematical model are correlated with estimates of impacts on water quality, including negative impacts on eelgrass (the primary indicator), as well as dissolved oxygen, chlorophyll, and benthic infauna.

The TMDL can be defined by the equation:

TMDL = BG + WLAs + LAs + MOS

Where

TMDL = loading capacity of receiving water
BG = natural background
WLAs = portion allotted to point sources
LAs = portion allotted to (cultural) non-point sources
MOS = margin of safety

Background Loading

Natural background N loading estimates are presented in Table ES-1 of the MEP Technical Report. Background loading was calculated on the assumption that the entire watershed is forested, with no anthropogenic sources of N.

Wasteload Allocations

Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of storm water be included in the waste load component of the TMDL. On Cape Cod there are no surface water NPDES discharges discharging directly the surface waters in the Centerville Harbor embayment system and the vast majority of storm water percolates into the ground and aquifer and proceeds into the embayment systems through groundwater migration. The Linked Model accounts for storm water loadings and groundwater loading in one aggregate allocation as a non-point source – combining the assessments of waste water and storm water (including storm water that infiltrates into the soil and direct discharge pipes into water bodies) for the purpose of developing control strategies. Although the vast majority of storm water percolates into the ground, there are a few storm water pipes that discharge directly to water bodies that are subject to the requirements of the Phase II Storm Water NPDES Program. Therefore, any storm water discharges subject to the requirements of storm water Phase II NPDES permit must be treated as a waste load allocation. Since the majority of the nitrogen loading comes from septic systems, fertilizer, and storm water that infiltrates into the groundwater, the allocation of nitrogen for any storm water pipes that discharge directly to any of the embayments is insignificant as compared to the overall groundwater load. Based on land use, the Linked Model accounts for loading for storm water, but does not differentiate storm water into a load and waste load allocation. Nonetheless, based on the fact that there are few storm water discharge pipes within NPDES Phase II communities that discharge directly to embayments or waters that are connected to the embayments, the total waste load allocation for these sources is considered to be insignificant. This is based on the percent of impervious surface within 200 feet of the waterbodies and the relative load from this area compared to the overall load (Table IV-4 of the MEP Technical Report). Although most stormwater infiltrates into the ground on Cape Cod, some impervious areas within approximately 200 feet of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of waste load allocation it was assumed that all impervious surfaces within 200 feet of

the shoreline discharge directly to the waterbody. This calculated load is 0.5% of the total load or 3972 kg/year as compared to the overall nitrogen load of 48,277 kg/year to the embayments. Looking at individual sub-embayments this load ranged from 0.3-1.3% compared to the individual nitrogen load to each sub-embayment (see Appendix C for details). This conservative load is obviously negligible when compared to other sources.

EPA policy also requires that stormwater regulated under the NPDES program be identified and included as a wasteload allocation. As discussed below, for the purpose of this TMDL, stormwater loadings are not differentiated into point and non-point sources.

EPA and MassDEP authorized the Town of Barnstable for coverage under the NPDES Phase II General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003.The Phase II general permit requires the permittee to determine whether the approved TMDL is for a pollutant likely to be found in storm water discharges from the MS4. The MS4 is required to implement the storm water waste load allocation, BMP recommendations, or other performance requirements of a TMDL and assess whether the waste load allocation is being met through implementation of existing stormwater control measures or if additional control measures are necessary.

Load Allocations

Load allocations identify the portion of loading capacity allocated to existing and future nonpoint sources. In the case of the Centerville River - East Bay embayment system, the nonpoint source loadings are primarily from the on-site subsurface wastewater disposal systems Additional N sources include land use (runoff and fertilizers) and atmospheric deposition.

Generally, stormwater that is subject to the EPA Phase II Program would be considered a part of the wasteload allocation, rather than the load allocation. As presented in Chapter IV, V, and VI, of the MEP Technical Report, on Cape Cod the vast majority of stormwater percolates into the aquifer and enters the embayment system through groundwater. Given this, the TMDL accounts for stormwater loadings and groundwater loadings in one aggregate allocation as a non-point source, thus combining the assessments of wastewater and storm water for the purpose of developing control strategies. Ultimately, when the Phase II Program is implemented in Barnstable, new studies, and possibly further modeling, will identify what portion of the stormwater load may be controllable through the application of Best Management Practices (BMPs).

The sediment loading rates incorporated into the TMDL are lower than the existing sediment flux rates listed in Table 3 above because projected reductions of N loadings from the watershed will result in reductions of nutrient concentrations in the sediments, and therefore, over time, reductions in loadings from the sediments will occur. Benthic N flux is a function of N loading and particulate organic nitrogen (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed N loads, and are calculated by multiplying the present N flux by the ratio of projected PON to present PON, using the following formulae:

Projected N flux = (present N flux) (PON projected / PON present)

When: $PON_{projected} = (R_{load}) (D_{PON}) + PON_{present\ offshore}$

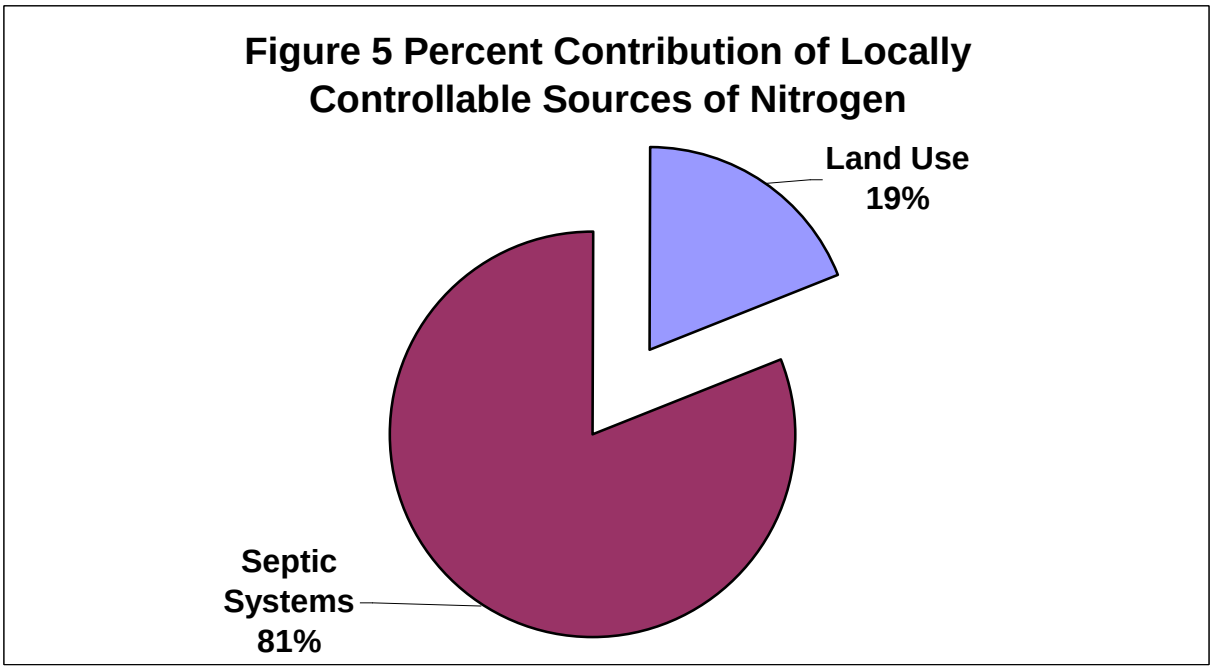
When R_{load} = (projected N load) / (Present N load)

And D_{PON} is the PON concentration above background determined by:

$D_{PON} = (PON_{present\ embayment} - PON_{present\ offshore})$

The benthic flux modeled for the Centerville River – East Bay system is reduced from existing conditions based on the load reduction and the observed PON concentrations within each sub-embayment relative to Nantucket Sound (boundary condition). The benthic flux input to each sub-embayment was reduced (toward zero) based on the reduction of N in the watershed load. The loadings from atmospheric sources incorporated into the TMDL, however, are the same rates presently occurring, because, as discussed above, local control of atmospheric loadings is not considered feasible.

Locally controllable sources of N within the watersheds are categorized as on-site subsurface wastewater disposal system wastes and land use (which includes stormwater runoff and fertilizers). Figure 5 emphasizes the fact that the overwhelming majority of locally controllable N comes from on-site subsurface wastewater disposal systems.



Margin of Safety

Statutes and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA para 303 (d)(20©, 40C.G.R. para 130.7©(1)]. The EPA's 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. The MOS for the Centerville River - East Bay System TMDL is implicit, and the conservative assumptions in the analyses that account for the MOS are described below.

1. Use of conservative data in the linked model

The watershed N model provides conservative estimates of N loads to the embayments. Nitrogen transfer through direct groundwater discharge to estuarine waters is based upon studies indicating negligible aquifer attenuation and dilution, i.e. 100% of load enters embayment. This is a conservative estimate of loading because studies have also shown that in some areas less than 100% of the load enters the estuary. Nitrogen from the upper watershed regions, which travel through ponds or wetlands, almost always enter the embayment via stream flow, are directly measured (over 12-16 months) to determine attenuation. In these cases the land-use model has shown a slightly higher predicted N load than the measured discharges in the streams/rivers that have been assessed to date. Therefore, the watershed model as applied to the surface water watershed areas again presents a conservative estimate of N loads because the actual measured N in streams was lower than the modeled concentrations.

The hydrodynamic and water quality models have been assessed directly. In the many instances where the hydrodynamic model predictions of volumetric exchange (flushing) have also been directly measured by field measurements of instantaneous discharge, the agreement between modeled and observed values has been $\geq$95%. Field measurement of instantaneous discharge was performed using acoustic doppler current profilers (ADCP) at key locations within the embayment (with regards to the water quality model, it was possible to conduct a quantitative assessment of the model results as fitted to a baseline dataset - a least squares fit of the modeled versus observed data showed an R^2>0.95, indicating that the model accounted for 95% of the variation in the field data). Since the water quality model incorporates all of the outputs from the other models, this excellent fit indicates a high degree of certainty in the final result. The high level of accuracy of the model provides a high degree of confidence in the output; therefore, less of a margin of safety is required.

In the case of N attenuation by freshwater ponds, attenuation was derived from measured N concentrations, pond delineations and pond bathymetry. These attenuation factors were higher than that used in the land-use model. The reason was that the pond data were temporally limited and a more conservative value of 40% was more protective and defensible.

In the case of the nitrogen load assessed to lawn fertilization rates for residential lawns, based on an actual survey, it is likely that this represents a conservative estimate of the nitrogen load. This

too makes a more conservative margin of safety. The nitrogen loading calculations are based on a wastewater engineering assumption that 90% of water used is converted to wastewater. Actual water use and conversion studies in the area have shown that this conversion rate is conservative adding to the margin of safety.

The nitrogen loading calculations for homes, which do not have metered water use, are based on a conservative estimate of water use compared to actual water use in the metered sections of the watershed. This adds to the margin of safety.

Similarly, the water column N validation dataset was also conservative. The model is validated to measured water column N. However, the model predicts average summer N concentrations. The very high or low measurements are marked as outliers. The effect is to make the N threshold more accurate and scientifically defensible. If a single measurement two times higher than the next highest data point in the series, raises the average 0.05 mg/L N, this would allow for a higher "acceptable" load to the embayment. Marking the very high outlier is a way of preventing a single and rare bloom event from changing the N threshold for a system. This effectively strengthens the data set so that a higher margin of safety is not required.

2. Conservative sentinel station/target threshold nitrogen concentrations

Conservatism was used in the selection of the sentinel stations and target threshold N concentrations. Sites were chosen that had stable eelgrass or benthic animal (infaunal) communities, and not those just starting to show impairment, which would have slightly higher N concentrations. Meeting the target threshold N concentrations at the sentinel station will result in reductions of N concentrations in the rest of the system.

3 Conservative approach

The target loads were based on tidally-averaged N concentrations on the outgoing tide, which is the worst case condition because that is when the N concentrations are the highest. The N concentrations will be lower on the flood tides; therefore, this approach is conservative.

In addition to the margin of safety within the context of setting the N threshold levels, described above, a programmatic margin of safety also derives from continued monitoring of these subembayments to support adaptive management. This continuous monitoring effort provides the ongoing data to evaluate the improvements that occur over the multi-year implementation of the N management plan. This will allow refinements to the plan to ensure that the desired level of restoration is achieved.

Seasonal Variation

Since the TMDL for the waterbody segment is based on the most critical time period, i.e. the summer growing season, the TMDL is protective for all seasons. The daily loads can be converted to annual loads by multiplying by 365 (the number of days in a year). Nutrient loads to the embayment are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Second, as a practical matter, the types of controls necessary to control the N load, the nutrient of primary concern, by their very nature do not lend themselves to intra-annual

manipulation since the majority of the N is from non-point sources. Thus, the annual loads make sense, since it is difficult to control non-point sources of nitrogen on a seasonal basis and nitrogen sources can take considerable time to migrate to impacted waters.

TMDL Values for Centerville River - East Bay embayment system

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of the embayment were calculated by considering all sources of N grouped by point sources and non-point sources. A more meaningful way of presenting the loadings data, from an implementation perspective, is presented in Table 5. In this table the N loadings from the atmosphere and nutrient-rich sediments are listed separately from the target watershed threshold loads, which are composed of locally controllable N from the on-site subsurface wastewater disposal systems, stormwater runoff, and fertilizer sources. In the case of the Centerville River - East Bay embayment system the TMDL was calculated by projecting reductions in locally controllable on-site subsurface wastewater disposal systems. Once again the goal of this TMDL is to achieve the identified N threshold concentration at the identified sentinel station. The target load identified in this table represents one alternative loading scenario to achieve that goal but other scenarios may be possible and approvable as well. These waterbody segment TMDLs are also presented in Appendix D.

Table 5. The Total Maximum Daily Load (TMDL) for Centerville River - East Bay embayment system, represented as the sum of the calculated target threshold load (from controllable watershed sources), atmospheric deposition, and benthic input.

Sub-embayment	Target Threshold Watershed Load [1] (kg/day)	Atmospheric Deposition (kg/day)	Benthic Input (kg/day)	TMDL [2] (kg/day)
Centerville River	34.18	1.17	7.78	43
East Bay	8.63	1.13	12.69	22
Scudder Bay	52.63	0.69	0	53

[1] Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table 2
[2] Sum of target threshold watershed load, atmospheric deposition load, and the benthic input load.

Two waterbody segments, East Bay and Scudder Bay, were not found to be impaired for nitrogen, but it was determined that a "pollution prevention" TMDL for nitrogen was needed since these waterbody segments are linked to the larger embayment system and any future impairment of these two segments could further contribute to impairment of the segments at issue in this TMDL (Appendix D). "Pollution prevention" TMDLs on these two waterbody segments will encourage the maintenance and protection of existing water quality and help prevent further degradation to

waterbodies that are downstream or linked. These pollution prevention TMDLs will serve as a guide to help ensure that these waterbodies do not become impaired for nitrogen.

Implementation Plans

The critical element of this TMDL process is achieving the sentinel station specific N concentrations presented in Table 2 above, that are necessary for the restoration and protection of water quality and eelgrass habitat within the Centerville River - East Bay embayment system. In order to achieve those target concentrations, N loading rates must be reduced throughout these three embayments. Table 5, above, lists the target watershed threshold load. If this threshold loads is achieved, this embayment will be protected.

As previously noted, this loading reduction scenario is not the only way to achieve the target N concentrations. Barnstable is free to explore other loading reduction scenarios through additional modeling as part of the Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated, however, that any alternative implementation strategies will be protective of Centerville River - East Bay, and that none of the embayment will be negatively impacted. To this end, additional linked model runs can be performed by the MEP at a nominal cost to assist the planning efforts of the Town in achieving target N loads that will result in the desired threshold concentrations.

The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, the MassDEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results.

Because the vast majority of controllable N load is from individual on-site subsurface wastewater disposal systems for private residences, the CWMP should assess the most cost-effective options for achieving the target N watershed loads, including but not limited to, sewering and treatment for N control of sewage and septage at either centralized or de-centralized locations, and denitrifying systems for all private residences.

Barnstable is urged to meet the target threshold N concentrations by reducing N loadings from any and all sources, through whatever means are available and practical, including reductions in stormwater runoff and/or fertilizer use within the watershed through the establishment of local by-laws and/or the implementation of stormwater BMPs, in addition to reductions in on-site subsurface wastewater disposal system loadings.

MassDEP's MEP Implementation Guidance report (http://www.mass.gov/dep/water/resources/restore.htm) provides N loading reduction strategies that are available to Barnstable and that could be incorporated into the implementation plans. The following topics related to N reduction are discussed in the Guidance:

- Wastewater Treatment
    - On-Site Treatment and Disposal Systems
    - Cluster Systems with Enhanced Treatment
    - Community Treatment Plants

        - Municipal Treatment Plants and Sewers
- Tidal Flushing
        - Channel Dredging
        - Inlet Alteration
        - Culvert Design and Improvements
- Stormwater Control and Treatment *
        - Source Control and Pollution Prevention
        - Stormwater Treatment
- Attenuation via Wetlands and Ponds
- Water Conservation and Water Reuse
- Management Districts
- Land Use Planning and Controls
        - Smart Growth
        - Open Space Acquisition
        - Zoning and Related Tools
- Nutrient Trading

* The Town of Barnstable is one of the 237 communities in Massachusetts covered by the Phase II stormwater program requirements.

Monitoring Plan for TMDL Developed Under the Phased Approach

MassDEP is of the opinion that there are two forms of monitoring that are useful to determine progress towards achieving compliance with the TMDL. They include 1) tracking implementation progress as approved in the Town CWMP plan and 2) monitoring ambient water quality conditions at the sentinel stations identified in the MEP Technical Report.

The CWMP will evaluate various options to achieve the goals set out in the TMDL and Technical Report. It will also make a final recommendation based on existing or additional modeling runs, set out required activities, and identify a schedule to achieve the most cost effective solution that will result in compliance with the TMDL. Once approved by the Department tracking progress on the agreed upon plan will, in effect, also be tracking progress towards water quality improvements in conformance with the TMDL.

Relative to water quality, MassDEP believes that an ambient monitoring program, much reduced from the data collection activities needed to properly assess conditions and to populate the model, will be important to determine actual compliance with water quality standards. Although the TMDL load values are not fixed, the target threshold nitrogen concentrations at the sentinel stations are fixed. In addition, there are target threshold N concentrations that are provided for many other non-sentinel locations in subembayments to protect nearshore benthic habitat. These are the water quality targets, and a monitoring program should encompass these stations at a minimum. Through discussions amongst the MEP it is generally agreed that existing monitoring programs, which were designed to thoroughly assess conditions and populate water quality models, can be substantially reduced for compliance monitoring purposes. Although more specific details need to be developed on a case by case basis MassDEP's current thinking is that about half the current effort (using the same data collection procedures) would be sufficient to

monitor compliance over time and to observe trends in water quality changes. In addition, the benthic habitat and communities would require periodic monitoring on a frequency of about every 3-5 years. Finally, in addition to the above, existing monitoring conducted by MassDEP for eelgrass should continue into the future to observe any changes that may occur to eelgrass populations as a result of restoration efforts.

The MEP will continue working with the Towns to develop and refine monitoring plans that remain consistent with the goals of the TMDL. It must be recognized however that development and implementation of a monitoring plan will take some time, but it is more important at this point to focus efforts on reducing existing watershed loads to achieve water quality goals.

Reasonable Assurances

MassDEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act (CWA), to implement and enforce the provisions of the TMDL, including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Barnstable has demonstrated this commitment through the comprehensive wastewater planning that they initiated well before the generation of the TMDL. The Town expects to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers), and to prevent any future degradation of these valuable resources. Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations; availability of financial incentives; and local, state, and federal programs for pollution control. Storm water NPDES permit coverage will address discharges from municipally owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act; Title 5 regulations for on-site subsurface wastewater disposal systems, and other local regulations such as the Town of Rehoboth's stable regulations. Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement between MassDEP and EPA. Other potential funds and assistance are available through Massachusetts' Department of Agriculture's Enhancement Program and the United States Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

As the town implements this TMDL, the TMDL values (kg/day of nitrogen) will not be used by MassDEP as an enforcement tool. There will be slight variations in these values depending on the scenario the towns use to implement it. They are also modeled values and thus would be very awkward and difficult to use as an enforcement tool. There could also be slight variations between the actual nitrogen concentration at the sentinel stations and the site specific target threshold nitrogen concentration at the sentinel stations as the nitrogen load is reduced and the waterbodies begin to approach the water quality standards (Description of the Applicable Water

Quality Standards section**).** It will be these latter two standards, the nitrogen concentration at the sentinel station and more importantly, the applicable water quality standards that will be used as the measure of full implementation and compliance with these water quality standards.

Appendix A: Summarizes the nitrogen concentrations for Centerville River - East Bay embayment system (from Chapter VI of the accompanying MEP Technical Report)

Table VI-1. Pond-Watcher measured data, and modeled Nitrogen concentrations for the Centerville River System used in the model calibration plots of Figure VI-2. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means.

Sub-Embayment	Scudder Bay	Bumps River	Centerville River	Centerville River	Centerville River	Centerville River	East Bay
Monitoring station	BC-3	BC-4	BC-5	BC-7	BC-8	BC-9	BC-10
2001 mean	0.593	0.325	0.697	0.484	0.423	0.332	0.330
2002 mean	0.628	0.505	0.759	0.618	0.513	0.460	0.466
2003 mean	0.661	0.542	0.793	0.589	0.588	0.433	0.413
2004 mean	0.569	0.485	0.710	0.536	0.552	0.453	0.390
2005 mean	0.610	0.423	0.720	0.467	0.474	0.399	0.382
mean	0.619	0.481	0.745	0.551	0.526	0.430	0.408
s.d. all data	0.105	0.113	0.147	0.117	0.125	0.112	0.086
N	28	28	29	29	57	55	57
model min	0.386	0.333	0.457	0.385	0.335	0.316	0.310
model max	0.695	0.616	0.749	0.670	0.584	0.514	0.442
model average	0.524	0.451	0.609	0.526	0.454	0.389	0.349

Appendix B: Summarizes the present septic system loads, and the loading reductions that would be necessary to achieve the TMDL by reducing septic system loads, ignoring all other sources.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Centerville River estuary system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Centerville River East	45.929	9.184	-80.0%
Scudder Bay	11.619	11.619	+0.0%
Centerville River West	7.704	7.704	+0.0%
East Bay	6.301	6.301	+0.0%
Surface Water Sources			
Pine Street Stream	2.512	2.512	+0.0%
Lake Elizabeth Stream	1.836	1.836	+0.0%
Bumps River	14.321	14.321	+0.0%
Skunknett River	17.337	17.337	+0.0%

Appendix C

The Centerville River - East Bay embayment system estimated wasteload allocation (WLA) from runoff of all impervious areas within 200 feet of waterbodies.

Subwatershed Name	Impervious Subwatershed buffer areas[1]		Total Subwatershed Impervious areas		Total Impervious Subwatershed load	Total Subwatershed load	Impervious Subwatershed buffer area WLA	
	Acres	%	Acres	%	Kg/year	Kg/year	Kg/year[2]	%[3]
Centerville River East	13.7	10.7	351.8	17.0	2006	22466	78.1	0.3
Centerville River West	9.1	9.4	36.3	10.1	180	3454	45.1	1.3
Scudder Bay	23.6	7.6	381.4	13.3	1577	19208	97.6	0.5
East Bay	5.2	9.1	41.5	12.8	210	3149	26.3	0.8
Total	51.6	8.7	811.0	14.4	3972	48277	252.7	0.5

[1]The entire impervious area within a 200 foot buffer zone around all waterbodies as calculated from GIS. Due to the soils and geology of Cape Cod it is unlikely that runoff would be channeled as a point source directly to a waterbody from areas more than 200 feet away. Some impervious areas within approximately 200 feet of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of the wasteload allocation (WLA) it was assumed that all impervious surfaces within 200 feet of the shoreline discharge directly to the waterbody.

[2]The impervious subwatershed buffer area (acres) divided by total subwatershed impervious area (acres) then multiplied by total impervious subwatershed load (kg/year).

[3]The impervious subwatershed buffer area WLA (kg/yr) divided by the total subwatershed load (kg/yr) multiplied by 100.

Appendix D
3 Total Nitrogen TMDL, 1 Pollution Prevention TMDL

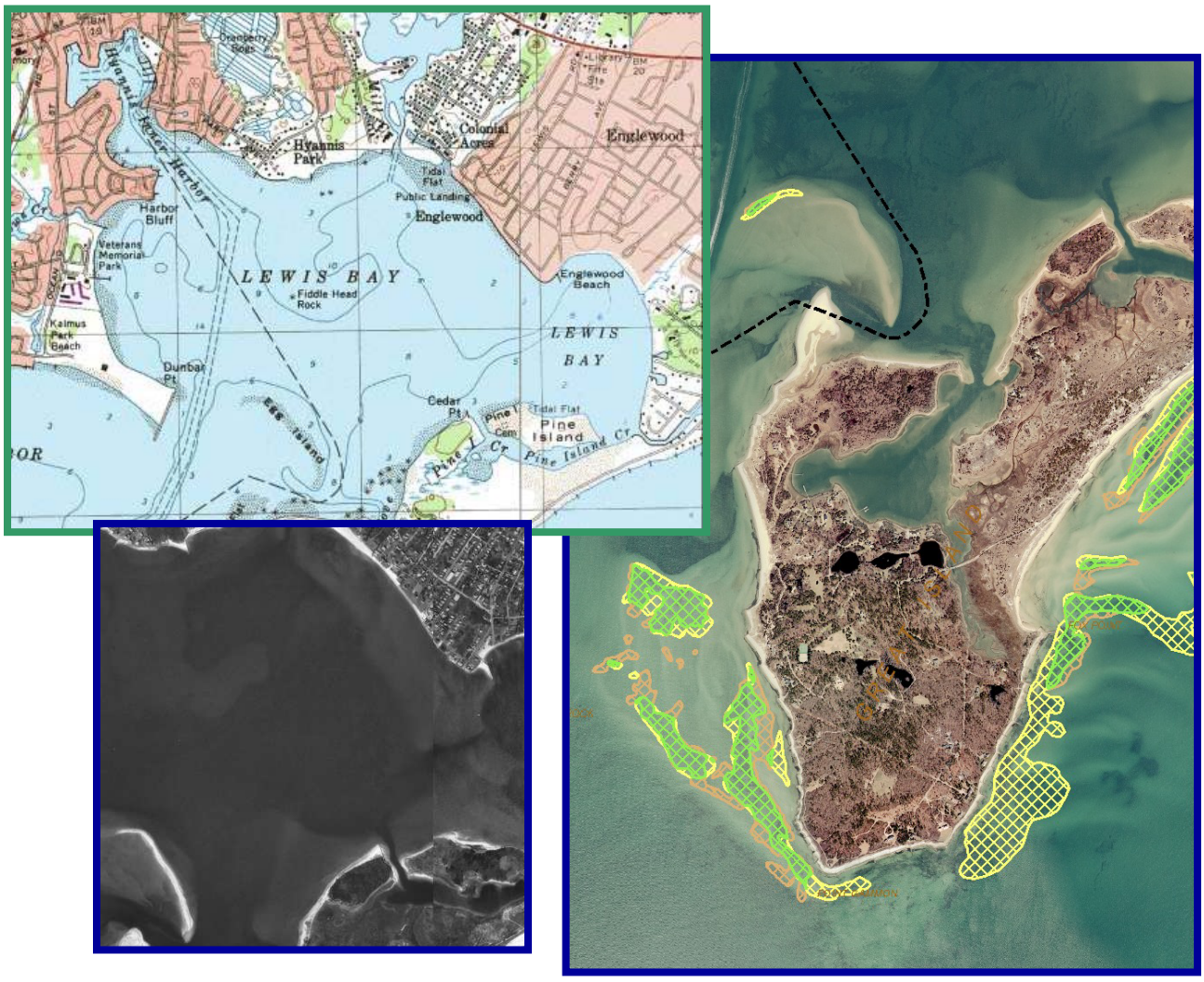
Sub-Embayment	Segment ID	Description	TMDL (kg/day)
Centerville River	MA96-04_2006	Previously determined to be impaired for pathogens by MassDEP. Determined to be impaired for nutrients during the development of this TMDL.	43
East Bay		Restorative TMDL (impaired by total nitrogen) for Eel grass	22
Scudder Bay		Restorative TMDL (impaired by total nitrogen, but never supported eel grass) for Benthic Fauna Habitat. Secondary nitrogen threshold limit applies for TMDL restoration.	53
Bumps River	MA96-02_2006	Previously determined to be impaired for pathogens by MassDEP. Not impaired for total nitrogen but embayments are linked (Pollution Prevention TMDL).	

Appendix AA

MEP Technical Report for Lewis Bay (and Halls Creek); MEP, December 2008

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Lewis Bay Embayment System, Barnstable/Yarmouth, MA



University of Massachusetts Dartmouth
School of Marine Science and Technology

Massachusetts Department of Environmental Protection

FINAL REPORT – December 2008

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Lewis Bay Embayment System, Barnstable/Yarmouth, MA

FINAL REPORT – December 2008

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First and foremost we would like to recognize and applaud the significant time and effort in data collection and discussion spent by members of the Town of Barnstable Water Quality Monitoring Program, the Town of Yarmouth Water Quality Monitoring Program, the Three Bays Water Quality Monitoring Program, the Lewis Bay Research Center and SMAST "volunteers". The Monitoring of the Lewis Bay System was truely a coordinated joint effort between these Towns, their citizens and staff. These individuals gave of their time to collect nutrient related water quality from this system, without which the present analysis would not have been possible. Of particular note are Lindsey Counsell of Three Bays Preservation, Coordinator of the Three Bays Monitoring Program, and John Jacobsen and Dale Saad of the Town of Barnstable, Coordinators of the Barnstable Town-wide Monitoring Program; Karl von Honne and Conrad Caia, Coordinators of the Yarmouth Town-wide Monitoring Program. Similarly, many in the Town of Barnstable helped in this effort, the Barnstable Department of Public Works and the Barnstable Shellfish Department, as well as the Barnstable Nutrient Management Committee; many in the Town of Yarmouth, but particularly the Nutrient Management Group and the Department of Public Works. The technical team would like to specifically acknowledge the efforts of Mark Els and George Allaire for helping to move this effort forward from its inception and to Three Bays Preservation for their energy and perseverance in the stewardship of one of the regions key coastal resources.

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I. INTRODUCTION

The Lewis Bay Embayment System is a complex estuary located within the Towns of Barnstable and Yarmouth on Cape Cod, Massachusetts with a southern shore bounded by water from Nantucket Sound (Figure I -1 and I-2). The estuary is composed of a lagoon formed behind a barrier spit (Dunbar Point) and bounded to the south by Smiths Point on Great Island. Lewis Bay is comprised of a number of sub-embayments tributary to the main basin such as Hyannis Inner Harbor, Mill Creek, and Uncle Roberts Cove. Just seaward of Dunbar Point which defines the entrance to the main basin of Lewis Bay is an area of previously open water that is currently sheltered by a constructed breakwater thereby defining what is commonly referred to as Hyannis Harbor into which discharges Stewarts Creek.

The Lewis Bay watershed is also distributed only between the Town of Barnstable and the Town of Yarmouth. A large portion of the overall watershed includes the sub-watersheds contributing direct groundwater discharge to the estuary and contributing to the five surface water discharges flowing to the Hyannis Harbor portion of the system (Stewarts Creek), directly into Lewis Bay (Snows Creek, Creek from Hospital Bog) or into the salt marsh basin of Mill Creek (stream from Mill Pond and Chase Brook). Although land-uses closest to an embayment generally have greater impact than those in the upper portions of the watershed, which are subject to nitrogen attenuation during transport through natural aquatic systems (e.g. ponds, rivers, wetlands etc.) prior to discharge to the embayment, effective restoration of the Lewis Bay System, will require the Towns to be active in nutrient management throughout the watershed to the overall system.

The number of sub-embayments (Hyannis Inner Harbor, Mill Creek, and Uncle Roberts Cove) to the Lewis Bay System greatly increases the shoreline and decreases the travel time of groundwater (and its pollutants) from the watershed recharge areas to bay regions of discharge. The nature of enclosed embayments in populous regions brings two opposing elements to bear: as protected marine shoreline they are popular regions for boating, recreation, and land development; as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the Lewis Bay system and its sub-embayments along the Barnstable and Yarmouth shores are at risk of eutrophication (over enrichment) from high nitrogen loads in the groundwater and runoff from the associated watersheds.

The Lewis Bay embayment system is a complex estuary with one inlet connecting the main basin to Nantucket Sound through the artificial basin of Hyannis Harbor. The Lewis Bay Embayment System consists primarily of the large main lagoonal basin of Lewis Bay with three tributary sub-embayments (Figure I-1 and Figure I-2). Lewis Bay terminates on its northern shore in two distinctly different aquatic environments, one being a salt marsh system commonly referred to as Mill Creek, the other being Hyannis Inner Harbor which services marinas, boatyards, restaurants and an active ferry terminal. The third sub-embayment is located on the barrier spit, Uncle Roberts Cove. Lewis Bay abuts Nantucket Sound and is bounded to the west by Kalmus Park Beach in the vicinity of the inlet to the estuary and Smiths Point located along the most eastern boundary of the entrance to Lewis Bay on Grand Island. The Lewis Bay Estuary receives twice daily tidal waters from Nantucket Sound. The inlet to Lewis Bay is a feature that prior to being armored, very likely migrated along the beach as a function of longshore transport of sediments and coastal storms effectively impinging on the waters of the



Figure I-1. Study area for the Massachusetts Estuaries Project analysis of the Lewis Bay Embayment System. Tidal waters enter to the main basin of Lewis Bay through a single large inlet from Nantucket Sound. Freshwaters enter from the watershed primarily through direct groundwater discharge and 4 surface water discharges (Snows Creek, a creek from Hospital Bog, a stream from Mill Pond and Chase Brook) and discharge through the Stewarts Creek Salt Marsh adjacent the outer basin, Hyannis Harbor.

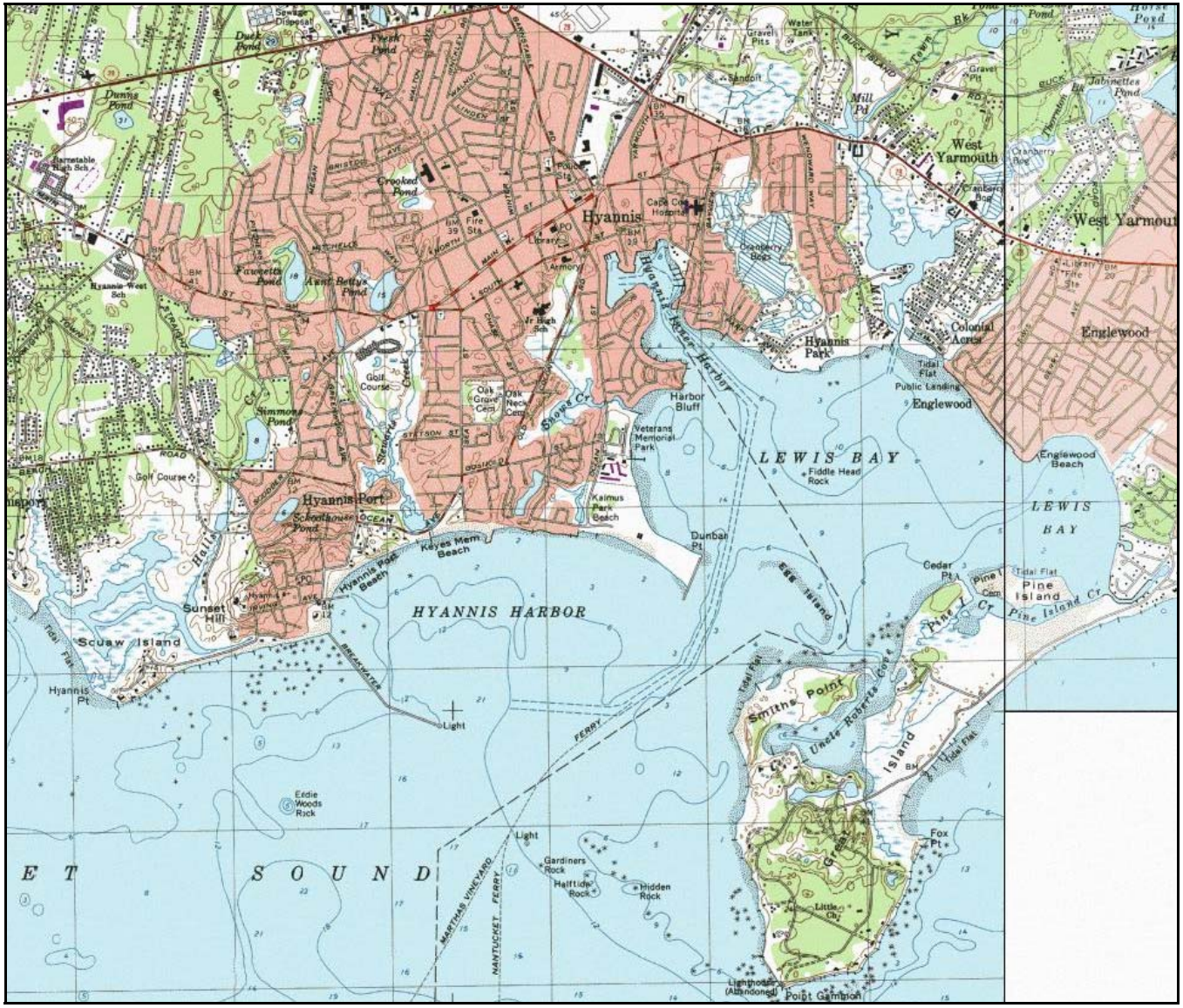


Figure I-2. Topographic Map of the Lewis Bay System depicting major geographic features. Note the barrier spit that joined Great Island to the mainland and created Lewis Bay.

inlet. Even as an armored feature, the inlet to Lewis Bay is characterized by shifting sand shoals (Egg Island), which must be periodically dredged to maintain navigability of the channel in and out of the system. Currently, the armored inlet is stable and the Town of Barnstable periodically dredges the inlet channel to keep the inlet and Hyannis Harbor-Lewis Bay navigable.

The present Lewis Bay system results from tidal flooding of small drowned river valleys formed primarily by the streams discharging into Stewarts Creek, Snows Creek and Mill Creek and the formation of the Lewis Bay lagoon by coastal processes. Drowning of the river valleys occurred gradually as a result of rising sea level following the last glaciation approximately 18,000 years BP. The extension of the barrier spit, is much more recent.

The primary ecological threat to the Lewis Bay System as a coastal resource is degradation resulting from nutrient enrichment. Although the significantly enclosed portions of the Lewis Bay estuarine system (Stewarts Creek, Snows Creek, Hyannis Inner Harbor, Mill Creek, Uncle Roberts Cove) have varying and periodic levels of bacterial contamination related to stormwater run-off from the watershed, these do not appear to be having large system-wide impacts. Bacterial contamination causes periodic closures of shellfish harvest areas within the Mill Creek (SC28.5) sub-embayment as well as portions of Hyannis Inner Harbor (SC28.2), Snows Creek (SC28.8) and the northeastern shore of Lewis Bay (SC28.7). In contrast, loading of the critical eutrophying nutrient, nitrogen, to the Lewis Bay System has greatly increased over recent decades with further increases certain unless nitrogen management is implemented. The nitrogen loading to the Lewis Bay Estuary, like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater.

The Towns of Barnstable and Yarmouth have been among the fastest growing towns in the Commonwealth over the past two decades. Hyannis is predominantly on municipal sewers in the dense downtown areas which flow to the Barnstable Wastewater Treatment Facility, with treated effluent discharged within the Lewis Bay, Hyannis Harbor (Stewarts Creek) and Halls Creek sub-watersheds. Even so, the vast majority of the Lewis Bay System watershed is not connected to any municipal sewerage system and wastewater treatment and disposal is primarily based on privately maintained septic systems. As existing and future increased levels of nutrients impact the coastal systems of Barnstable and Yarmouth, water quality degradation will accelerate, with further harm to invaluable environmental resources.

As the primary stakeholder to the Lewis Bay System, the Towns of Barnstable and Yarmouth were among the first communities to become concerned over perceived degradation of the Bay's environments. The concern over declining habitat quality led directly to the establishment by both municipalities of comprehensive water quality monitoring programs aimed at determining the degree to which the waters of each Town might be impaired by nitrogen enrichment. The Towns of Barnstable and Yarmouth Water Quality Monitoring Programs coordinated efforts on the shared resource waters of Lewis Bay, with technical and analytical assistance provided by the Coastal Systems Program at SMAST-UMD. This successful joint effort provided the high quality quantitative water column nitrogen data (2001-2006) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study.

The common focus of the coordinated Barnstable-Yarmouth Water Quality Monitoring effort has been to gather site-specific data on the current nitrogen related water quality throughout the Lewis Bay System and determine its relationship to watershed nitrogen loads. This multi-year effort has provided the necessary baseline information required for determining

the link between upland loading, tidal flushing, and estuarine water quality. The MEP effort builds upon the Water Quality Monitoring Program, and considers as appropriate previous historical hydrodynamic analyses (conducted by ASA, Inc. for Tetra Tech EM, Inc.) and water quality analyses. The MEP approach includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for each major sub-embayment. These critical nitrogen targets and the link to specific ecological criteria form the basis for the nitrogen threshold limits necessary to complete wastewater planning and nitrogen management alternatives development needed by the Town of Barnstable and Yarmouth. While the completion of this complex multi-step process of rigorous scientific investigation to support watershed based nitrogen management has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, the results stem directly from the efforts of large number of Town staff and volunteers over many years, inclusive of members of the local non-governmental organization (NGO) Three Bays Preservation.

The modeling tools developed as part of this program provide the quantitative information necessary for the Towns of Barnstable and Yarmouth to develop and evaluate the most cost effective nitrogen management alternatives to restore this valuable coastal resource which is currently being degraded by nitrogen overloading. It is important to note that the Lewis Bay System has been significantly altered by human activities over the past ~100 years or more (see Section I.2, below). As a result, the present nitrogen "overloading" appears to result partly from alterations to the geomorphology and some of its buffering ecological systems. These alterations subsequently affect nitrogen loading and transport within the watershed and influence the degree to which nitrogen loads impact the estuary. Therefore, restoration of this system should focus on managing nitrogen through both management of nitrogen loading within the watershed and restoration/management of processes which serve to lessen the amount or impact of nitrogen entering the estuary.

I.1 THE MASSACHUSETTS ESTUARIES PROJECT APPROACH

Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The nutrients are primarily related to changes in watershed land-use associated with increasing population within the coastal zone over the past half century. Many of Massachusetts' embayments have nutrient levels that are approaching or are currently over this assimilative capacity, which begins to cause declines in their ecological health. The result is the loss of fisheries habitat, eelgrass beds, and a general disruption of benthic communities and the food chain which they support. At higher levels, nitrogen loading from surrounding watersheds causes aesthetic degradation and inhibits even recreational uses of coastal waters. In addition to nutrient related ecological declines, an increasing number of embayments are being closed to swimming, shellfishing and other activities as a result of bacterial contamination. While bacterial contamination does not generally degrade the habitat, it restricts human uses. However like nutrients, bacterial contamination is frequently related to changes in land-use as watersheds become more developed. The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities.

The primary nutrient causing the increasing impairment of the Commonwealth's coastal embayments is nitrogen and the primary sources of this nitrogen are wastewater disposal, fertilizers, and changes in the freshwater hydrology associated with development. At present there is a critical need for state-of-the-art approaches for evaluating and restoring nitrogen sensitive and impaired embayments. Within southeastern Massachusetts alone, almost all of

the municipalities are grappling with Comprehensive Wastewater Planning and/or environmental management issues related to the declining health of their estuaries, such is the present situation with the Towns of Barnstable and Yarmouth.

Municipalities are seeking guidance on the assessment of nitrogen sensitive embayments, as well as available options for meeting nitrogen goals and approaches for restoring impaired systems. Many of the communities have encountered problems with "first generation" watershed based approaches, which do not incorporate estuarine processes. The appropriate method must be quantitative and directly link watershed and embayment nitrogen conditions. This "Linked" Modeling approach must also be readily calibrated, validated, and implemented to support planning. Although it may be technically complex to implement, results must be understandable to the regulatory community, town officials, and the general public.

The Massachusetts Estuaries Project represents the next generation of watershed based nitrogen management approaches. The Massachusetts Department of Environmental Protection (MassDEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool for watershed-embayment management for communities throughout Southeastern Massachusetts.

The Massachusetts Estuary Project is founded upon science-based management. The Project is using a consistent, state-of-the-art approach throughout the region's coastal waters and providing technical expertise and guidance to the municipalities and regulatory agencies tasked with their management, protection, and restoration. The overall goal of the Massachusetts Estuaries Project is to provide the DEP and municipalities with technical guidance to support policies on nitrogen loading to embayments. In addition, the technical reports prepared for each embayment system will serve as the basis for the development of Total Maximum Daily Loads (TMDLs). Development of TMDLs is required pursuant to Section 303(d) of the Federal Clean Water Act. TMDLs must identify sources of the pollutant of concern (in this case nitrogen) from both point and non-point sources, the allowable load to meet the state water quality standards and then allocate that load to all sources taking into consideration a margin of safety, seasonal variations, and several other factors. In addition, each TMDL must contain an outline of an implementation plan. For this project, the DEP recognizes that there are likely to be multiple ways to achieve the desired goals, some of which are more cost effective than others and therefore, it is extremely important for each Town to further evaluate potential options suitable to their community. As such, DEP will likely be recommending that specific activities and timelines be further evaluated and developed by the Towns (sometimes jointly) through the Comprehensive Wastewater Management Planning process.

In appropriate estuaries, bacterial technical reports will be developed in support of a Cape Cod wide TMDL for bacterial contamination. As possible, these analyses of bacterial contamination will be conducted in concert with the nutrient effort (particularly if there is a 303d listing), as was the case for the Prince's Cove sub-embayment to the Three Bays system. Currently, the MEP (through SMAST) has not been tasked with a technical assessment of bacterial contamination in the Lewis Bay System for inclusion of this system into the Cape Cod wide bacterial TMDL that the MassDEP is in the process of producing.

The MEP nitrogen threshold analysis includes site-specific habitat assessments and watershed/embayment modeling approaches to develop and assess various nitrogen management alternatives for meeting selected nitrogen goals supportive of restoration/protection of embayment health.

The major MEP nitrogen management goals are to:

- provide technical analysis and supporting documentation to Towns as a basis for sound nutrient management decision making towards embayment restoration
- develop a coastal TMDL working group for coordination and rapid transfer of results,
- determine the nutrient sensitivity of each of the 89 embayments in Southeastern MA
- provide necessary data collection and analysis required for quantitative modeling,
- conduct quantitative TMDL analysis, outreach, and planning,
- keep each embayment's model "alive" to address future municipal needs.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. This approach represents the "next generation" of nitrogen management strategies. It fully links watershed inputs with embayment circulation and nitrogen characteristics. The Linked Model builds on and refines well accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied for watershed nitrogen management in approximately 30 embayments throughout southeastern Massachusetts. In these applications it has become clear that the Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options.

The Linked Watershed-Embayment Model when properly parameterized, calibrated and validated for a given embayment becomes a nitrogen management planning tool, which fully supports TMDL analysis. The Model facilitates the evaluation of nitrogen management alternatives relative to meeting water quality targets within a specific embayment. The Linked Watershed-Embayment Model also enables Towns to evaluate improvements in water quality relative to the associated cost. In addition, once a model is fully functional it can be "kept alive" and updated for continuing changes in land-use or embayment characteristics (at minimal cost). In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

Linked Watershed-Embayment Model Overview: The Model provides a quantitative approach for determining an embayment's: (1) nitrogen sensitivity, (2) nitrogen threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is both calibrated and fully field validated and unlike many approaches, accounts for nutrient sources,

attenuation, and recycling and variations in tidal hydrodynamics (Figure I-3). This methodology integrates a variety of field data and models, specifically:

- Water column Monitoring - multi-year embayment nutrient sampling
- Hydrodynamics -
  - embayment bathymetry
  - site specific tidal record
  - current records (in complex systems only)
  - hydrodynamic model
- Watershed Nitrogen Loading
  - watershed delineation
  - stream flow (Q) and nitrogen load
  - land-use analysis (GIS)
  - watershed N model
- Embayment TMDL - Synthesis
  - linked Watershed-Embayment N Model
  - salinity surveys (for linked model validation)
  - rate of N recycling within embayment
  - D.O record
  - Macrophyte survey
  - Infaunal survey

I.2 SITE DESCRIPTION

The Lewis Bay Embayment System exchanges tidal water with Nantucket Sound through one inlet at the southern end of the system demarcated by a barrier spit (Dunbar Point) and bounded to the south by Smiths Point on Great Island. The inlet connecting Lewis Bay to Hyannis Harbor on the seaward side of Dunbar Point is maintained by periodic dredging and is armored on the west side and remains in a "natural" un-stabilized state on the east side (Smiths Point). Nantucket Sound exhibits a moderate to low tide range, with a mean range of about 2.5 ft. Since the water elevation difference between Nantucket Sound and the Lewis Bay System is the primary driving force for tidal exchange, the local tide range naturally limits the volume of water flushed during a tidal cycle (note the tide range off Stage Harbor Chatham is ~4.5 ft, Wellfleet Harbor is ~10 ft).

Tidal damping (reduction in tidal amplitude) through an embayment can range from negligible, indicating "well-flushed" conditions, or show tidal attenuation caused by constricted channels and marsh plains, indicating a "restrictive" system, where tidal flow and the associated flushing are inhibited. Tidal data indicate only minimal tidal damping through the inlet into the Lewis Bay system. It appears that the tidal inlet is operating efficiently being that it is periodically dredged to maintain navigability. Within the Hyannis Inner Harbor, Mill Creek and Uncle Roberts Cove portion of the System, the tide propagates to the sub-embayments with negligible attenuation, consistent with generally well-flushed conditions throughout.

For the MEP analysis, the Lewis Bay Estuarine System has been partitioned into four general sub-embayment groups: the 1) Lewis Bay, 2) Hyannis Inner Harbor, 3) Mill Creek, and 4) Uncle Roberts Cove as depicted in Figure I-1. Hyannis Harbor with Stewarts Creek was examined as an outer basin as it effects the boundary waters of Nantucket Sound which flow through it to Lewis Bay.

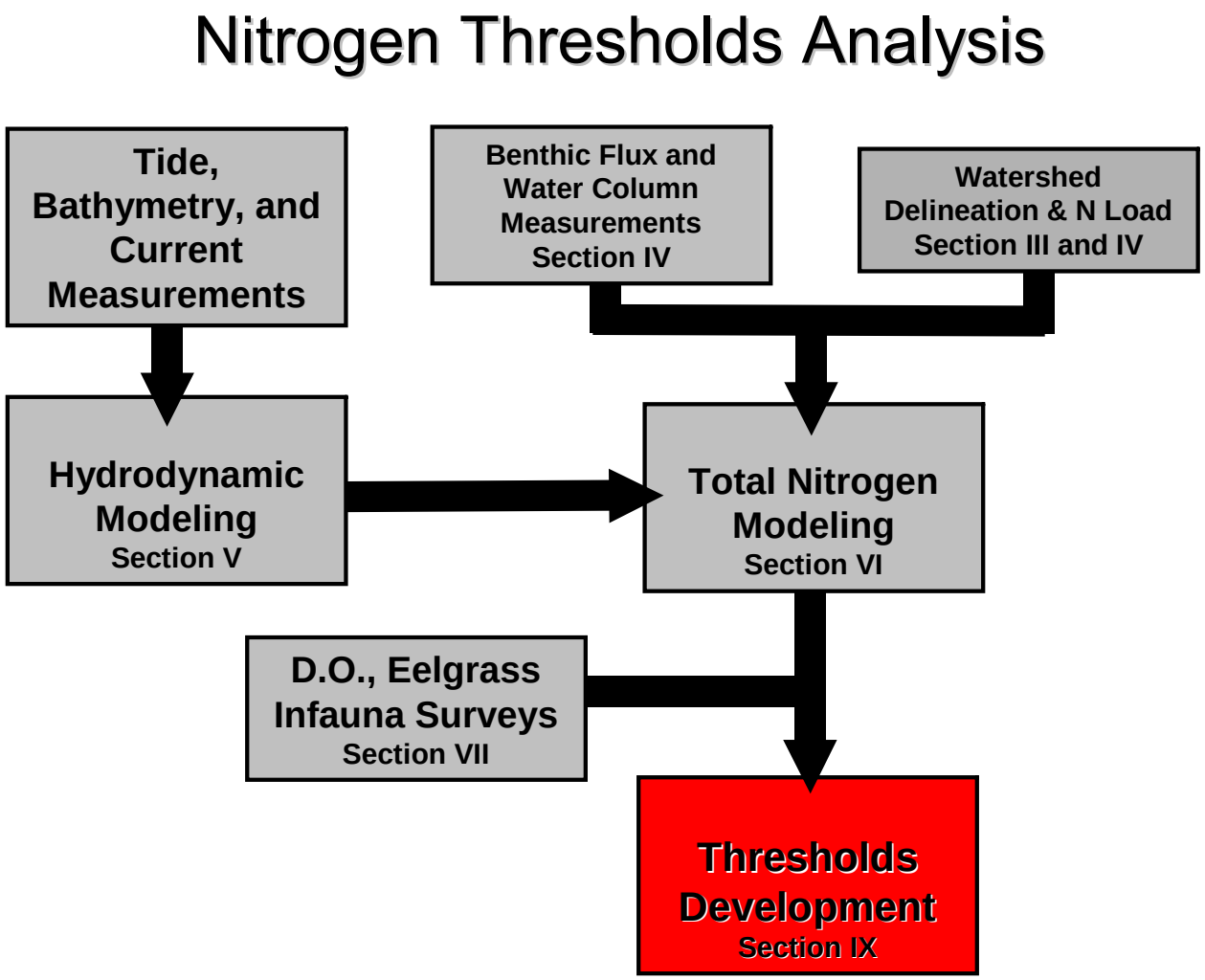


Figure I-3. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

The overall Lewis Bay System supports a diversity of estuarine habitats, including the main open water embayment basin of Lewis Bay, the salt marshes of Snow Creek and Mill Creek and the dredged harbor basin of Hyannis Inner Harbor. The Mill Creek basin functions primarily as a salt marsh "pond" of shallow depth with large bordering tidal marshes. Mill Creek is a moderately nutrient enriched sub-basin. However, as to the extent that it is functioning as primarily a salt marsh basin, it's level of impairment has been unclear. The present MEP analysis takes into account the much lower sensitivity of salt marshes to nutrient inputs compared to tidal embayments, so as to establish the proper nutrient threshold for restoration/protection of this estuarine system.

Most of the Lewis Bay System's salt marsh area is to the north and associated with Mill Creek with shallow tidal flats and large fluctuating salinity. In contrast, the main basin of Lewis Bay shows more typical embayment characteristics with a mixture of open water areas and channels, small fringing salt marshes and relatively stable salinity gradients.

I.3 NUTRIENT LOADING

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the Lewis Bay System, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even Cape Cod "rivers" are primarily groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1998, Weiskel and Howes 1992, Smith *et al.* 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within the Lewis Bay Estuary follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. This point can be termed the "nutrient threshold" and in estuarine management this threshold sets the target nutrient level for restoration or protection. Because nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 and in press, Ramsey et al., 1995, Howes and Taylor, 1990, and the Falmouth Coastal Overlay Bylaw). While each approach may be different, they all focus on changes in nitrogen loading from watershed to embayment, and aim at projecting the level of increase in nitrogen concentration within the receiving waters. Each approach depends upon estimates of circulation within the embayment; however, few directly link the watershed and hydrodynamic models, and virtually none include internal recycling of nitrogen (as was done in the present effort). However, determination of the "allowable N concentration increase" or "threshold nitrogen concentration" used in previous studies had a significant uncertainty due to the need for direct linkage of watershed and embayment models and site-specific data. In the present effort we have integrated site-specific data on nitrogen levels and the gradient in N concentration throughout the Lewis Bay System monitored by the Town of Barnstable and Yarmouth. Data from the Water Quality Monitoring Program combined with site-specific habitat quality data (D.O., eelgrass, phytoplankton blooms, benthic animals) was utilized to "tune" general nitrogen thresholds typically used by the Cape Cod Commission, Buzzards Bay Project, and Massachusetts State Regulatory Agencies.

Unfortunately, almost all of the estuarine reaches within the Lewis Bay System are presently beyond their ability to assimilate additional nutrients without impacting their ecological health (nitrogen related habitat impairment). Nitrogen levels are elevated throughout the System and eelgrass beds have been lost from this system for more than a decade. Nitrogen related habitat impairment within the Lewis Bay Estuary shows a gradient of high to low moving from the inland, less well flushed sub-basins, to the tidal inlet. The result is that nitrogen management of the Lewis Bay System is aimed at restoration, not protection or maintenance of existing conditions. In general, nutrient over-fertilization is termed "eutrophication" and in certain instances can occur naturally over long periods of time. When the nutrient loading is rapid and primarily from human activities leading to changes in a coastal watershed, nutrient enrichment of coastal waters is termed "cultural eutrophication". Although it is clear that human-induced changes have increased nitrogen loading to this estuary and contributed to the degradation of its resources, the MEP analysis also examined the level to which eutrophication within the Lewis Bay sub-embayments (e.g. Uncle Roberts Cove, Mill Creek, Snows Creek, Stewarts Creek, Halls Creek) could potentially result from natural processes. Both natural and human-induced changes to an estuary must be considered in the nutrient threshold analysis. While this finding would not change the need for restoration, it would change the approach and potential targets for management. As part of future restoration efforts, it is important to understand that it may not be possible to turn each embayment or sub-embayment into a "pristine" system.

I.4 WATER QUALITY MODELING

Evaluation of upland nitrogen loading provides important "boundary conditions" (e.g. watershed derived and offshore nutrient inputs) for water quality modeling of the Lewis Bay System; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within each component of the system. Therefore, water quality modeling of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal

hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. The spread of pollutants may be analyzed from tidal current information developed by the numerical models.

The MEP water quality evaluation examined the potential impacts of nitrogen loading into the Lewis Bay System, including the tributary sub-embayments of Snows Creek, Hyannis Inner Harbor, Mill Creek, and Uncle Roberts Cove. A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for each of the systems. Once the hydrodynamic properties of each estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates.

Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic models were then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis, based upon watershed delineations by USGS using a modification of the West Cape model for sub-watershed areas designated by MEP. Almost all watershed sourced nitrogen entering the Lewis Bay System is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Nantucket Sound source waters and throughout the Lewis Bay system were provided by the coordinated Town of Barnstable and Yarmouth Water Quality Monitoring Program. Measurements of the salinity and nitrogen distributions throughout estuarine waters of the Lewis Bay System (2001-2006) were used to calibrate and validate the water quality model (under existing loading conditions).

I.5 REPORT DESCRIPTION

This report presents the results generated from the implementation of the Massachusetts Estuaries Project linked watershed-embayment approach to the Lewis Bay System for the Towns of Barnstable and Yarmouth. A review of existing water quality studies is provided (Section II). The development of the watershed delineations and associated detailed land use analysis for watershed based nitrogen loading to the coastal system is described in Sections III and IV. In addition, nitrogen input parameters to the water quality model are described. Since benthic flux of nitrogen from bottom sediments is a critical (but often overlooked) component of nitrogen loading to shallow estuarine systems, determination of the site-specific magnitude of this component also was performed (Section IV). Nitrogen loads from the watershed and sub-watershed surrounding the estuary were derived from Cape Cod Commission data and offshore water column nitrogen values were derived from an analysis of monitoring stations in Nantucket Sound (Section IV). Intrinsic to the calibration and validation of the linked-watershed embayment modeling approach is the collection of background water quality monitoring data (conducted by municipalities) as discussed in Section IV. Results of hydrodynamic modeling of embayment circulation are discussed in Section V and nitrogen (water quality) modeling, as well as an analysis of how the measured nitrogen levels correlate to observed estuarine water quality are described in Section VI. This analysis includes modeling of current conditions, conditions at watershed build-out, and with removal of anthropogenic nitrogen sources. In addition, an ecological assessment of the component sub-embayments was performed that included a review of existing water quality information and the results of a benthic analysis (Section VII). The modeling and assessment information is synthesized and nitrogen threshold levels developed for restoration/protection of the Bay in Section VIII. Additional modeling is

conducted to produce an example of the type of watershed nitrogen reduction required to meet the determined system threshold for restoration or protection. This latter assessment represents only one of many solutions and is produced to assist the Towns in developing a variety of alternative nitrogen management options for this system. Finally, analyses of the Lewis Bay System were undertaken relative to potential alterations of circulation and flushing, including an analysis to identify hydrodynamic restrictions and an examination of dredging options to improve nitrogen related water quality. The results of the nitrogen modeling for each scenario have been presented in Section IX.

II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

Nutrient additions to aquatic systems cause shifts in a series of biological processes that can result in impaired nutrient related habitat quality. Effects include excessive plankton and macrophyte growth, which in turn lead to reduced water clarity, organic matter enrichment of waters and sediments with the concomitant increased rates of oxygen consumption and periodic depletion of dissolved oxygen, especially in bottom waters, and the limitation of the growth of desirable species such as eelgrass. Even without changes to water clarity and bottom water dissolved oxygen, the increased organic matter deposition to the sediments generally results in a decline in habitat quality for benthic infaunal communities (animals living in the sediments). This habitat change causes a shift in infaunal communities from high diversity deep burrowing forms (which include economically important species), to low diversity shallow dwelling organisms. This shift alone causes significant degradation of the resource and a loss of productivity to both the local shell fisherman and to the sport-fishery and offshore fin fishery, which are dependant upon these highly productive estuarine systems as a habitat and food resource during migration or during different phases of their life cycles. This process is generally termed “eutrophication” and in embayment systems, unlike in shallow lakes and pond, it is not a necessarily a part of the natural evolution of a system.

In most marine and estuarine systems, such as the Lewis Bay System, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if nitrogen addition is controlled, then eutrophication is controlled. This approach has been formalized through the development of tools for predicting nitrogen loads from watersheds and the concentrations of water column nitrogen that may result. Additional development of the approach generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2002).

These tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specifics for any given water body. The present Massachusetts Estuaries Project (MEP) study focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species. The linked watershed-embayment model is built using embayment specific measurements, thus enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including the Lewis Bay System. As the MEP approach requires substantial amounts of site specific data collection, part of the program is to review previous data collection and modeling efforts. These reviews are both for purposes of “data mining” and to gather additional information on an estuary’s habitat quality or unique features.

A number of studies relating to nitrogen loading, hydrodynamics and habitat health have been conducted within the Lewis Bay System over the past decade. A preliminary analysis of the circulation and nitrogen loading was performed, ca. 2001 for the Bureau of Resource Protection, Massachusetts Department of Environmental Protection (Tetra Tech EM Inc. 2005). The study was an initial assessment of watershed nitrogen loading to Lewis Bay (inclusive of Parker’s River and Swan Pond). The project employed an earlier generation watershed loading model (Waquoit Bay Nitrogen Loading Model, Valiela et. al., 1996), which pre-dates the MEP Linked Watershed-Embayment Modeling Approach. Loading was based upon a historical watershed derived by the Cape Cod Commission based upon available water table elevations. The watershed loading estimates were based upon MASSGIS land-use data, rather than local

municipal assessors data. No site specific nitrogen attenuation measurements were made relative to the surface freshwater systems within the Bay's watershed and approximations were used to determine the load from the Hyannis WWTF. The hydrodynamic modeling employed RMA Numerical Models, but collection of data against which the model performance could be assessed, was limited by the project's scope. For example, two tide gages were deployed for 29 days in the summer of 2001, one in upper Lewis Bay and the other in Mill Creek in order to calibrate the hydrodynamic model simulations, however the offshore driving tide was not measured.

Review of the results relative to the Lewis Bay system, brought forward a variety of issues, summarized below:

- This model is not calibrated nor validated relative to Total Nitrogen within the waters of the Lewis Bay System (i.e. modeled results were not compared to observation data).

- The watershed N model employed general nitrogen loading and attenuation factors and is not site specific (an occupancy rate of 1.79 people per house for each system compared to the 2000 Census data which lists Barnstable as having a rate of 2.44). No assessment of seasonal occupancy was made.

- As regards the WWTF nitrogen plume analysis:

    1. Total Nitrogen levels in discharged effluent estimates were based upon only inorganic forms (ammonium and nitrate), without inclusion of the organic fraction;

    2. Ratios of TN/Cl from 4 groundwater sampling wells at various distances from the discharge site were used to determine denitrification during transport using a linear regression approach, but the statistical analysis showed a very weak relationship, with the near regressions functionally based on a single point. The result suggested a 57% loss of nitrogen during aquifer transport, in spite of detailed wastewater plume studies by the USGS (Ashumet Valley Plume, Tri-Town Septage Facility in Orleans) and MEP (West Falmouth WWTF) showing negligible removal in Cape Cod soils;

    3. Much of the error in the WWTF TN load can be attributed to the assumption by the project team that the effluent discharge was ca. 28 mg N/L, rather than the 5 mg N/L measured by the facility as part of its discharge permit.

Given that this was a preliminary effort and did not use site-specific land-use or nitrogen attenuation factors, had limited data collection to support the hydrodynamic modeling and did not calibrate/validate the water quality model, and since the watershed delineation has been refined by the MEP and USGS using the West Cape groundwater model, the MassDEP has determined that the present MEP assessment and modeling effort should supersede its previous project and provides the sufficient accuracy for watershed nitrogen management planning, under the CWMP process.

An important ecological restoration effort within the Lewis Bay System has recently been initiated by the US Army Corps of Engineers in collaboration with the Town of Barnstable. The project is focused upon the restoration of the Stewarts Creek Salt Marsh, which is tidally restricted at its outlet to Hyannis Harbor (Stewarts Creek Restoration Project) Stewarts Creek is

a 55 acre tidal wetland site whose inlet has been restricted by a roadway/culvert. The salt marsh pond drains into Hyannis Harbor through a 60-foot-long, 3-foot diameter culvert, and the restriction has resulted in degradation of the salt marsh system. The major feature of the project includes the construction of a new, larger inlet to the pond to replace the existing culvert. Improving tidal flow is expected to restore the degraded salt marsh and riverine/ benthic habitat, including open water habitat. The restoration is scheduled to start in October of 2007 and be completed in 2008.

The Towns of Barnstable and Yarmouth, while both being actively engaged in the study and management of municipal infrastructure and natural resources, committed early on to gathering baseline water quality monitoring data in support of the MEP. Each Town operates a Water Quality Monitoring Program collecting water quality data on all of its embayment systems. The focus of the effort has been to gather site-specific data on the current nitrogen related water quality to support evaluations of observed water quality and habitat health. Water quality monitoring of the Lewis Bay System has been a joint coordinated effort initiated in 2001 with support from Three Bays Preservation and the Coastal Systems Programs at SMAST-UMD. The Barnstable/Yarmouth Water Quality Monitoring Program for Lewis Bay developed the baseline data from sampling stations distributed throughout the main basin and its tributaries (Figure II-1). Additionally, as remediation plans for this and other various systems are implemented throughout the Towns of Barnstable and Yarmouth, the continued monitoring is planned to provide quantitative information to the Towns relative to the efficacy of remediation efforts.

The joint Town of Barnstable/Yarmouth Water Quality Monitoring Program provided the quantitative water column nitrogen data (2001-2006) required for the implementation of the MEP's Linked Watershed-Embayment Approach. The MEP effort also builds upon previous watershed delineation and land-use analyses, the previous embayment hydrodynamic and water quality modeling and historical eelgrass surveys. This information is integrated with MEP higher order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for the Lewis Bay Estuarine System. The MEP has incorporated all appropriate data from all previous studies to enhance the determination of nitrogen thresholds for the Lewis Bay System and to reduce costs to the Towns of Barnstable and Yarmouth.

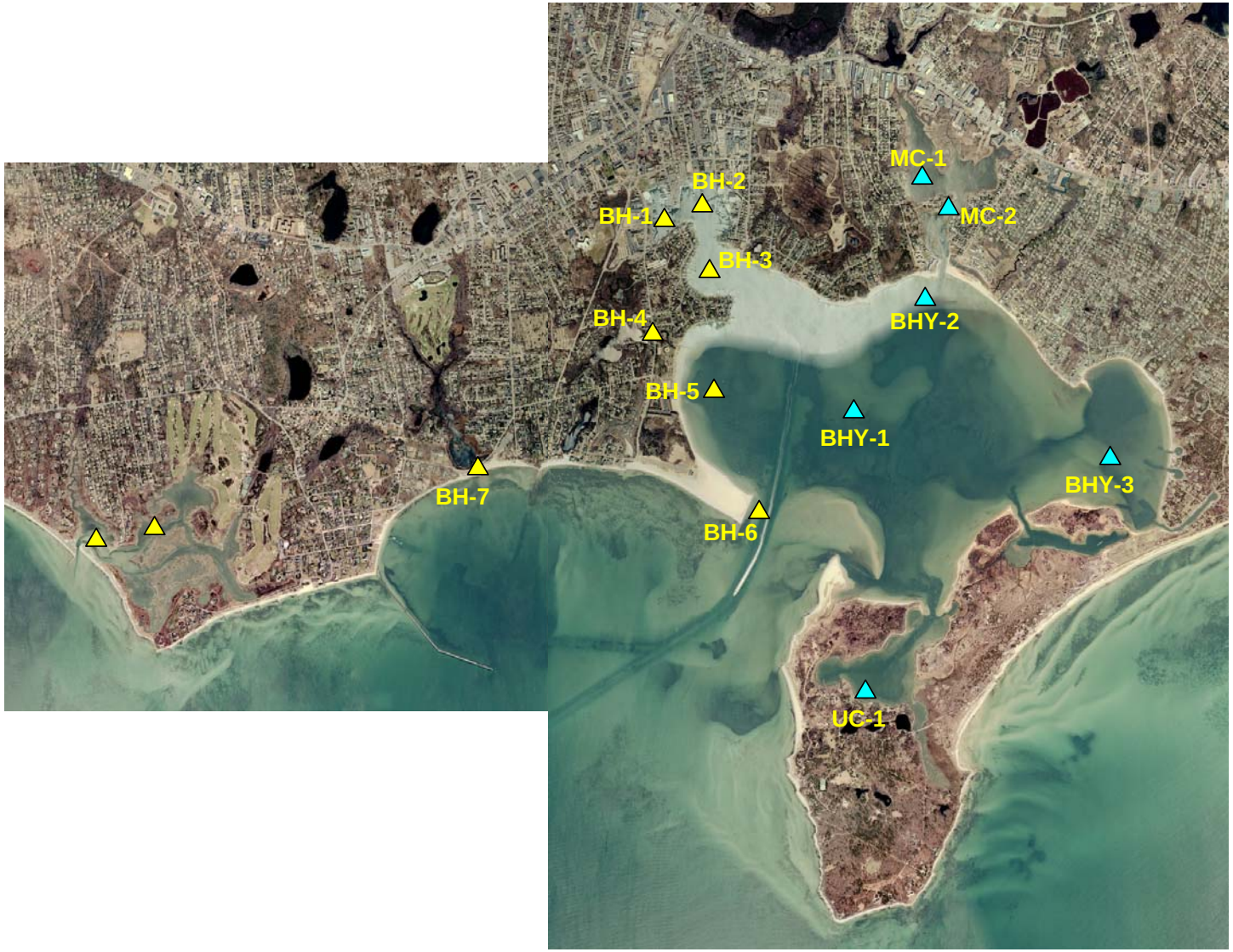


Figure II-1. Town of Barnstable/Yarmouth Water Quality Monitoring Program. Estuarine water quality monitoring stations sampled by the Town and volunteers. Stream water quality stations sampled weekly by the MEP. Halls Creek along the eastern shore of Centerville Harbor will be assessed in a future MEP Technical Report on the Lewis Bay System.

III. DELINEATION OF WATERSHEDS

III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). These USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. The USGS has a long history of developing regional models for the six-groundwater flow cells on Cape Cod. Through the years, advances in computing, lithologic information from well installations, water level monitoring, stream flow measurements, and reconstruction of glacial history have allowed the USGS to update and refine the groundwater models. The MODFLOW and MODPATH models utilized by the USGS organize and analyze the available data using up-to-date mathematical codes and create better tools to answer the wide variety of questions related to watershed delineation, surface water/groundwater interaction, groundwater travel time, and drinking water well impacts that have arisen during the MEP analysis of southeastern Massachusetts estuaries, including the Lewis Bay embayment system located in Barnstable, Massachusetts. The Lewis Bay watershed is situated along the southern edge of Cape Cod and is bounded by Vineyard/Nantucket Sound.

In the present investigation, the USGS was responsible for the application of its groundwater modeling approach to define the watershed or contributing area to the Lewis Bay embayment system under evaluation by the Project Team. The Lewis Bay estuarine system is a moderately complex estuary and includes wetland dominated portions at its northern edge. Further watershed modeling was undertaken to sub-divide the overall watershed to the Lewis Bay system into functional sub-units based upon: (a) defining inputs from contributing areas to each major portion within the embayment system, (b) defining contributing areas to major freshwater aquatic systems which generally attenuate nitrogen passing through them on the way to the estuary (lakes, streams, wetlands), and (c) defining 10 year time-of-travel distributions within each sub-watershed as a procedural check to gauge the potential mass of nitrogen from “new” development, which has not yet reached the receiving estuarine waters. The three-dimensional numerical model employed is also being used to evaluate the contributing areas to public water supply wells in the Sagamore flow cell on Cape Cod. Model assumptions for calibration were matched to surface water inputs and flows from MEP stream flow measurements (2003 to 2004).

The relatively transmissive sand and gravel deposits that comprise most of Cape Cod create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994a,b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the sources of nitrogen that they carry requires determination of the portion of the watershed that contributes directly to a stream and the portion of the groundwater system that discharge directly into an estuary as groundwater seepage.

III.2 MODEL DESCRIPTION

Contributing areas to the Lewis Bay system were delineated using a regional model of the Sagamore Lens flow cell (Walter and Whealan, 2005). The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh, *et al.*, 2000) was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program MODPATH4 (Pollock,

2000), which uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. This approach was used to determine the contributing areas to Lewis Bay system including sub-watersheds to Halls Creek, outer Lewis Bay (Hyannis Harbor), Stewarts Creek, Snows Creek, and Mill Creek and also to determine portions of recharged water that may flow through fresh water ponds and streams prior to discharging into coastal water bodies.

The Sagamore Flow Model grid consists of 246 rows, 365 columns and 20 layers. The horizontal model discretization, or grid spacing, is 400 by 400 feet. The top 17 layers of the model extend to a depth of 100 feet below NGVD 29 and have a uniform thickness of 10 ft. The top of layer 8 resides at NGVD 29 with layers 1-7 stacked above and layers 8-20 below. Layer 18 has a thickness of 40 feet and extends to 140 feet below NGVD 29, while layer 19 extends to 240 feet below NGVD 29. The bottom layer, layer 20, extends to the bedrock surface and has a variable thickness depending upon site characteristics (up to 519 feet below NGVD 29); since bedrock is 300 to 400 feet below NGVD 29 in the Lewis Bay area the two lowest model layers were active in this area of the model. The rewetting capabilities of MODFLOW-2000, which allows drying and rewetting of model cells, was used to simulate the top of the water table, which varies in elevation depending on the location in the Lens.

The glacial sediments that comprise the aquifer of the Sagamore Lens consist of gravel, sand, silt, and clay that were deposited in a variety of depositional environments. The sediments generally show a fining downward with sand and gravel deposits deposited in glaciofluvial (river) and near-shore glaciolacustrine (lake) environments underlain by fine sand, silt and clay deposited in deeper, lower-energy glaciolacustrine environments. Most groundwater flow in the aquifer occurs in shallower portions of the aquifer dominated by coarser-grained sand and gravel deposits. The Lewis Bay system watershed (including Snows and Stewarts Creeks) is generally split between the Barnstable Outwash Plain Deposits to the west and Harwich Outwash Plain Deposits to the east; the dividing line between the two deposits follows a line north from the northern portion of Mill Creek (Oldale, 1974a; Oldale, 1974b). The Halls Creek watershed is exclusively in the Barnstable Outwash Plain Deposits (Oldale, 1974a). Modeling and field measurements of contaminant transport at the MMR have shown that similar deposited materials are highly permeable (*e.g.*, Masterson, *et al*., 1996). Given their high permeability, direct rainwater run-off is typically rather low for this type of watershed system. Lithologic data used to determine hydraulic conductivities used in the groundwater model were obtained from a variety of sources including well logs from USGS, local Town records and data from previous investigations. Final aquifer parameters in the groundwater model were determined through calibration to observed water levels and stream flows. Hydrologic data used for model calibration included historic water-level data obtained from USGS records and local Towns and stream flow data collected in 1989-1990 as well as 2003.

The groundwater model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Large withdrawals of groundwater from pumping wells may have a significant influence on water tables and watershed boundaries and therefore the flow and distribution of nitrogen within the aquifer. After accounting for the consumptive loss and measured discharge at the Hyannis Water Pollution Control Facility (WPCF), water withdrawn from the modeled aquifer by public

drinking water supply wells is evenly returned within residential areas designated as using on-site septic systems.

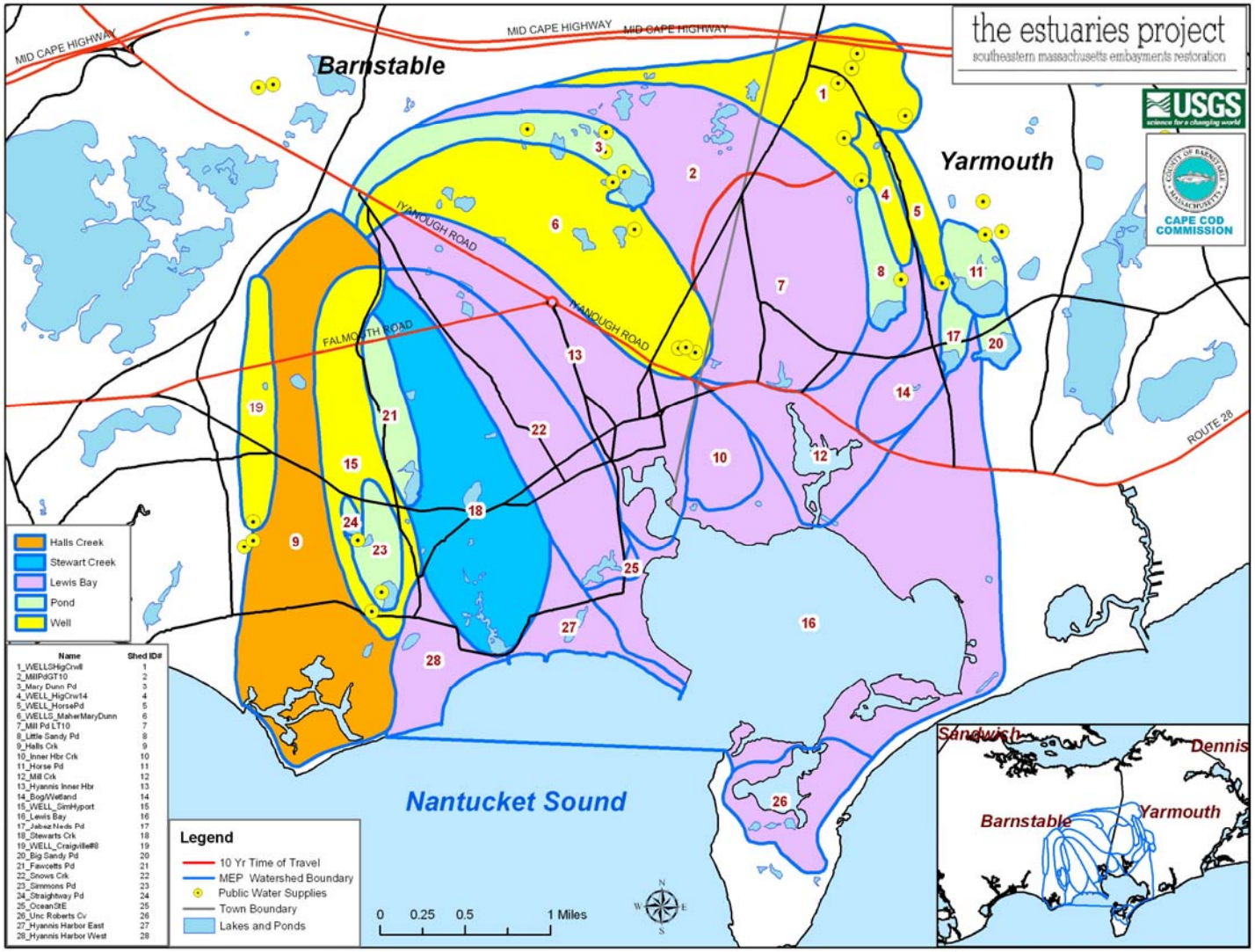
III.3 LEWIS BAY SYSTEM AND HALLS CREEK CONTRIBUTORY AREAS

Newly revised watershed and sub-watershed boundaries were determined by the United States Geological Survey (USGS) for the Lewis Bay embayment system, including the Mill Creek and Hyannis Inner Harbor sub-embayments, and Halls Creek estuary (Figure III-1). Model outputs of MEP watershed boundaries were "smoothed" to (a) correct for the grid spacing, (b) to enhance the accuracy of the characterization of the pond and coastal shorelines, (c) to include water table data in the lower regions of the watersheds near the coast (as available), and (d) to more closely match the sub-embayment segmentation of the tidal hydrodynamic model. The smoothing refinement was a collaborative effort between the USGS and the rest of the MEP Technical Team. The MEP sub-watershed delineation includes one 10 yr time of travel boundary. Overall, twenty-eight (28) sub-watershed areas, including eight freshwater ponds, were delineated within the Lewis Bay/Halls Creek study area.

Table III-1 provides the daily discharge volumes for various sub-watersheds as calculated from the groundwater model. These volumes were used to assist in the salinity calibration of the tidal hydrodynamic models and to determine hydrologic turnover in the lakes/ponds, as well as for comparison to measured surface water discharges. The overall estimated groundwater flow into the Lewis Bay system, including outer Lewis Bay and Stewarts Creek based on the MEP delineated watershed is 61,743 m3/d. The estimated groundwater flow into Hall Creek is 9,796 m3/d.

The delineations completed for the MEP project are the second watershed delineation completed in recent years for portions of the Lewis Bay system and Halls Creek. Figure III-2 compares the delineation completed under the current effort with the study area delineations completed by the Cape Cod Commission in 1998 as part of the Coastal Embayment Project (Eichner, *et al*., 1998). The delineation completed in 1998 was defined based on regional water table measurements collected from available wells over a number of years and normalized to average conditions. Delineations based on this previous effort were incorporated into the Commission's regulations through the Regional Policy Plan (CCC, 1996 & 2001).

The MEP watershed area for the Lewis Bay system as a whole is 9% larger (658 acres) than the 1995 CCC delineation. The differences are largely attributable to the inclusion of the outer Lewis Bay portion of the MEP delineation. The Halls Creek MEP watershed is 14% smaller than the 1995 CCC delineation; this is likely due to a better understanding of stream flow out of the Creek that were developed for the MEP (see Chapter IV). The MEP area calculations include corrections for portions of the pond and well sub-watersheds that discharge outside of the system, as well as accounting for differential flow from the Hyannis WPCF. Modeling completed by the USGS to assist the Wastewater Implementation Committee of Barnstable County helped the Town of Barnstable evaluate how much of the WPCF's flows are received by various ponds, public water supply wells, and estuary components in the study area. This effort was another benefit of the update of the regional groundwater model (Walter and Whealan, 2005). Interior sub-watersheds to individual freshwater ponds and public water supplies were not delineated in the CCC watersheds.



Name	Shed ID#
1_WELLSHigCrwll	1
2_MillPdGT10	2
3_Mary Dunn Pd	3
4_WELL_HigCrw14	4
5_WELL_HorsePd	5
6_WELLS_MaherMaryDunn	6
7_Mill Pd LT10	7
8_Little Sandy Pd	8
9_Halls Crk	9
10_Inner Hbr Crk	10
11_Horse Pd	11
12_Mill Crk	12
13_Hyannis Inner Hbr	13
14_BogWetland	14
15_WELL_SimHyport	15
16_Lewis Bay	16
17_Jabez Neds Pd	17
18_Stewarts Crk	18
19_WELL_Craigville#8	19
20_Big Sandy Pd	20
21_Fawcetts Pd	21
22_Snows Crk	22
23_Simmons Pd	23
24_Straightway Pd	24
25_OceanStE	25
26_Unc Roberts Cv	26
27_Hyannis Harbor East	27
28_Hyannis Harbor West	28

Figure III-1. Watershed and sub-watershed delineations for the Lewis Bay estuary system. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a "10" in the watershed names (above). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

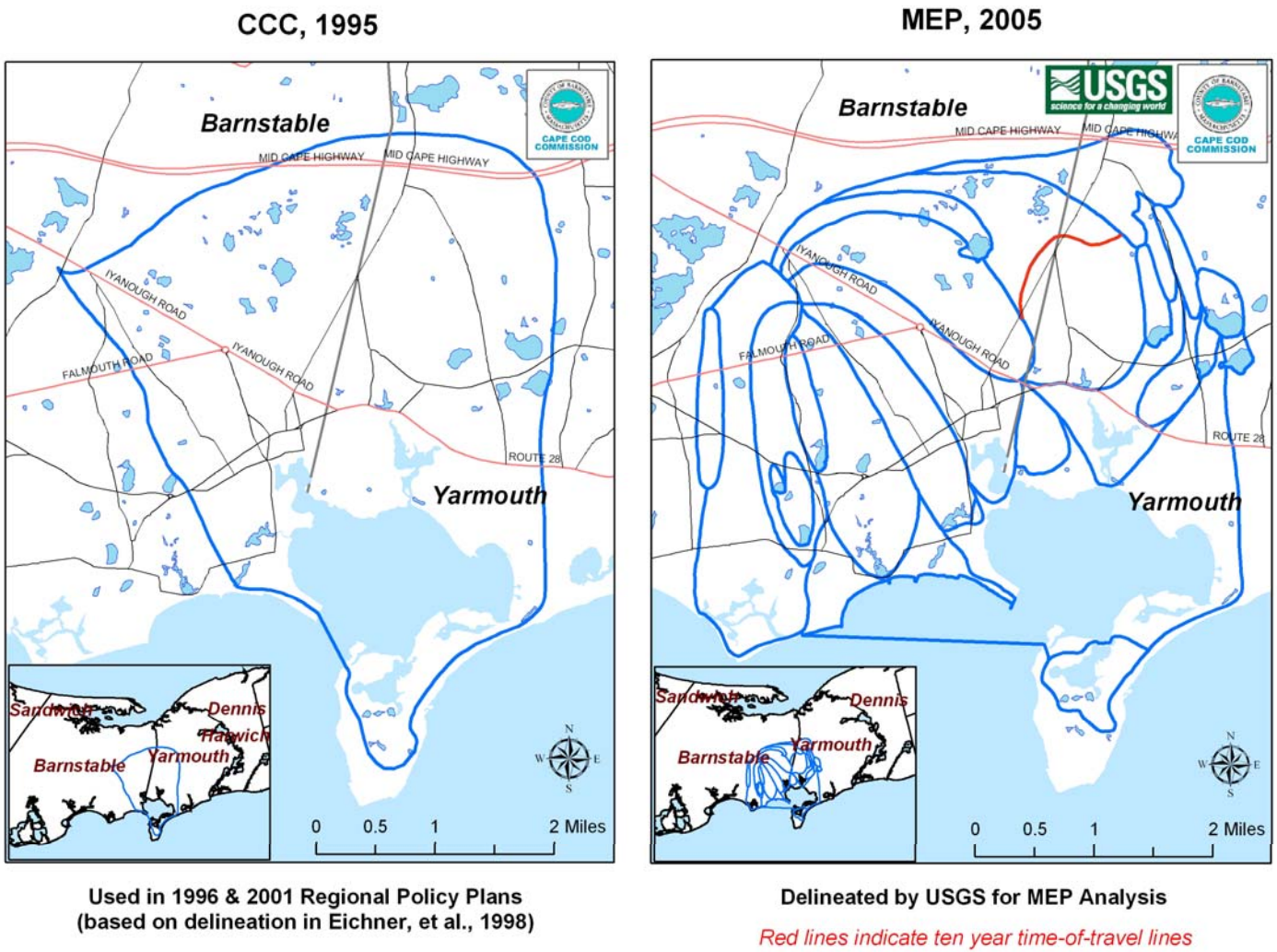


Figure III-2. Comparison of 1998 Cape Cod Commission and current Lewis Bay watershed and sub-watershed delineations.

Table III-1. Daily groundwater discharge to each of the sub-watersheds in the watershed to the Lewis Bay system estuary and Halls Creek estuary, as determined from the USGS groundwater model.

Watershed	#	Watershed Area (acres)	% contributing to Estuaries	Discharge	
				m^3/day	ft^3/day
WELLS_HigginsCrowell	1	455	49	1,698	59,972
Mill Pond GT10	2	511	100	3,920	138,443
Mary Dunn Pond	3	245	100	1,878	66,337
WELL_HigginsCrowell14	4	73	100	560	19,785
WELL_HorsePond	5	85	100	655	23,126
WELLS_MaherMaryDunn	6	801	100	6,144	216,973
Mill Pond LT10	7	693	100	5,322	187,934
Little Sandy Pond	8	89	100	686	24,210
Halls Creek	9	935	100	7,174	253,346
Inner Harbor Creek	10	147	100	1,126	39,762
Horse Pond	11	98	24	180	6,359
Mill Creek	12	359	100	2,752	97,189
Hyannis Inner Harbor	13	638	100	4,895	172,854
Bog/Wetland	14	148	100	1,137	40,139
WELL_SimmonsHyannisport	15	372	100	2,856	100,856
Lewis Bay	16	955	100	7,330	258,852
Jabez Neds Pond	17	44	100	334	11,805
Stewarts Creek	18	695	100	5,334	188,366
WELL_Craigville#8	19	84	50	324	11,444
Big Sandy Pond	20	40	27	83	2,938
Fawcetts Pond	21	127	100	977	34,501
Snows Creek	22	544	100	4,178	147,554
Simmons Pond	23	100	100	767	27,076
Straightway Pond	24	12	100	93	3,278
OceanStE	25	8	100	64	2,243
Uncle Roberts Cove	26	174	100	1,332	47,031
Hyannis Harbor East	27	141	100	1,121	39,584
Hyannis Harbor West	28	186	100	1,437	50,748
Hyannis WPC Facility*			100	6,435	227,257
TOTAL LEWIS BAY SYSTEM				61,743	2,180,432
TOTAL HALLS CREEK				9,796	345,931

*Hyannis Water Pollution Control Facility is assumed to discharge 1.7 million gallons per day based on average effluent discharge 2002-2006 (n=1,504)

Note: discharge volumes are based on 27.25 in of annual recharge over the watershed area; up-gradient ponds often discharge to numerous down-gradient sub-watersheds, percentage of outflow is determined by length of down-gradient shoreline going to each sub-watershed; totals may not exactly match columns sums due to apportionment of WPC facility flows. Measured flow at stream gage locations will not exactly match calculated whole watershed recharge values as ponds often sit on groundwater divides thereby splitting flows between different sub-watersheds.

The evolution of the watershed delineations for the Lewis Bay system and Halls Creek have allowed increasing accuracy as each new version adds new hydrologic data to that previously collected; the model allows all this data to be organized and to be brought into congruence with adjacent watersheds. The evaluation of older data and incorporation of new data during the development of the model is important as it decreases the level of uncertainty in the final calibrated and validated linked watershed-embayment model used for the evaluation of nitrogen management alternatives. Errors in watershed delineations do not necessarily result in proportional errors in nitrogen loading as errors in loading depend upon the land-uses that are included/excluded within the contributing areas. Small errors in watershed area can result in large errors in loading if a large source is counted in or out. Conversely, large errors in watershed area that involve only natural woodlands have little effect on nitrogen inputs to the down-gradient estuary. The MEP watershed delineation was used to develop the watershed nitrogen loads to each of the aquatic systems and ultimately to the estuarine waters of the Lewis Bay system and Halls Creek (Section IV.1).

IV. WATERSHED NITROGEN LOADING TO EMBAYMENT: LAND USE, STREAM INPUTS, AND SEDIMENT NITROGEN RECYCLING

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS

Management of nutrient related water quality and habitat health in coastal waters requires determination of the amount of nitrogen transported by freshwaters (surface water flow, groundwater flow) from the surrounding watershed to the receiving embayment of interest. In southeastern Massachusetts, the nutrient of management concern for estuarine systems is nitrogen and this is true for the Lewis Bay system and Halls Creek. Determination of watershed nitrogen inputs to these embayment systems requires the (a) identification and quantification of the nutrient sources and their loading rates to the land or aquifer, (b) confirmation that a groundwater transported load has reached the embayment at the time of analysis, and (c) quantification of nitrogen attenuation that can occur during travel through lakes, ponds, streams and marshes. This latter natural attenuation process results from biological processes that naturally occur within ecosystems. Failure to account for attenuation of nitrogen during transport results in an over-estimate of nitrogen inputs to an estuary and an underestimate of the sensitivity of a system to new inputs (or removals). In addition to the nitrogen transport from land to sea, the amount of direct atmospheric deposition on each embayment surface must be determined as well as the amount of nitrogen recycling within the embayment, specifically nitrogen regeneration from sediments. Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms, which may be released to the overlying waters or lost to denitrification within the sediments. Burial of nitrogen is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters or in some cases a sink for nitrogen reaching the bottom. Failure to include the nitrogen balance of estuarine sediments generally leads to errors in predicting water quality, particularly in determination of summertime nitrogen load to embayment waters.

The MEP Technical Team includes technical staff from the Cape Cod Commission (CCC). In coordination with other MEP Technical Team members, CCC staff developed nitrogen-loading rates (Section IV.1) to the Lewis Bay embayment system and the Halls Creek estuary (Section III). The Lewis Bay and Halls Creek watersheds were sub-divided to define contributing areas to each of the major inland freshwater systems and to each major sub-embayment to Lewis Bay and sub-estuary to Halls Creek. Further sub-divisions were made to identify watershed areas where a nitrogen discharge reaches embayment waters in less than 10 years or greater than 10 years, although these are somewhat limited in this system due to all the up gradient wells and freshwater ponds. A total of 28 sub-watersheds were delineated for the Lewis Bay/Halls Creek estuary study area. The nitrogen loading effort also involved further refinement of watershed delineations to accurately reflect shoreline areas to freshwater ponds and each embayment/estuary (see Chapter III).

The initial task in the MEP land use analysis is to gage whether or not nitrogen discharges to the watershed have reached the estuary. This involves a temporal review of land use changes, the time of groundwater travel provided by the USGS watershed model, and review of data at natural collection points, such as streams and ponds. Evaluation and delineation of ten-year time of travel zones are a regular part of the watershed analysis, but for the Lewis Bay/Halls Creek study area only one ten-year travel line was delineated. This is the result of numerous up gradient ponds and wells intercepting flow and these resources being within 10

years of travel; more refined modeling would be required to better ascertain flow times within this complicated system. In one specific watershed (Mill Pond), most of the existing development is below the ten-year travel line and most of the area beyond the ten-year travel line is protected open space for Yarmouth's public water supply wells. MEP staff also reviewed land use development records for the age of developed properties in the watershed. Based on all these reviews, it was determined that Lewis Bay and Halls Creek are currently in balance with their watershed load. This finding is consistent with other MEP analysis where ten-year travel lines have been more prevalent. The overall result of the timing of development relative to groundwater travel times is that the present watershed nitrogen load appears to accurately reflect the present nitrogen sources to the estuaries (after accounting for natural attenuation, see below).

In order to determine nitrogen loads from the watersheds, detailed individual lot-by-lot data is used for some portion of the loads, while information developed from other detailed studies is applied to other fractions of the watershed nutrient load. The Linked Watershed-Embayment Management Model (Howes and Ramsey, 2001) uses a land-use Nitrogen Loading Sub-Model based upon sub-watershed specific land uses and pre-determined nitrogen loading rates. For the Lewis Bay and Halls Creek estuary systems, the model used Town of Barnstable and Town of Yarmouth land-use data transformed to nitrogen loads using both regional nitrogen loading factors and local watershed specific data (such as parcel by parcel water use or groundwater monitoring wells). Determination of the nitrogen loads required obtaining watershed specific information regarding wastewater, fertilizers, runoff from impervious surfaces and atmospheric deposition. The primary regional factors were derived for southeastern Massachusetts from direct measurements. The resulting nitrogen loads represent the "potential" or unattenuated nitrogen load to each receiving embayment, since attenuation during transport has not yet been included.

Natural attenuation of nitrogen during transport from land-to-sea (Section IV.2) within the Lewis Bay System watershed was determined based upon a site-specific study of stream flow from Mill Pond, Stewarts Creek, Chase Brook, Snows Creek, and a small stream near Hyannis Inner Harbor. Halls Creek had a site-specific study of stream flow in a stream leading into the estuarine portion of the Creek. Sub-watersheds to these various portions allowed comparisons between field collected data from the streams and ponds and estimates from the nitrogen-loading sub-model. Attenuation through the ponds were conservatively assumed to equal 50% based on available monitoring of selected Cape Cod lakes; calculations for individual ponds were also determined. Stream flow and associated surface water attenuation is included in the MEP's nitrogen attenuation and freshwater flow investigation, presented in Section IV.2.

Natural attenuation during stream transport or in passage through fresh ponds of sufficient size to effect groundwater flow patterns (area and depth) is a standard part of the data collection effort of the MEP. In the present effort, measurements were made of attenuation in Mary Dunn Pond, Fawcetts Pond, Big Sandy Pond, Horse Pond, Jabez Neds Pond, Little Sandy Pond and in the stream complexes mentioned above. Simmons and Straightway Ponds have sub-watershed level land use data, but do not have water quality monitoring data, so nitrogen attenuation in these systems cannot be compared to site-specific data. However, if smaller aquatic features that have not been included in this MEP analysis were providing additional attenuation of nitrogen, nitrogen loading to the estuary would only be slightly (~10%) overestimated given the distribution of nitrogen sources within the watershed. Based upon these considerations, the MEP Technical Team used the Nitrogen Loading Sub-Model estimate

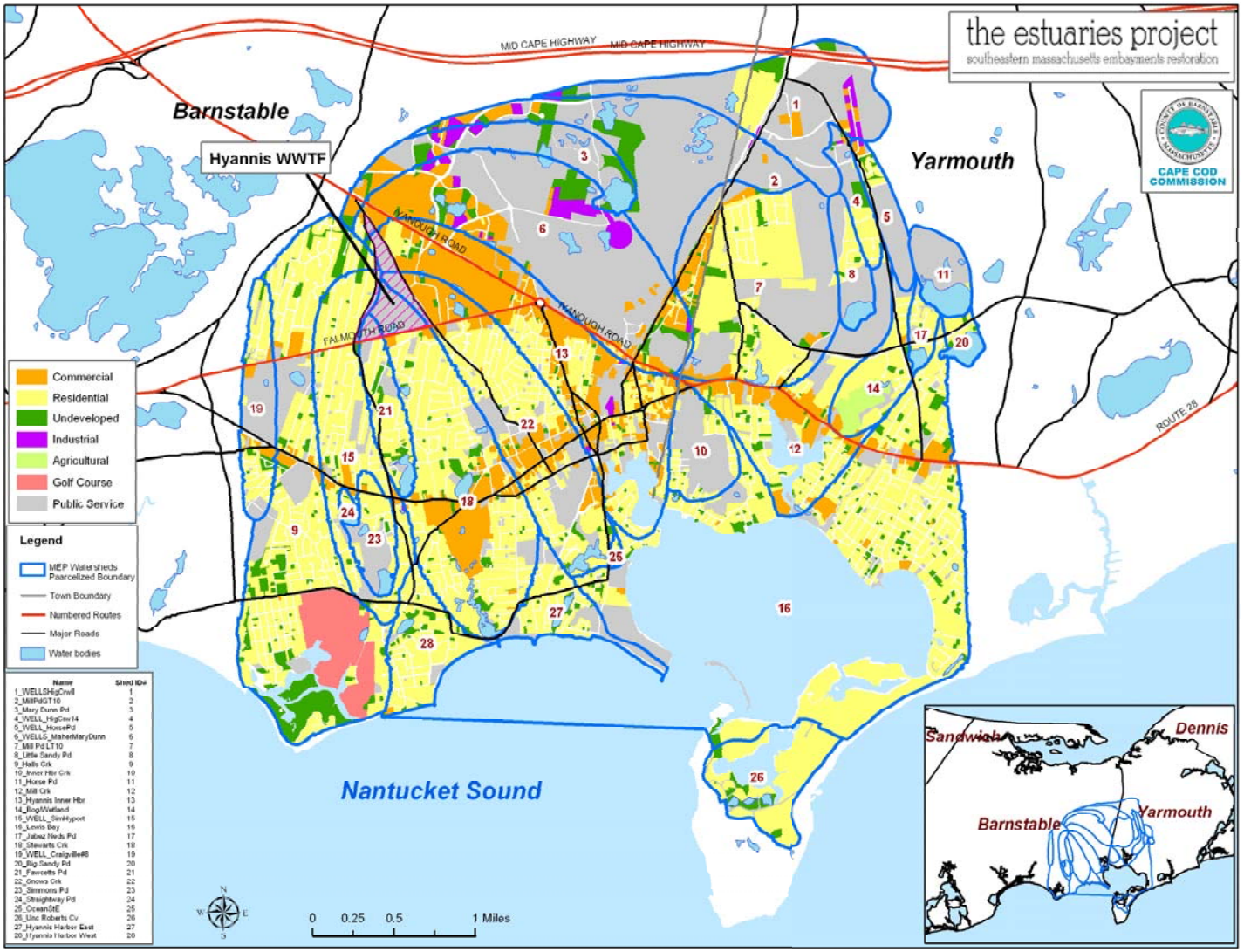


Figure IV-1. Land-use in the Lewis Bay and Halls Creek system watersheds. The Halls Creek system watershed is completely contained within the Town of Barnstable, while the Lewis Bay system watershed is split between the Town of Barnstable and the Town of Yarmouth. Land use classifications are based on assessors' records provided by the towns.

of nitrogen loading for the eight sub-watersheds that directly discharge groundwater to the estuary without flowing through one of these interim measuring points. Internal nitrogen recycling was also determined throughout the tidal reaches of the Lewis Bay and Halls Creek Estuarine Systems; measurements were made to capture the spatial distribution of sediment nitrogen regeneration from the sediments to the overlying water-column. Nitrogen regeneration focused on summer months, the critical nitrogen management interval and the focal season of the MEP approach and application of the Linked Watershed-Embayment Management Model (Section IV.3).

IV.1.1 Land Use and Water Use Database Preparation

Estuaries Project staff obtained Town of Barnstable digital parcel and tax assessors data from the town Geographic Information Systems Department and the Town of Yarmouth parcel and assessor data via the Town Department of Public Works. Digital parcels and land use/assessors data for both towns are from 2004. These land use databases contain traditional information regarding land use classifications (MADOR, 2002) plus additional information developed by the Towns. The parcel data and assessors' databases were combined for the MEP analysis by using the Cape Cod Commission Geographic Information System (GIS).

Figure IV-1 shows the land uses within the Lewis Bay and Halls Creek estuary watershed areas. Land uses in the study area are grouped into nine land use categories: 1) residential, 2) commercial, 3) industrial, 4) mixed use, 5) undeveloped, 6) agricultural, 7) golf course, 8) public service/government, including road rights-of-way, and 9) freshwater features (e.g. ponds and streams). These land use categories, except the freshwater features, are aggregations derived from the major categories in the Massachusetts Assessors land uses classifications (MADOR, 2002). These categories are common to each town in the watershed. “Public service” in the MADOR system is tax-exempt properties, including lands owned by government (e.g., wellfields, schools, golf courses, open space, roads) and private groups like churches and colleges.

In the overall Lewis Bay System watershed, the predominant land use based on area is public service/government, which accounts for 42% of the overall watershed area (Figure IV-2). Most of this area is due to the Hyannis Airport and the protected public water supply areas in both Barnstable and Yarmouth. In the individual sub-watersheds, public service/government land uses vary between 25 and 55% of the sub-watershed areas. Residential land uses are the second highest percentage (35%) of the Lewis Bay system watershed area and are the predominant parcel type in the watershed, accounting for 74% of the parcels in the system watershed. Single-family residences (MADOR land use code 101) are 84% of the residential parcels and single-family residences are 63% of the residential land area. In the individual sub-watersheds, residential land uses vary between 19 and 52% of the sub-watershed areas. After residential land use, commercial land use is the third highest percentage (12%) of the Lewis Bay system watershed area and occupies 37% of the Hyannis Inner Harbor sub-watershed. Undeveloped land uses are 8% of the system watershed.

In the overall Halls Creek System watershed, the predominant land use based on area is residential, which accounts for 52% of the overall watershed area (Figure IV-2). Residential land uses are also the predominant parcel type, accounting for 89% of the parcels in the watershed. Single-family residences (MADOR land use code 101) are 89% of the residential land area and 97% of the residential parcels. Public service/government land uses are the second highest percentage (25%) of the Halls Creek watershed area and developable and golf course are tied for third with 10% each. Commercial land uses are 2% of the watershed area.

In order to estimate wastewater flows within the Lewis Bay study area, the Cape Cod Commission obtained parcel-by-parcel water use information from the Towns of Barnstable and Yarmouth. The Barnstable water use data includes information from the Centerville, Osterville, Marstons Mills (COMM) Water District and the Town of Barnstable Water Supply Division (WSD). The Yarmouth water use data was provided by the Town of Yarmouth Department of Public Works. The water use data from both Barnstable water suppliers, as well as from Yarmouth, is from 2001 through 2005. The Town of Barnstable Department of Public Works also provided a listing of parcels that are connected to the municipal sewer system and the Hyannis Water Pollution Control Facility (WPCF), as well as effluent quantities and total nitrogen concentration data for January 2002 through November 2006. Three private wastewater treatment facilities also discharge within the Yarmouth portion of the watershed to Lewis Bay; effluent flow and total nitrogen data was supplied by MassDEP. Three alternative, denitrifying septic systems also discharge within the study area; the Barnstable County Department of Health and the Environment supplied effluent total nitrogen data for these systems. Wastewater-based nitrogen loading from the individual parcels using on-site septic systems is based upon the measured water-use, nitrogen concentration, and consumptive loss of water before the remainder is treated in a septic system (see Section IV.1.2).

IV.1.2 Nitrogen Loading Input Factors

Wastewater/Water Use

The Massachusetts Estuaries Project septic system nitrogen loading rate is fundamentally based upon a per Capita Nitrogen load to the receiving aquatic system. Specifically, the MEP septic system wastewater nitrogen loading is based upon a number of studies and additional information that directly measured septic system and per capita loads on Cape Cod or in similar geologic settings (Nelson et al. 1990, Weiskel & Howes 1991, 1992, Koppelman 1978, Frimpter et al. 1990, Brawley et al. 2000, Howes and Ramsey 2000, Costa et al. 2001). Variation in per capita nitrogen load has been found to be relatively small, with average annual per capita nitrogen loads generally between 1.9 to 2.3 kg person-yr^{-1}.

However, given the seasonal shifts in occupancy and rapid population growth throughout southeastern Massachusetts, decennial census data yields accurate estimates of total population only in selected watersheds. To correct for this uncertainty and more accurately assess current nitrogen loads, the MEP employs a water-use approach. The water-use approach is applied on a parcel-by-parcel basis within a watershed, where annual water meter data is linked to assessors parcel information using GIS techniques. The parcel specific water use data is converted to septic system nitrogen discharges (to the receiving aquatic systems) by adjusting for consumptive use (e.g. irrigation) and applying a wastewater nitrogen concentration. The water use approach focuses on the nitrogen load, which reaches the aquatic receptors down gradient in the aquifer.

All nitrogen losses within the septic system are incorporated into the MEP analysis. For example, information developed at the MASSDEP Alternative Septic System Test Center at the Massachusetts Military Reservation on Title 5 septic systems have shown nitrogen removals between 21% and 25%. Multi-year monitoring from the Test Center has revealed that nitrogen removal within the septic tank was small (1% to 3%), with most (20 to 22%) of the removal occurring within five feet of the soil adsorption system (Costa et al. 2001). Down gradient studies of septic system plumes indicate that further nitrogen loss during aquifer transport is negligible (Robertson et al. 1991, DeSimone and Howes 1996).

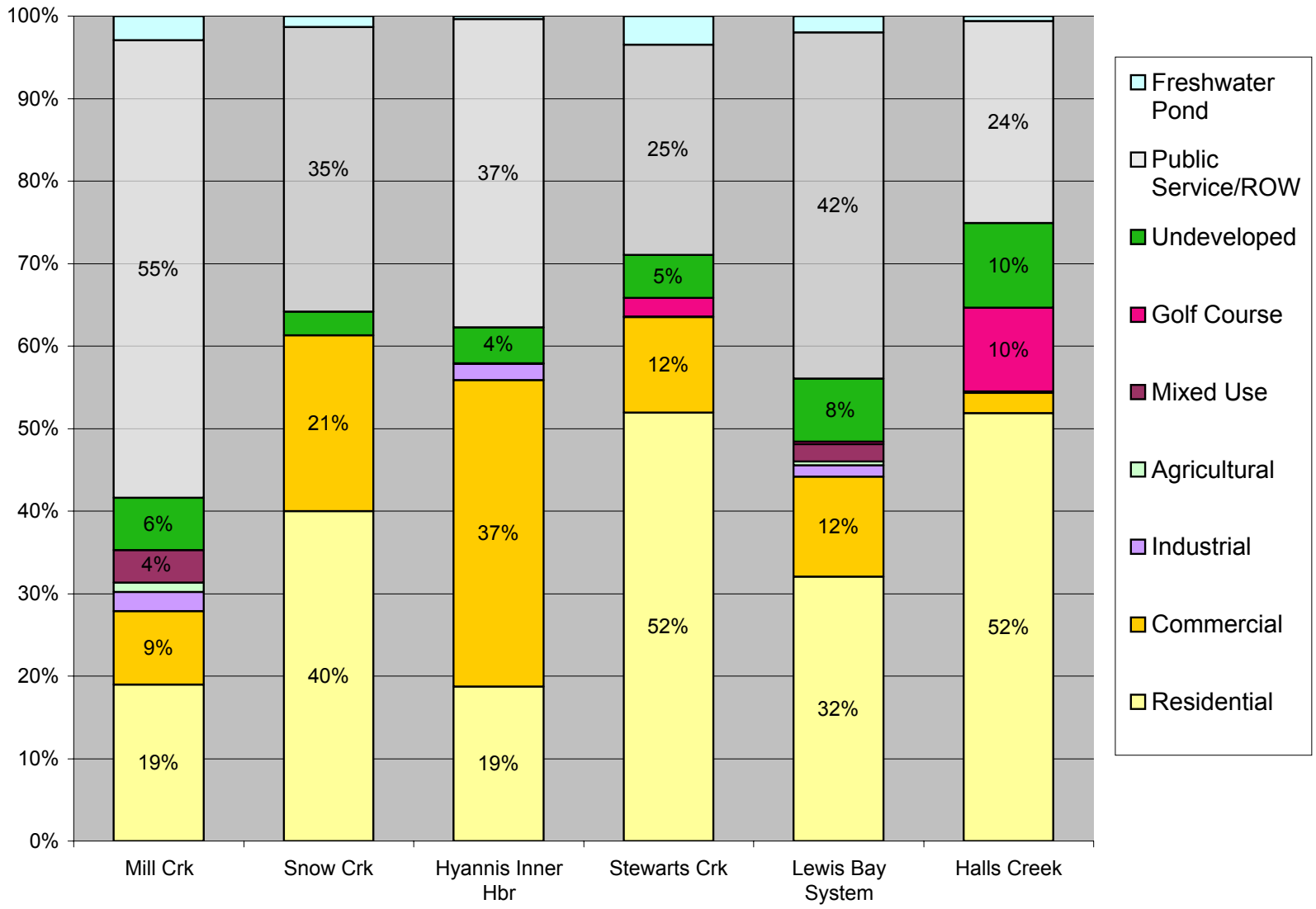


Figure IV-2. Distribution of land-uses within the major sub-watersheds and whole watershed to the Lewis Bay estuary system and the watershed to Halls Creek. Only percentages greater than or equal to 4% are shown.

In its application of the water-use approach to septic system nitrogen loads, the MEP has ascertained for the Estuaries Project region that while the per capita septic load is well constrained by direct studies, the consumptive use and nitrogen concentration data are less certain. As a result, the MEP has derived a combined term for an effective N Loading Coefficient (consumptive use times N concentration) of 23.63, to convert water (per volume) to nitrogen load (N mass). This coefficient uses a per capita nitrogen load of 2.1 kg N person-yr^{-1} and is based upon direct measurements and corrects for changes in concentration that result from per capita shifts in water-use (e.g. due to installing low plumbing fixtures or high versus low irrigation usage).

The nitrogen loads developed using this approach have been validated in a number of long and short term field studies where integrated measurements of nitrogen discharge from watersheds could be directly measured. Weiskel and Howes (1991, 1992) conducted a detailed watershed/stream tube study that monitored septic systems, leaching fields and the transport of the nitrogen in groundwater to adjacent Buttermilk Bay. This monitoring resulted in estimated annual per capita nitrogen loads of 2.17 kg (as published) to 2.04 kg (if new attenuation information is included). Modeled and measured nitrogen loads were determined for a small sub-watershed to Mashapaquit Creek in West Falmouth Harbor (Smith and Howes, manuscript in review) where measured nitrogen discharge from the aquifer was within 5% of the modeled N load. Another evaluation was conducted by surveying nitrogen discharge to the Mashpee River in reaches with swept sand channels and in winter when nitrogen attenuation is minimal. The modeled and observed loads showed a difference of less than 8%, easily attributable to the low rate of attenuation expected at that time of year in this type of ecological situation (Samimy and Howes, unpublished data).

While census based population data has limitations in the highly seasonal MEP region, part of the regular MEP analysis is to compare expected water used based on average residential occupancy to measured average water uses. This is performed as a quality assurance check to increase certainty in the final results. This comparison has shown that the larger the watershed the better the match between average water use and occupancy. For example, in the cases of the combined Great Pond, Green Pond and Bournes Pond watershed in the Town of Falmouth and the Popponesset Bay/Eastern Waquoit Bay watershed, which covers large areas and have significant year-round populations, the septic nitrogen loading based upon the census data is within 5% of that from the water use approach. This comparison matches some of the variability seen in census data itself. Census blocks, which are generally smaller areas of any given town, have shown up to a 13% difference in average occupancy form town-wide occupancy rates. These analyses provide additional support for the use of the water use approach in the MEP study region.

Overall, the MEP water use approach for determining septic system nitrogen loads has been both calibrated and validated in a variety of watershed settings. The approach: (a) is consistent with a suite of studies on per capita nitrogen loads from septic systems in sandy outwash aquifers; (b) has been validated in studies of the MEP Watershed “Module”, where there has been excellent agreement between the nitrogen load predicted and that observed in direct field measurements corrected to other MEP Nitrogen Loading Coefficients (e.g., stormwater, lawn fertilization); (c) the MEP septic nitrogen loading coefficient agrees in specific studies of consumptive water use and nitrogen attenuation between the septic tank and the discharge site; and (d) the watershed module provides estimates of nitrogen attenuation by freshwater systems that are consistent with a variety of ecological studies. It should be noted that while points b-d support the use of the MEP Septic N Coefficient, they were not used in its development. The MEP Technical Team has developed the septic system nitrogen load over

many years, and the general agreement among the number of supporting studies has greatly enhanced the certainty of this critical watershed nitrogen loading term.

The independent validation of the water quality model (Section VI) and the reasonableness of the freshwater attenuation (Section IV.2) add additional weight to the nitrogen loading coefficients used in the MEP analyses and a variety of other MEP embayments. While the MEP septic system nitrogen load is the best estimate possible, to the extent that it may underestimate the nitrogen load from this source reaching receiving waters provides a safety factor relative to other higher loads that are generally used in regulatory situations. The lower concentration results in slightly higher amounts of nitrogen mitigation (estimated at 1% to 5%)) needed to lower embayment nitrogen levels to a nitrogen target (e.g. nitrogen threshold, cf. Section VIII). The additional nitrogen removal is not proportional to the septic system nitrogen level, but is related to the how the septic system nitrogen mass compares to the nitrogen loads from all other sources that reach the estuary (i.e. attenuated loads).

In order to provide an independent validation of the average residential water use within the Lewis Bay System and Halls Creek watersheds, MEP staff reviewed US Census population values for the Towns of Barnstable and Yarmouth. The state on-site wastewater regulations (*i.e.*, 310 CMR 15, Title 5) assume that two people occupy each bedroom and each bedroom has a wastewater flow of 110 gallons per day (gpd), so for the purposes of Title 5 each person generates 55 gpd of wastewater. Based on data collected during the 2000 US Census, average occupancy within Barnstable is 2.44 people per housing unit, while year-round occupancy of available housing units is 78%. Average water use for single-family residences with municipal water accounts in the Lewis Bay/Halls Creek study area is 175 gpd. If this flow is multiplied by 0.9 to account for consumptive use, the watershed average is 158 gpd. If this flow is then divided by 55 gpd, the average estimated occupancy in the study area is 2.87 people per household.

In most previously completed MEP studies, average population and average water use have generally agreed fairly well. Since review of water use in the Lewis Bay/Halls Creek study area suggests that on average occupancy rates are higher, MEP staff reviewed more refined US Census information, 1990 Census information, and data from previous MEP reviews, and water use information for each parcel within the watershed. Besides reviewing data on town and state levels, the US Census also develops information for smaller areas (i.e., tracts and block groups). Portions of four Census tracts are contained within the watershed to Lewis Bay; year 2000 Census residential occupancy rates in the tracts range from 2.26 to 2.45 people per house. Average occupancy for these tracts reported for the 1990 Census range from 2.12 to 2.49 people per house. While these occupancies suggest that the area is given to a fairly wide range of readings, these occupancies are less than the occupancy expected based on water use.

MEP staff then reviewed the average water uses measured in the sub-watersheds of the Lewis Bay/Halls Creek study area. While the overall average for single-family residences (SFRs) is 175 gpd, averages in the sub-watersheds varied widely with a range between 119 and 246 gpd. Review of individual SFR water uses within sub-watershed ranged as high as 3,767 gpd, but even this use was consistent across five years of data. The standard deviation among all the watershed averages is 41 gpd; the population-based estimate of wastewater flow is within one standard deviation of the measured estimate of wastewater flow.

In addition to the above analyses, MEP staff encountered a similar situation with the Centerville River water use data (Howes, et al., 2006). In that analysis, which also involved Barnstable water use, a similar relationship of water use being seemingly too high for the 2000 Census population estimates was also encountered. In that case, further analysis by staff also found that the difference was larger than usually found but within a reasonable range, especially if a conservative factoring of summer population was added.

At the outset of the MEP, project staff decided to utilize the water use approach for determining residential wastewater generation by septic systems because of the inherent difficulty in accurately gauging actual occupancy in areas impacted by seasonal population fluctuations such as most of Cape Cod. Estimates of summer populations on Cape Cod derived from a number of approaches (*e.g.*, traffic counts, garbage generation, sewer use) suggest average population increases from two to three times year-round residential populations measured by the US Census. While land use characteristics in the Lewis Bay and Halls Creek sub-watersheds may be unlikely to see summer population increases at the upper end of regional estimates, a doubling of the watershed occupancy for four months would be sufficient to increase the average annual water use based on Title 5 to 171 gpd, which is approximately the same as the average measured flow in the watershed. The above analysis suggests that additional analysis of water uses within the Lewis Bay and Halls Creek watersheds should be considered, but review of the water uses on the parcel, Census tract, and watershed scales do not suggest that there are any consistent inaccuracies. Given all the above analysis and the difficulty in accurately gauging seasonal population fluctuations, MEP staff decided to continue to use the Lewis Bay and Halls Creek watershed-specific water uses without any additional factors. Additionally, the MEP used the average water use for the residential parcels without water use data and for the 851 additional residential parcels included in the buildout analysis that will not be connected to the Hyannis municipal sewer system.

Although water use information exists for 89% of the 8,085 developed parcels in the Lewis Bay/Halls Creek study area, there are 899 parcels that are assumed to utilize private wells for drinking water. These are properties that were classified with land use codes that should be developed (e.g., 101 or 325), have been confirmed as having buildings on them through a review of aerial photographs, and do not have a listed account in the water use databases. Of the 899 parcels, 77% of them (696) are classified as residential with 580 of these being classified as single-family residences (land use code 101). The remaining 23% of the parcels are commercial and industrial properties (300s and 400s land use codes, respectively). MEP staff used current water use to develop a watershed-specific water use estimate for the residential uses that were assumed to utilize private wells. Commercial and industrial properties assumed to have private wells were assigned a water use based on percentage of parcel building coverage and average water uses for commercial properties and industrial properties in the Lewis Bay/Halls Creek study area.

Hyannis Water Pollution Control Facility

The Hyannis Water Pollution Control Facility (WPCF) is located at the intersection of Route 28 and Bearses Way. The facility operators use a sequence of treatment processes to denitrify effluent prior to its discharge in sand beds located on site. The Town of Barnstable is currently in the process of completing review of a Final Environmental Impact Report for its Facilities Plan that will provide a strategy for operation and upgrades to the WPCF and its sewer system over the next 20 years (Stearns and Wheler, 2007).

Effluent flow and total nitrogen concentration data was provided to MEP staff by staff at the Town of Barnstable Department of Public Works. This data covers the period from January 2002 through November 2006. Total flow at the WPCF is generally consistent across the years reviewed (Figure IV-3). Median total nitrogen effluent concentrations are a bit more variable, but tend to fluctuate within a 4 to 8 mg/l range. The available dataset includes 430 readings of effluent total nitrogen concentrations and 1,504 readings of daily effluent quantity. Average effluent quantity during this period is 1.7 million gallons per day (MGD), while total nitrogen concentration averages 5.51 mg/l. The total nitrogen concentration has a standard deviation of 1.98 mg/l and a range of 0.02 to 13.1 mg/l. Median concentration is 5.20 mg/l. For the purposes of the watershed nitrogen loading modeling, MEP staff used an effluent flow of 1.7 MGD and an effluent total nitrogen concentration of 5.51 mg/l. These factors result in an annual current nitrogen load of 12,947 kg/yr from the WPCF.

In order to assess whether there was significant unaccounted for wastewater flows in the sewer collection system, MEP staff also reviewed water flows for all properties listed in available coverages as being connected to the WPCF. This review found a number of parcels that were unaccounted for in the original matching of water use and parcel databases. CCC GIS staff worked to identify these parcels and accounted for their flow in the nitrogen-loading model. This review also identified a few parcels with exceptionally high average water use rates; rates were reviewed for consistency and generally the high average was the result of one exceptionally high year. Water uses for these properties were adjusted to an average of the four remaining years in the watershed nitrogen-loading model.

The WPCF is located in the midst of a number of watersheds. USGS completed additional groundwater modeling for the Town of Barnstable through a grant from the Barnstable County Wastewater Implementation Committee. This groundwater modeling utilized the same model used for the MEP watershed delineations (Walter and Whealan, 2005). The USGS used the model to quantitatively determine which wells, streams, ponds, and estuaries received groundwater flow from effluent discharged at the WPCF. Through the grant, the USGS provided the town with a number of flow scenarios. MEP staff utilized a 1.7 MGD discharge scenario to distribute effluent flow and nitrogen loads from the WPCF to the respective sub-watersheds listed in Table IV-1.

Table IV-1. Nitrogen Loads from the Wastewater Treatment Facilities to Estuary Watersheds in the Lewis Bay/Halls Creek Study Area

Sub-watershed	Nitrogen Load (kg/y)		
	Hyannis WPCF	Private WWTF	TOTAL
Mill Creek		237	237
Mill Pond		172	172
Hyannis Inner Harbor	627		627
Snows Creek	4,219		4,219
Stewarts Creek Total	7,112		7,112
Halls Creek	988		988
TOTAL	12,947	409	13,356

Loads based on monitoring data from facilities within each watershed or from the Hyannis WPCF, which discharges to multiple watersheds

Yarmouth Private Wastewater Treatment Facilities

Three private wastewater treatment facilities exist in the Yarmouth portion of the Lewis Bay watershed: Mayflower Place, Buck Island Village, and The Cove. MEP staff obtained effluent flow and total nitrogen discharge concentrations for 2004 through 2006 from MassDEP based on discharge permit reporting (B. Dudley, personal communication). Buck Island and the Cove discharge within the Mill Creek sub-watershed, while Mayflower Place discharges within the Mill Pond sub-watershed.

From the available dataset, Mayflower Place has an average effluent discharge of 11,519 gpd with an average effluent total nitrogen concentration of 10.96 mg/l (n=34). Buck Island Village has an average effluent discharge of 9,046 gpd with an average effluent total nitrogen concentration of 8.63 mg/l (n=35). The Cove has an average effluent discharge of 11,804 gpd with an average effluent total nitrogen concentration of 8.14 mg/l (n=35). MEP staff determined monthly nitrogen loads for each facility and summed these on an annual basis. The annual nitrogen load from each facility was determined based on the average of three years of annual loads: Mayflower Place, 171.9 kg/y; Buck Island, 106.8 kg/y; and The Cove, 129.9 kg/y. These loads are summarized by sub-watershed in Table IV-1.

Alternative Septic Systems

Three alternative septic systems are identified in Barnstable County Department of Health and the Environment tracking system as being located within the Lewis Bay/Halls Creek study area (S. Rask, personal communication, 1/07). Total nitrogen concentrations were available from 41 samples collected from these three systems between 2000 and 2006. The average total nitrogen concentration (22.23 mg/l) times a 0.9 consumptive use factor was used for these three properties instead of the 23.63 wastewater coefficient used for properties with standard Title 5 septic systems.

Nitrogen Loading Input Factors: Fertilized Areas

The second largest source of estuary watershed nitrogen loading is usually fertilized lawns, golf courses, and cranberry bogs, with lawns being the predominant source within this category. In order to add this source to the nitrogen loading model for the Lewis Bay system, MEP staff reviewed available information about residential lawn fertilizing practices and incorporated site-specific information to determine nitrogen loading from large tracks of turf in the watershed. MEP staff contacted the staff at appropriate organizations regarding the following large turf areas: the Hyannisport Club and Twin Brooks golf courses and playing fields for the Barnstable Public Schools. Cranberry bog nitrogen loading was determined based on previous studies conducted in southeastern Massachusetts.

Residential lawn fertilizer use has rarely been directly measured in watershed-based nitrogen loading investigations. Instead, lawn fertilizer nitrogen loads have been estimated based upon a number of assumptions: a) each household applies fertilizer, b) cumulative annual applications are 3 pounds per 1,000 sq. ft., c) each lawn is 5000 sq. ft., and d) only 25% of the nitrogen applied reaches the groundwater (leaching rate). Because many of these assumptions had not been rigorously reviewed in over a decade, the MEP Technical Staff undertook an assessment of lawn fertilizer application rates and a review of leaching rates for inclusion in the Watershed Nitrogen Loading Sub-Model.

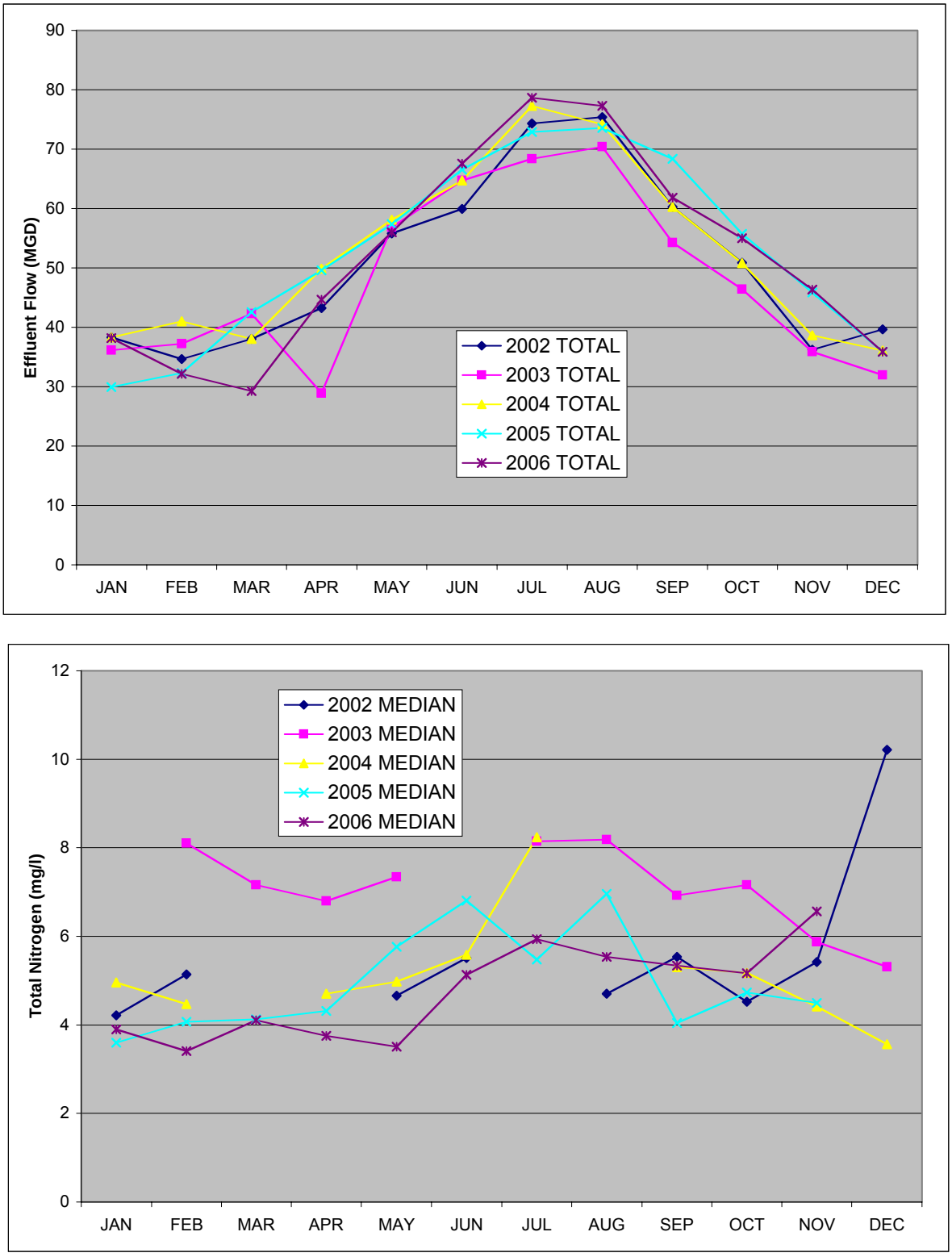


Figure IV-3. Total effluent discharge and median effluent total nitrogen concentration at the Hyannis Water Pollution Control Facility (2002-2006)

The initial effort in this assessment was to determine nitrogen fertilization rates for residential lawns in the Towns of Falmouth, Mashpee and Barnstable. The assessment accounted for proximity to fresh ponds and embayments. Based upon ~300 interviews and over 2,000 site surveys, a number of findings emerged: 1) average residential lawn area is ~5000 sq. ft., 2) half of the residences did not apply lawn fertilizer, and 3) the weighted average application rate was 1.44 applications per year, rather than the 4 applications per year recommended on the fertilizer bags. Integrating the average residential fertilizer application rate with a leaching rate of 20% results in a fertilizer contribution of N to groundwater of 1.08 lb N per residential lawn; these factors are used in the MEP nitrogen loading calculations. It is likely that this still represents a conservative estimate of nitrogen load from residential lawns. It should be noted that professionally maintained lawns were found to have the higher rate of fertilizer application and hence higher estimated loss to groundwater of 3 lb/lawn/yr.

MEP staff contacted Mark Egan and Kevin Young at the Hyannisport Club and Twin Brooks Golf Course, respectively, to obtain current information about fertilizer application rates at the two golf courses. Golf courses usually have different fertilizer application rates for different turf areas, usually higher annual application rates for tees and greens (~3-4 pounds per 1,000 square feet) and lower rates for fairways and roughs (~2-3.5 pounds per 1,000 square feet). At the Hyannisport Club, Mr. Egan reported the following annual nitrogen application rates (in lbs/1,000 ft2) for the various turf areas: greens, 3.0; tees, 2.75; fairways, 3.75, and rough, 3.25. Mr. Young reported the following annual nitrogen application rates (in lbs/1,000 ft2) for the various turf areas at the Twin Brooks Golf Course: greens, 2.75; tees, 3.5; fairways, 3.0, and rough, 2.75.

As has been done in all MEP reviews, MEP staff reviewed the layout of the Hyannisport Club and Twin Brooks Golf Course from aerial photographs, classified the turf types, and assigned these areas to the appropriate sub-watersheds. The nitrogen application rates were then applied to these areas and a load was calculated. The Hyannisport Club is located within the Halls Creek sub-watershed, while the Twin Brooks Golf Course is located within the Stewarts Creek sub-watershed.

MEP staff also contacted Lee Saarkinnen of the Barnstable Public Schools. Mr. Saarkinnen indicated that turf at the Barnstable Public Schools playing fields have an annual nitrogen application rate of 0.75 lbs per acre. These playing fields are located at the Barnstable Middle and High School. Field areas were determined based on review of aerial photographs. A portion of these fields is located within the Halls Creek sub-watershed.

Cranberry bog fertilizer application rate and percent nitrogen attenuation in the bogs is based on the only annual study of nutrient cycling and loss from cranberry agriculture that has been conducted in southeastern Massachusetts (Howes and Teal, 1995). Only the bog loses measurable nitrogen, the forested upland releases only very low amounts. For the watershed nitrogen loading analysis, the areas of active bog surface are based on review of aerial photographs for properties classified as cranberry bogs in the town-supplied land use classifications. Cranberry bogs are located within the Chase Brook sub-watershed.

Nitrogen Loading Input Factors: Other

The nitrogen loading factors for atmospheric deposition, impervious surfaces and natural areas are from the MEP Embayment Modeling Evaluation and Sensitivity Report (Howes and Ramsey 2001). The factors are similar to those utilized by the Cape Cod Commission's Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and Massachusetts DEP's

Nitrogen Loading Computer Model Guidance (1999). The recharge rate for natural areas and lawn areas is the same as utilized in the MEP-USGS groundwater modeling effort (Section III). Factors used in the MEP nitrogen loading analysis for the Lewis Bay watershed are summarized in Table IV-2.

The impervious surface factors were also used to add nitrogen load from the runways, taxiways, and tarmac at the Hyannis Airport. The area of these surfaces was determined from aerial photographs and the corresponding loads were added to the nitrogen-loading model. Loads from impervious surfaces at the airport are within the sub-watersheds to Mill Pond and Hyannis Inner Harbor.

IV.1.3 Calculating Nitrogen Loads

Once all the land and water use information was linked to the parcel coverages, parcels were assigned to various watersheds based initially on whether at least 50% or more of the land area of each parcel was located within a respective watershed. Following the assigning of boundary parcels, all large parcels were examined individually and were split (as appropriate) in order to obtain less than a 2% difference between the total land area of each sub-watershed and the sum of the area of the parcels within each sub-watershed. The resulting "parcelized" watersheds to Lewis Bay and Halls Creek are shown in Figure IV-4.

The review of individual parcels straddling watershed boundaries included corresponding reviews and individualized assignment of nitrogen loads associated with lawn areas, septic systems, and impervious surfaces. Individualized information for parcels with atypical nitrogen loading (condominiums, golf courses, etc.) was also assigned at this stage. It should be noted that small shifts in nitrogen loading due to the above assignment procedure generally have a negligible effect on the total nitrogen loading to the Lewis Bay estuary. The assignment effort was undertaken to better define sub-estuary loads and enhance the use of the Linked Watershed-Embayment Model for the analysis of management alternatives.

Following the assignment of all parcels, sub-watershed modules were generated for each of the 28 sub-watersheds summarizing water use, parcel area, frequency, sewer connections, private wells, and road area. The individual sub-watershed modules were then integrated to create a Lewis Bay Watershed and a Hall Creek Nitrogen Loading module with summaries for each of the individual sub-embayments and sub-estuaries. The sub-embayments represent the functional embayment units for the Linked Watershed-Embayment Model's water quality component.

For management purposes, the aggregated estuary watershed nitrogen loads are partitioned by the major types of nitrogen sources in order to focus development of nitrogen management alternatives. Within the Lewis Bay/Halls Creek study area, the major types of nitrogen loads are: wastewater (e.g., septic systems), wastewater treatment facilities, fertilizer, impervious surfaces, direct atmospheric deposition to water surfaces, and recharge within natural areas (Table IV-3). The output of the watershed nitrogen-loading model is the annual mass (kilograms) of nitrogen added to the contributing area of component sub-embayments, by each source category (Figure IV-5 a-f). In general, the annual watershed nitrogen input to the watershed of an estuary is then adjusted for natural nitrogen attenuation during transport to the estuarine system before use in the embayment water quality sub-model.

Table IV-2. Primary Nitrogen Loading Factors used in the Lewis Bay MEP analyses. General factors are from MEP modeling evaluation (Howes and Ramsey 2001). Site-specific factors are derived from Barnstable and Yarmouth data. *Data from MEP lawn study in Falmouth, Mashpee & Barnstable 2001.

Nitrogen Concentrations:	mg/l	Recharge Rates:	in/yr	
Road Run-off	1.5	Impervious Surfaces	40	
Roof Run-off	0.75	Natural and Lawn Areas	27.25	
Direct Precipitation on Embayments and Ponds	1.09	Water Use/Wastewater:		
Natural Area Recharge	0.072	Existing developed residential parcels wo/water accounts and buildout residential parcels:	175 gpd	
Wastewater Coefficient	23.63			
Hyannis Water Pollution Control Facility				
Effluent Flow (million gallons per day)	1.7			
Effluent Total Nitrogen concentration (mg/l)	5.51	Existing developed parcels w/water accounts:	Measured annual water use	
Fertilizers:		Commercial and Industrial Buildings wo/WU and buildout additions		
Average Residential Lawn Size (sq ft)*	5,000	Commercial	BAR	YAR
Residential Watershed Nitrogen Rate (lbs/lawn)*	1.08	Wastewater flow (gpd/1,000 ft2 of building):	52	146
Cranberry Bogs nitrogen application (lbs/ac)	31	Building coverage:	20%	13%
Cranberry Bogs nitrogen attenuation	34%	Industrial	BAR	YAR
Nitrogen Fertilizer Rate for golf courses, cemeteries, and public parks determined from site-specific information		Wastewater flow (gpd/1,000 ft2 of building):	5	32
Average Building Size from watershed data (sq ft)	1,175	Building coverage:	15%	20%

Since groundwater outflow from a pond can enter more than one down gradient sub-watershed, the length of shoreline on the down gradient side of the pond was used to apportion the pond-attenuated nitrogen load to respective down gradient watersheds. The apportionment was based on the percentage of discharging shoreline bordering each down gradient sub-watershed. So for example, Mary Dunn Pond has a down gradient shoreline of 942 feet; 72% of that shoreline discharges into the Mill Pond GT10 sub watershed (watershed 2 in Figure IV-1) and 28% discharges to the Maher/Mary Dunn combined wellfield sub-watershed (watershed 6). The attenuated nitrogen load discharging from Lake Wequaquet is divided among these sub-watersheds based on the percentage of the down-gradient shoreline.

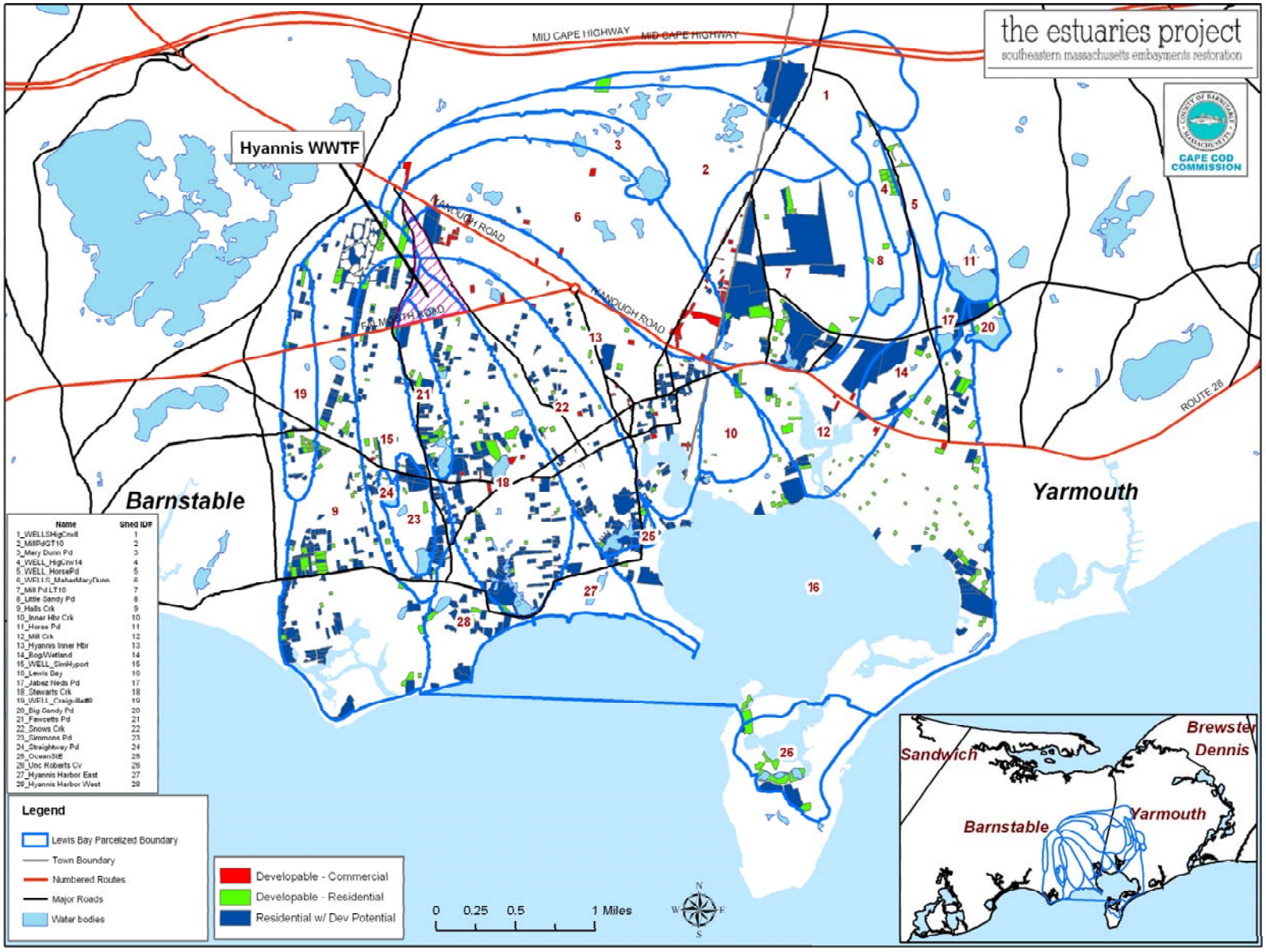
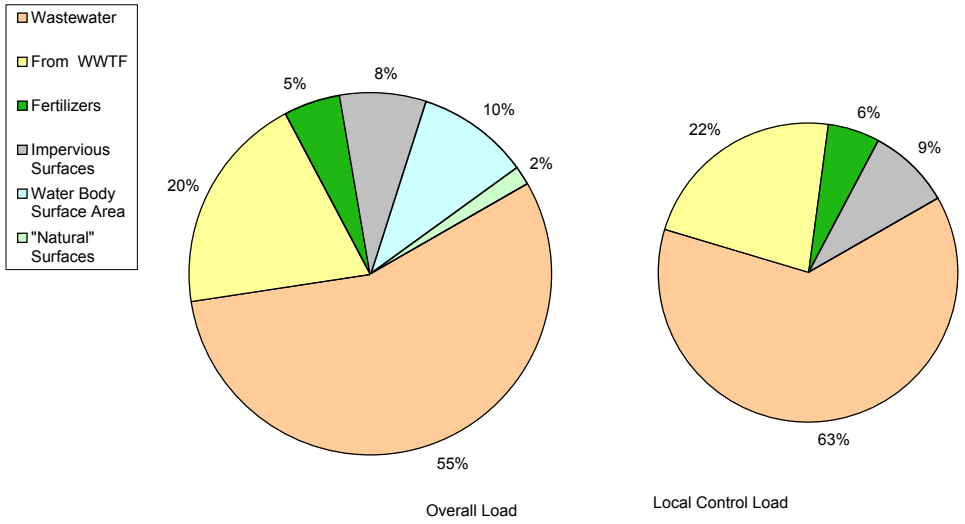


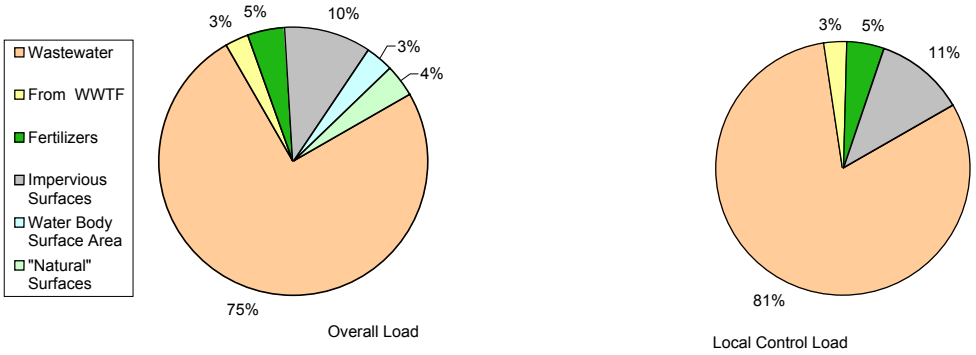
Figure IV-4. Parcels, Parcelized Watersheds, and Developable Parcels in the Lewis Bay and Halls Creek watersheds.

Table IV-3. Lewis Bay and Halls Creek Nitrogen Loads. Attenuation of Lewis Bay and Halls Creek system nitrogen loads occurs as nitrogen moves through up-gradient ponds and streams during transport to the estuary. All values are kg N yr^{-1}.

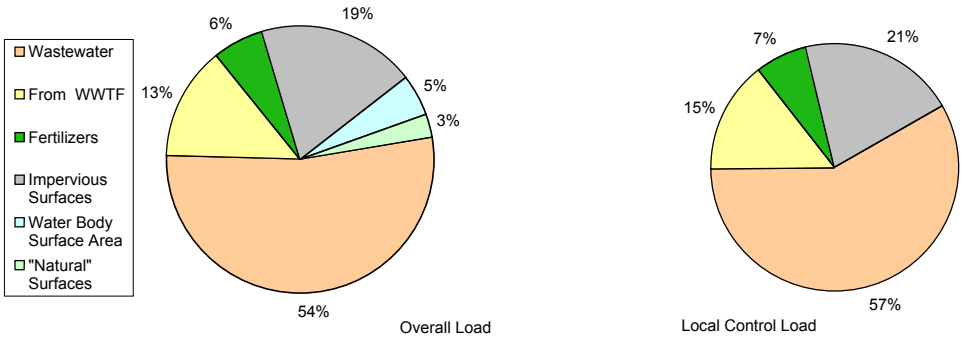
		Lewis Bay and Halls Crk N Loads by Input (kg/y):								***Present N Loads***			***Buildout N Loads***		
Watershed Name	**Watershed ID#**	**Wastewater**	**From WWTF**	**Fertilizers**	**Impervious Surfaces**	**Water Body Surface Area**	**"Natural" Surfaces**	**Buildout**	**% of Pond Outflow**	**UnAtten N Load**	**Atten %**	**Atten N Load**	**UnAtten N Load**	**Atten %**	**Atten N Load**
Lewis Bay System Total		35149	12367	3096	4951	6182	1115	17601		62860		57750	80461		73590
Lewis Bay Estuary TOTAL		26657	5255	2062	3895	6040	964	11911		44873		40490	56784		50826
Stewarts Creek TOTAL		6170	7112	782	749	125	106	5649		15045		14318	20694		19781
Hyannis Harbor Estuary surface deposition															
Lewis Bay Estuary TOTAL		26657	5255	2062	3895	6040	964	11911		44873		40490	56784		50826
Lewis Bay Estuary surface deposition						4930				4930		4930	4930		4930
Uncle Roberts Cove Estuary surface deposition						277				277		277	277		277
Mill Creek Total	12, CB, MP	10727	409	652	1499	476	553	6065		14315		12766	20380		18287
Mill Pond Total	MP	4309	172	163	1072	164	385	3437		6266	10%	5489	9703	10%	8520
Chase Brook	CB	1412	0	289	106	52	52	393		1911	30%	1221	2304	30%	1484
Mill Creek Estuary surface deposition						229				229		229	229		229
Hyannis Inner Harbor Total	6,13	2496	627	290	885	241	128	1015		4668		4668	5683		5683
Hyannis Inner Harbor Estuary surface deposition						231				231		231	231		231
Snows Creek Total	22,25	2559	4219	366	621	34	77	3342		7875		5517	11217		7859
Stewarts Creek TOTAL		6170	7112	782	749	125	106	5649		15045		14318	20694		19781
Stewarts Creek Estuary surface deposition						86				86		86	86		86
Halls Creek Total		6221	988	1554	731	269	160	1516		9924		8674	11440		10111
Halls Creek Stream Total	21, SP	648	988	63	77	39	19	98		1834	58%	584	1932	58%	603
Simmons Pond Total	SP	515	0	52	64	33	17	39		680	50%	319	718	50%	335
Halls Creek Estuary surface deposition						230				230		230	230		230



a. Lewis Bay System Overall

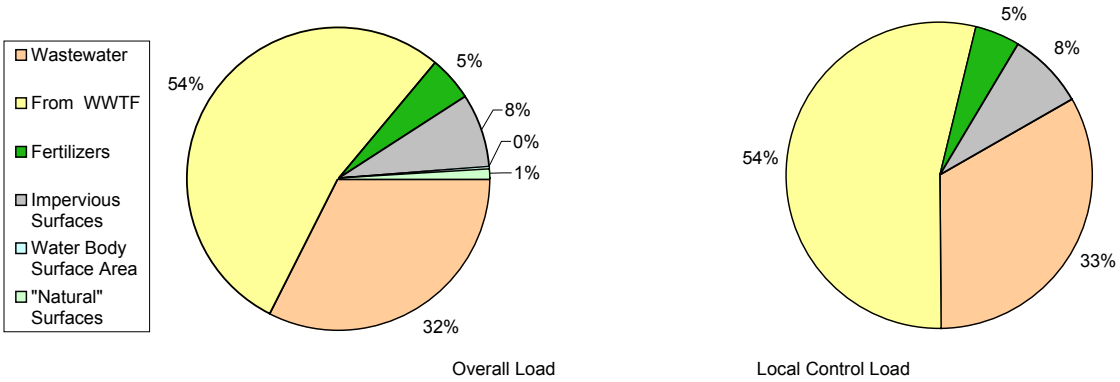


b. Mill Creek subwatershed

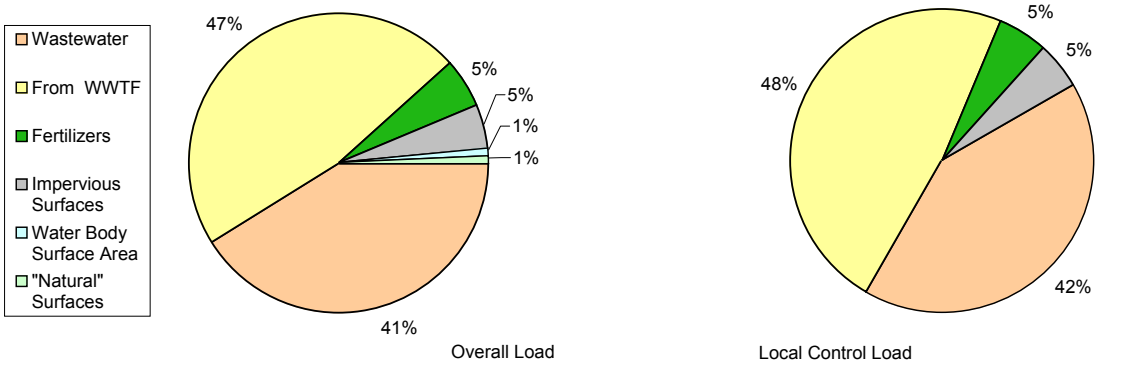


c. Hyannis Inner Harbor subwatershed

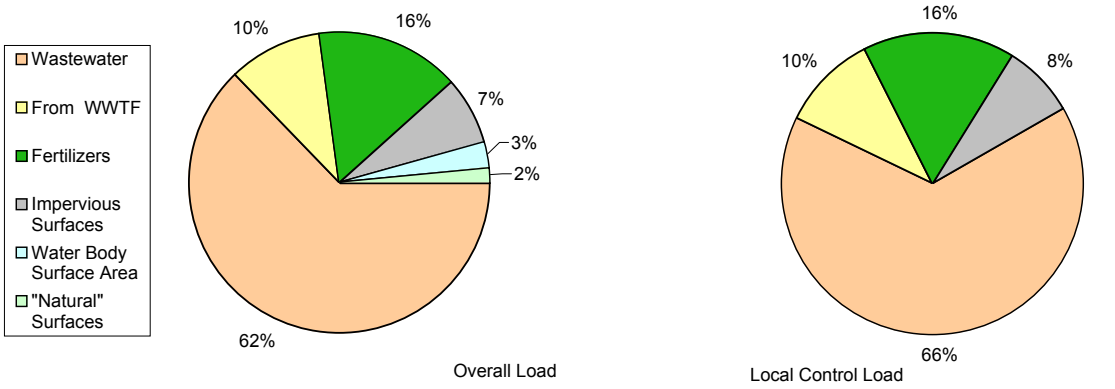
Figure IV-5 (a-c). Land use-specific unattenuated nitrogen load (by percent) to the (a) overall Lewis Bay System watershed, (b) Mill Creek sub-watershed, and (c) Hyannis Inner Harbor sub-watershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control.



d. Snows Creek subwatershed



e. Stewarts Creek System Overall



f. Halls Creek System Overall

Figure IV-5 (d-f). Land use-specific unattenuated nitrogen load (by percent) to the (d) Snows Creek sub-watershed, (e) Stewarts Creek sub-watershed and (f) the Halls Creek system. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control.

Freshwater Pond Nitrogen Loads

Freshwater ponds on Cape Cod are generally kettle hole depressions that intercept the surrounding groundwater table revealing what some call "windows on the aquifer." Groundwater typically flows into the pond along the up gradient shoreline, then lake water flows back into the groundwater system along the down gradient shoreline. Occasionally a Cape Cod pond will also have a stream outlet or herring run that also acts as a discharge point. Since the nitrogen loads flow into the pond with the groundwater, the relatively more productive pond ecosystems incorporate some of the nitrogen, retain some nitrogen in the sediments, and change the nitrogen among its various oxidized and reduced forms. As result of these interactions, some of the nitrogen is removed from the watershed system, mostly through burial in the sediments and denitrification that returns it to the atmosphere. Following these reductions, the remaining (reduced or attenuated) loads flow back into the groundwater system along the down gradient side of the pond or through a stream outlet and eventual discharge into the down gradient embayment. The nitrogen load summary in Table IV-3 includes both the unattenuated (nitrogen load to each sub watershed) and attenuated nitrogen loads.

Pond nitrogen attenuation in freshwater ponds has generally been found to be at least 50% in MEP analyses, so the watershed model contains a conservative attenuation rate of 50%. However, in some cases, if sufficient monitoring information is available, a pond-specific attenuation rate is incorporated into the watershed nitrogen loading modeling (Three Bays MEP Report, 2005). Detailed studies of other southeastern Massachusetts freshwater systems including Ashumet Pond (AFCEE, 2000) and Agawam/Wankinco River Nitrogen Discharges (CDM, 2001) have also supported a 50% attenuation factor. In order to estimate nitrogen attenuation in the ponds, physical and chemical data for each pond is reviewed. Available bathymetric information is reviewed relative to measured pond temperature profiles to determine whether an epilimnion (*i.e.*, well mixed, homothermic, upper portion of the water column) exists in each pond. Bathymetric information is necessary to develop a residence or turnover time and complete an estimate of nitrogen attenuation. In the Lewis Bay and Halls Creek watersheds, bathymetric information is available for only Mary Dunn Pond; in order to complete nitrogen attenuation estimates, MEP staff estimated the volumes based on maximum depths that had been measured during PALS Snapshot sampling. Given these ponds relatively small areas, it would be likely that none are deep enough to develop strong temperature stratification and samples from all depths generally can be used for determining average nitrogen concentrations. Deepest samples must be checked for potential impact by sediment regeneration of nitrogen, especially if low oxygen conditions occur.

In MEP analyses, available nitrogen concentrations from individual ponds are reviewed to establish whether sediment regeneration is a significant factor in a pond and, if not, the entire volume of the pond is used to determine a turnover time. Turnover time is how long it takes the recharge from the up gradient watershed to completely exchange the water in the pond or, in the case of a thermally stratified pond, exchange just the epilimnion. The total mass of nitrogen in the pond or epilimnion is adjusted using the pond turnover time to determine the annual nitrogen load returned to the aquifer through the down gradient shoreline. This mass is then compared to the nitrogen load coming from the pond's watershed to determine the nitrogen attenuation factor for the pond. Monitoring of ponds within the Lewis Bay and Halls Creek system watersheds is insufficient to support use of a factor different than the standard 50% attenuation.

The standard attenuation assumption for the ponds in the Lewis Bay watershed was checked through the use of pond water quality information collected from the annual Cape Cod Pond and Lake Stewardship (PALS) water quality snapshot. The PALS Snapshot is a collaborative Cape Cod Commission/SMAST Program that allows trained, citizen volunteers of each of the 15 Cape Cod towns to collect pond samples in August and September using a standard protocol. Snapshot samples have been collected every year between 2001 and 2005. The standard protocol for the Snapshot includes field collection of dissolved oxygen and temperature profiles, Secchi disk depth readings and water samples at various depths depending on the total depth of the pond. PALS Snapshot data is available in the Lewis Bay watershed for the following ponds: Mary Dunn, Fawcetts, Big Sandy, Horse, Jabez Neds, and Little Sandy. Data is not available for Simmons or Straightway Ponds. Water samples were analyzed at the SMAST laboratory for total nitrogen, total phosphorus, chlorophyll a, alkalinity, and pH. Table IV-4 presents the turnover times and attenuation factors for the ponds in the Lewis Bay and Halls Creek watersheds.

Table IV-4 also summarizes the pond attenuation estimates calculated from land-use modeled nitrogen inflow loads and nitrogen loads recharged to the down gradient aquifer or to outflow streams from each pond based on pond characteristics and measured nitrogen levels. Nitrogen attenuation within the ponds was approximately 65% based on the results of attenuation calculations for Mary Dunn Pond where bathymetry data was available. However, a caveat to the attenuation estimates is that they are based upon nitrogen outflow loads from water column samples collected at one time during the year, that are not necessarily representative of the annual nitrogen loads that are transferred down gradient, and there are only a small number of samples for review.

Buildout

Part of the regular MEP watershed nitrogen loading modeling is to prepare a buildout assessment of potential development within the study area watershed. For the Lewis Bay/Halls Creek modeling, MEP staff consulted with Town of Barnstable and Town of Yarmouth planners to determine the factors that would be used in the assessment (Patty Daley, Tom Broadrick, and Terry Sylvia, personal communications). The buildout analysis was complicated by accounting for the Hyannis Growth Incentive Zone (GIZ) and future connections to the Hyannis Water Pollution Control Facility. MEP staff first reviewed the development potential of each property based on existing zoning within both Yarmouth and Barnstable. The buildout procedure used, and generally completed for MEP analyses, is to evaluate town zoning to determine minimum lot sizes in each of the zoning districts, including overlay districts (*e.g.*, water resource protection districts). Larger lots are subdivided by the minimum lot size to determine the total number of new lots and existing developed properties are reviewed for additional development potential; for example, residential lots that are twice the minimum lot size, but have only one residence. MEP staff also included additional development on residential parcels that are classified as developable residential (state class land use codes 130 and 131) but are less than the minimum lot size and are greater than 5,000 square feet. These parcels are assigned one residence in the buildout; 5,000 square feet is a common minimum buildable lot size in Cape Cod town regulations. Properties classified by the Barnstable and Yarmouth assessors as "undevelopable" (e.g., codes 132, 392, and 442) were not assigned any development at buildout. Commercially developable properties were not subdivided; the area of each parcel and the factors in Table IV-3 were used to determine a wastewater flow for these properties. MEP staff then met individually with town planning staff to review the initial buildout analysis and modified the results based on their local knowledge of other site constraints. All the parcels

included in the buildout assessment of the Lewis Bay and Halls Creek watersheds are shown in Figure IV-4.

Table IV-4. Nitrogen attenuation by Freshwater Ponds in the Lewis Bay and Halls Creek watersheds based upon 2001 through 2005 Cape Cod Pond and Lakes Stewardship (PALS) program sampling. These data were collected to provide a site-specific check on nitrogen attenuation by these systems. The MEP Linked N Model for Lewis Bay and Halls Creek uses a standard value of 50% for all the pond systems.

Pond	PALS ID	Area acres	Maximum Depth m	Overall turnover time yrs	TN samples for Attenuation calculation	N Load Attenuation %
Mary Dunn	BA-646	18.0	1.7	0.2	3	65%
Fawcetts	BA-748	11.9	1.3	No Bathymetric Info	4	Not calculated due to lack of bathymetry
Simmons	BA-789	7.2			0	
Straightway	BA-771	4.3			0	
Big Sandy	YA-711	19.4	4.0		4	
Horse	YA-692	30.3	3.5		8	
Jabez Neds	YA-716	7.5	3.1		2	
Little Sandy	YA-700	14.0	8.0		4	
					Mean	65%
					std dev	n/a

Data sources: all areas from CCC GIS; Max Depth from Cape Cod PALS monitoring; TN concentrations for attenuation calculations from annual PALS Snapshot provided by SMAST lab; Volume for turnover time calculations for Mary Dunn Pond from MADFW bathymetric maps (www.mass.gov/dfwele/dfw/dfw_pond.htm);

Because of the sewer system in Hyannis has the potential to remove wastewater nitrogen loads from the individual sites and move this load to the WPCF site, the next step was to identify properties that are already connected to the municipal sewer system or are included within the Hyannis GIZ. Based on discussion with Town of Barnstable staff, it was determined that any additional development within the GIZ would be connected to the municipal sewer system. Based on this analysis, buildout within the watershed would add 1.25 MGD of flow to the WPCF; bringing the total WPCF flow at buildout to 2.95 MGD. Nitrogen loads from the WPCF under buildout conditions are based on the buildout flow and the current effluent total nitrogen concentration of 5.51 mg/l. This analysis does not include any additional flows from Areas of Concern identified through the town Facilities Plan; additional scenario analyses would be necessary to explore these impacts. Distribution of the estimated buildout flows and nitrogen loads from the WPCF to various sub-watersheds are based on a USGS scenario of 2.0 MGD discharge at the WPCF; this scenario is the closest flow to the estimated buildout flow of the scenarios completed by the USGS for the town by the Barnstable County Wastewater Implementation Committee modeling grant.

Overall, each additional residential, commercial, or industrial property added at buildout is assigned nitrogen loads for wastewater (if not connected to the WPCF), fertilizer, and impervious surfaces. Wastewater loads from parcels using a septic system for wastewater treatment are assigned within the watershed that contains the parcel, while those connected to the WPCF do not have wastewater loads on site. Cumulative unattenuated buildout loads are indicated in a separate column in Table IV-3. Buildout additions within the overall Lewis Bay System watershed will increase the unattenuated loading rate by 28% and within the Halls Creek watershed by 15%.

Scenarios

At the request of Town of Barnstable and Town of Yarmouth staff, MEP staff completed six additional scenarios. Through a current Comprehensive Wastewater Management Planning process, the Town of Yarmouth delineated a potential sewer district (Figure IV-6). Both town staffs agreed to the following scenarios: A) collection of wastewater within the proposed district and removal of wastewater loads from Lewis Bay watershed, B) collection of wastewater within the proposed district and treatment and discharge at the Hyannis WPCF, and C) collection of wastewater within the proposed district, treatment at the Hyannis WPCF, and discharge within an abandoned bog system to the east of Cape Cod Hospital. Wastewater flows were developed under both current and buildout conditions.

MEP staff developed a separate “sewershed” module for the proposed district, which cuts across six sub-watersheds. The sewershed module contains all the properties in the proposed district according to their current sub-watershed assignments. Just as in the standard nitrogen loading analysis, staff determined water use for all developed properties within the sewershed and potential future water use at buildout based on a review of developable land and additional development on existing developed properties. Total existing wastewater load within the whole sewershed is 7,792 kg/yr and buildout will add 2,486 kg/yr.

Under scenario A, the existing and buildout loads from the sewershed are removed from the respective sub-watersheds. Under scenario B, wastewater flows are assumed to be discharged at the Hyannis WPCF and redistributed to various sub-watersheds based on the analyses described above. Under scenario C, the WPCF-treated effluent from the sewershed is discharged at the abandoned bogs in the Inner Harbor Creek sub-watershed. The scenario C loads receive an additional 30% attenuation from the bog system. Overall impacts on all loads are shown in Table IV-5.

Table IV-5. Existing and buildout unattenuated nitrogen loading changes due to proposed scenarios for wastewater discharge from Town of Yarmouth potential sewer service area. Scenario A removes the wastewater nitrogen loads from the Lewis Bay watershed. Scenario B treats the wastewater at the Hyannis Water Pollution Control Facility. Scenario C treats the wastewater at the WPCF and discharges it at abandoned bogs to the east of Cape Cod Hospital. All values are kg N yr^{-1}.

		SCENARIO A		SCENARIO B		SCENARIO C	
		Remove YAR sewer		YAR Sewer to Hyannis WPCF		YAR Sewer to Hyannis WPCF/Bog discharge	
Watershed Name	Wtrshd ID#	Existing	BO	Existing	BO	Existing	BO
Lewis Bay	16	-1769	-243				
Inner Harbor Creek	10	-824	-23			1788	389
Mill Creek	12	-4250	-1716				
Mill Pond LT10	7	-145	-410				
Bog/Wetland	14	-13	-76				
Hyannis Inner Harbor	13	-791	-17	87	19		
Snows Creek	22			583	127		
Stewarts Creek	18			925	202		
Fawcetts Pond	21			57	12		
Halls Creek Stream Total	21, SP			136	30		
SCENARIO TOTAL		-7792	-2486	1788	389	1788	389
NET LOAD TO LEWIS BAY		-7792	-2486	-6141	-2127	-6004	-2097
NET LOAD TO HALLS CREEK				136	30		

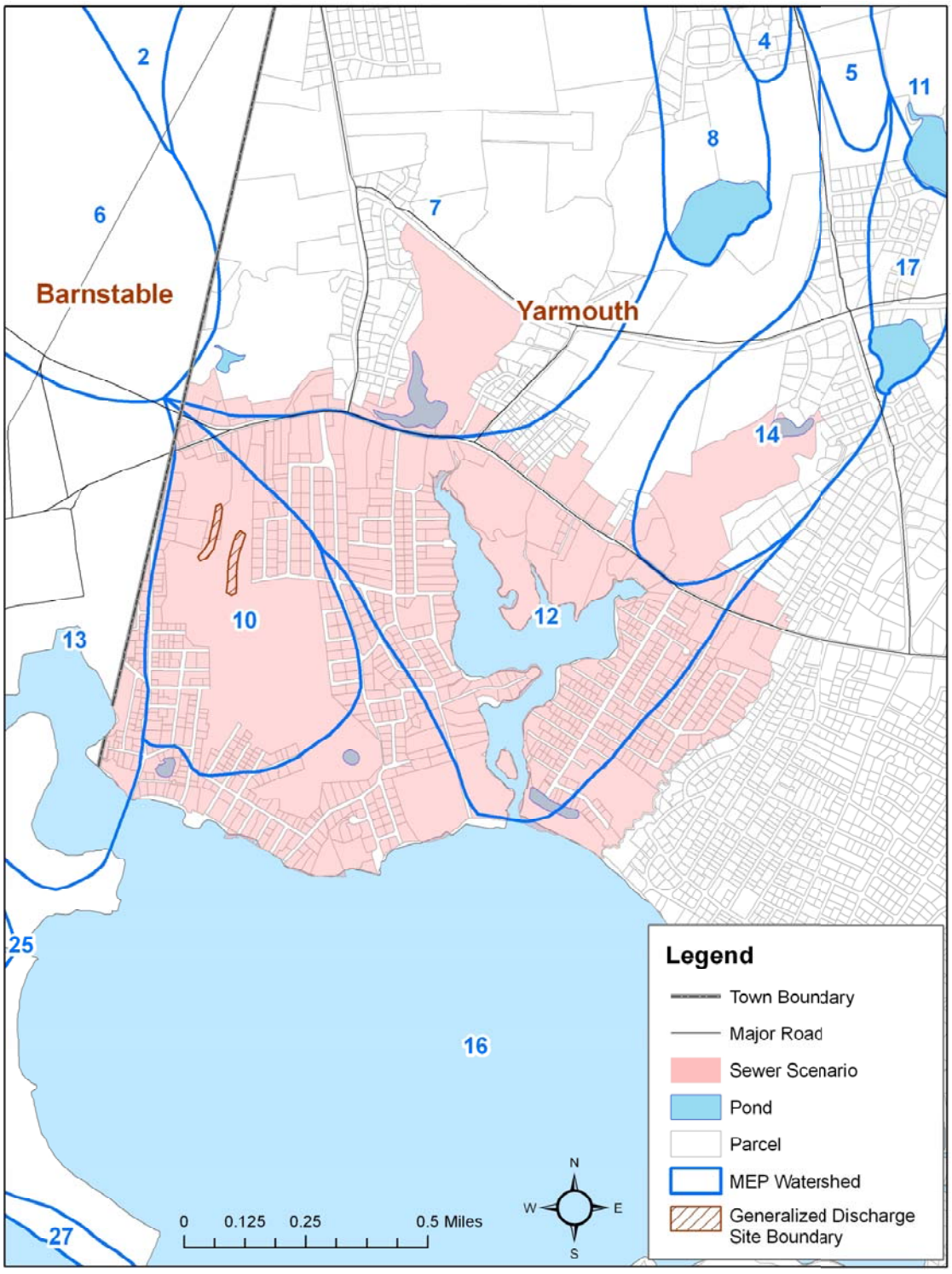


Figure IV-6. Lewis Bay Sewer Scenario Collection Area. Potential sewer collection area is shown in pink. Potential Scenario C discharge areas are shown based on Barnstable Facilities Plan (2007).

IV.2 Attenuation of nitrogen in surface water transport

IV.2.1 Background and Purpose

Modeling and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land or watershed. This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out, sewering analysis, enhanced flushing, pond/wetland restoration for natural attenuation, etc.) to changes in water quality and habitat health. Therefore, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems. Rates of nitrogen loading to the sub-watersheds of the Lewis Bay System (inclusive of Hyannis Inner Harbor and Mill Creek estuarine reaches) being investigated under this nutrient threshold analysis was based upon the delineated watersheds (Section III) and their land-use coverages (Section IV.1). If all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters. This condition exists in watersheds where nitrogen transport from source to estuarine waters is through groundwater flow in sandy outwash aquifers (such as the developed region of the Lewis Bay System watershed). The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. However, in most watersheds in southeastern Massachusetts, nitrogen passes through a surface water ecosystem (pond, wetland, stream) on its path to the adjacent embayment. Surface water systems, unlike sandy aquifers, do support the needed conditions for nitrogen retention and denitrification. The result is that the mass of nitrogen passing through lakes, ponds, streams and marshes (fresh and salt) is diminished by natural biological processes that represent removal (not just temporary storage). However, this natural attenuation of nitrogen load is not uniformly distributed within the watershed, but is associated with ponds, streams and marshes. In the case of the Lewis Bay embayment system watersheds, a portion of the freshwater flow and transported nitrogen passes through several surface water systems (Hall's Creek, Stewart's Creek, Snow's Creek, Creek to Hyannis Inner Harbor from Hospital Bog, Stream from Mill Pond to the estuarine reach of Mill Creek, Chase Brook to Mill Creek, Bumps River, stream from Long Pond, stream from Lake Elizabeth) prior to entering the estuary, producing the opportunity for significant nitrogen attenuation.

Failure to determine the attenuation of watershed derived nitrogen overestimates the nitrogen load to receiving estuarine waters. If nitrogen attenuation is significant in one portion of a watershed and insignificant in another the result is that nitrogen management would likely be more effective in achieving water quality improvements if focused on the watershed region having unattenuated nitrogen transport (other factors being equal). In addition to attenuation by freshwater ponds (see Section IV.1.3, above), attenuation in surface water flows is also important. An example of the significance of surface water nitrogen attenuation relating to embayment nitrogen management was seen in the Agawam River, where >50% of nitrogen originating within the upper watershed was attenuated prior to discharge to the Wareham River Estuary (CDM 2000). Similarly, MEP analysis of the Quashnet River indicates that in the upland watershed, which has natural attenuation predominantly associated with riverine processes, the integrated attenuation was 39% (Howes et al. 2004). In addition, a preliminary study of Great, Green and Bournes Ponds in Falmouth, measurements indicated a 30% attenuation of nitrogen during stream transport (Howes and Ramsey 2001). An example where natural attenuation played a significant role in nitrogen management can be seen relative to West Falmouth Harbor (Falmouth, MA), where ~40% of the nitrogen discharge to the Harbor originating from the groundwater effluent plume emanating from the WWTF was attenuated by a small salt marsh prior to reaching Harbor waters. Clearly, proper development and evaluation of nitrogen

management options requires determination of the nitrogen loads reaching an embayment, not just loaded to the watershed.

Given the importance of determining accurate nitrogen loads to embayments for developing effective management alternatives and the potentially large errors associated with ignoring natural attenuation, direct integrated measurements of upper watershed attenuation were undertaken as part of the MEP Approach. MEP conducted long-term measurements of natural attenuation relating to surface water discharges to the perimeter of the embayment system in addition to the natural attenuation measures by fresh kettle ponds, addressed above (Section IV.1). These additional site-specific studies were conducted in the 6 major surface water flow systems in the watershed to Lewis Bay, 1) Halls Creek discharging to the outermost portion of Lewis Bay, 2) Stewart's Creek discharging to outer Lewis Bay, 3) Snow's Creek discharging to Inner Lewis Bay, 4) Creek from Hospital Bog discharging to Hyannis Inner Harbor, 5) Stream from Mill Pond discharging to the estuarine reach of Mill Creek and 6) Chase Brook discharging to the estuarine reach of Mill Creek (Figure IV-7).

Quantification of watershed based nitrogen attenuation is contingent upon being able to compare nitrogen load to the embayment system directly measured in freshwater stream flow (or in tidal marshes, net tidal outflow) to nitrogen load as derived from the detailed land use analysis (Section IV.1). Measurement of the flow and nutrient load associated with the freshwater streams discharging to the estuary provides a direct integrated measure of all of the processes presently attenuating nitrogen in the contributing area up gradient from the various gauging sites. Flow and nitrogen load were measured at the gages in each freshwater stream site for between 15 and 26 months of record depending on the stream gauging location (Figures IV-8 to IV-12). During each study period, velocity profiles were completed on each river every month to two months. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities represent the computation of instantaneous stream flow (Q).



Figure IV-7. Location of Stream gages (red symbols) in the Lewis Bay embayment system.

Determination of stream flow at each gage was calculated and based on the measured values obtained for stream cross sectional area and velocity. Stream discharge was represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity measurement were obtained. Velocity measurements across the entire stream cross section were not averaged and then applied to the total stream cross sectional area.

The formula that was used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma(A * V)$$

where by:

Q = Stream discharge (m^3/s)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection will have a calculated stream discharge value and the summation of all the sub-sectional stream discharge values will be the total calculated discharge for the stream.

Periodic measurement of flows over the entire stream gage deployment period allowed for the development of a stage-discharge relationship (rating curve) that could be used to obtain flow volumes from the detailed record of stage measured by the continuously recording stream gages. Water level data obtained every 10-minutes was averaged to obtain hourly stages for a given river. These hourly stages values where then entered into the stage-discharge relation to compute hourly flow. Hourly flows were summed over a period of 24 hours to obtain daily flow and further, daily flows summed to obtain annual flow. In the case of tidal influence on stream stage, the diurnal low tide stage value was extracted on a day-by-day basis in order to resolve the stage value indicative of strictly freshwater flow. The two low tide stage values for any given day were averaged and the average stage value for a given day was then entered into the stage – discharge relation in order to compute daily flow. A complete annual record of stream flow (365 days) was generated for the surface water discharges flowing into the Lewis Bay embayment system.

The annual flow record for the surface water flow at each gage was merged with the nutrient data set generated through the weekly water quality sampling performed at the gage locations to determine nitrogen loading rates to the perimeter of the Lewis Bay system. Nitrogen discharge from the streams was calculated using the paired daily discharge and daily nitrogen concentration data to determine the mass flux of nitrogen through a specific gauging site. For each of the stream gage locations, weekly water samples were collected (at low tide for a tidally influenced stage) in order to determine nutrient concentrations from which nutrient load was calculated. In order to pair daily flows with daily nutrient concentrations, interpolation between weekly nutrient data points was necessary. These data are expressed as nitrogen mass per unit time (kg/d) and can be summed in order to obtain weekly, monthly, or annual nutrient load to the embayment system as appropriate. Comparing these measured nitrogen loads based on stream flow and water quality sampling to predicted loads based on the land use analysis allowed for the determination of the degree to which natural biological processes within the watershed to each pond currently reduces (percent attenuation) nitrogen loading to the embayment system.

IV.2.2 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Halls Creek to Outer portion of Lewis Bay

Simmons Pond, located up gradient of the Halls Creek gage site is a small freshwater pond and unlike many of the freshwater ponds on Cape Cod, this pond has stream outflow rather than discharging solely to the aquifer along its down-gradient shore. This stream outflow, Halls Creek, may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetlands and streambed associated with Halls Creek. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to Halls Creek above the gage site and the measured annual discharge of nitrogen to the tidal portion of the Halls Creek marsh system, Figure IV-7.

At the Halls Creek gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the Halls Creek-Halls Creek marsh estuarine system that carries the flows and associated nitrogen load to the outer portion of Lewis Bay. As portions of the Halls Creek system are tidally influenced, the gage was located above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to be 0.1 ppt. Therefore, the gage location was deemed acceptable for making freshwater flow measurements. Calibration of the gage was checked monthly. The gage on Halls Creek was installed on April 24, 2003 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Stage data collection continued until November 8, 2004 for a total deployment of 18 months.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Halls Creek site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the estuarine portion of the Halls Creek Marsh system flowing into the outer portion of Lewis Bay **(Figure IV-8 and Table IV-6**). In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for Halls Creek measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from Halls Creek was 25% below the long-term average modeled flows. The average daily flow based on the MEP measured flow data for one hydrologic year beginning September and ending in August (low flow to low flow) was 1,185 m^3/day compared to the long term average flows determined by the USGS modeling effort (1,485 m^3/day).

The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Halls Creek was considered to be negligible given the relatively small flow and associated load. The negligible difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured

Table IV-6. Comparison of water flow and nitrogen discharges from Rivers and Streams (freshwater) discharging to estuarine reach of Lewis Bay. The "Stream" data is from the MEP stream gauging effort. Watershed data is based upon the MEP watershed modeling effort by USGS.

Stream Discharge Parameter	Halls Crk. Discharge[a]	Stewart's Crk. Discharge[a]	Snow's Crk. Discharge[a]	Hospital Bog Discharge[a]	Mill Pond Discharge[a]	Chase Brk. Discharge[a]	Data Source
Total Days of Record	365[b]	365[b]	365[b]	365[b]	365[b]	365[b]	(1)
Flow Characteristics							
Stream Average Discharge (m3/day) **	1185	13966	5298	1318	15655	3255	(1)
Contributing Area Average Discharge (m3/day)	1485	9712	6339	1126	15699	2321	(2)
Discharge Stream 2003-04 vs. Long-term Discharge	-25%	30%	-20%	15%	-0.28%	29%	
Nitrogen Characteristics							
Stream Average Nitrate + Nitrite Concentration (mg N/L)	0.848	1.166	1.14	0.643	0.606	0.45	(1)
Stream Average Total N Concentration (mg N/L)	1.348	2.072	1.899	1.167	1.010	1.035	(1)
Nitrate + Nitrite as Percent of Total N (%)	63%	56%	60%	55%	60%	43%	(1)
Total Nitrogen (TN) Average Measured Stream Discharge (kg/day)	1.6	28.93	10.06	1.54	15.81	3.37	(1)
TN Average Contributing UN-attenuated Load (kg/day)	5.02	40.98	21.58	2.72	17.17	5.24	(3)
Attenuation of Nitrogen in Pond/Stream (%)	68%	29%	53%	43%	8%	36%	(4)

(a) Flow and N load to streams discharging to Lewis Bay includes apportionments of Pond contributing areas.
(b) September 1, 2003 to August 31, 2004.
** Flow is an average of annual flow for 2003-2004

(1) MEP gage site data
(2) Calculated from MEP watershed delineations to ponds upgradient of specific gages;
the fractional flow path from each sub-watershed which contribute to the flow in the streams to Lewis Bay;
and the annual recharge rate.
(3) As in footnote (2), with the addition of pond and stream conservative attentuation rates.
(4) Calculated based upon the measured TN discharge from the rivers vs. the unattenuated watershed load.

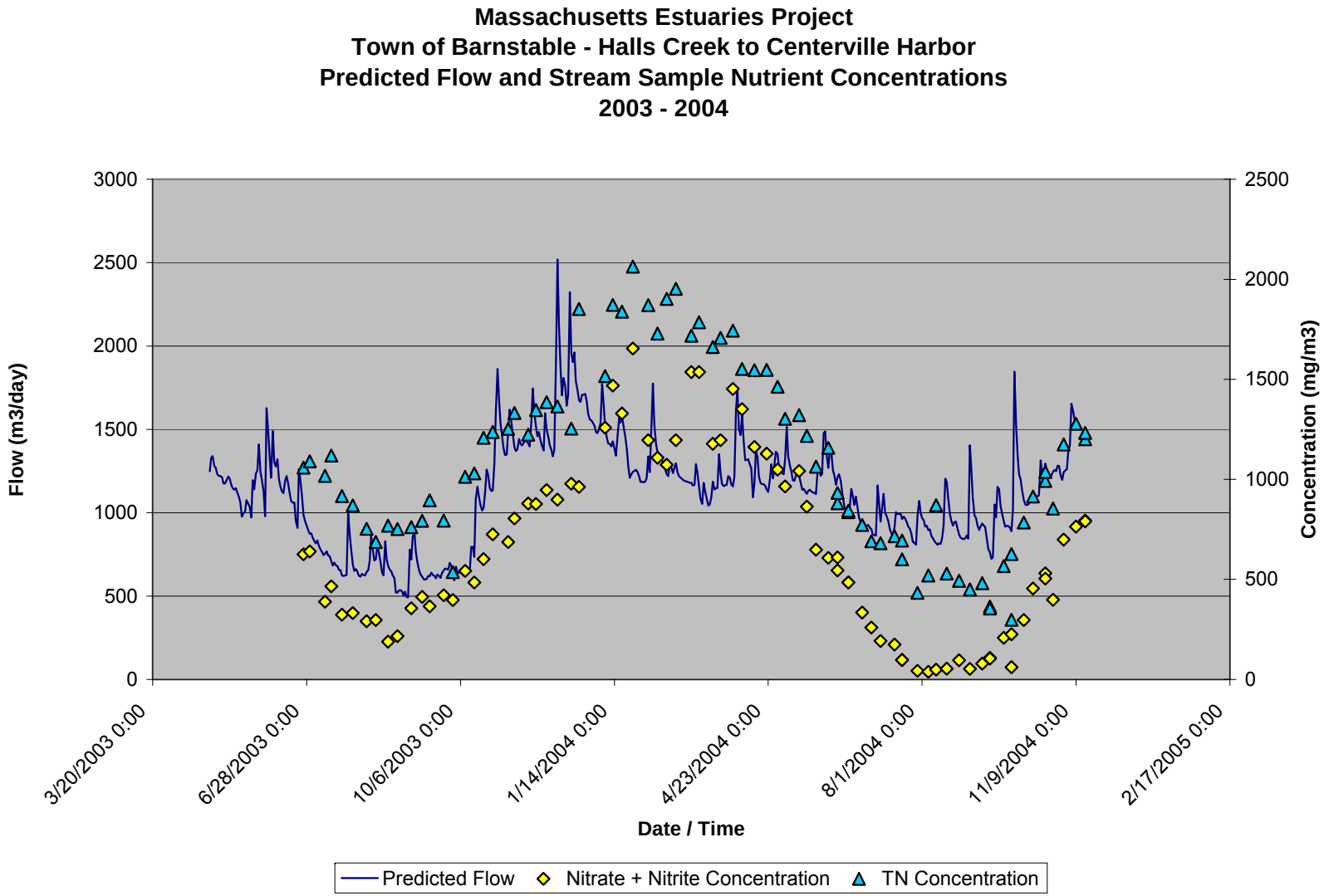


Figure IV-8. Halls Creek discharge (solid blue line), nitrate+nitrite (yellow diamond) and total nitrogen (blue triangle) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Halls Creek Marsh (Table IV-6).

flow in Halls Creek discharging from Simmons Pond would indicate that the Creek is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within the Halls Creek outflow were moderate, 1.348 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 1.60 kg/day and a measured total annual TN load of 583 kg/yr. In Halls Creek, nitrate was the predominant form of nitrogen (63%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the out flowing stream waters also suggests that plant production within the up gradient freshwater ecosystems is not nitrogen limited. In addition, the high nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system either within Simmons Pond or along the freshwater reach of Halls Creek.

From the measured nitrogen load discharged by Halls Creek to the Halls Creek marsh/estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon lower total nitrogen load (583 kg yr^{-1}) discharged from the freshwater Halls Creek compared to that added by the various land-uses to the associated watershed (1,834 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is 68% (i.e. 68% of nitrogen input to watershed does not reach the estuary). This level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the network of up gradient ponds capable of attenuating nitrogen . The directly measured nitrogen loads from the river was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

IV.2.3 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Stewart's Creek to the Outer portion of Lewis Bay

Fawcett's Pond and Aunt Bettys Pond located immediately up gradient of the Stewarts Creek gage site are small freshwater ponds and unlike many of the freshwater ponds, these ponds each have stream outflows rather than discharging solely to the aquifer along its down-gradient shore. These stream outflows come together in a wetland area that discharges directly to the outer portion of Lewis Bay through a control structure where the MEP gage was located. These stream outflows to the wetland up gradient of the gage may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetland and must be considered in quantifying the attenuated load of nutrients to outer Lewis Bay. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the wetland above the gage site and the measured annual discharge of nitrogen to outer Lewis Bay relative to the gage, Figure IV-7.

At the Stewarts Creek gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the discharge that carries nitrogen load from the wetland to the outer portion of Lewis Bay. As the Stewarts Creek discharge is tidally influenced the gage was located as far above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to range between 2.5 ppt and 9.8 ppt depending on the season. Based on the salinity, a correction was made to the predicted daily flows obtained at the gage to account for the tidal influence. Considering the weekly salinity data, a

boundary salinity obtained from a nearby offshore water quality monitoring station and the ability to correct gage data for salinity, the gage location was deemed acceptable for making freshwater flow measurements at low tide. Calibration of the gage was checked monthly. The gage on Stewarts Creek was installed on April 24, 2003 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Stage data collection continued until November 8, 2004 for a total deployment of 18 months. The 12-month uninterrupted record used in this analysis encompasses the summer 2003 and 2004 field season.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Stewarts Creek site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the outer portion of Lewis Bay **(Figure IV-9 and Table IV-6)**. In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for Stewarts Creek measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from Stewarts Creek was 30% above the long-term average modeled flows. Measured flow in Stewarts Creek was obtained for one hydrologic year (September 2003 to August 2004). The average daily flow based on the MEP measured flow data was 13,966 m^3/day compared to the long term average flows determined by the USGS modeling effort (9,712 m^3/day). The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Stewarts Creek flowing to outer portion of Hyannis Harbor is in part be due to a slight tidal influence confounding the freshwater flow record. Due to site constraints, it was necessary to position the stream gage further down gradient in the stream flowing out of the associated marsh. As such, even at low tide, the flow measured in the stream showed a slight salinity as mentioned above. The flow was corrected based on seasonal trends in salinity, however, it is possible that the flow in the stream is a slight over estimate of the freshwater flow discharging to outer Hyannis Harbor. The MEP Technical Team concurred that the over-estimate on flow and therefore load was conservative and used the measured flow and load in the water quality modeling.

Total nitrogen concentrations within the Stewarts Creek outflow were high, 2.072 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 28.93 kg/day and a measured total annual TN load of 10,560 kg/yr. In the Stewarts Creek surface water system, nitrate was the predominant form of nitrogen (56%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond, wetland or stream ecosystems. The high concentration of inorganic nitrogen in the out flowing stream waters also suggests that plant production within the up gradient freshwater ecosystems is not nitrogen limited. In addition, the high nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system either within Fawcetts Pond, Aunt Bettys Pond or the wetland up gradient of the Stewarts Creek gage.

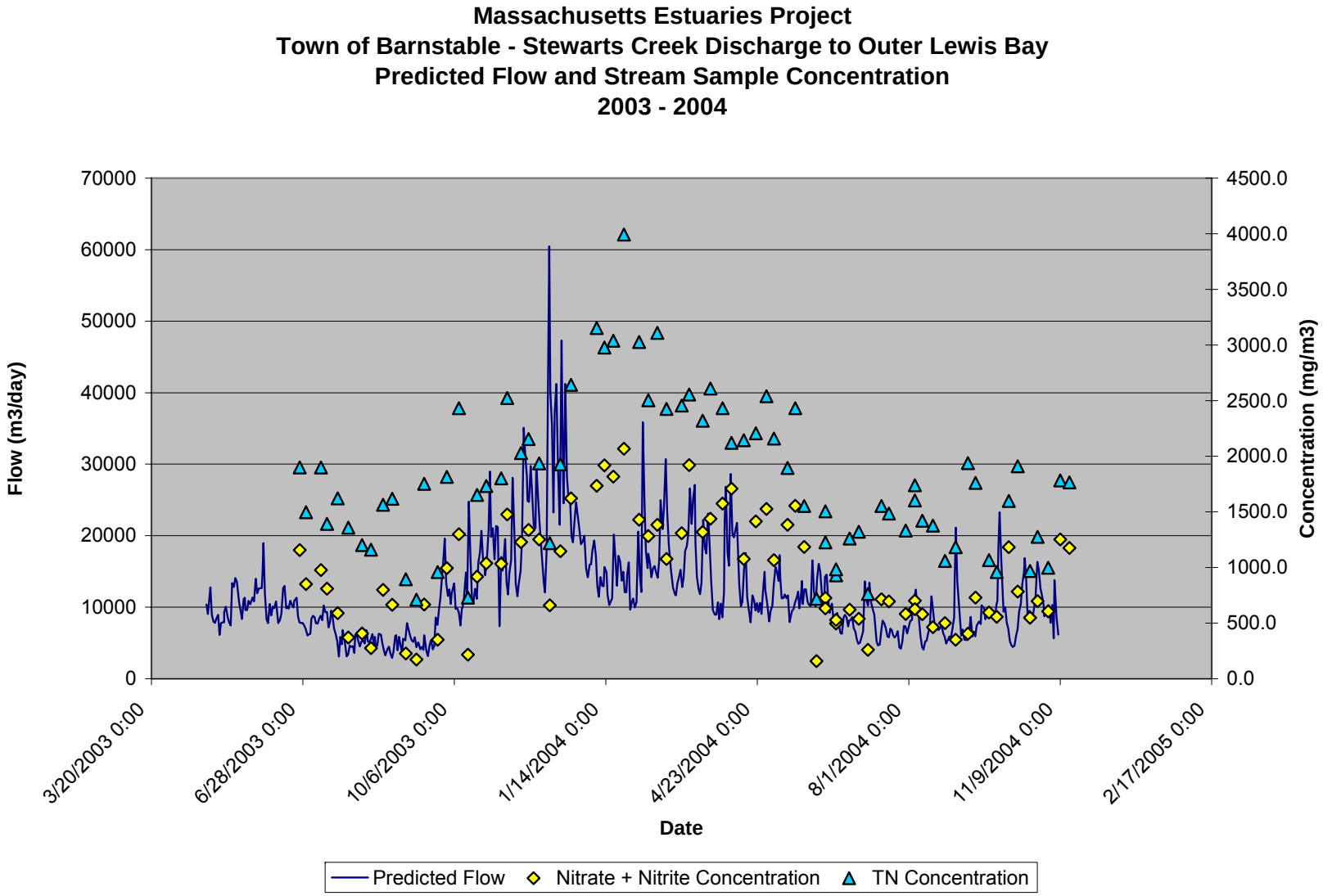


Figure IV-9. Stewart's Creek discharge (solid blue line), nitrate+nitrite (yellow diamond) and total nitrogen (blue triangle) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to outer Lewis Bay (Table IV-6).

From the measured nitrogen load discharged by Stewarts Creek to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon lower nitrogen load (10,560 kg yr^{-1}) discharged from the freshwater Stewarts Creek compared to that added by the various land-uses to the associated watershed (14,959 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and wetland prior to discharge to the estuary is 29% (i.e. 29% of nitrogen input to watershed does not reach the estuary). This slightly lower level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the up gradient ponds and wetland which are essentially shallow flow through systems. The directly measured nitrogen loads from the creek was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

IV.2.4 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge Snow's Creek to Inner Lewis Bay

Snows Creek is a wetland area with open water that resembles a shallow Pond located immediately up gradient of the gage site. The stream outflow from the wetland up gradient of the gage serves as a location for a direct measurement of the nitrogen attenuation occurring in the wetland. The rate of nitrogen attenuation by biogeochemical processes occurring in the wetland was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the wetland above the gage site and the measured annual discharge of nitrogen to inner Lewis Bay relative to the gage, Figure IV-7.

At the Snows Creek gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the discharge that carries nitrogen load from the wetland to the outer portion of Lewis Bay. As the Snows Creek discharge is tidally influenced the gage was located as far above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to range between 4.5 ppt and 11.3 ppt depending on the season. Based on the salinity, a correction was made to the predicted daily flows obtained at the gage to account for the tidal influence. Considering the weekly salinity data, a boundary salinity obtained from a nearby offshore water quality monitoring station and the ability to correct gage data for salinity, the gage location was deemed acceptable for making freshwater flow measurements at low tide. Calibration of the gage was checked monthly. The gage on Snows Creek was installed on April 24, 2003 and was set to operate continuously for 16 months such that two summer seasons would be captured in the flow record. Stage data collection continued until November 8, 2004 for a total deployment of 18 months. The 12-month uninterrupted record used in this analysis encompasses the summer 2003 and 2004 field season.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Snows Creek site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the inner portion of Lewis Bay **(Figure IV-10 and Table IV-6)**. In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for Snows Creek measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from Snows Creek was 20% below the long-term average modeled flows. Measured flow in Snows Creek was obtained for one hydrologic year (September 2003 to August 2004). The average daily flow based on the MEP measured flow data was 5,298 m^3/day compared to the long term average flows determined by the USGS modeling effort (6,339 m^3/day). The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Snows Creek are in part due to a slight tidal influence confounding the freshwater flow record. Due to site constraints, it was necessary to position the stream gage further down gradient in the stream flowing out of the associated marsh. As such, even at low tide, the flow measured in the stream showed a slight salinity as mentioned above. The flow was corrected based on seasonal trends in salinity, however, it is possible that the flow in the stream is a slight under estimate of the freshwater flow discharging to outer Hyannis Harbor. The MEP Technical Team concurred that the under-estimate on flow and therefore load was negligible and used the measured flow and load in the water quality modeling.

Total nitrogen concentrations within the Snows Creek outflow were high, 1.899 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 10.06 kg/day and a measured total annual TN load of 3,673 kg/yr. In the Snows Creek surface water system, nitrate was the predominant form of nitrogen (60%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond, wetland or stream ecosystems. The high concentration of inorganic nitrogen in the out flowing stream waters also suggests that plant production within the up gradient freshwater ecosystems is not nitrogen limited. In addition, the high nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system within the wetland up gradient of the Snows Creek gage.

From the measured nitrogen load discharged by Snows Creek to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon lower nitrogen load (3,673 kg yr^{-1}) discharged from the freshwater Snows Creek compared to that added by the various land-uses to the associated watershed (7,875 kg yr^{-1}), the integrated attenuation in passage through the wetland prior to discharge to the estuary is 53% (i.e. 53% of nitrogen input to watershed does not reach the estuary). This moderate level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the up gradient wetland which is essentially shallow flow through system and the lack of ponds in the sub-watershed to this gage. The directly measured nitrogen loads from the creek was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

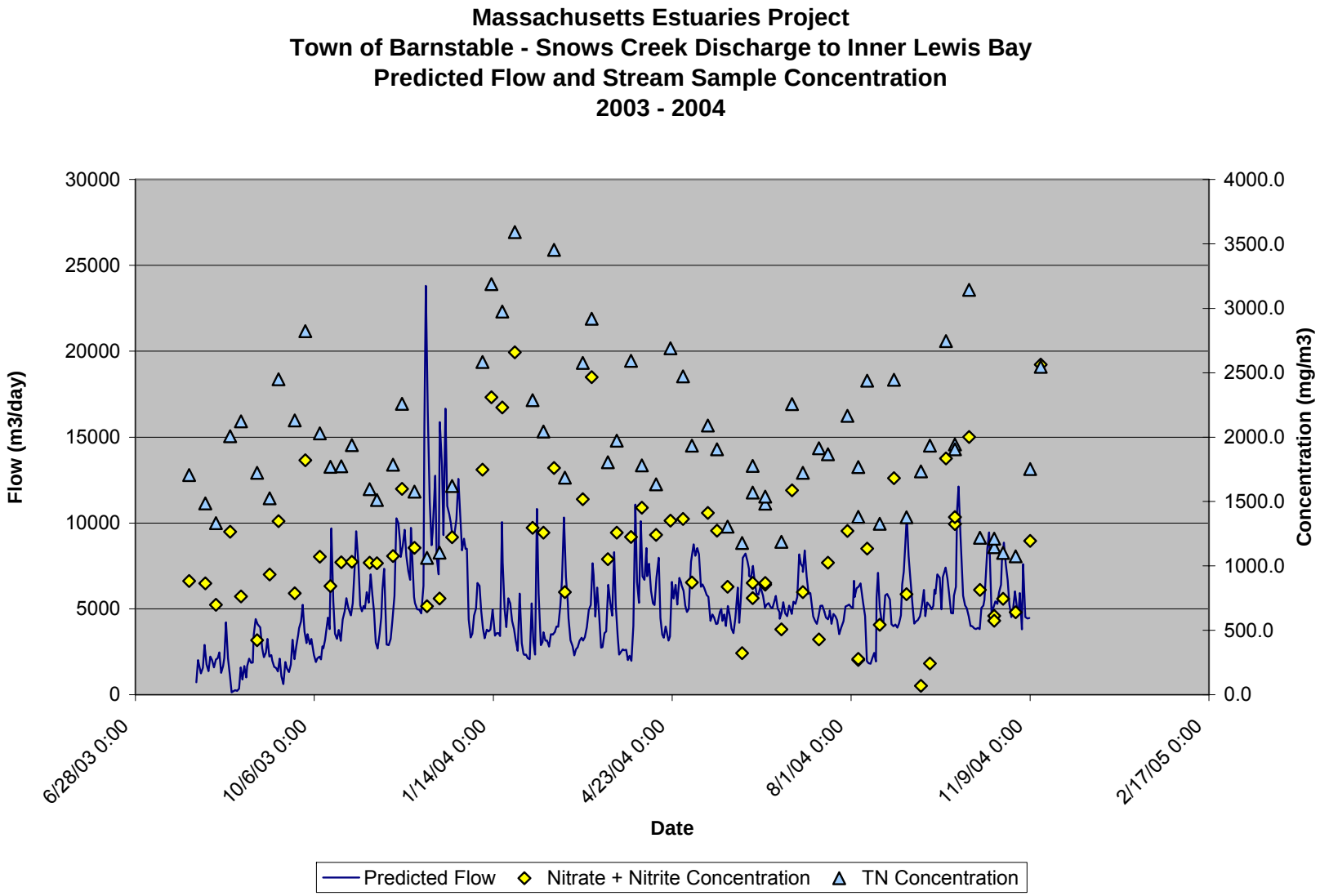


Figure IV-10. Discharge from Snow's Creek (solid blue line), nitrate+nitrite (yellow diamonds) and total nitrogen (blue triangles) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Lewis Bay (Table IV-6).

IV.2.5 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Hospital Bog to Hyannis Inner Harbor

Hospital Bog, located up-gradient of the stream gage site, is a small abandoned cranberry bog that has a stream outflow that provides for a direct measurement of the nitrogen loads and potential attenuation taking place prior to discharge to the inner portion of Hyannis Harbor. In addition, nitrogen attenuation also occurs within the small up-gradient ponds, wetlands and streambed associated with the abandoned bog and the small out flowing stream. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the bog and stream above the gage site and the measured annual discharge of nitrogen to the Lewis Bay system, Figure IV-5.

At the Hospital Bog stream gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the stream that carries the flows and associated nitrogen load to the estuarine reach of Lewis Bay via Hyannis Inner Harbor. As the Hospital Bog stream is tidally influenced the gage was located above the saltwater reach such that freshwater flow at low tide could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to be <0.6 ppt. Therefore, the gage location was deemed acceptable for making freshwater flow measurements. Calibration of the gage was checked monthly. The gage on the stream from Hospital Bog was installed on September 17, 2003 and was set to operate continuously for 16 months such that a complete hydrologic year encompassing both low flow and high flow conditions would be captured in the flow record. Stage data collection continued until April 1, 2005 for a total deployment of 18 months. The 12-month uninterrupted record used in this analysis encompasses the summer 2004 field season. Due to instrument failures, the hydrologic year captured ran from March 2004 to April 2005

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Hospital Bog stream site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the estuarine portion of Hyannis Inner Harbor flowing into Lewis Bay (Figure IV-11 and Table IV-6). In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for the stream from Hospital Bog measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from the Hospital Bog stream was 15% above the long-term average modeled flows. Measured flow in the Hospital Bog stream was obtained for one hydrologic year (March 2004 to April 2005). The average daily flow based on the MEP measured flow data was 1,318 m^3/day compared to the long term average flows determined by the USGS modeling effort (1,126 m^3/day). The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in the Hospital Bog stream was considered to be negligible given the relatively small flow and associated load, as well as the complexity inherent to developing rating curves and predicted

flows in marsh/wetland/bog environments. The negligible difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in the Creek discharging from Hospital Bog would indicate that the Creek is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within the Hospital Bog stream outflow were moderate to low, 1.167 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 1.54 kg/day and a measured total annual TN load of 561 kg/yr. In the Hospital Bog stream, nitrate was slightly more than half of the total nitrogen load (55%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the up-gradient pond, bog or stream ecosystems. The concentration of inorganic nitrogen in the out-flowing stream waters also suggests that plant production within the up gradient freshwater ecosystems is not nitrogen limited. In addition, the high nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system either within Hospital Bog, small up-gradient ponds or along the freshwater reach of the stream.

From the measured nitrogen load discharged by the Hospital Bog stream discharge to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon the lower nitrogen load (561 kg yr^{-1}) discharged from the freshwater stream compared to that added by the various land-uses to the associated watershed (994 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is 43% (i.e. 43% of nitrogen input to watershed does not reach the estuary). This level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the up-gradient bog. The directly measured nitrogen loads from the Hospital Bog stream outflow was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

IV.2.6 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Mill Pond to Mill Creek

Mill Pond, located up gradient of the stream gage site is a moderately sized freshwater pond and unlike many of the freshwater ponds, this pond has stream outflow rather than discharging solely to the aquifer along its down-gradient shore. This stream outflow, the Mill Pond stream, may serve to decrease the pond attenuation of nitrogen, but it also provides for a direct measurement of the nitrogen attenuation. In addition, nitrogen attenuation also occurs within the wetlands and streambed associated with the pond and its out-flowing stream. The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to Mill Pond and the stream above the gage site and the measured annual discharge of nitrogen to the tidal portion of Mill Creek discharging to Lewis Bay, Figure IV-7.

At the Mill Pond stream gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the stream that carries the flows and associated nitrogen load to the estuarine reach of Mill Creek and down-gradient Lewis Bay. As the Mill Pond stream is tidally influenced the gage was located above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly

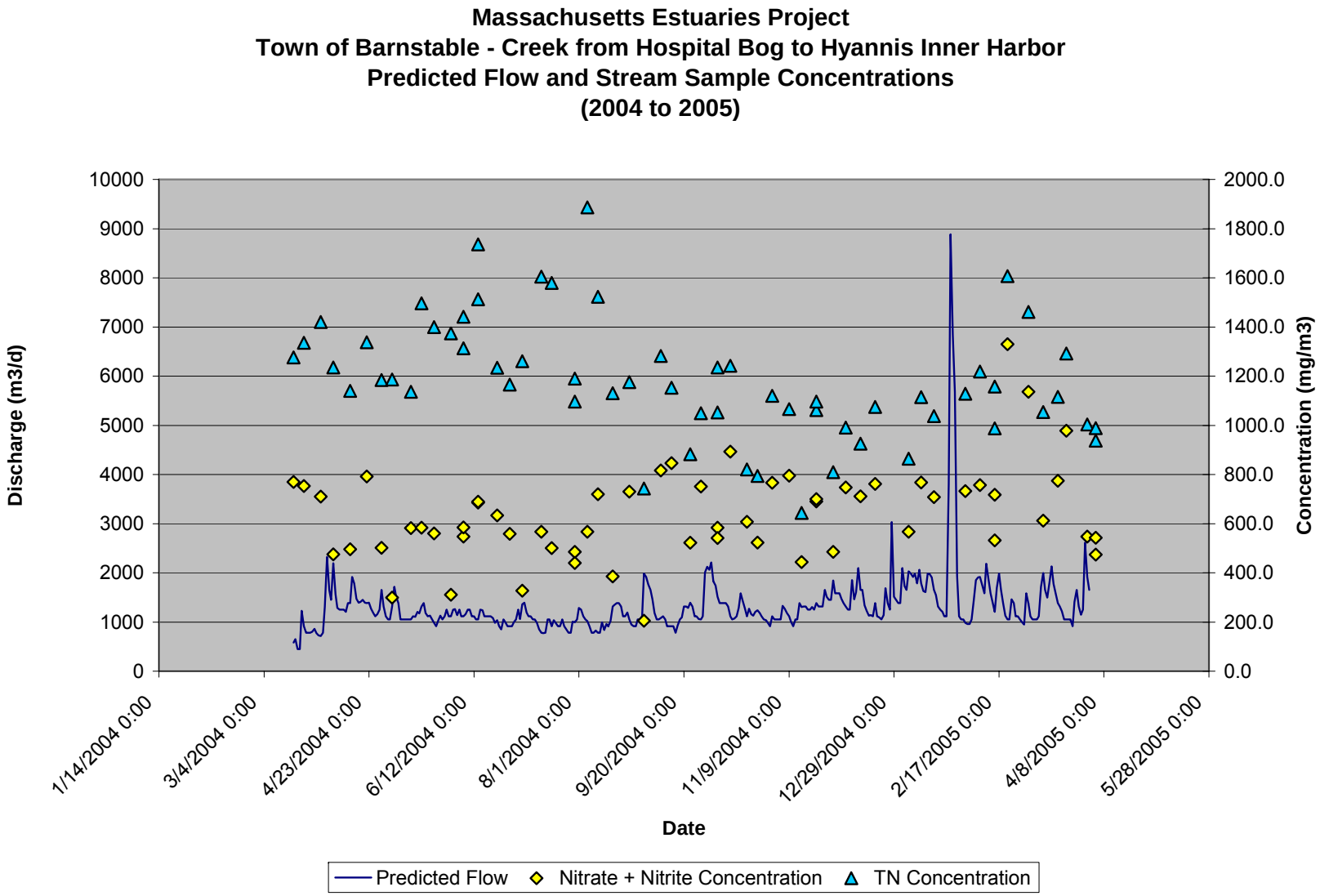


Figure IV-11. Discharge from Hospital Bog (solid blue line), nitrate+nitrite (yellow diamonds) and total nitrogen (blue triangles) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Hyannis Inner Harbor (Table IV-6).

water quality samples collected from the gage site. Average low tide salinity was determined to be <0.2 ppt. Therefore, the gage location was deemed acceptable for making freshwater flow measurements. Calibration of the gage was checked monthly. The gage on the stream from Mill Pond was installed on August 28, 2003 and was set to operate continuously for 16 months such that a complete hydrologic year comprised of both high and low flow periods would be captured in the flow record. Stage data collection continued until April 1, 2005 for a total deployment of 19 months. The 12-month uninterrupted record used in this analysis encompasses the summer 2004 field season.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Mill Pond stream site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the estuarine portion of Mill Creek flowing into Lewis Bay (Figure IV-12 and Table IV-6). In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for the stream from Mill Pond to Mill Creek measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from the Mill Pond stream compared favorably with the long-term average modeled flows. Measured flow in the Mill Pond stream was obtained for one hydrologic year (September 2003 to September 2004). The average daily flow based on the MEP measured flow data was 15,655 m^3/day compared to the long term average flows determined by the USGS modeling effort (15,699 m^3/day). The lack of difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in the Mill Pond stream would indicate that the stream is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within the Mill Pond stream outflow were low to moderate, 1.010 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 15.81 kg/day and a measured total annual TN load of 5,772 kg/yr. In the Mill Pond stream, nitrate was the predominant form of nitrogen (60%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. The high concentration of inorganic nitrogen in the out flowing stream waters also suggests that plant production within the up-gradient freshwater ecosystems is not nitrogen limited. In addition, the high nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system either within Lake Elizabeth or along the freshwater reach of the stream.

From the measured nitrogen load discharged by the Mill Pond stream discharge to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon the lower nitrogen load (5,772 kg yr^{-1}) discharged from the freshwater stream compared to that added by the various land-uses to the associated watershed (6,266 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is 8% (i.e. 8% of nitrogen input to

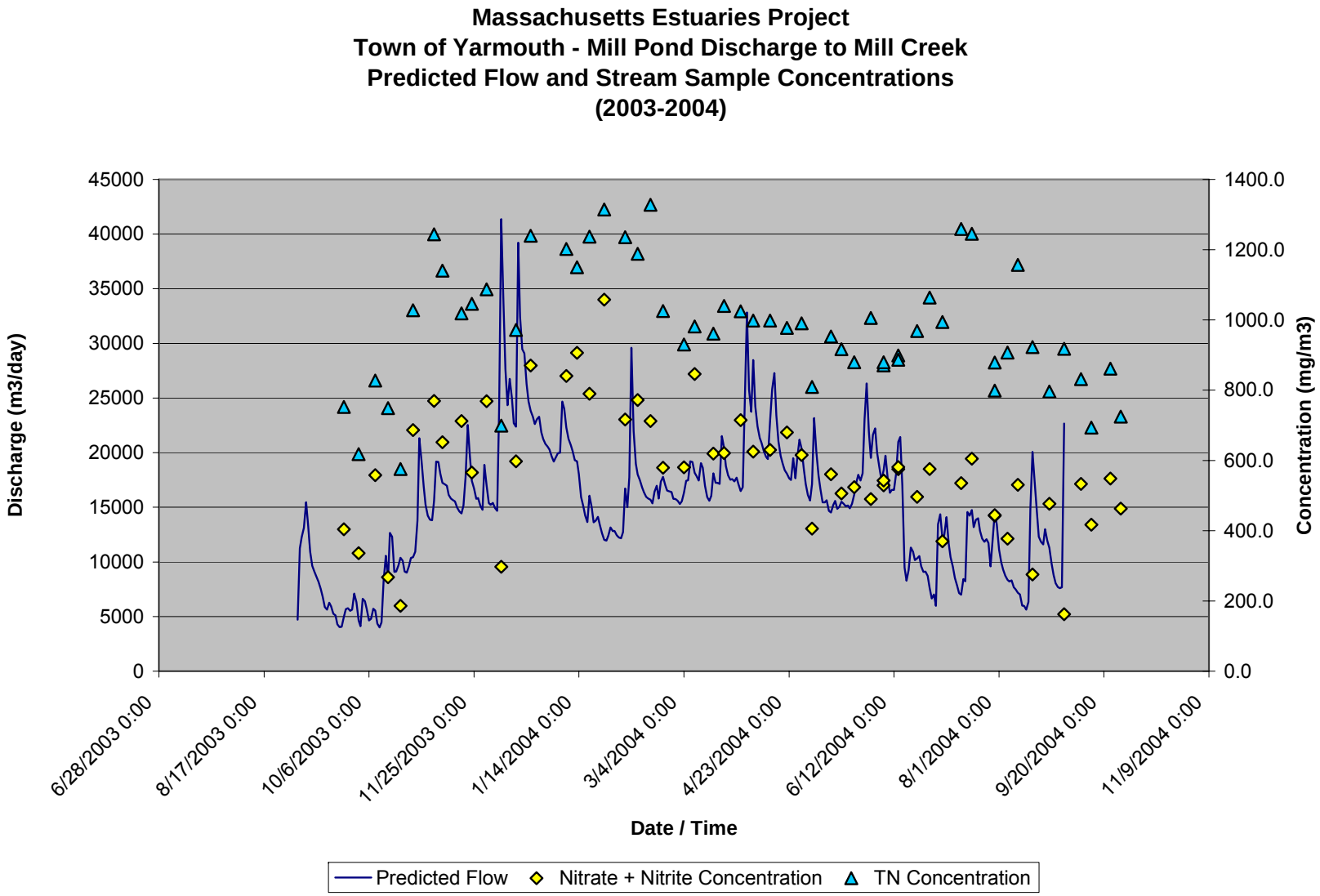


Figure IV-12. Discharge from Mill Pond (solid blue line), nitrate+nitrite (yellow diamond) and total nitrogen (blue triangle) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Mill Creek (Table IV-6).

watershed does not reach the estuary). This low level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the up-gradient pond which is essentially a shallow flow through pond system with small residence time. The directly measured nitrogen loads from the stream was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

IV.2.7 Surface water Discharge and Attenuation of Watershed Nitrogen: Chase Brook Discharge to Mill Creek

Horse Pond, Jabinettes Pond and the cranberry bog up-gradient of the stream gage site is a network of small freshwater ponds and bogs and unlike some aquatic systems on Cape Cod, has stream outflow rather than discharging solely to the aquifer along down-gradient shorelines. The stream outflow, Chase Brook, may serve to decrease the attenuation of nitrogen in up gradient ponds, however, it does provide for a direct measurement of the nitrogen attenuation occurring within the freshwater aquatic system as a whole. In addition, nitrogen attenuation also occurs within the wetlands and streambed associated with the ponds, bogs and the out flowing stream (Chase Brook). The combined rate of nitrogen attenuation by these processes was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the ponds, bogs and stream above the gage site and the measured annual discharge of nitrogen to the tidal portion of Mill Creek discharging to Lewis Bay, Figure IV-7.

At the Chase Brook stream gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the stream that carries the flows and associated nitrogen load to the estuarine reach of Mill Creek and down gradient Lewis Bay. As Chase Brook is tidally influenced the gage was located above the saltwater reach such that freshwater flow could be measured without tidal influence. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gage site. Average low tide salinity was determined to be <0.4 ppt. Therefore, the gage location was deemed acceptable for making freshwater flow measurements. Calibration of the gage was checked monthly. The gage on Chase Brook flowing from the active up-gradient cranberry bog was installed on April 29, 2004 and was set to operate continuously for 16 months such that two summer seasons (2004 and 2005) would be captured in the flow record. Stage data collection continued until November 8, 2005 for a total deployment of 19 months. The 12-month uninterrupted record used in this analysis encompasses the summer 2005 field seasons.

River flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Chase Brook gage site based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allowed for the determination of nitrogen mass discharge to the estuarine portion of Mill Creek and Down gradient Lewis Bay (Figure IV-13 and Table IV-6**)**. In addition, a water balance was constructed based upon the US Geological Survey groundwater flow model to determine long-term average freshwater discharge expected at each gage site.

The annual freshwater flow record for Chase Brook measured by the MEP was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from Chase Brook was 29% above the long-term average modeled flows. Measured flow in Chase Brook was obtained for one hydrologic year

(September 2004 to August 2005). The average daily flow based on the MEP measured flow data was 3,255 m^3/day compared to the long term average flows determined by the USGS modeling effort (2,321 m^3/day). The difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Chase Creek flowing to the estuarine reach of Mill Creek is in part be due to a slight tidal influence confounding the freshwater flow record. Due to site constraints, it was necessary to position the stream gage further down gradient in the stream flowing under Route 28. As such, for small portions of the day head differentials vary thereby potentially limiting freshwater discharge for a small fraction of a 24 hr period. The flow was corrected to account for tidal influence based on the 2 to 4 hours out of every day where the highest part of the tide would be limiting flow in the creek. Even so, it is possible that the flow in the stream is a slight over estimate of the freshwater flow discharging to Mill Creek. The MEP Technical Team concurred that the over-estimate on flow and therefore load was conservative and used the measured flow and load in the water quality modeling.

Total nitrogen concentrations within the Chase Brook outflow were low to moderate, 1.035 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 3.37 kg/day and a measured total annual TN load of 1,230 kg/yr. In Chase Brook, nitrate was nearly half the total nitrogen load (43%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond, bog or stream ecosystems. The concentration of inorganic nitrogen in the out flowing stream water also suggests that plant production within the up gradient freshwater ecosystems is not nitrogen limited. In addition, the moderate nitrate level suggests the possibility for additional uptake by freshwater systems might be accomplished in this system either within the bog, Horse Pond, Jabinettes Pond or along the freshwater reach of the stream.

From the measured nitrogen load discharged by Chase Brook to the estuary and the nitrogen load determined from the watershed based land use analysis, it appears that there is nitrogen attenuation of upper watershed derived nitrogen during transport to the estuary. Based upon the lower nitrogen load (1,230 kg yr^{-1}) discharged from the freshwater stream compared to that added by the various land-uses to the associated watershed (1,911 kg yr^{-1}), the integrated attenuation in passage through ponds, streams and freshwater wetlands prior to discharge to the estuary is 36% (i.e. 36% of nitrogen input to watershed does not reach the estuary). This relatively low level of attenuation compared to other streams evaluated under the MEP is expected given the hydraulic nature of the up-gradient ponds and bog which are essentially flow through aquatic systems with relatively short residence times. The directly measured nitrogen loads from Chase Brook was used in the Linked Watershed-Embayment Modeling of water quality (see Chapter VI, below).

IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS

The overall objective of the benthic nutrient flux Surveys was to quantify the summertime exchange of nitrogen, between the sediments and overlying waters throughout the Lewis Bay Embayment System. The mass exchange of nitrogen between water column and sediments is a fundamental factor in controlling nitrogen levels within coastal waters. These fluxes and their associated biogeochemical pools relate directly to carbon, nutrient and oxygen dynamics and the nutrient related ecological health of these shallow marine ecosystems. In addition, these data are required for the proper modeling of nitrogen in shallow aquatic systems, both fresh and salt water.

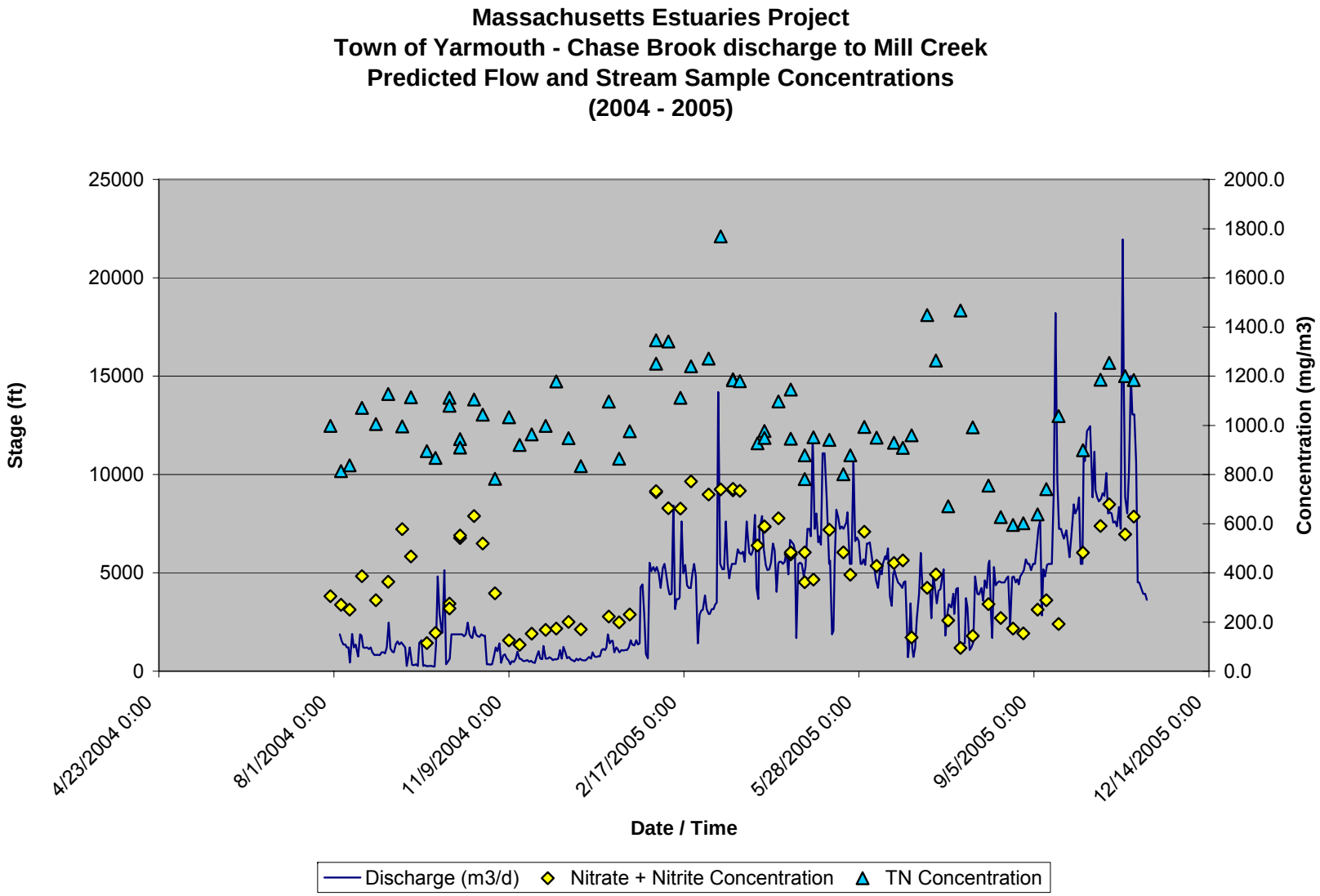


Figure IV-13. Discharge from Chase Brook (solid blue line), nitrate+nitrite (yellow diamond) and total nitrogen (blue triangle) concentrations for determination of annual volumetric discharge and nitrogen load from the upper watershed to Mill Creek (Table IV-6).

Table IV-7. Summary of annual volumetric discharge and nitrogen load from the Rivers and Streams (freshwater) discharging to the Lewis Bay system based upon the data presented in Figures IV-6 through IV-9 and Table IV-6.

EMBAYMENT SYSTEM	PERIOD OF RECORD	DISCHARGE (m3/year)	ATTENUATED LOAD (Kg/yr)	
			Nox	TN
Halls Creek (MEP)	**September 1, 2003 to August 31, 2004**	**432597**	**367**	**583**
Halls Creek (CCC)	Based on Watershed Area and Recharge	541985	--	--
Stewart's Creek (Freshwater) MEP	**September 1, 2003 to August 31, 2004**	**5097413**	**5943**	**10560**
Stewart's Creek (Freshwater) CCC	Based on Watershed Area and Recharge	3544836	--	--
Snow's Creek (Freshwater) MEP	**September 1, 2003 to August 31, 2004**	**1933944**	**2206**	**3673**
Snow's Creek (Freshwater) CCC	Based on Watershed Area and Recharge	2313712	--	--
Creek to Hyannis Inner Harbor (MEP) aka. Hospital Bog	**September 1, 2004 to August 31, 2005**	**480912**	**309**	**561**
Creek to Hyannis Inner Harbor (CCC) aka. Hospital Bog	Based on Watershed Area and Recharge	410961	--	--
Mill Pond Stream (MEP)	**September 24, 2003 to September 23, 2004**	**5714176**	**3465**	**5772**
Mill Pond Stream (CCC)	Based on Watershed Area and Recharge	5730166	--	--
Chase Brook (MEP)	**September 1, 2004 to August 31, 2005**	**1188175**	**535**	**1230**
Chase Brook (CCC)	Based on Watershed Area and Recharge	847273	--	--

IV.3.1 Sediment-Watercolumn Exchange of Nitrogen

As stated in above sections, nitrogen loading and resulting levels within coastal embayments are the critical factors controlling the nutrient related ecological health and habitat quality within a system. Nitrogen enters the complex Lewis Bay Embayment System predominantly in highly bioavailable forms from the surrounding upland watershed and more refractory forms in the inflowing tidal waters. If all of the nitrogen remained within the water column (once it entered) then predicting water column nitrogen levels would be simply a matter of determining the watershed loads, dispersion, and hydrodynamic flushing. However, as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bioavailable form nitrate. This nitrate and other bioavailable forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved forms into phytoplankton "particles". Most of these "particles" remain in the water column for sufficient time to be flushed out to a down gradient larger water body (like Nantucket Sound). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals and deposited on the bottom. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence), a fraction of the phytoplankton with their associated nitrogen "load" become incorporated into the surficial sediments of the bays.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within enclosed tributary basins, particularly if they are deeper than the adjacent embayment. To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary.

Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic (oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter with its nitrogen content that bioavailable nitrogen is returned to the embayment water column for another round of uptake by phytoplankton. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that have been investigated by SMAST and the MEP, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. In contrast in some systems, with salt marsh tidal creeks, the sediments can be a net sink for nitrogen even during summer (e.g. Mashapaquit Creek Salt Marsh, West Falmouth Harbor; Centerville River Salt Marsh). The Mill Creek sub-embayment of the Lewis Bay System is predominantly such a salt marsh basin, as is the adjacent estuary of Halls Creek. Embayment basins can also be net sinks for nitrogen to the extent that they support relatively oxidized surficial sediments, such as found within much of the bordering region to the Lewis Bay main basin. In contrast, regions of high deposition like Hyannis Inner Harbor, which is essentially a dredged boat basin and channel, typically support anoxic sediments with elevated rates of nitrogen release during summer months. The consequence of this deposition is that the basin sediments are unconsolidated, organic rich and sulfidic nature (MEP field observations).

Failure to account for the site-specific nitrogen balance of the sediments and its spatial variation from the tidal creeks and embayment basins will result in significant errors in determination of the threshold nitrogen loading to the Lewis Bay System. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both

recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

IV.3.2 Method for determining sediment-watercolumn nitrogen exchange

For the Lewis Bay Embayment System, and Halls Creek in order to determine the contribution of sediment regeneration to nutrient levels during the most sensitive summer interval (July-August), sediment samples were collected and incubated under *in situ* conditions. Sediment samples were collected from 28 sites, 24 within Lewis Bay and its tributary sub-embayments and 4 in the nearby Halls Creek Salt Marsh (Figure IV-14) in July-August 2004. Measurements of total dissolved nitrogen, nitrate + nitrite, ammonium were made in time-series on each incubated core sample.

Rates of nitrogen release were determined using undisturbed sediment cores incubated for 24 hours in temperature-controlled baths. Sediment cores (15 cm inside diameter) were collected by SCUBA divers and cores transported by small boat to a shore side field lab. Cores were maintained from collection through incubation at *in situ* temperatures. Bottom water was collected and filtered from each core site to replace the headspace water of the flux cores prior to incubation. The number of core samples from each site (Figure IV-14 per incubation are as follows:

Lewis Bay Embayment System Benthic Nutrient Regeneration Cores

- Lewis Bay East-1 1 core (Basin)
- Lewis Bay East-2 1 core (Basin)
- Lewis Bay East-3 1 core (Basin)
- Lewis Bay East-4 1 core (Basin)
- Lewis Bay Main-5 1 core (Basin)
- Lewis Bay Main-6 1 core (Basin)
- Lewis Bay Main-12 1 core (Basin)
- Lewis Bay Main-13 1 core (Basin)
- Lewis Bay Main-14 1 core (Basin)
- Lewis Bay Main-15 1 core (Basin)
- Lewis Bay Main-16 1 core (Basin)
- Lewis Bay West-17 1 core (Basin)
- Lewis Bay West-18 1 core (Basin)
- Lewis Bay West-19 1 core (Basin)
- Mill Creek - 9 1 core (Marsh Basin)
- Mill Creek -10 1 core (Marsh Basin)
- Mill Creek -11 1 core (Marsh Basin)
- Hyannis Hbr Outer-20 1 core (Basin)
- Hyannis Hbr Inner-21 1 core (Basin)
- Hyannis Hbr Inner-22 1 core (Basin)
- Hyannis Hbr Marina-23 1 core (Basin)
- Uncle Roberts Cove-7 1 core (Basin)
- Uncle Roberts Cove-8 1 core (Basin)

Halls Creek Salt Marsh Benthic Nutrient Regeneration Cores

- Halls Creek -7 1 core (Marsh Creek)
- Halls Creek -8 1 core (Marsh Creek)
- Halls Creek Lower -5 1 core (Marsh Creek)
- Halls Creek -6 1 core (Marsh Creek)



Figure IV-14. Lewis Bay and Halls Creek embayment system sediment sampling sites (green symbols) for determination of nitrogen regeneration rates. Numbers are for reference to station identifications listed above.

Sampling was distributed throughout the primary embayment sub-basins of this system: Mill Creek, Hyannis Inner Harbor, Uncle Roberts Cove, Lewis Bay (and adjacent Halls Creek Salt Marsh) and the results for each site combined for calculating the net nitrogen regeneration rates for the water quality modeling effort.

Sediment-water column exchange follows the methods of Jorgensen (1977), Klump and Martens (1983), and Howes *et al.* (1998) for nutrients and metabolism. Upon return to the field laboratory (Harbormasters Office) the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with filtered water), filtered into acid leached polyethylene bottles and held on ice for nutrient analysis. Ammonium (Scheiner 1976) and ortho-phosphate (Murphy and Reilly 1962) assays were conducted within 24 hours and the remaining samples frozen (-20°C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia *et al.* 1977). Rates were determined from linear regression of analyte concentrations through time.

Chemical analyses were performed by the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST) at the University of Massachusetts in New Bedford, MA. The laboratory follows standard methods for saltwater analysis and sediment geochemistry.

IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments

Water column nitrogen levels are the balance of inputs from direct sources (land, rain etc), losses (denitrification, burial), regeneration (water column and benthic), and uptake (e.g. photosynthesis). As stated above, during the warmer summer months the sediments of shallow embayments typically act as a net source of nitrogen to the overlying waters and help to stimulate eutrophication in organic rich systems. However, some sediments may be net sinks for nitrogen and some may be in "balance" (organic N particle settling = nitrogen release). Sediments may also take up dissolved nitrate directly from the water column and convert it to dinitrogen gas (termed "denitrification"), hence effectively removing it from the ecosystem. This process is typically a small component of sediment denitrification in embayment sediments, since the water column nitrogen pool is typically dominated by organic forms of nitrogen, with very low nitrate concentrations. However, this process can be very effective in removing nitrogen loads in some systems, particularly in streams, ponds and salt marshes, where overlying waters support high nitrate levels.

In addition to nitrogen cycling, there are ecological consequences to habitat quality of organic matter settling and mineralization within sediments, these relate primarily to sediment and water column oxygen status. However, for the modeling of nitrogen within an embayment it is the relative balance of nitrogen input from water column to sediment versus regeneration which is critical. Similarly, it is the net balance of nitrogen fluxes between water column and sediments during the modeling period that must be quantified. For example, a net input to the sediments represents an effective lowering of the nitrogen loading to down-gradient systems and net output from the sediments represents an additional load.

The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the organic levels within the sediment (oxic/anoxic) and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake

throughout the summer months, even though organic nitrogen is being mineralized and released to the overlying water as well. The rate of nitrate uptake, simply dominates the overall sediment nitrogen cycle.

In order to model the nitrogen distribution within an embayment it is important to be able to account for the net nitrogen flux from the sediments within each part of each system. This requires that an estimate of the particulate input and nitrate uptake be obtained for comparison to the rate of nitrogen release. Only sediments with a net release of nitrogen contribute a true additional nitrogen load to the overlying waters, while those with a net input to the sediments serve as an "in embayment" attenuation mechanism for nitrogen.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure IV-15).

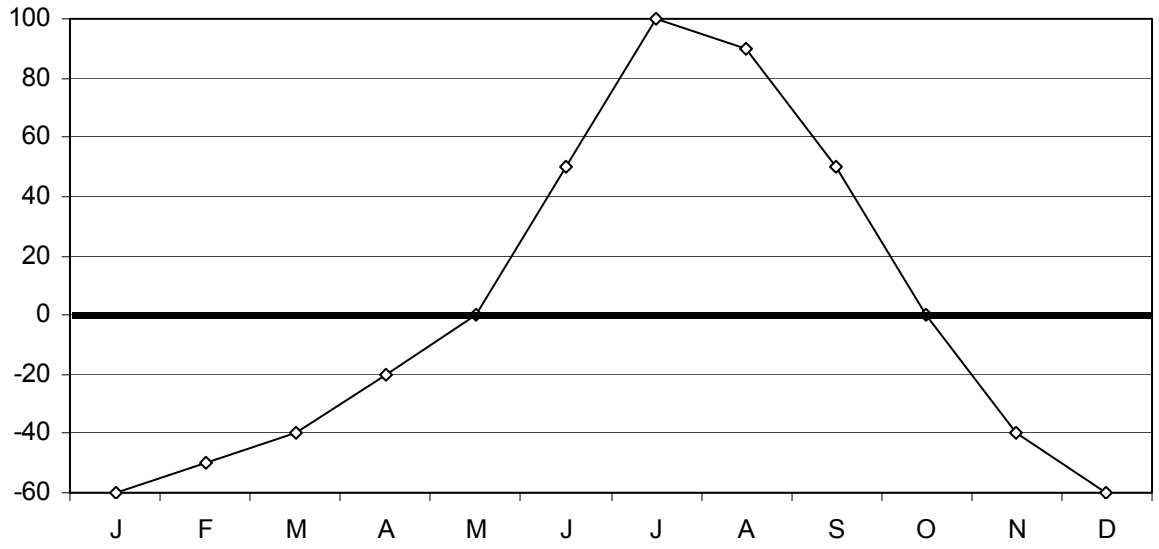


Figure IV-15 Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen

during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates.

In order to determine the net nitrogen flux between water column and sediments, all of the above factors were taken into account. The net input or release of nitrogen within a specific embayment was determined based upon the measured total dissolved nitrogen uptake or release, and estimate of particulate nitrogen input.

Sediment sampling was conducted throughout the primary embayment sub-basins of this system: Mill Creek, Hyannis Inner Harbor, Uncle Roberts Cove, Lewis Bay (and adjacent Halls Creek Salt Marsh) in order to obtain the nitrogen regeneration rates required for parameterization of the water quality model. The distribution of cores was established to cover gradients in sediment type, flow field and phytoplankton density. For each core the nitrogen flux rates (described in the section above) were evaluated relative to measured sediment organic carbon and nitrogen content and sediment type and an analysis of each site's tidal flow velocities. The maximum bottom water flow velocity at each coring site was determined from the hydrodynamic model. These data were then used to determine the nitrogen balance within each sub-embayment.

The magnitude of the settling of particulate organic carbon and nitrogen into the sediments was accomplished by determining the average depth of water within each sediment site, the average summer particulate carbon and nitrogen concentration within the overlying water and the tidal velocities from the hydrodynamic model (Chapter V). Two levels of settling were used. If the sediments were organic rich and fine grained, and the hydrodynamic data showed low tidal velocities, then a water column particle residence time of 8 days was used (based upon phytoplankton and particulate carbon studies of poorly flushed basins). If the sediments indicated coarse-grained sediments and low organic content and high velocities, then half this settling rate was used. Adjusting the measured sediment releases was essential in order not to over-estimate the sediment nitrogen source and to account for those sediment areas which are net nitrogen sinks for the aquatic system. This approach has been previously validated in outer Cape Cod embayments (Town of Chatham embayments) by examining the relative fraction of the sediment carbon turnover (total sediment metabolism), which would be accounted for by daily particulate carbon settling. This analysis indicated that sediment metabolism in the highly organic rich sediments of the wetlands and depositional basins is driven primarily by stored organic matter (ca. 90%). Also, in the more open lower portions of larger embayments, storage appears to be low and a large proportion of the daily carbon requirement in summer is met by particle settling (approximately 33% to 67%). This range of values and their distribution is consistent with ecological theory and field data from shallow embayments. Additional, validation has been conducted on deep enclosed basins (with little freshwater inflow), where the fluxes can be determined by multiple methods. In this case the rate of sediment regeneration determined from incubations was comparable to that determined from whole system balance.

Net nitrogen release or uptake from the sediments within the Lewis Bay Embayment System (and adjacent Halls Creek) were comparable to other similar embayments with similar configuration and flushing rates in southeastern. Massachusetts. In addition, the pattern of sediment N release was also similar to other systems, with the salt marsh basins and creeks showing net nitrogen uptake, the embayment depositional basins showing net nitrogen release and the marginal main basin sediments, which were oxidized, showing net nitrogen uptake. Sediment nitrogen release in the central basin of Lewis Bay and the smaller enclosed basins of Uncle Roberts Cove and Hyannis Harbor were low to moderate, ranging from 6.9 mg N m^{-2} d^{-1}

in the main basin to 1.73 - 63.8 mg N m^{-2} d^{-1} in the enclosed basins. These rates are consistent with the depositional nature of these basins and the more nutrient enriched waters of the smaller tributary basins. Only the highly organic anoxic sediments of the dredged basin in the marina region of inner Hyannis Harbor showed high rates of nitrogen release. This data is consistent with the clearly high deposition in this region and the sulfidic nature of the sediments. The finding of higher rates of summer nitrogen release in smaller semi enclosed basins is common on Cape Cod. For example Rock Harbor, Orleans, showed moderate/high rates of nitrogen release, 80.8 mg N m^{-2} d^{-1}, similar to the Pleasant Bay sub-basins of Meetinghouse Pond, Areys Pond, Paw Wah Pond, 79.5, 107.3, 120.7 mg N m^{-2} d^{-1}, respectively, whereas the main basins of Pleasant Bay were similar to the main basin of Lewis Bay, -1.1 to 16.0 mg N m^{-2} d^{-1}. In addition, the salt marsh rates of uptake were also similar to other nearby marsh systems. For example, net nitrogen uptake Mill Creek (-14.3 mg N m^{-1} d^{-1}) was similar to that observed for the salt marsh areas in the Centerville River System (-4.5 to -13.2 mg N m^{-1} d^{-1}) and lower Halls Creek, -11.1 mg N m^{-1} d^{-1} (MEP Centerville River Final Nutrient Technical Report 2006) a general pattern seen in a number of estuaries of similar structure within the MEP region (MEP Cockle Cove Technical Memorandum-Howes et al. 2006).

Net nitrogen release rates for use in the water quality modeling effort for the component sub-basins of the Lewis Bay Embayment System (Chapter VI) are presented in Table IV-8. There was a clear spatial pattern of sediment nitrogen flux, with net uptake of nitrogen by the salt marsh basin and marginal Lewis Bay basin sediments and net release by the sediments of the depositional regions of the embayment system. The sediments within the Lewis Bay Embayment System showed nitrogen fluxes typical of similarly structured systems within the region and appear to be in balance with the overlying waters and the nitrogen flux rates consistent with the level of nitrogen loading to this system and its relatively high flushing rate.

Table IV-8. Rates of net nitrogen return from sediments to the overlying waters of the Lewis Bay Estuarine System and the adjacent Halls Creek Salt Marsh. These values are combined with the basin areas to determine total nitrogen mass in the water quality model (see Chapter VI). Measurements represent July -August rates.

Location	Sediment Nitrogen Flux (mg N m^{-2} d^{-1})			i.d. *
	Mean	S.E.	# sites	
Lewis Bay Embayment System				
Mill Creek Salt Marsh Basin	-14.3	7.6	3	LWB 9,10,11
Hyannis Harbor - Outer	63.8	39.6	2	LWB 20, 21
Hyannis Harbor - Inner	20.4	16.2	2	LWB 22,23
Hyannis Harbor - Marina	143.5	3.6	1	LWB 24
Uncle Roberts Cove	17.3	13.4	2	LWB 7,8
Lewis Bay East Basin	-11.6	12.7	4	LWB 1,2,3,4
Lewis Bay Main Basin	6.9	18.7	7	LWB 5,6,12-16
Lewis Bay West Basin	-32.0	8.8	3	LWB 17-19
Halls Creek Salt Marsh				
Halls Creek Upper	31.6	2.3	2	HC 7,8
Halls Creek Lower	-11.1	7.0	2	HC 5,6

* Station numbers refer to Figure IV-14.

V. HYDRODYNAMIC MODELING

V.1 INTRODUCTION

This section summarizes field data collection effort and the development of hydrodynamic models for the Lewis Bay and Hyannis Harbor estuary and the separate Halls Creek salt marsh systems (Figure V-1). For these systems, the final calibrated hydrodynamic model offers an understanding of water movement through each estuary, and provides the first step towards evaluating water quality, as well as tool for later determining nitrogen loading "thresholds". Tidal flushing information is utilized as the basis for a quantitative evaluation of water quality. Nutrient loading data combined with measured environmental parameters within the various sub-embayments become the basis for an advanced water quality model based on total nitrogen concentrations. This type of model provides a tool for evaluating existing estuarine water quality, as well as determining the likely positive impacts of various alternatives for improving overall estuarine health, enabling the bordering residence to understand how pollutant loadings into the estuary will affect the biochemical environment and its ability to sustain a healthy marine habitat.

In general, water quality studies of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. For example, the spread of pollutants may be analyzed from tidal current information developed by the numerical models.

Estuarine water quality is dependent upon nutrient and pollutant loading and the processes that help flush nutrients and pollutants from the estuary (e.g., tides and biological processes). Relatively low nutrient and pollutant loading and efficient tidal flushing are indicators of high water quality. The ability of an estuary to flush nutrients and pollutants is proportional to the volume of water exchanged with a high quality water body (i.e. Nantucket Sound). Several embayment-specific parameters influence tidal flushing and the associated residence time of water within an estuary. For the Lewis Bay and Halls Creek systems, the most important parameters are the tide range along with the shape, length and depth of the estuary.

Shallow coastal embayments are the initial recipients of freshwater flows (i.e., groundwater and surface water) and the nutrients they carry. An embayment's shape influences the time that nutrients are retained in them before being flushed out to adjacent open waters, and their shallow depths both decrease their ability to dilute nutrient (and pollutant) inputs and increase the secondary impacts of nutrients recycled from the sediments. Degradation of coastal waters and development are tied together through inputs of pollutants in runoff and groundwater flows, and to some extent through direct disturbance, i.e. boating, oil and chemical spills, and direct discharges from land and boats. Excess nutrients, especially nitrogen, promote phytoplankton blooms and the growth of epiphytes on eelgrass and attached algae, with adverse consequences including low oxygen, shading of submerged aquatic vegetation, and aesthetic problems.

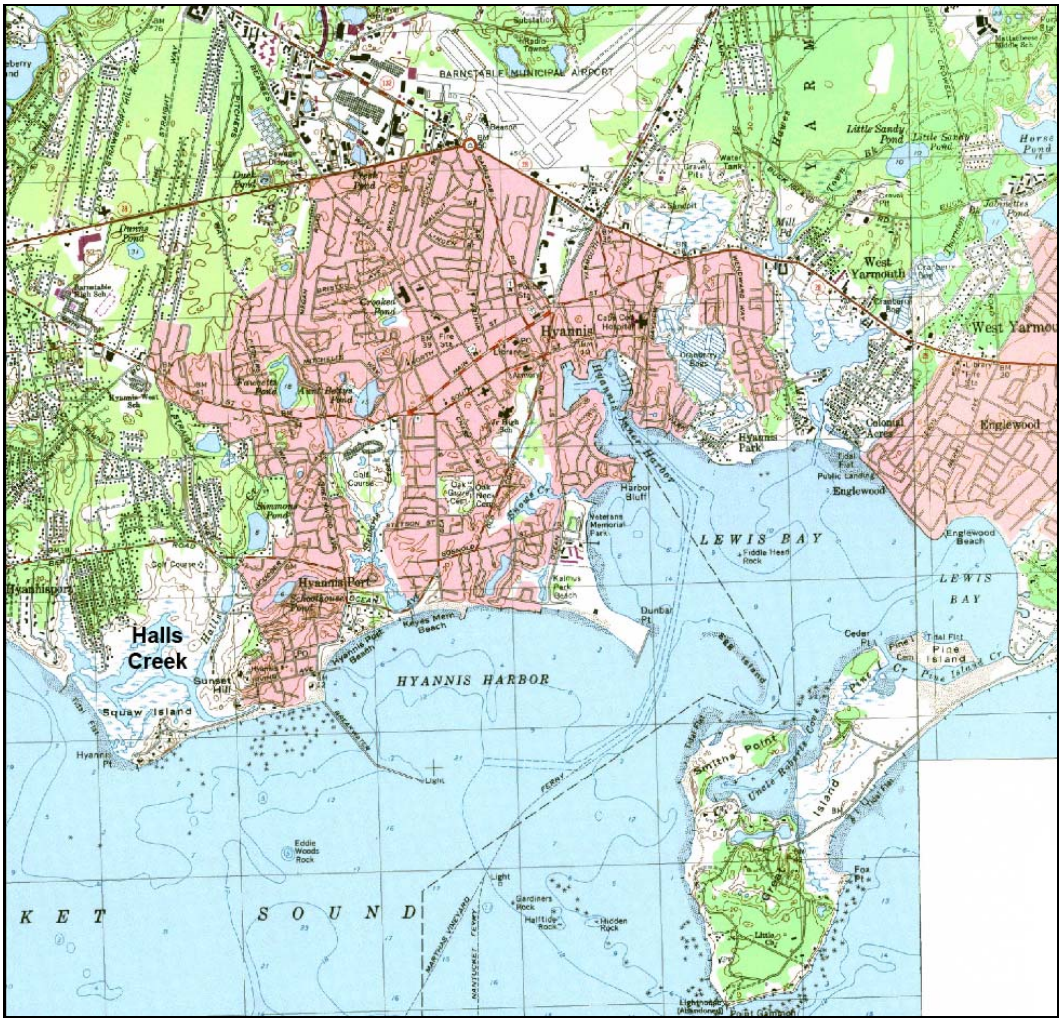


Figure V-1. Map of the Lewis Bay and Halls Creek estuary systems (from United States Geological Survey topographic maps).

To understand the dynamics of Lewis Bay and Halls Creek, a hydrodynamic study was performed for both separate systems. Lewis Bay is surrounded by the towns of Barnstable and Yarmouth along the south coast of Cape Cod, Massachusetts, while Halls Creek lies within the municipal boundary of Barnstable. A site map showing the study area is shown in Figure V-1.

The Lewis Bay system includes Hyannis Harbor which is the entrance to the system from Nantucket Sound. There is minimal restriction from Nantucket Sound into Hyannis Harbor, except for a rubble mound jetty located along the west edge of the harbor. Along the north side of the Hyannis Harbor is Stewarts Creek, a shallow sub-embayment connected through a 36-inch culvert. Lewis Bay opens out from Hyannis Harbor and has a number of smaller embayments along its boundary. Snows Creek to the west, Hyannis Inner Harbor and Mill Creek to the north, Sweetheart and Pine Island Creeks to the east, and to the south is Uncle Roberts Cove. The approximate tidal range within the system is 5.5 feet, with Nantucket Sound tidal variations providing the hydraulic forcing that drives water movement throughout the system.

Lewis Bay and the adjoining embayments are shallow tidal estuaries, with a mean water depth of only 3.0 feet. Salt marsh areas are contained on the margins of the smaller embayments off of Lewis Bay. The smaller embayments contain approximately 110 acres of marsh, which accounts for 5 percent of the total estuary surface area.

The entire Halls Creek system has a surface coverage of 140 acres, which includes 82 acres of marsh plain. Like Lewis Bay, circulation in Halls Creek is dominated by tidal exchange with Nantucket Sound, through an inlet with one jetty. This system also has a shallow mean depth (approximately -0.4 feet NGVD)

Since the water elevation difference between Nantucket Sound and the inland reaches of Lewis Bay and Halls Creek are the primary driving force for tidal exchange, the local tide range naturally limits the volume of water flushed during a tidal cycle. Tidal damping (reduction in tidal amplitude) along the length of the bay is negligible, indicating a system that flushed efficiently. Any issues with water quality, therefore, would likely be due other factors including nutrient loading conditions from the system's watersheds, and the tide range in Nantucket Sound.

Circulation in Lewis Bay and Halls Creek systems were simulated using the RMA-2 numerical hydrodynamic model. To calibrate the model, field measurements of water elevations and bathymetry were required. For Lewsi Bay, tide data were acquired within Nantucket Sound at a gage station installed offshore of Hyannis Harbor, and also at nine stations located within the estuary (Figure V-2). For Halls Creek, tide data were collected at a station offshore in the system, in Nantucket Sound, and also at a station inside the Creek Inlet (Figure V-3). All temperature-depth recorders (TDRs or tide gages) were installed for at least a 30-day period to measure tidal variations through one lunar month. In this manner, attenuation of the tidal signal as it propagates through the various sub-embayments was evaluated accurately.

V.2 FIELD DATA COLLECTION AND ANALYSIS

Accurate modeling of system hydrodynamics is dependent upon measured conditions within an estuary for two important reasons:

- To define accurately the system geometry and boundary conditions for the numerical model
- To provide 'real' observations of hydrodynamic behavior to calibrate and verify the model results

System geometry is defined by the shoreline of the system, including all coves, creeks, and marshes, as well as accompanying depth (or bathymetric) information. The three-dimensional surface of the estuary is mapped as accurately as possible, since the resulting hydrodynamic behavior is strongly dependent upon features such as channel widths and depths, sills, marsh elevations, and inter-tidal flats. Hence, this study included an effort to collect bathymetric information in the field.

Boundary conditions for the numerical model consist of variations of water surface elevations measured in Nantucket Sound. These variations result principally from tides, and provide the dominant hydraulic forcing for the system, and are the principal forcing function applied to the model. Additional pressure sensors were installed at selected interior locations to measure variations of water surface elevation along the length of the system (gauging locations are shown in Figure V-2). These measurements were used to calibrate and verify the model results, and to assure that the dynamic of the physical system were properly simulated.

To complete the field data collection effort for this study, and to provide model verification data, a survey of velocities was completed at the entrance to Lewis Bay, Inner Hyannis Harbor, and Mill Creek. The survey was performed to determine flow rates at the inlets at discreet times during the course of a full tide cycle.

V.2.1. Bathymetry

Bathymetry data (i.e., depth measurements) for the hydrodynamic models of the Lewis Bay and Halls Creek systems were assembled from a hydrographic survey performed specifically for this study and historical NOS survey data, where availible. The NOS data were used for areas in Nantucket Sound that were not covered by the more recent survey.

The hydrographic surveys of both systems were conducted in July of 2004. The survey of Lewis Bay was designed to collect coverage of the shallow water areas between Hyannis Harbor and Lewis Bay, Mill Creek, Pine Island Creek, Uncle Roberts Cove, and Snows Creek. Survey transects were densest in the vicinity of the inlets, were the greatest variability in bottom bathymetry was expected. Bathymetry data in the inlets of each separate system are important from the standpoint that it has the most influence on tidal circulation in and out of the estuary.

Each survey utilized a small boat with an installed precision fathometer (with a depth resolution of approximately 0.1 foot), coupled together with a differential GPS to provide position measurements accurate to approximately 1-3 feet. In the shallow channels of each system, soundings were collected manually using a graduated staff. For both the fathometer and manual portions of the survey, positioning data were collected using a differential GPS.

All bathymetry data were tide corrected, and referenced to the North Geodetic Vertical Datum of 1929 (NGVD 29), using survey benchmarks located in the project area. Once rectified, the finished processed data were archived as ‘xyz’ files containing x-y horizontal position (in Massachusetts State Plan 1983 coordinates) and vertical elevation of the bottom (z). These xyz files were then interpolated into the finite element mesh used for the hydrodynamic simulations. The final processed bathymetric data from the survey are presented in Figure V-3 for Lewis Bay and V-4 for Halls Creek.

Results from the survey show that the deepest point (-9.9 ft NGVD) within Halls Creek is located in the inlet channel. The remaining channels of the Creek are generally shallow, between -2.0 and 0.0 ft NGVD. Apart from the marsh plain, the shallowest area of the Creek is located at the small flood shoal near the inlet, were the minimum depth is +1.5 NGVD.

In Lewis Bay, the greatest depths (approximately -15 ft NGVD) are found within the main navigation channel. Beyond the channel, the greatest natural depth is approximately -13 ft NGVD. Outside Lewis Bay, in Hyannis Harbor the greatest water depths within the breakwater are more than 20 ft.

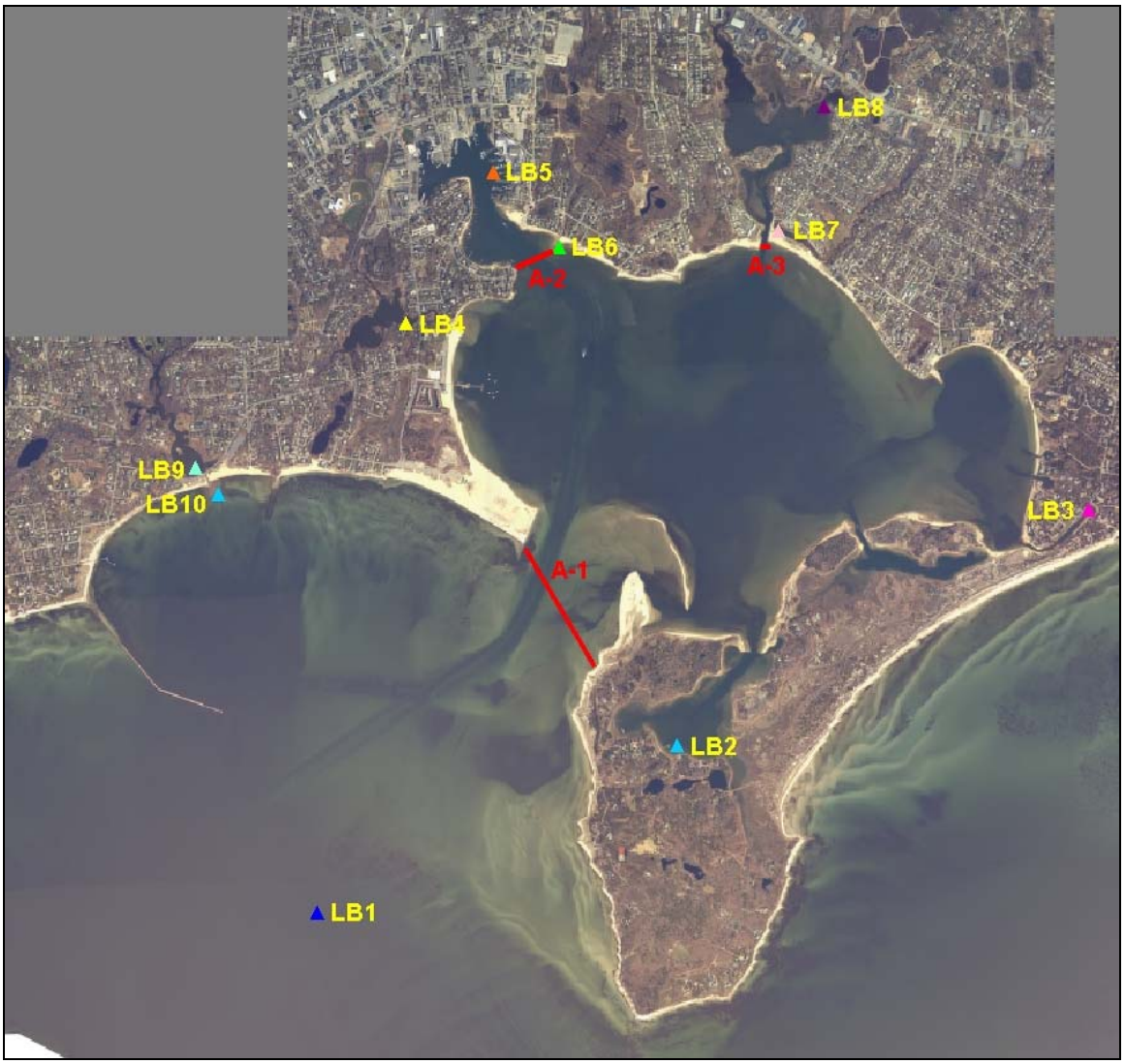


Figure V-2. Map of the study region identifying locations of the tide gauges used to measure water level variations throughout the system. Eight (8) gauges were deployed for the 55-day period between May 27, and July 21, 2004. The colored triangles represents the approximate locations of the tide gauges: (LB1) represents the gage in Nantucket Sound (Offshore), (LB2) inside the Uncle Roberts Cove, (LB3) in Sweetheart Creek, (LB4) in Snows Creek, (LB5) Hyannis Inner Harbor at Hyannis Marine, (LB6) at Bayview Beach, (LB7) lower end of Mill Creek, and (LB8) upper reach of Mill Creek. Two (2) gauges (LB9 and LB10) were deployed at Stewarts Creek for a 16-day period between May 12, and May 31, 2007.

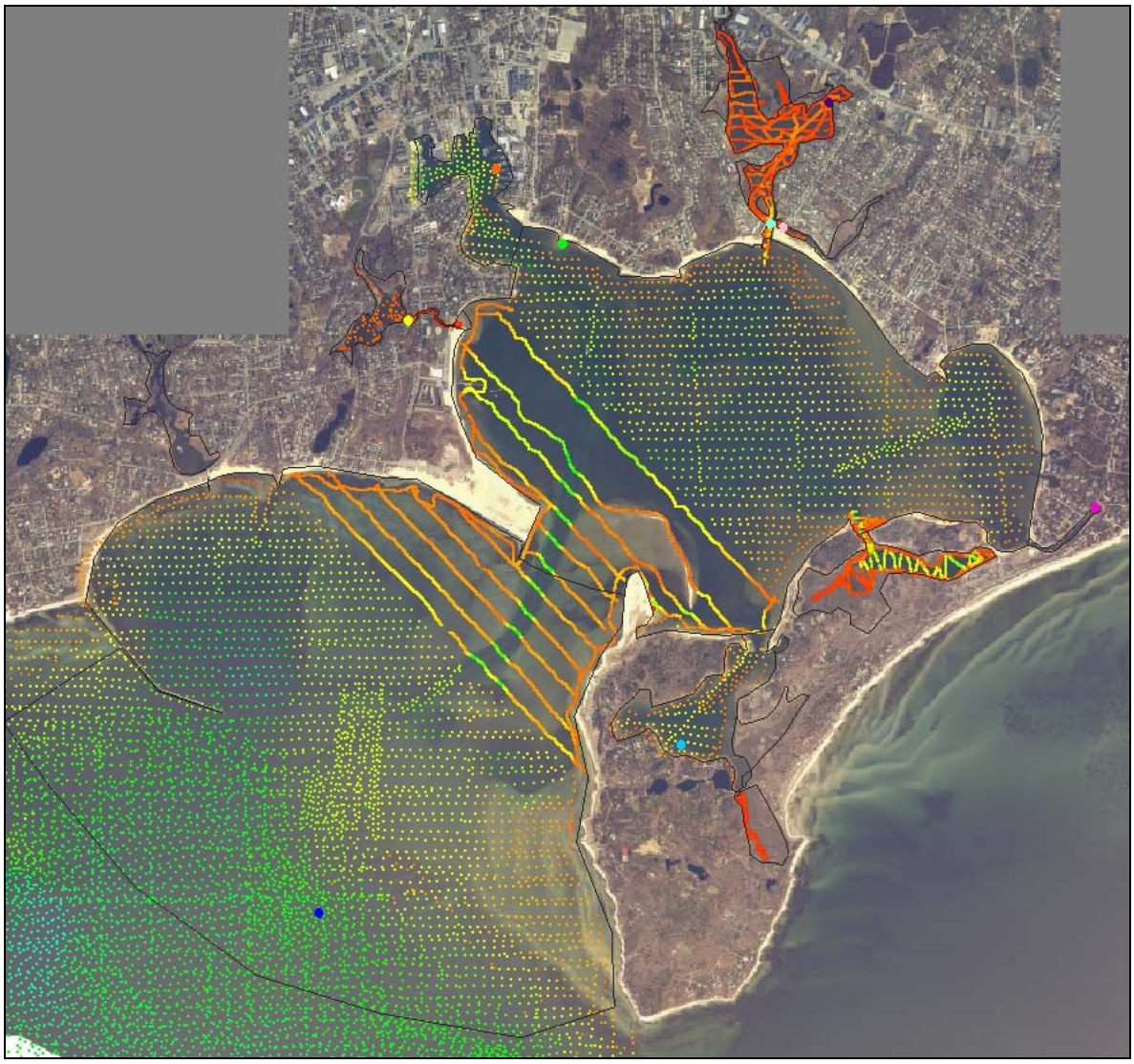


Figure V-3. Bathymetric data interpolated to the finite element mesh of hydrodynamic model.

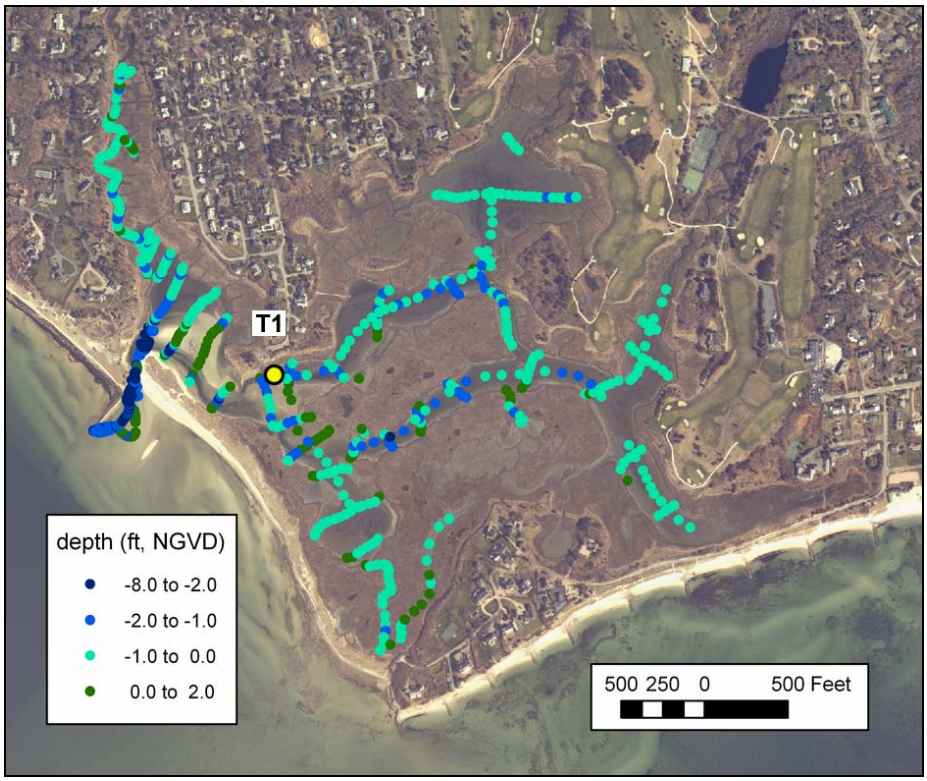


Figure V-4. Transects from the bathymetry survey of the Halls Creek. The yellow marker shows the location of the tide data recorder deployed inside the Creek for this study.

V.2.2 Tide Data Collection and Analysis

V.2.2.1 Lewis Bay

Variations in water surface elevation were measured at a station in at nine locations in the Lewis Bay, and at a single station in Nantucket Sound. Stations within the Lewis Bay were located inside the Uncle Roberts Cove (LB2), in Sweetheart Creek (LB3), in Snows Creek (LB4), at Hyannis Marine with Hyannis Inner Harbor (LB5), at Bayview Beach in Lewis Bay (LB6), at the lower end of Mill Creek (LB7), and (LB8) upper reach of Mill Creek. These eight gauges were deployed for the 55-day period between May 27, and July 21, 2004. The gauging stations for Stewarts Creek were deployed over a later time period between May 12, and May 31, 2007. Station LB9 is within Stewarts Creek, and Station LB10 is within the Lewis Bay located at the end of the jetty. The duration of the TDR deployment allowed time to conduct the ADCP and bathymetric surveys, as well as sufficient data to perform a thorough analysis of the tides in the system.

The tide records from Lewis Bay were corrected for atmospheric pressure variations and then rectified to the NGVD 29 vertical datum. Atmospheric pressure data, available in one-hour intervals from the NDBC Nantucket Sound C-MAN platform, were used to pressure correct the raw tide data. Final processed tide data from stations used for this study are presented in Figure V-5, for the complete 55-day period of the TDR deployment.

Tide records longer than 29 days are necessary for a complete evaluation of tidal dynamics within the estuarine system. Although a one-month record likely does not include extreme high or low tides, it does provide an accurate basis for typical tidal conditions governed

by both lunar and solar motion. For numerical modeling of hydrodynamics, the typical tide conditions associated with a one-month record are appropriate for driving tidal flows within the estuarine system.

The loss of amplitude together with increasing phase delay with increasing distance from the inlet is described as tidal attenuation. Tide attenuation can be a useful indicator of flushing efficiency in an estuary. Attenuation of the tidal signal is caused by the geomorphology of the nearshore region, where channel restrictions (e.g., bridge abutments, roadway culverts, inlets) and also the depth of an estuary are the primary factors which influence tidal damping in estuaries. For Lewis Bay, a visual comparison in Figure V-6 between tide elevations at seven stations along the system demonstrates how little change there is between the tide range and timing from Nantucket Sound to the farthest inland reaches of the Lewis Bay, Uncle Roberts Cove, Mill Creek, and Sweetheart Creek. The only significant amplitude reduction being caused by the culvert under Ocean Street connecting Snows Creek to Lewis Bay. This provides an initial indication that flushing conditions in the prior mentioned are ideal, with minimal loss of tidal energy along the length of the system except into Snows Creek.

To better quantify the changes to the tide from the inlet to inside the system, the standard tide datums were computed from the tide records. These datums are presented in Table V-1. The Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) levels represent the mean of the daily highest and lowest water levels. The Mean High Water (MHW) and Mean Low Water (MLW) levels represent the mean of all the high and low tides of a record, respectively. The Mean Tide Level (MTL) is simply the mean of MHW and MLW. The tides in Nantucket Sound are semi-diurnal, meaning that there are typically two tide cycles in a day. There is usually a small variation in the level of the two daily tides. This variation can be seen in the differences between the MHHW and MHW, as well as the MLLW and MLW levels. The computed datums for Lewis Bay and Nantucket Sound compare well to similar datums computed for the Centerville River using a 29-day record from 2004 (MTL 0.6 ft, MHW 1.9 ft, MLW -0.7 ft NGVD).

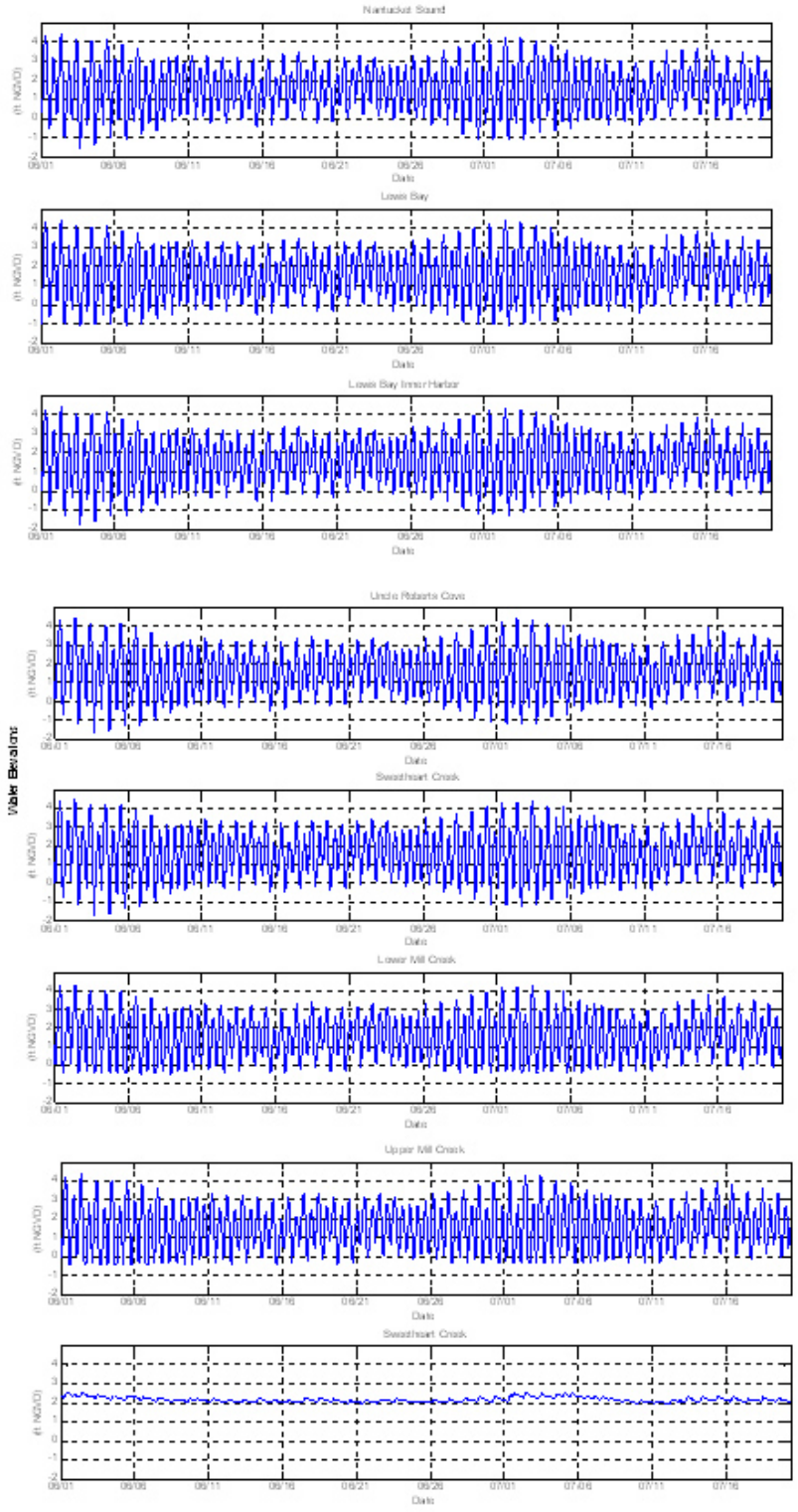


Figure V-5 Water elevation variations as measured at the seven locations within the Lewis Bay system, between June 1 and July 21, 2004.

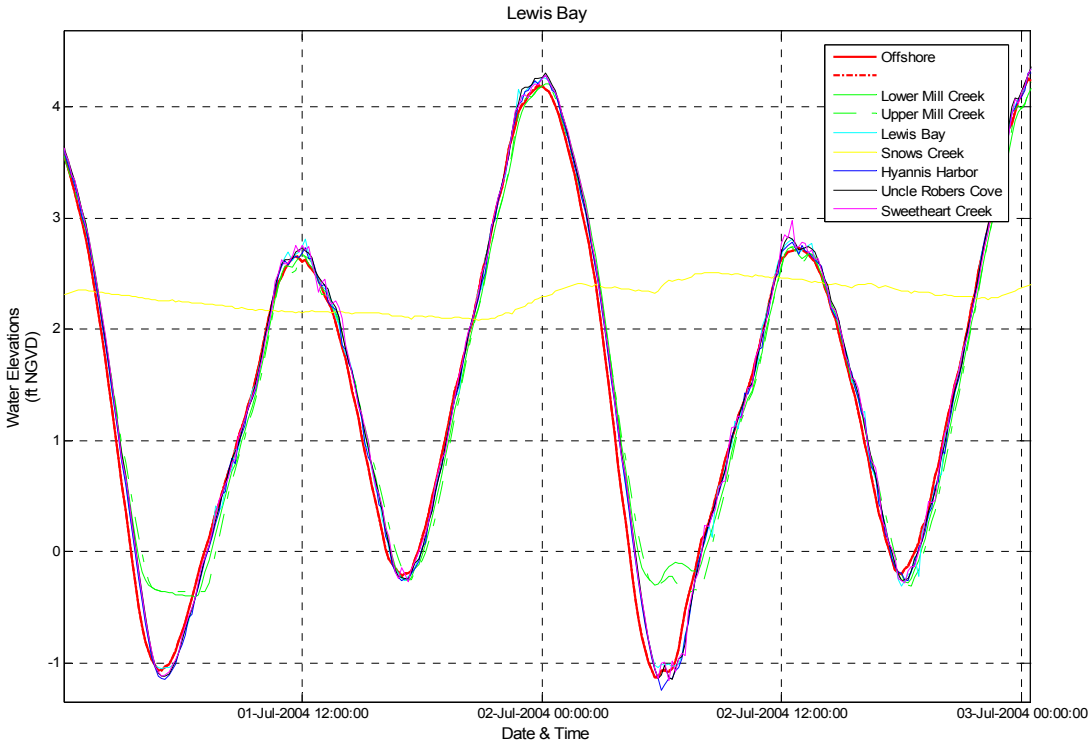


Figure V-6 Plot showing two tide cycles tides at seven stations in the Lewis Bay system plotted together. Demonstrated in this plot is the amplitude reduction in Snows Creek caused by the propagation of the tide through the culvert under Ocean Street.

For most NOAA tide stations, these datums are computed using 19 years of tide data, the definition of a tidal epoch. For this study, a significantly shorter time span of data was available; however, these datums still provide a useful comparison of tidal dynamics within the system. From the computed datums, it further apparent that there is little tide damping throughout the system (with the noted exception of Snows Creek). Again, the absence of tide damping exhibited in Lewis Bay indicates that it flush efficiently.

Table V-1. Tide datums computed from records collected in the Lewis Bay system June 1 - July 21, 2004. Datum elevations are given in feet relative to NGVD 27.

Tide Datum	Nantucket Sound	Lewis Bay	Inner Harbor	Uncle Roberts Cove	Sweetheart Creek	Upper Mill Creek	Lower Mill Creek	Snows Creek
Maximum Tide	4.36	4.46	4.50	4.48	4.49	4.46	4.46	3.06
MHHW	3.49	3.56	3.63	3.57	3.60	6.59	3.56	2.79
MHW	3.05	3.09	3.16	3.10	3.10	3.09	3.09	2.73
MTL	1.52	1.51	1.57	1.51	1.51	1.59	1.51	2.67
MLW	-0.01	-0.7	-0.07	-0.07	-0.08	0.09	-0.07	2.61
MLLW	-0.36	-0.41	-0.39	-0.44	-0.47	-0.14	-0.41	2.57
Minimum Tide	-1.54	-1.08	-1.65	-1.69	-1.70	-0.34	-1.08	2.47

A more thorough harmonic analysis was also performed on the time series data from each gauging station in an effort to separate the various component signals which make up the observed tide. The analysis allows an understanding of the relative contribution that diverse physical processes (i.e. tides, winds, etc.) have on water level variations within the estuary. Harmonic analysis is a mathematical procedure that fits sinusoidal functions of known frequency to the measured signal. The amplitudes and phase of 23 tidal constituents, with periods between 4 hours and 2 weeks, result from this procedure. The observed tide is therefore the sum of an astronomical tide component and a residual atmospheric component. The astronomical tide in turn is the sum of several individual tidal constituents, with a particular amplitude and frequency. For demonstration purposes a graphical example of how these constituents add together is shown in Figure V-7.

Table V-2 presents the amplitudes of eight significant tidal constituents. The M_2, or the familiar twice-a-day lunar semi-diurnal, tide is the strongest contributor to the signal with an amplitude of 1.4 feet in Nantucket Sound. The range of the M_2 tide is twice the amplitude, or about 2.8 feet. The diurnal (once daily) tide constituents, K_1 (solar) and O_1 (lunar), possess amplitudes of approximately 0.43 and 0.34 feet respectively and account for the higher high tide followed by the lower low tide seen in figure V-5. The N_2 tide, a lunar constituent with a semi-diurnal period, is the next largest tidal constituent and is a little more then 3 times smaller then the main semi-diurnal constituent (M_2) with an amplitude of 0.45 feet. The M_4 tide, a higher frequency harmonic of the M_2 lunar tide (twice the frequency of the M_2), results from frictional dissipation of the M_2 tide in shallow water. The M_2 and N_2 have more influence on the shape of the tide signal than the other tidal constituents. The effect of the comparatively large amplitude can be seen most clearly in Figure V-5 as the semi-diurnal high and low tides.

Table V-2. Tidal Constituents, Lewis Bay System June 1 - July 21, 2004

AMPLITUDE (feet)								
	M2	M4	M6	S2	N2	K1	O1	Msf
Period (hours)	12.42	6.21	4.14	12.00	12.66	23.93	25.82	354.61
Nantucket Sound	1.41	0.15	0.07	0.09	0.45	0.43	0.34	0.06
Lewis Bay	1.45	0.14	0.08	0.09	0.46	0.43	0.33	0.07
Inner Harbor	1.44	0.14	0.09	0.10	0.46	0.43	0.33	0.06
Uncle Roberts Cove	1.45	0.14	0.09	0.10	0.46	0.43	0.33	0.06
Sweetheart Creek	1.45	0.14	0.09	0.10	0.46	0.44	0.34	0.06
Upper Mill Creek	1.40	0.09	0.06	0.08	0.42	0.42	0.33	0.09
Lower Mill Creek	1.40	0.12	0.06	0.08	0.42	0.41	0.33	0.08
Snows Creek	0.04	0.01	0.00	0.01	0.01	0.03	0.05	0.09

Table V-3 presents the phase delay (in other words, the travel time required for the tidal wave to propagate throughout the system) of the M_2 tide at all tide gauge locations inside the bay. The greatest delay occurs between the Nantucket Sound and Snows Creek gauging stations. There is a minor phase delay of the tide inside Lewis Bay between the main bay and the smaller fringing embayments. Mill Creek shows a great delay at both gauges which is a result of the inlet and narrow channels leading up into the creek. The degree of attenuation is not significant relative to the hydraulic efficiency of the system because the effects of attenuation are observed only in the phase delay across the system, and not as a reduction in

the amplitude of the tide. The exception being Snows Creek which has a significant delay and reduction in amplitude.

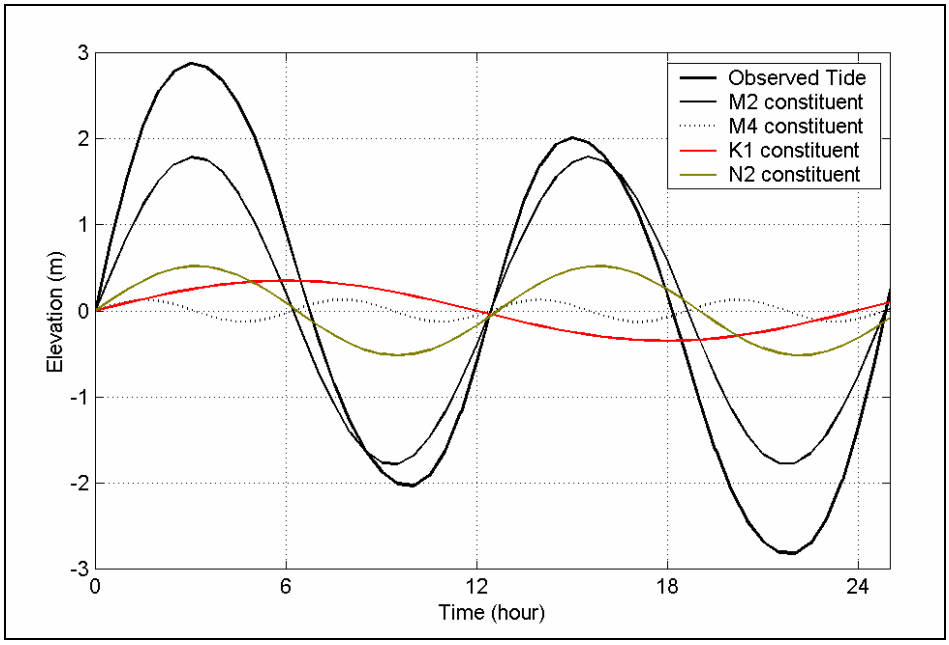


Figure V-7. Example of observed astronomical tide as the sum of its primary constituents. In this example the observed tide signal is the sum of individual constituents (M2, M4, K1, N2), with varying amplitude and frequency.

Table V-3. M_2 Tidal Attenuation, Lewis Bay.

June 1 – July 21 2004
(Delay in minutes relative to Nantucket Sound)

Location	Delay (minutes)
Lewis Bay	5.024
Inner Harbor	5.045
Uncle Roberts Cove	5.665
Sweetheart Creek	5.273
Upper Mill Creek	12.482
Lower Mill Creek	10.229
Snows Creek	171.855

The tide data were further evaluated to determine the importance of tidal versus non-tidal processes to changes in water surface elevation. Non-tidal processes include wind forcing (set-up or set-down) within the estuary, as well as sub-tidal oscillations of the sea surface. Variations in water surface elevation can also be affected by freshwater discharge into the system, if these volumes are relatively large compared to tidal flow. The results of an analysis to determine the energy distribution (or variance) of the original water elevation time series for the system is presented in Table V-4 compared to the energy content of the astronomical tidal signal (re-created by summing the contributions from the 23 constituents determined by the harmonic analysis). Subtracting the tidal signal from the original elevation time series resulted with the non-tidal, or residual, portion of the water elevation changes. The energy of this non-tidal signal is compared to the tidal signal, and yields a quantitative measure of how important

these non-tidal physical processes are relative to hydrodynamic circulation within the estuary. Figure V-8 shows the comparison of the measured tide from Nantucket Sound, with the computed astronomical tide resulting from the harmonic analysis, and the resulting non-tidal residual.

Table V-4 shows that the percentage contribution of tidal energy was essentially equal in all parts of the system, which indicates that local effects due to winds and other non-tidal processes are minimal throughout the systems. The analysis also shows that tides are responsible for approximately 97% of the water level changes in Lewis Bay. The remaining 3% was the result of atmospheric forcing, due to winds, or barometric pressure gradients acting upon the collective water surface of Nantucket Sound and Lewis Bay. The total energy content of the tide signal from each gauging station does not change significantly, nor does the relative contribution of tidal vs. non-tidal forces along the estuary basin. This is further indication that tide attenuation across the inlet and through the system is negligible. It is also an indication that the source of the non-tidal component of the tide signal is generated completely offshore, with no additional non-tidal energy input inside the system (e.g., from wind set-up of the pond surface). Snows Creek is the noted exception. It was shown to have a significant reduction in amplitude relative to Lewis Bay and this is again seen by a significant increase of non-tidal energy.

The results from Table V-4 indicate that hydrodynamic circulation throughout Lewis Bay is dependent primarily upon tidal processes. When wind and other non-tidal effects are a less significant portion of the total variance, the residual signal should not be ignored. Therefore, for the hydrodynamic modeling effort described below, the actual tide signal from Nantucket Sound was used to force the model so that the effects of non-tidal energy are included in the modeling analysis.

Table V-4. Percentages of Tidal versus Non-Tidal Energy, Lewis Bay, 2004

	Total Variance	Total	Tidal	Non-tidal
Unit	(ft^2)	(%)	(%)	(%)
Nantucket Sound	1.36	100	97.4	2.6
Lewis Bay	1.41	100	97.2	2.8
Inner Harbor	1.42	100	97.2	2.8
Uncle Roberts Cove	1.42	100	97.4	2.6
Sweetheart Creek	1.43	100	97.2	2.8
Upper Mill Creek	1.31	100	96.9	3.1
Lower Mill Creek	1.31	100	97.2	2.8
Snows Creek	0.02	100	46.6	53.4

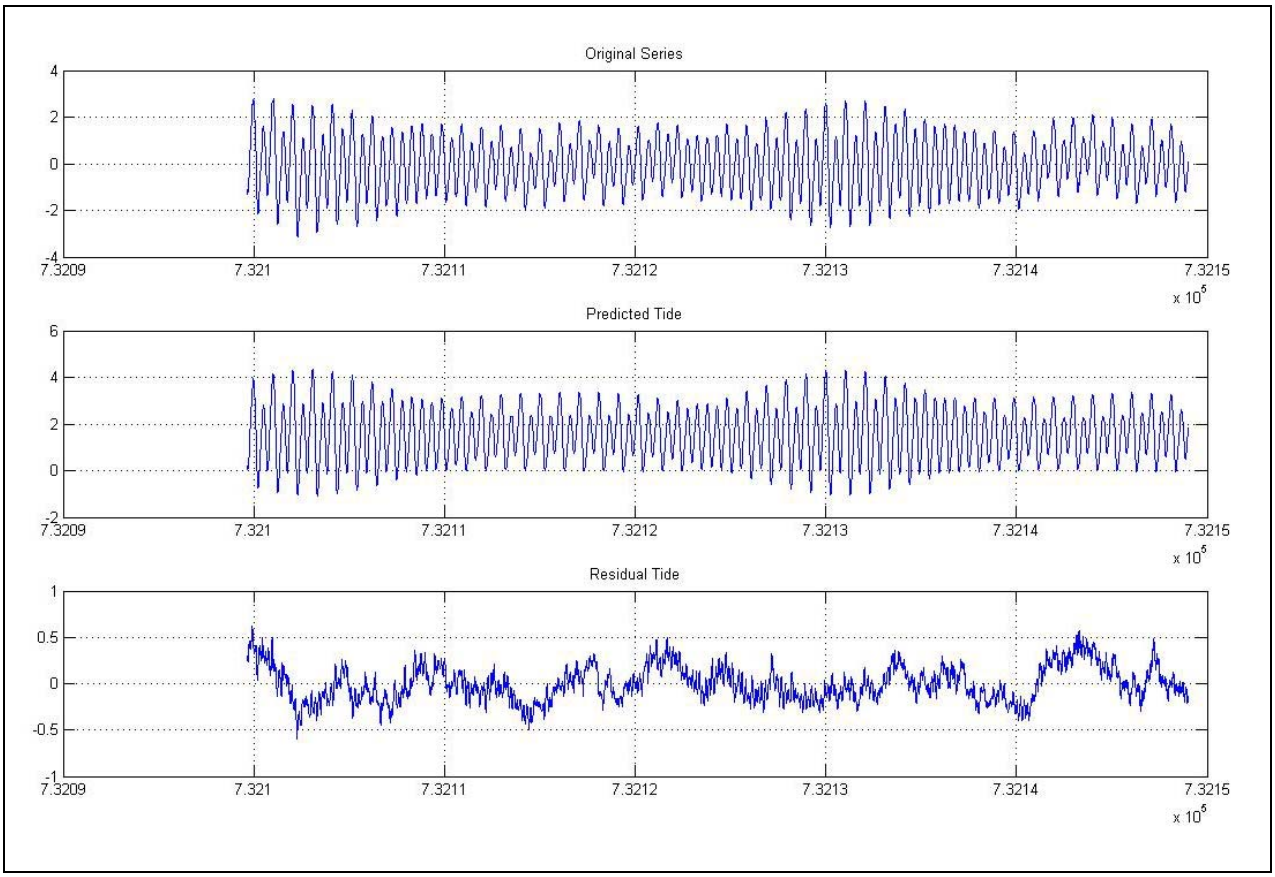


Figure V-8. Results of the harmonic analysis and the separation of the tidal from the non-tidal, or residual, signal measured in Nantucket Sound (LB1).

V.2.2.1 Halls Creek

Tide data records were collected at two locations for the Halls Creek analysis: offshore the Creek's inlet in Nantucket Sound and inside the Creek (see Figure V-4). The TDRs used to record the tide data were deployed for a 54-day period between May 27 and July 21, 2004. The elevation of each gauge was rectified relative to the NGVD 29 vertical datum. Duplicate offshore gauges were deployed to ensure data recovery, since the offshore tide record is crucial for developing the open boundary condition of the hydrodynamic model. Data collected by the gauge stationed inside the Creek were used in turn to calibrate and validate the hydrodynamic model.

Plots of the tide data from the tow tide stations used for this study are shown in Figure V-9, for the entire 54-day deployment. From the plot of the data from offshore Halls Creek, the maximum spring tide range of approximately 5.7 feet occurs June 3. About seven days later the neap tide range is much smaller, as small as 2.6 feet. The second spring tide should occur around June 17, at the time of the new moon, but the tide range is not clearly larger than seven days earlier during the spring tide range. The spring tides that occur during the full moon are easier to distinguish in the record.

The visual comparison in Figure V-10 between tide elevations measured in Nantucket Sound and inside the Creek shows that there is some decrease in the range of the tide through

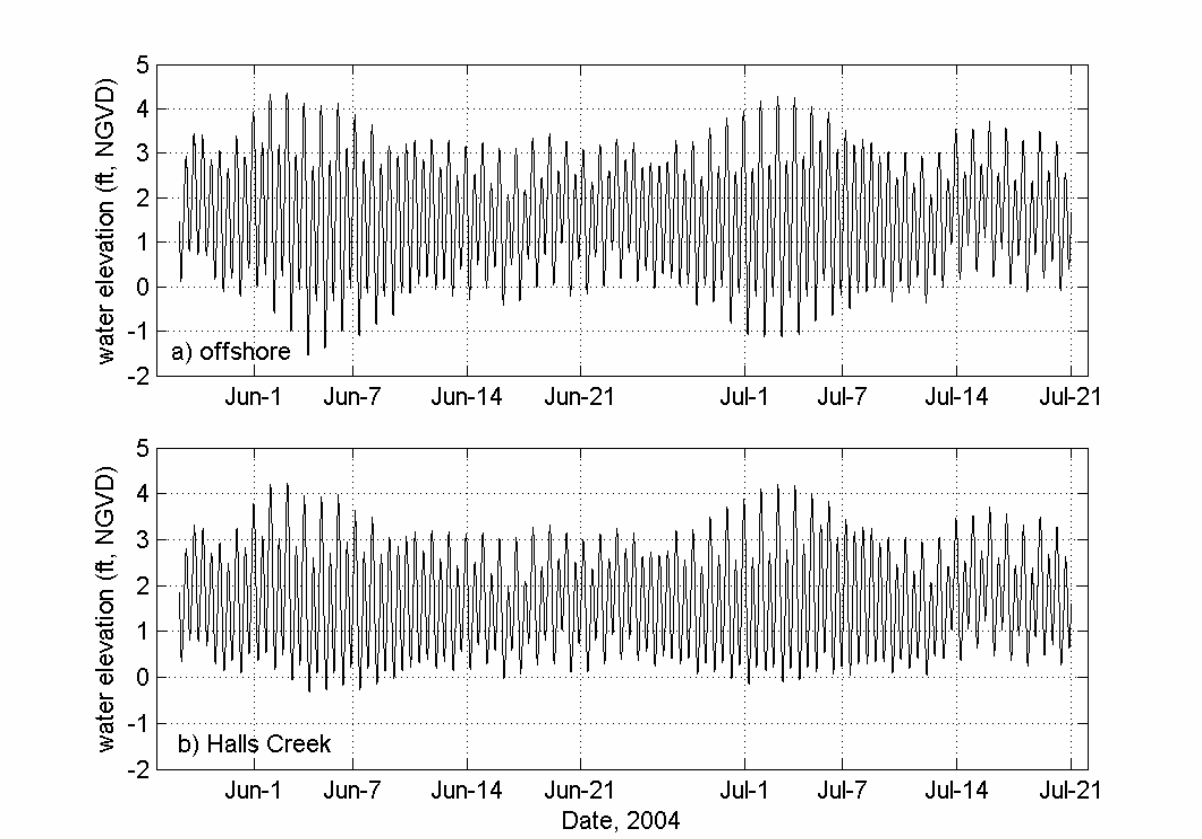


Figure V-9. Plots of observed tides for Halls Creek, for the 56-day period between May 27 and July 21, 2004. The top plot shows tides offshore Halls Creek inlet, in Nantucket Sound. The bottom plot shows the gauge record measured in Halls Creek. All water levels are referenced to NGVD 29.

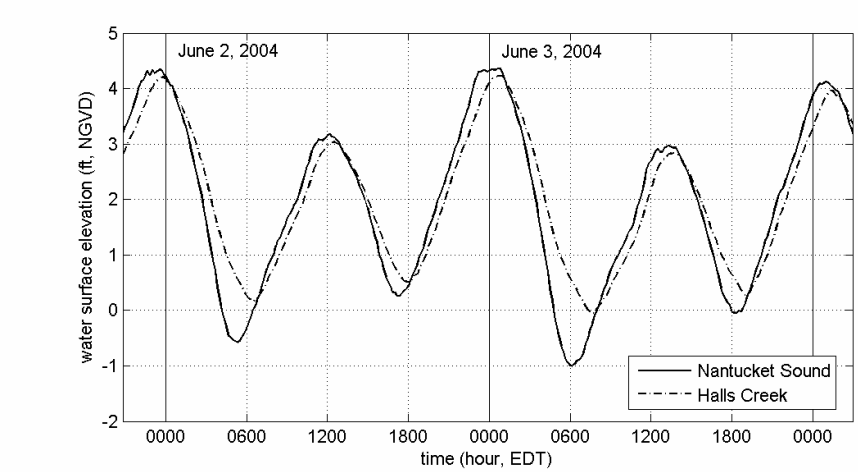


Figure V-10. Plot showing two tide cycles tides from the Halls Creek and Nantucket Sound tide data records, plotted together. Demonstrated in this plot is the minor frictional damping effect caused by flow restrictions at the inlets. The damping effects are seen only as a lag in time of high and low tides from Nantucket Sound. The maximum time lag of low tide between the Sound and Halls Creek in this plot is 103 minutes.

the system inlet. In Halls Creek, the low tide occurs approximately 100 minutes after low tide in Nantucket Sound. The delay at high tide is smaller, approximately 20 minutes.

The results of the analyses of the Hlas Creek tide data are presented in Tables V-2 and V-6. The standard tide are presented in Table V-5. Tide attenuation in Halls Creek through is apparent as an elevated MLW and MTL, compared to the offshore, which is typical of tides in marsh creeks. The results of the harmonic analysis of Halls Creek tides are presented in Table V-6. The harmonic analysis shows that the M_2 phase is shifted by 32 minutes compared to offshore. This means that the maximum and minimum elevations of the M_2 occur in Halls Creek 32 minutes after they have offshore.

Table V-5. Tide datums computed from a 28-day period from the tide records collected in the Halls Creek system. Datum elevations are given relative to NGVD 29.

Tide Datum	Offshore	Halls Creek
Maximum Tide	4.4	4.2
MHHW	3.4	3.3
MHW	3.1	3.0
MTL	1.5	1.6
MLW	0.0	0.3
MLLW	-0.4	0.1
Minimum Tide	-1.5	-0.3

Table V-6. Major tidal constituents determined for gauge locations in Halls Creek, May 27 through July 21, 2004.

	Amplitude (feet)							
Constituent	M_2	M_4	M_6	S_2	N_2	K_1	O_1	M_{sf}
Period (hours)	12.42	6.21	4.14	12.00	12.66	23.93	25.82	354.61
Nantucket Sound (offshore)	1.42	0.15	0.07	0.10	0.44	0.42	0.34	0.06
Halls Creek	1.21	0.06	0.04	0.07	0.34	0.39	0.31	0.09

Results of the residual analysis for Halls Creek are presented in Figure Table V-7 and V-11. Table V-7 shows a reduction in the variance of tidal energy between the offshore tide and the tide measured inside Halls Creek. The analysis also shows that tides are responsible for approximately 96% of the water level changes in the Creek. The remaining 4% was the result of atmospheric forcing, due to winds, or barometric pressure gradients. Figure V-11 shows the comparison of the measured tide in Halls Creek, with the computed astronomical tide resulting from the harmonic analysis, and the resulting non-tidal residual.

Table V-7. Percentages of Tidal versus Non-Tidal Energy for Halls Creek gauging stations, May to July, 2004.

TDR LOCATION	Total Variance (ft^2)	Tidal (%)	Non-tidal (%)
Nantucket Sound (offshore)	1.34	96.9	3.1
Halls Creek	0.97	96.4	3.6

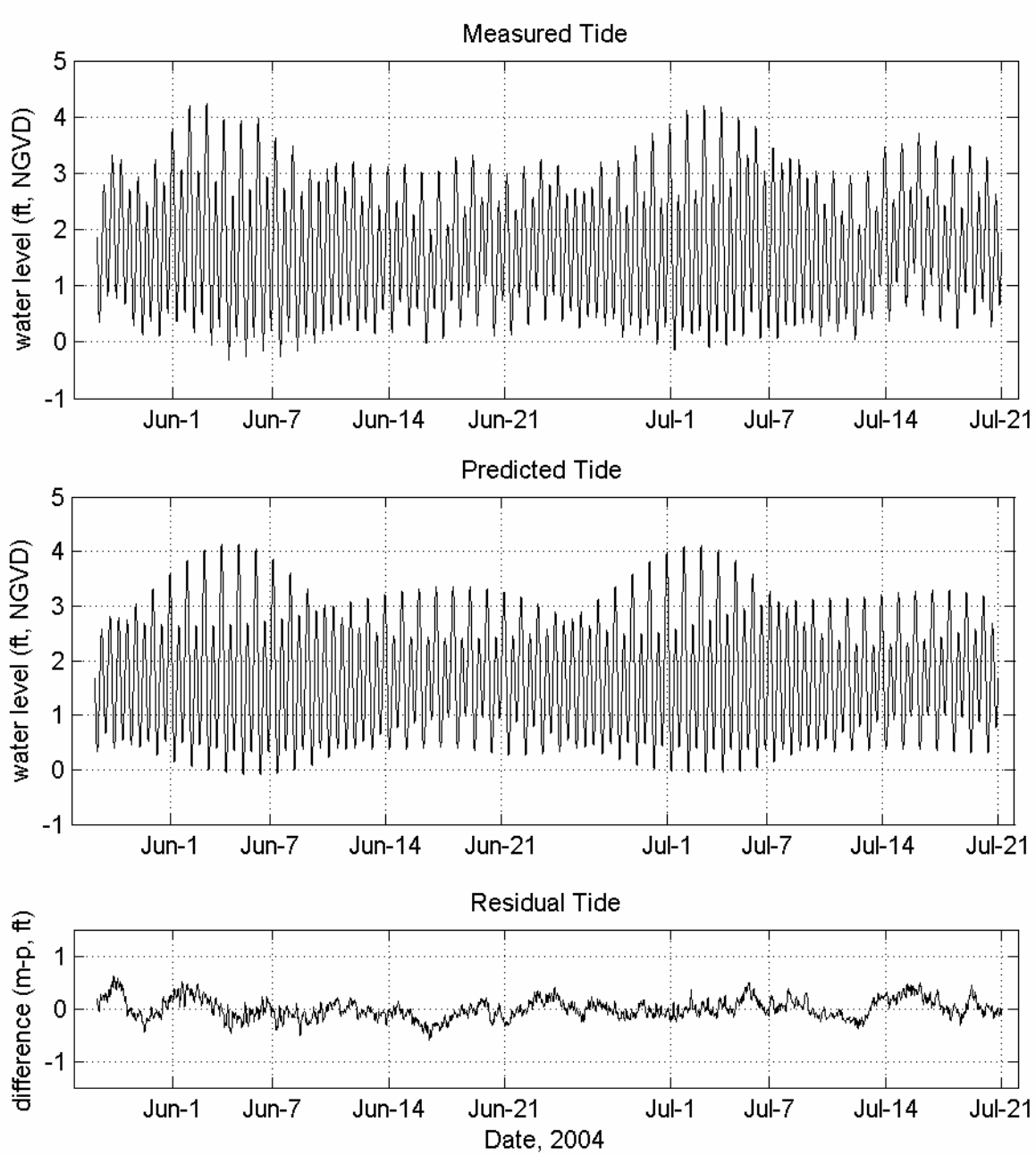


Figure V-11. Plot showing the comparison between the measured tide time series (top plot), and the predicted astronomical tide (middle plot) computed using the 23 individual tide constituents determine in the harmonic analysis of the Halls Creek gauge data. The residual tide shown in the bottom plot is computed as the difference between the measured and predicted time series (r=m-p).

V.2.3 ADCP Data Collection and Analysis

The measurements were collected using an Acoustic Doppler Current Profiler (ADCP) mounted aboard a small survey vessel. The boat repeatedly navigated a pre-defined set of transect lines through the area, approximately every 60 minutes, with the ADCP continuously collecting current profiles. This pattern was repeated for an approximate 13-hour duration to ensure measurements over the entire tidal cycle. The results of the data collection effort are high-resolution observations of the spatial and temporal variations in tidal current patterns throughout the survey area.

Measurements were obtained with a BroadBand 1200 kHz Acoustic Doppler Current Profiler (ADCP) manufactured by RD Instruments (RDI) of San Diego, CA. The ADCP was mounted to a specially constructed mast, which was rigidly attached to the rail of the survey vessel. The ADCP was oriented to look downward into the water column, with the sensors located approximately 1 foot below the water surface. The mounting technique assured no flow disturbance due to vessel wake.

The ADCP emits individual acoustic pulses from four angled transducers (at 20° from the vertical) in the instrument. The instrument then listens to the backscattered echoes from discrete depth layers in the water column. The difference in time between the emitted pulses and the returned echoes, reflected from ambient sound scatters (plankton, debris, sediment, etc.), is the time delay. BroadBand ADCPs measure the change in travel times from successive pulses. As particles move further away from the transducers sound takes longer to travel back and forth. The change in travel time, or propagation delay, corresponds to a change in distance between the transducer and the sound scatter, due to a Doppler shift. The propagation delay, the time lag between emitted pulses, and the speed of sound in water are used to compute the velocity of the particle relative to the transducer. By combining the velocity components for at least three of the four directional beams, the current velocities are transformed using the unit's internal compass readings to an orthogonal earth coordinate system in terms of east, north, and vertical components of current velocity.

Vertical structure of the currents is obtained using a technique called 'range-gating'. Received echoes are divided into successive segments (gates) based on discrete time intervals of pulse emissions. The velocity measurements for each gate are averaged over a specified depth range to produce a single velocity at the specified depth interval ('bin'). A velocity profile is composed of measurements in successive vertical bins.

The collection of accurate current data with an ADCP requires the removal of the speed of the transducer (mounted to the vessel) from the estimates of current velocity. 'Bottom tracking' is the strongest echo return from the emission of an additional, longer pulse to simultaneously measure the velocity of the transducer relative to the bottom. Bottom tracking allows the ADCP to record absolute versus relative velocities beneath the transducer. In addition, the accuracy of the current measurements can be compromised by random errors (or noise) inherent to this technique. Improvements in the accuracy of the measurement for each bin are achieved by averaging several velocity measurements together in time. These averaged results are termed 'ensembles'; the more pings used in the average, the lower the standard deviation of the random error.

Current measurements were collected by the ADCP as the vessel navigated repeatedly a series of two (2) pre-defined transect lines in Lewis Bay (Figure V-2). The line-cycles were repeated every hour throughout the survey. The first cycle was begun at 07:27 hours (Eastern

Daylight Time, EDT) and the final cycle was completed at 20:42 hours (EDT), for a survey duration of approximately 13 hours on June 23, 2004.

The transect lines A-1 and A-3 were run in ascending order. These lines were designed to measure as accurately as possible the volume flux through the constrictions during a complete tidal cycle. Line A-1 ran across the entrance to Lewis Bay between Kalmus Park and Smith's Point. Line A-3 ran across the inlet to Mill Cove.

V.3 HYDRODYNAMIC MODELING

The focus of this study was the development of a numerical model capable of accurately simulating hydrodynamic circulation within the Lewis Bay estuary and Halls Creek marsh system. Once calibrated, the model was used to calculate water volumes for selected subembayments (e.g., the Inner Hyannis Harbor, Mill Creek, Sweetheart Creek, etc.) as well as determine the volumes of water exchanged during each tidal cycle. These parameters are used to calculate system residence times, or flushing rates. The ultimate utility of the hydrodynamic model is to supply required input data for the water quality modeling effort described in Chapter VI.

V.3.1 Model Theory

Thie analyses of Lewis Bay and Halls Creek each utilized a state-of-the-art computer model to evaluate tidal circulation and flushing. The particular model employed was the RMA-2 model developed by Resource Management Associates (King, 1990). It is a two-dimensional, depth-averaged finite element model, capable of simulating transient hydrodynamics. The model is widely accepted and tested for analyses of estuaries or rivers. Applied Coastal staff members have utilized RMA-2 for numerous flushing studies for estuary systems in southeast Massachusetts, including Falmouth's 'finger' ponds, Centerville River, and Popponesset Bay.

In its original form, RMA-2 was developed by William Norton and Ian King under contract with the U.S. Army Corps of Engineers (Norton et al., 1973). Further development included the introduction of one-dimensional elements, state-of-the-art pre- and post-processing data programs, and the use of elements with curved borders. Recently, the graphic pre- and post-processing routines were updated by Brigham Young University through a package called the Surfacewater Modeling System or SMS (BYU, 1998). SMS is a front- and back-end software package that allows the user to easily modify model parameters (such as geometry, element coefficients, and boundary conditions), as well as view the model results and download specific data types. While the RMA model is essentially used without cost or constraint, the SMS software package requires site licensing for use.

RMA-2 is a finite element model designed for simulating one- and two-dimensional depth-averaged hydrodynamic systems. The dependent variables are velocity and water depth, and the equations solved are the depth-averaged Navier-Stokes equations. Reynolds assumptions are incorporated as an eddy viscosity effect to represent turbulent energy losses. Other terms in the governing equations permit friction losses (approximated either by a Chezy or Manning formulation), Coriolis effects, and surface wind stresses. All the coefficients associated with these terms may vary from element to element. The model utilizes quadrilaterals and triangles to represent the prototype system. Element boundaries may either be curved or straight.

The time dependence of the governing equations is incorporated within the solution technique needed to solve the set of simultaneous equations. This technique is implicit; therefore, unconditionally stable. Once the equations are solved, corrections to the initial

estimate of velocity and water elevation are employed, and the equations are re-solved until the convergence criterion is met.

V.3.2 Model Setup

There are three main steps required to implement RMA-2V:

- Grid generation
- Boundary condition specification
- Calibration

The extent of each finite element grid was generated using digital aerial photographs from the MassGIS online orthophoto database. A time-varying water surface elevation boundary condition (measured tide) was specified at the entrance of each separate system based on the tide gauge data collected in Nantucket Sound. Once the grid and boundary conditions were set, each model was calibrated to ensure accurate predictions of tidal flushing. Various friction and eddy viscosity coefficients were adjusted, through several model calibration simulations for each system, to obtain agreement between measured and modeled tides. The calibrated model provides the requisite information for future detailed water quality modeling.

V.3.2.1 Grid Generation

The finite element grid for each system provides the detail necessary to evaluate accurately the variation in hydrodynamic properties within the estuary. Fine resolution is required to simulate the numerous channel constrictions (e.g., entrance to Mill Creek) that significantly impact the estuarine hydrodynamics. Grid resolution is governed by two factors: 1) expected flow patterns, and 2) the bathymetric variability in each region. Smaller cross channel node spacing in the marsh channels was designed to provide a more detailed analysis in these regions of rapidly varying velocities and bathymetry. Widely spaced nodes were utilized in areas where velocity gradients were likely to be less acute; for example, on marsh plains and in broad, deep channel sections in the model domain. Appropriate implementation of wider node spacing and larger elements reduced computer run time with no sacrifice of accuracy.

The grid generation process for the models was assisted through the use of the SMS package. The digital shoreline and bathymetry data were imported to SMS, and a finite element grid was generated to represent the estuary with a number of computational elements. For Lewis Bay, 2295 elements, defined by 5660 computational nodes, were used to represent the system. In Halls Creek, the completed grid consists of 8,474 nodes, which describe 3,304 total elements. All regions in the system were represented by two-dimensional (depth-averaged) elements.

The completed grid is made up of quadrilateral and triangular two-dimensional elements. Reference water depths at each node of the model were interpreted from bathymetry data obtained in the recent field surveys and the NOS data archive. The mesh of Lewis Bay is shown in Figure V-12, and the interpolated grid bathymetry is shown in Figure V-13. The completed grid mesh of Halls Creek is shown in Figure V-14, and grid bathymetry is shown in Figure V-15.

V.3.2.2 Boundary Condition Specification

Three types of boundary conditions were employed for the RMA-2 model: 1) "slip" boundaries, and 2) tidal elevation boundaries. All of the elements with land borders have "slip"

boundary conditions, where the direction of flow was constrained shore-parallel. The model generated all internal boundary conditions from the governing conservation equations

The models are forced at the open boundary using water elevations measurements obtained in Nantucket Sound (described in section V.2.2). These measured time series consist of all physical processes affecting variations of water level: tides, winds, and other non-tidal oscillations of the sea surface. The rise and fall of the tide in Nantucket Sound is the primary driving force for estuarine circulation for these systems. Dynamic (time-varying) model simulations specified a new water surface elevation at each offshore boundary every 10 minutes. During the simulation, the model specifies the water elevation at the offshore boundary, and uses this value to calculate water elevations at every nodal point within the system, adjusting each value according to solutions of the model equations. Changing water levels in Nantucket Sound produce variations in surface slopes within the modeled estuary; these slopes drive water either into the system (if water is higher offshore) or out of the system (if water levels fall in the bay).

V.3.3 Calibration

After developing the finite element grid and specifying boundary conditions, the models were calibrated. Calibration ensured that each model predicts accurately what was observed during the field measurement program. Numerous model simulations were required to calibrate the model, with each run varying specific parameters such as friction coefficients, turbulent exchange coefficients, fresh water inflow, and subtle modifications to the system bathymetry to achieve a best fit to the data.

Calibration of the hydrodynamic model required a close match between the modeled and measured tides in each of the sub-embayments where tides were measured (e.g. the Mill Creek and Snows Creek). Initially, both models were calibrated by a visual agreement between modeled and measured tides. To refine the calibration procedure, water elevations were output from each model at the same locations in the estuary where tide gauges were installed, and the data were processed to calculate standard error as well harmonic constituents (of both measured and modeled data) over the seven-day calibration period. The amplitude and phase of four constituents (M_2, M_4, M_6, and K_1) were compared and the corresponding errors for each were calculated. The intent of the calibration procedure is to minimize the error in amplitude and phase of the individual constituents. In general, minimization of the M_2 amplitude and phase becomes the highest priority, since this is the dominant constituent. Emphasis is also placed on the M_4 constituent, as this constituent has the greatest impact on the degree of tidal distortion within the system, and provides the unique shape of the modified tide wave at various points in the system.

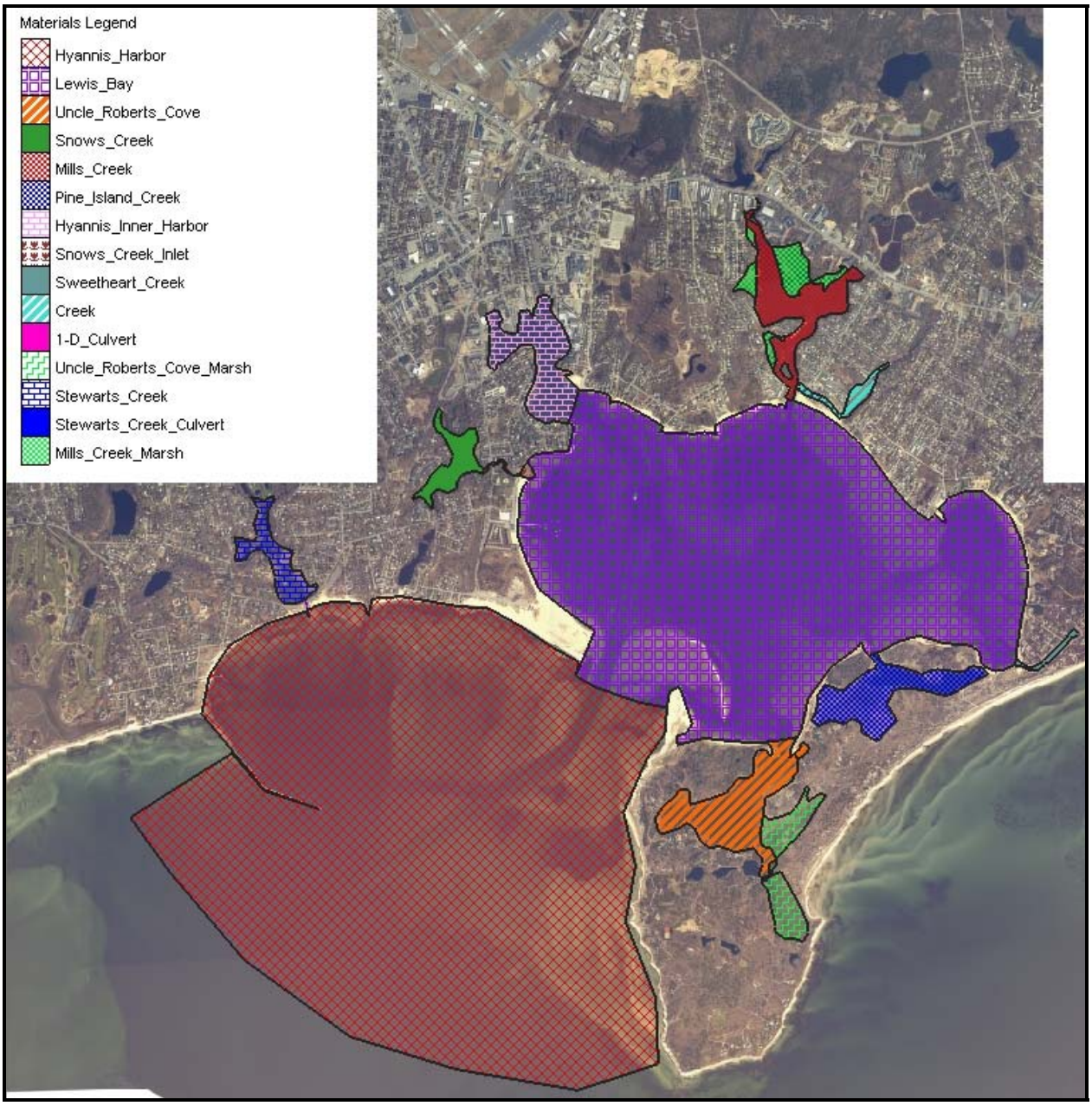


Figure V-12. The model finite element mesh developed for Lewis Bay estuary system. The model seaward boundary was specified with a forcing function consisting of water elevation measurements obtained in Nantucket Sound.

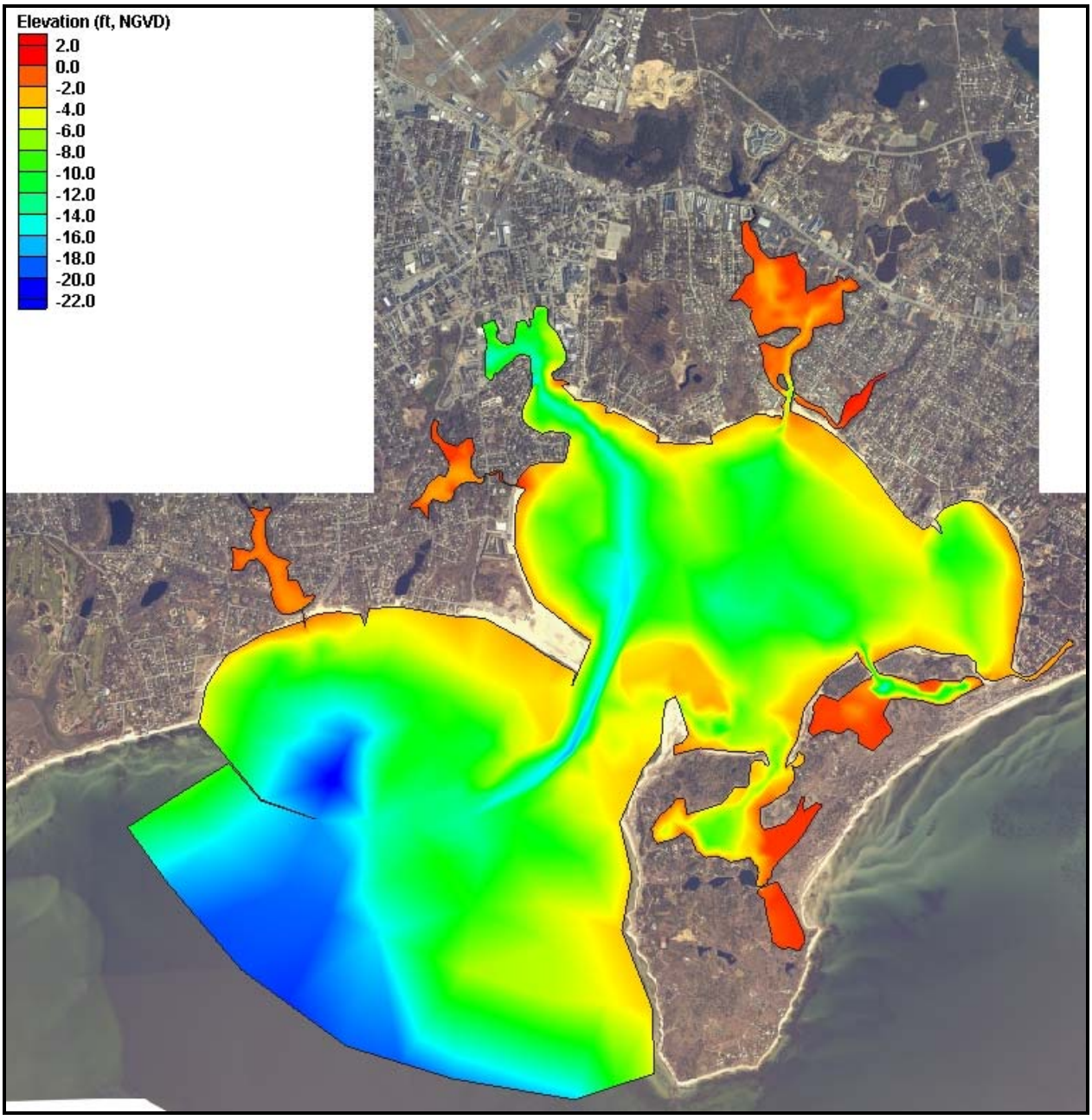


Figure V-13. Depth contours of the completed Lewis Bay finite element mesh.

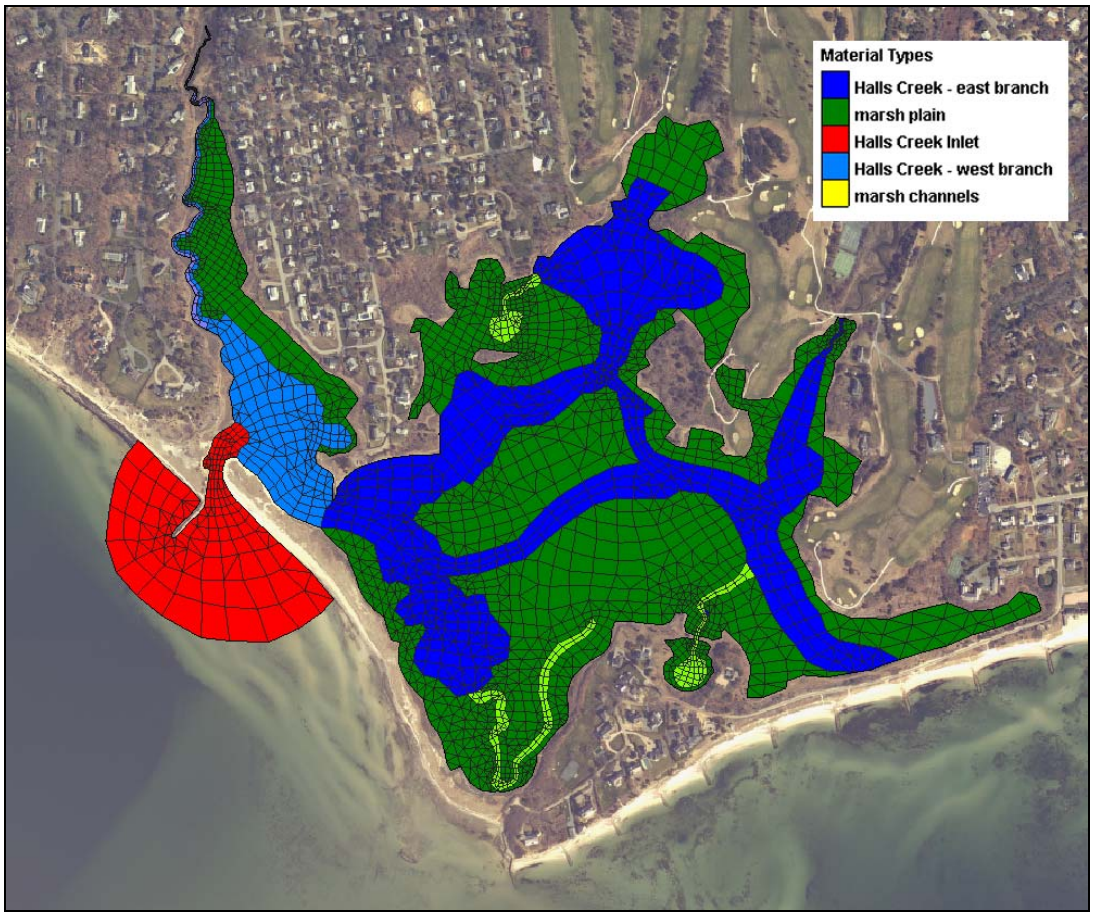


Figure V-14. Plot of hydrodynamic model grid mesh for Halls Creek. Colors designate the different model material types used to vary model calibration parameters and compute flushing rates.

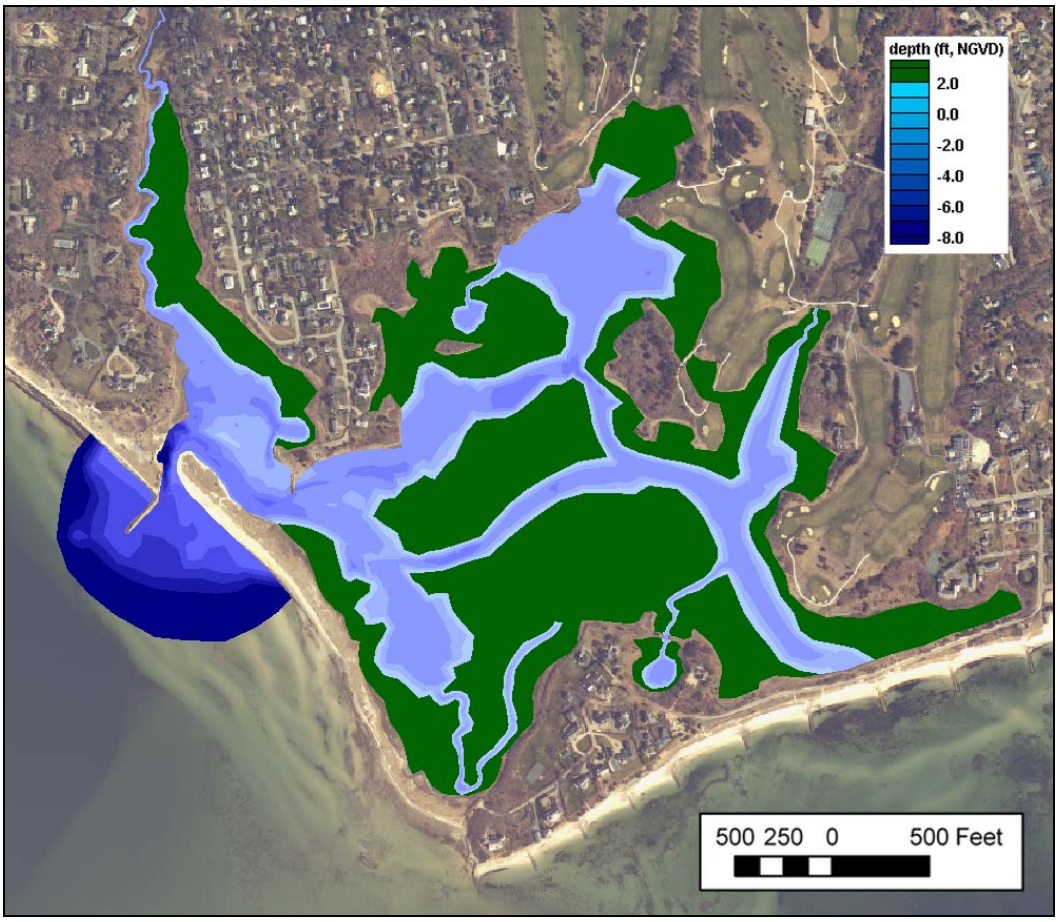


Figure V-15. Plot of interpolated finite-element grid bathymetry of the Halls Creek system, shown superimposed on 2005 aerial photos of the system locale. Bathymetric contours are shown in color at one-foot intervals.

For Lewis Bay, the calibration was performed for an approximate eight-day period, beginning 2000 hours EDT June 1, 2004 and ending 2000 EDT June 9, 2004. For Halls Creek, the calibration was performed for a five-day period beginning July 3, 2004 at 1200 EDT. These time periods include a 12-hour model spin-up period. This representative time periods were selected for each model because they included tidal conditions where the wind-induced portion of the signals (i.e. the residual) was minimal, hence more typical of tidal circulation within the estuary. The selected time periods also spanned the transition from spring (bi-monthly maximum) to neap (bi-monthly minimum) tide ranges, which is representative of average tidal conditions in the embayment system. For Lewis Bay, the selected 7.75 day simulation period, the tide ranged approximately 5.8 feet from minimum low to maximum high tides. At Halls Creek, the maximum tide range during the simulation is 5.3 feet. The ability to model a range of flow conditions is a primary advantage of a numerical tidal flushing model. Modeled tides were evaluated for time (phase) lag and height damping of dominant tidal constituents. The calibrated models were used to analyze existing detailed flow patterns and compute residence times.

V.3.3.1 Friction Coefficients

Friction inhibits flow along the bottom of estuary channels or other flow regions where water depths can become shallow and velocities relatively high. Friction is a measure of the

channel roughness, and can cause both significant amplitude attenuation and phase delay of the tidal signal. Friction is approximated in RMA-2 as a Manning coefficient. First, Manning's friction coefficient values of 0.025 were specified for all elements in each model. These values correspond to typical Manning's coefficients determined experimentally in smooth earth-lined channels with no weeds (low friction) to winding channels with pools and shoals with higher friction (Henderson, 1966). On the marsh plains of Mill Creek and Halls Creek, damping of flow velocities typically is controlled more by “form drag” associated with marsh plants than the bottom friction described above. However, simulation of this “form drag” is performed using Manning’s coefficients as well, with values ranging from 2-to-10 times friction coefficients used in sandy channels. Final calibrated friction coefficients (listed in Table V-8 for Lewis Bay and Halls Creek) were largest for marsh plain area, where values were set at between 0.033 and 0.070. Small changes in these values did not change the accuracy of the calibration.

Table V-8. Manning’s Roughness coefficients used in simulations of modeled systems.

Embayment	Bottom Friction
Lewis Bay and Hyannis Harbor	
Hyannis Harbor	0.024
Lewis Bay	0.024
Uncle Roberts Cove	0.025
Uncle Roberts Cove (marsh)	0.033
Snows Creek	0.030
Pine Island Creek	0.027
Mill Creek	0.026
Mill Creek (marsh)	0.030
Mill Creek (creek on eastern edge)	0.026
Mill Creek (culvert)	0.025
Hyannis Inner Harbor	0.025
Snows Creek Inlet	Varies
Sweetheart Creek	0.025
Stewarts Creek	0.025
Stewarts Creek (culvert)	0.035
Halls Creek	
Halls Creek - east branch	0.025
Marsh plain	0.070
Halls Creek inlet	0.035
Halls Creek - west branch	0.035
Marsh channels	0.025

V.3.3.2 Turbulent Exchange Coefficients

Turbulent exchange coefficients approximate energy losses due to internal friction between fluid particles. The significance of turbulent energy losses increases where flow is swift, such as inlets and bridge constrictions. According to King (1990), these values are proportional to element dimensions (numerical effects) and flow velocities (physics). The model was mildly sensitive to turbulent exchange coefficients, with areas of marsh plain being most sensitive. In other regions where the flow gradients were not as strong, the model was much less sensitive to changes in the turbulent exchange coefficients. Typically, model turbulence coefficients (D) are set between 20 and 200 lb-sec/ft^2 (as listed in Table V-9). Higher values (up to 500 lb-sec/ft^2) are used on the marsh plain, to ensure solution stability.

Table V-9. Turbulence exchange coefficients (D) used in simulations of the modeled embayment systems.	
Embayment	D (lb-sec/ft$^{2)}$
Lewis Bay and Hyannis Harbor	
Hyannis Harbor	50
Lewis Bay	75
Uncle Roberts Cove	70
Uncle Roberts Cove (marsh)	120
Snows Creek	50
Pine Island Creek	75
Mill Creek	75
Mill Creek (marsh)	75
Mill Creek (creek on eastern edge)	70
Mill Creek (culvert)	60
Hyannis Inner Harbor	60
Snows Creek Inlet	100
Sweetheart Creek	100
Stewarts Creek	100
Stewarts Creek (culvert)	150
Halls Creek	
Halls Creek - east branch	200
Marsh plain	200
Halls Creek inlet	100
Halls Creek - west branch	100
Marsh channels	20

V.3.3.3 Wetting and Drying/Marsh Porosity Processes

Modeled hydrodynamics were complicated by wetting/drying cycles on the marsh plain included in the model as part of both the Lewis Bay and Halls Creek systems. Cyclically wet/dry areas of marsh will tend to store waters as the tide begins to ebb and then slowly release water as the water level drops within the creeks and channels. This store-and-release characteristic of these marsh regions was partially responsible for the distortion of the tidal signal, and the elongation of the ebb phase of the tide. On the flood phase, water rises within the channels and creeks initially until water surface elevation reaches the marsh plain, when at this point the water level remains nearly constant as water 'fans' out over the marsh surface. The rapid flooding of the marsh surface corresponds to a flattening out of the tide curve approaching high water. Marsh porosity is a feature of the RMA-2 model that permits the modeling of hydrodynamics in marshes. This model feature essentially simulates the store-and-release capability of the marsh plain by allowing grid elements to transition gradually between wet and dry states. This technique allows RMA-2 to change the ability of an element to hold water, like squeezing a sponge. The marsh porosity feature of RMA-2 is typically utilized in estuarine systems where the marsh plain has a significant impact on the hydrodynamics of a system.

V.3.3.4 Comparison of Modeled Tides and Measured Tide Data

Several calibration model runs were performed for each system to determine how changes to various parameters (e.g. friction and turbulent exchange coefficients) affected the model results. These trial runs achieved excellent agreement between the model simulations and the field data.

V.3.3.4.a Lewis Bay

Comparison plots of modeled versus measured water levels in Lewis Bay, at the eight gauge locations, is presented in Figures V-15 through V-22. At all gauging stations RMS errors were less than 0.16 ft (<2.0 inches) and computed R^2 correlation was better than 0.99. Errors between the model and observed tide constituents were less than 0.06 inch for all locations, suggesting the model accurately predicts tidal hydrodynamics within the Lewis Bay system. Measured tidal constituent amplitudes and time lags (ϕ_{lag}) for the calibration time period are shown in Table V-7. The constituent values in for the calibration time period differ from those in

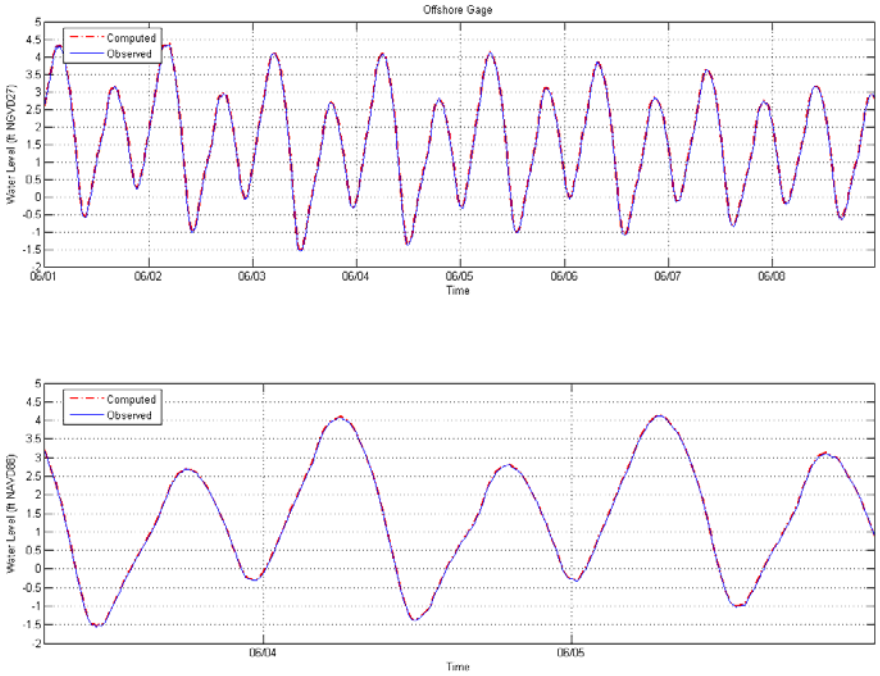


Figure V-15. Comparison of water surface variations simulated by the model (dashed line) to those measured within the system (solid line) for the calibration time period, for the offshore gauging station. The bottom plot is a 65-hour sub-section of the total modeled time period, shown in the top plot.

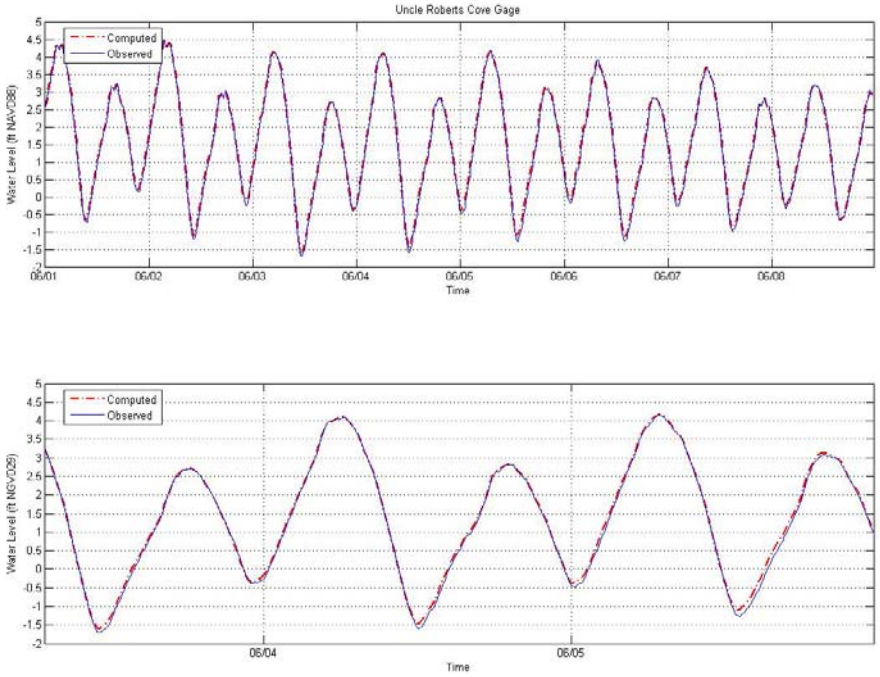


Figure V-16. Comparison of water surface variations simulated by the model (dashed line) to those measured within the system (solid line) for the verification time period at the Uncle Roberts Cove gauging station (LB2). The bottom plot is a 65-hour sub-section of the total modeled time period, shown in the top plot.

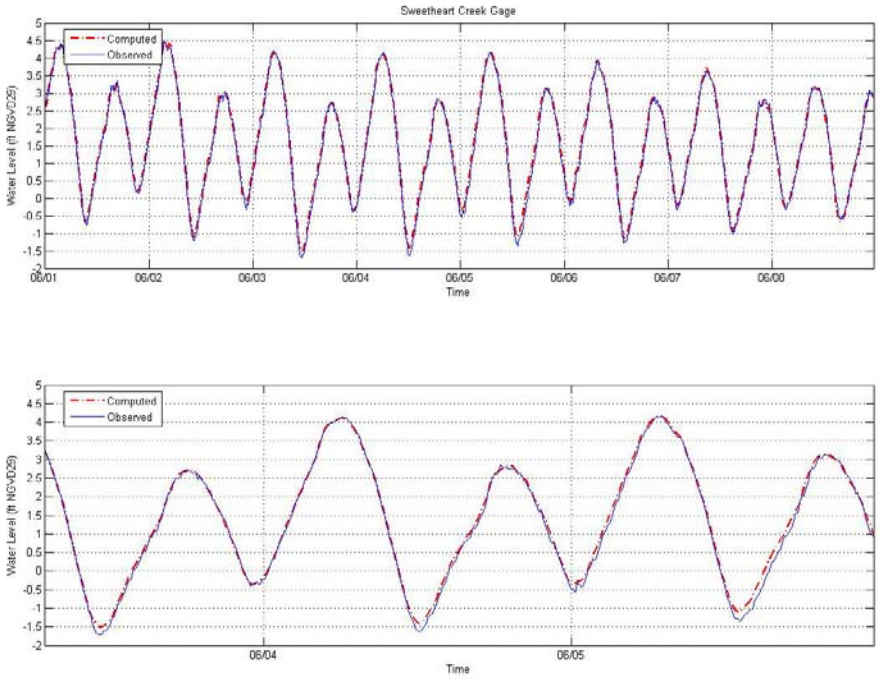


Figure V-17. Comparison of water surface variations simulated by the model (dashed line) to those measured within the system (solid line) for the verification time period at the Sweetheart Creek gauging station (LB3). The bottom plot is a 65-hour sub-section of the total modeled time period, shown in the top plot.

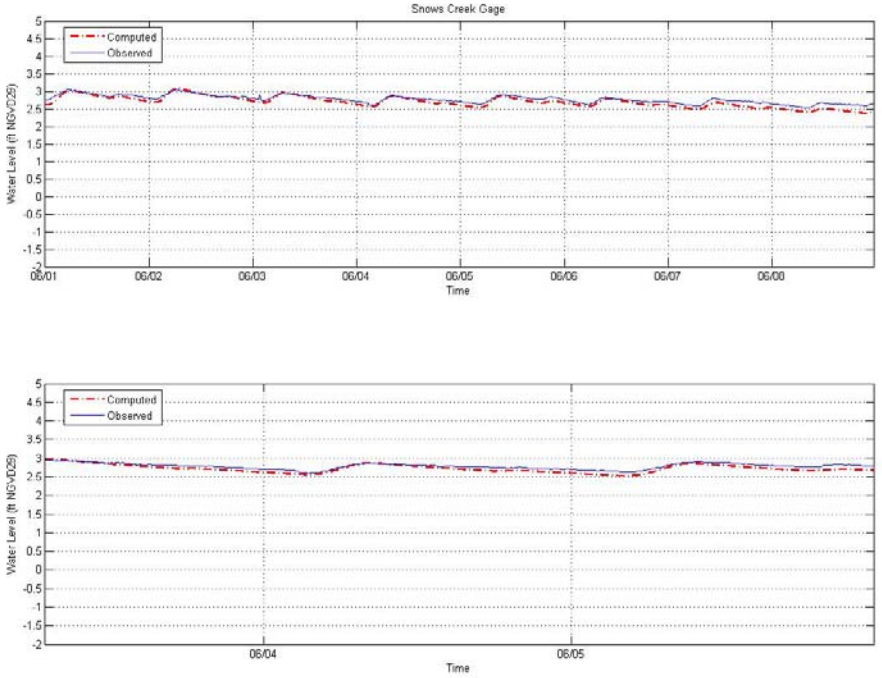


Figure V-18. Comparison of water surface variations simulated by the model (dashed line) to those measured within the system (solid line) for the verification time period at the Snows Creek gauging station (LB4). The bottom plot is a 65-hour sub-section of the total modeled time period, shown in the top plot.

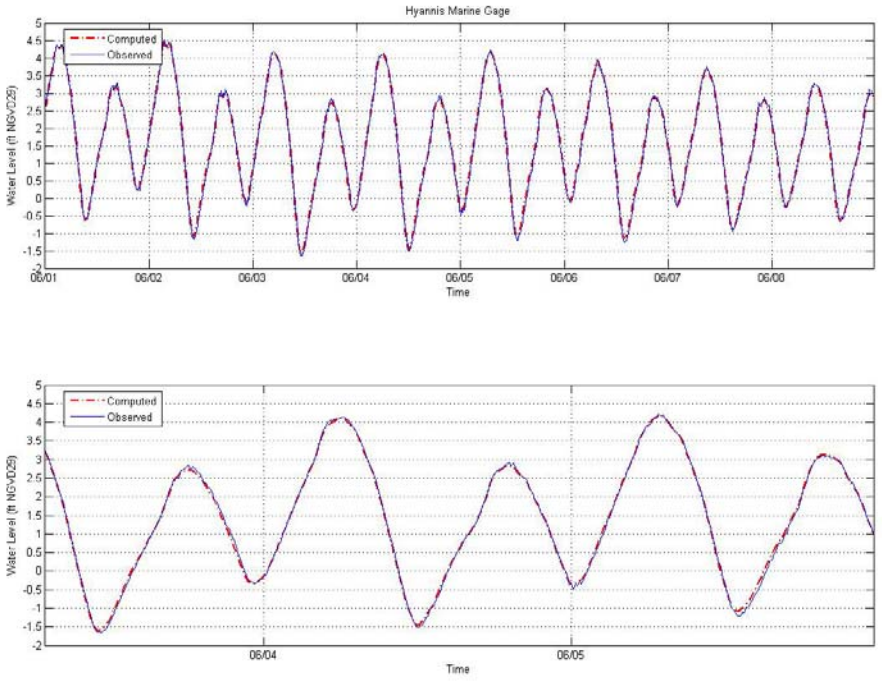


Figure V-19. Comparison of water surface variations simulated by the model (dashed line) to those measured within the system (solid line) for the verification time period at the Hyannis Inner Harbor gauging station (LB5). The bottom plot is a 65-hour sub-section of the total modeled time period, shown in the top plot.

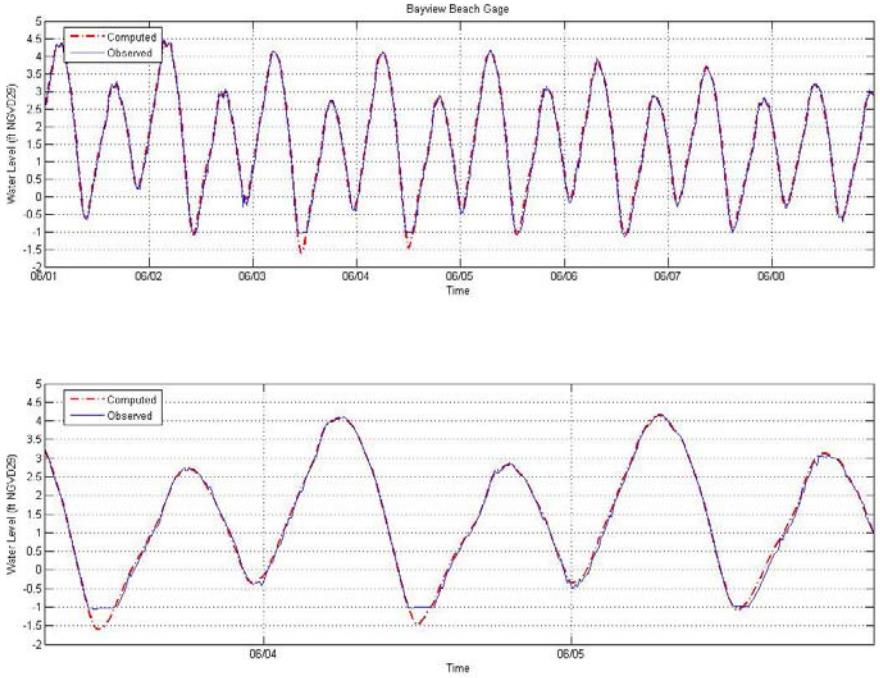


Figure V-20. Comparison of water surface variations simulated by the model (dashed line) to those measured within the system (solid line) for the verification time period for the Lewis Bay gauging station (LB6). The bottom plot is a 65-hour sub-section of the total modeled time period, shown in the top plot.

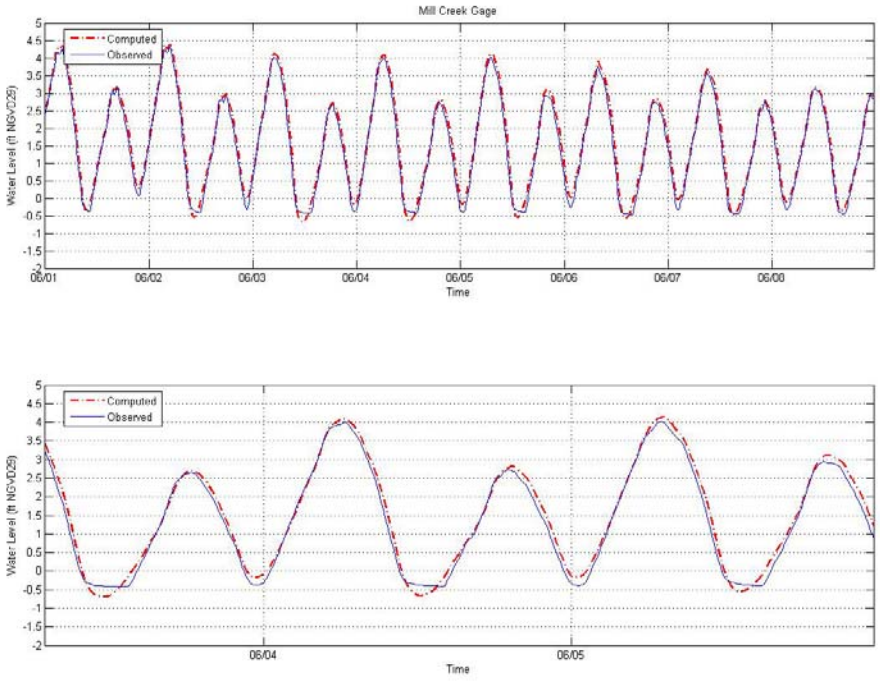


Figure V-21. Comparison of water surface variations simulated by the model (dashed line) to those measured within the system (solid line) for the verification time period at the Lower Mill Creek gauging station (LB7). The bottom plot is a 65-hour sub-section of the total modeled time period, shown in the top plot.

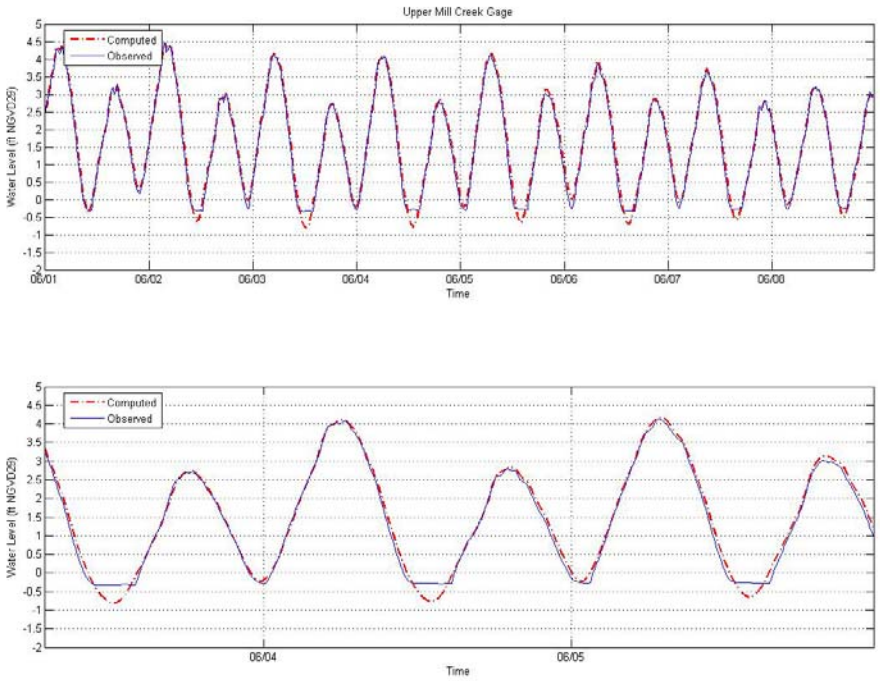


Figure V-22. Comparison of water surface variations simulated by the model (dashed line) to those measured within the system (solid line) for the verification time period at the Upper Mill Creek gauging station (LB8). The bottom plot is a 65-hour sub-section of the total modeled time period, shown in the top plot.

Tables V-2 because constituents were computed for only 7.75 days, rather than the entire 55-day period represented in Tables V-2. Errors associated with tidal constituent height were on the order of hundredths of feet, which was an order of magnitude better than the accuracy of the tide gage gauges (±0.12 ft). Time lag errors were less than the time increment resolved by the model and measured tide data (1/6 hours or 10 minutes), indicating good agreement between the model and data.

Table V-10. Comparison of tidal constituents from the calibrated RMA2 model of Lewis Bay versus measured tidal data for the period June 1 to June 8, 2004.

Model Verification Run						
Location	Constituent Amplitude (ft)				Phase (degrees)	
	M_2	M_4	M_6	K_1	ΦM_2	ΦM_4
Nantucket Sound	1.88	0.23	0.11	0.67	94.42	-60.33
Lewis Bay	1.89	0.22	0.13	0.67	96.34	-48.26
Inner Harbor	1.89	0.22	0.13	0.67	96.39	-48.01
Uncle Roberts Cove	1.89	0.21	0.13	0.68	96.92	-45.63
Sweetheart Creek	1.89	0.21	0.13	0.68	96.83	-45.67
Upper Mill Creek	1.79	0.07	0.07	0.65	104.35	25.91
Lower Mill Creek	1.78	0.19	0.09	0.63	103.88	-59.47
Snows Creek	0.07	0.02	0.00	0.08	-171.56	-66.63
Measured Tidal Data						
Location	Constituent Amplitude (ft)				Phase (degrees)	
	M_2	M_4	M_6	K_1	ΦM_2	ΦM_4
Nantucket Sound	1.86	0.22	0.11	0.65	1.68	-0.93
Lewis Bay	1.88	0.18	0.11	0.65	99.38	-39.59
Inner Harbor	1.90	0.20	0.13	0.66	99.24	-34.82
Uncle Roberts Cove	1.90	0.20	0.13	0.66	99.59	-32.50
Sweetheart Creek	1.90	0.20	0.13	0.66	99.48	-34.23
Upper Mill Creek	1.75	0.08	0.05	0.60	103.75	-96.68
Lower Mill Creek	1.76	0.14	0.06	0.60	102.44	-75.09
Snows Creek	0.05	0.01	0.00	0.05	-175.24	-85.07
Error						
Location	Constituent Amplitude (ft)				Phase (minutes)	
	M_2	M_4	M_6	K_1	ΦM_2	ΦM_4
Nantucket Sound	-0.02	-0.02	-0.01	-0.01	3.95	7.50
Lewis Bay	-0.03	-0.01	-0.04	-0.02	6.30	8.98
Inner Harbor	-0.02	0.01	-0.02	0.00	5.88	13.66
Uncle Roberts Cove	-0.02	0.01	-0.02	0.00	5.53	13.59
Sweetheart Creek	-0.01	0.01	-0.01	0.00	5.49	11.85
Upper Mill Creek	-0.06	-0.04	0.01	-0.02	-1.23	-126.9
Lower Mill Creek	-0.03	-0.01	-0.05	-0.03	-3.00	-16.17
Snows Creek	-0.03	-0.02	0.00	0.00	-7.61	-19.08

V.3.3.4.b Halls Creek Calibration

A best-fit of model predictions for the TDR deployment was achieved using the aforementioned values for friction and turbulent exchange. Figures V-23 and V-24 illustrate the five-day calibration simulation along with a 50-hour sub-section. Modeled (solid line) and measured (dotted line) tides are illustrated at each model location with a corresponding TDR.

Although visual calibration achieved reasonable modeled tidal hydrodynamics, further tidal constituent calibration was required to quantify and maximize the accuracy of the models. Calibration of M_2 (principle lunar semidiurnal constituent) was the highest priority since M_2 accounted for a majority of the forcing tide energy in the modeled system. Due to the duration of the model runs, four dominant tidal constituents were selected for constituent comparison: K_1,

M_2, M_4, and M_6. Measured tidal constituent heights (H) and time lags (ϕ_{lag}) shown in Table V-11 for the calibration period differ from those in Table V-11 because constituents were computed for only the five-day section of the 31-days represented in Table V-6. Table V-6 compares tidal constituent amplitude (height) and relative phase (time) for modeled and measured tides at the TDR locations. The constituent phase shows the relative timing of each separate constituent at a particular location, and also the change (or phase lag) in timing of a single constituent at different locations in an estuary.

The constituent calibration resulted in excellent agreement between modeled and measured tides. The largest errors associated with tidal constituent amplitude were on the order of 0.01 ft, which is better than the accuracy of the tide gauges (±0.12 ft). Time lag errors were typically less than the time increment resolved by the model (1/6 hours or 10 minutes), indicating good agreement between the model and data.

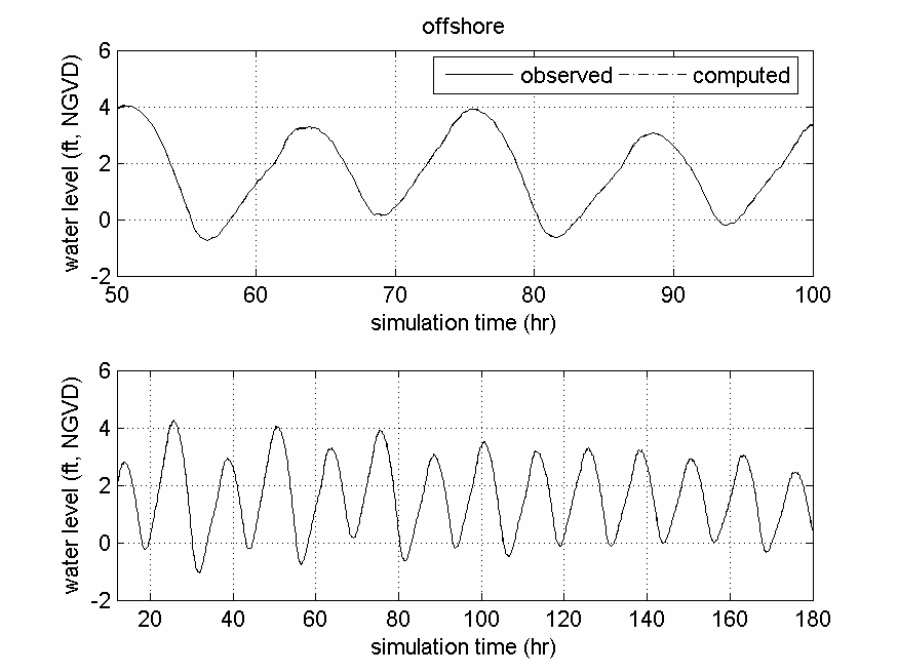


Figure V-23. Comparison of model output and measured tides for the TDR location offshore Hyannisport, in Nantucket Sound for the modeled calibration period. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

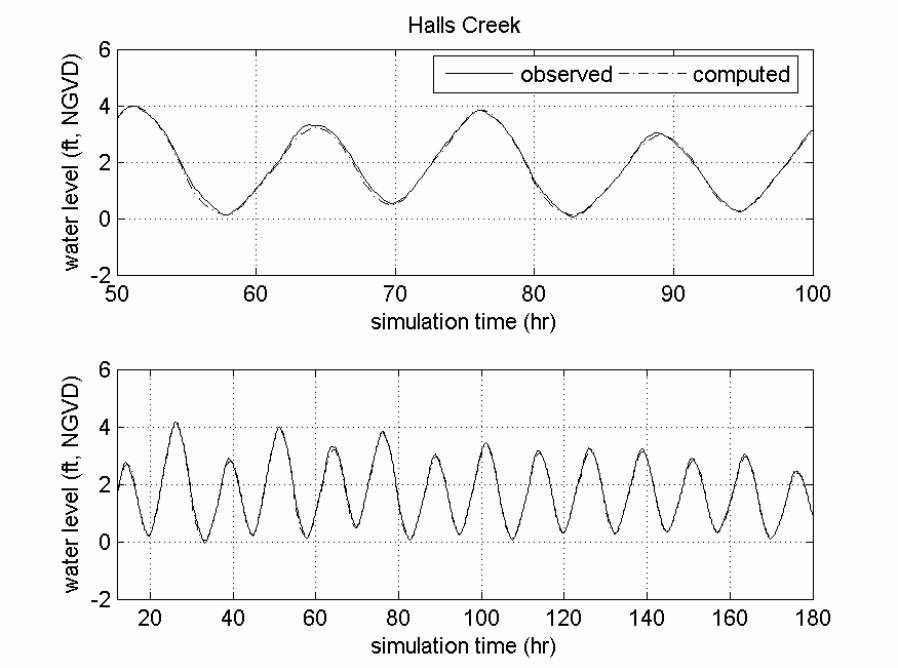


Figure V-24. Comparison of model output and measured tides for the TDR location in Halls Creek, for the modeled calibration period. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

Table V-11. Tidal constituents for measured water level data and calibrated model output, with model error amplitudes, for Halls Creek, during modeled calibration time period.

Model calibration run						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound	1.78	0.22	0.09	0.45	49.9	206.6
Halls Creek	1.50	0.10	0.02	0.41	66.8	210.8
Measured tide during calibration period						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound	1.80	0.22	0.10	0.45	51.0	211.8
Halls Creek	1.49	0.06	0.05	0.41	68.4	207.2
Error						
Location	Error Amplitude (ft)				Phase error (min)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound	0.02	0.00	0.01	0.00	2.3	5.4
Halls Creek	-0.01	-0.04	0.03	0.00	3.3	-3.7

V.3.3.4.c Halls Creek Tidal Verification

An additional verification model run was performed to further test the calibrated model. This step was performed for Halls Creek, unlike for the Lewis Bay Model, since ADCP data were not available for verification. Similar to the calibration procedure, tides for five-day period starting June 2, 2004 at 1200 EDT were simulated with model. However, for the verification run,

the friction and eddy viscosity coefficients, set during the model calibration process, were not modified. A comparison of tidal constituents from modeled and measured tides is presented in Table V-12. Plots of model output from the model calibration are presented in Figures V-25 and V-26. Similar to the calibration, errors in amplitude and phase of the extracted constituents are small and within the resolution of the instrument. The results of the verification provide further assurance of the skill of the model's calibration.

V.3.4 ADCP verification of the Lewis Bay system

An additional model verification check was possible by using collected ADCP velocity data to verify the performance of the model in representing the system dynamics. Computed flow rates from the model were compared to flow rates determined using the measured velocity data. The ADCP data survey efforts are described in Section V.2.3. For the model ADCP verification, the Lewis Bay model was run for the period covered during the ADCP survey on June 23, 2004.

The verification model period was performed for an approximate eight-day period, beginning 0000 hours EDT June 20, 2004 and ending 0000 EDT June 28, 2004. This time period included a 12-hour model spin-up period, and a tide cycle period used to compare to the ADCP data. Model flow rates were computed in RMA-2 at continuity lines (channel cross-sections) that correspond to the actual ADCP transects followed in the survey across the three locations in the Bay.

Table V-12. Tidal constituents for measured water level data and model output, with model error amplitudes, for Halls Creek, during modeled validation time period.

Model calibration run						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound	1.90	0.24	0.10	0.79	3.8	116.5
Halls Creek	1.53	0.12	0.03	0.68	21.4	94.2
Measured tide during calibration period						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound	1.93	0.25	0.11	0.80	4.8	120.6
Halls Creek	1.50	0.09	0.06	0.68	24.0	81.3
Error						
Location	Error Amplitude (ft)				Phase error (min)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Nantucket Sound	0.03	0.01	0.01	0.01	2.1	4.2
Halls Creek	-0.03	-0.03	0.03	0.00	5.4	-13.4

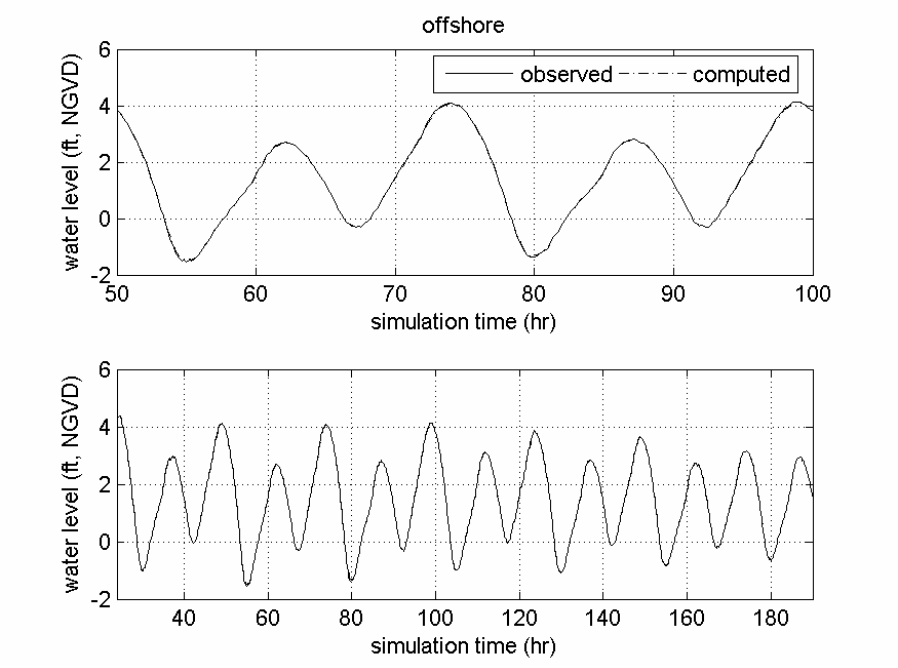


Figure V-25. Comparison of model output and measured tides for the TDR location offshore Hyannisport, in Nantucket Sound, for the modeled verification period. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

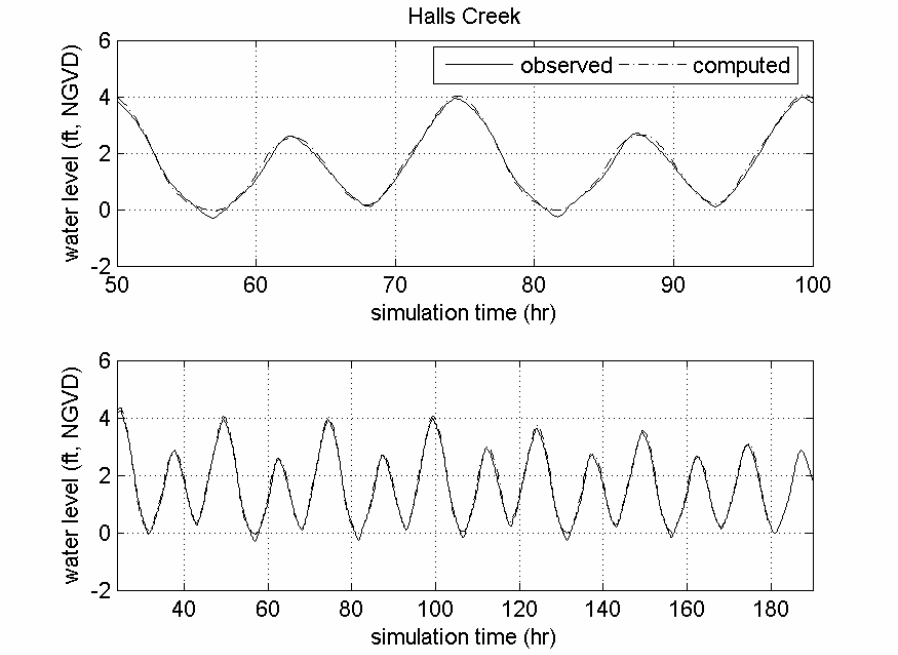


Figure V-26. Comparison of model output and measured tides for the TDR location in Halls Creek, for the modeled verification period. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.

Data comparisons at the Lewis Bay ADCP transects show good agreement with the model predictions, with R^2 correlation coefficients between data and model results range from 0.84 to 0.91. A comparison of the measured and modeled volume flow rates at the survey

transect are shown in Figures V-27 and V-28. The top plot in the figure shows the flow comparison, and the lower plot shows the time series of tide elevations for the same period. Each ADCP point (black circles shown on the plots) is a summation of flow measured along the ADCP transect at a discrete moment in time. The 'bumps' and 'skips' of the flow rate curve (more evident in the model output) can be attributed mostly to the peculiar nature of the forcing tide in this region, but also to the effects of winds (i.e., atmospheric effects) on the water surface and friction across the seabed periodically retarding or accelerating the flow through the inlets. If water surface elevations changed smoothly as a sinusoid, the volume flow rate would also appear as a smooth curve. However, since the rate at which water surface elevations change does not vary smoothly, the flow rate curve is expected to show short-period fluctuations.

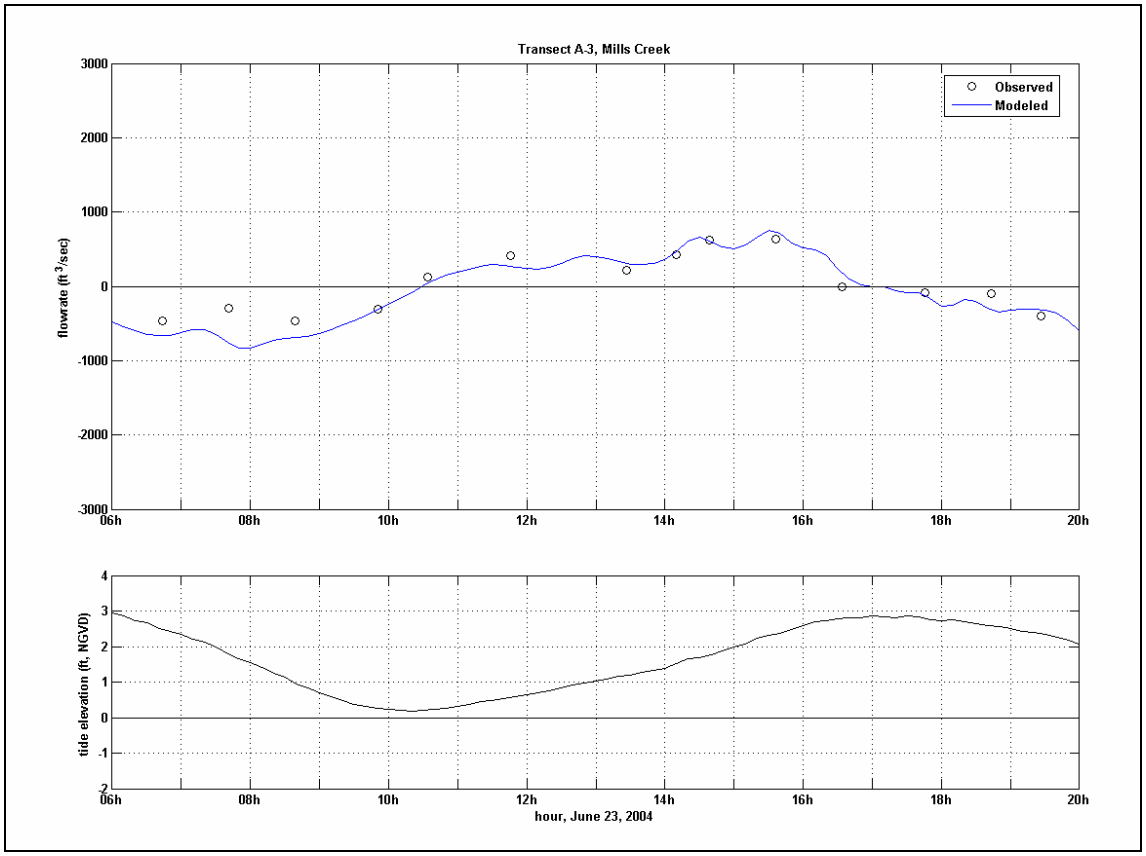


Figure V-27. Comparison of measured volume flow rates versus modeled flow rates (top plot) across Mill Creek inlet transect (A-3), over a tidal cycle on June 23, 2004 (R^2 = 0.84). Flood flows into the inlet are positive (+), and ebb flows out of the inlet are negative (-). The bottom plot shows the tide elevation offshore, in Nantucket Sound.

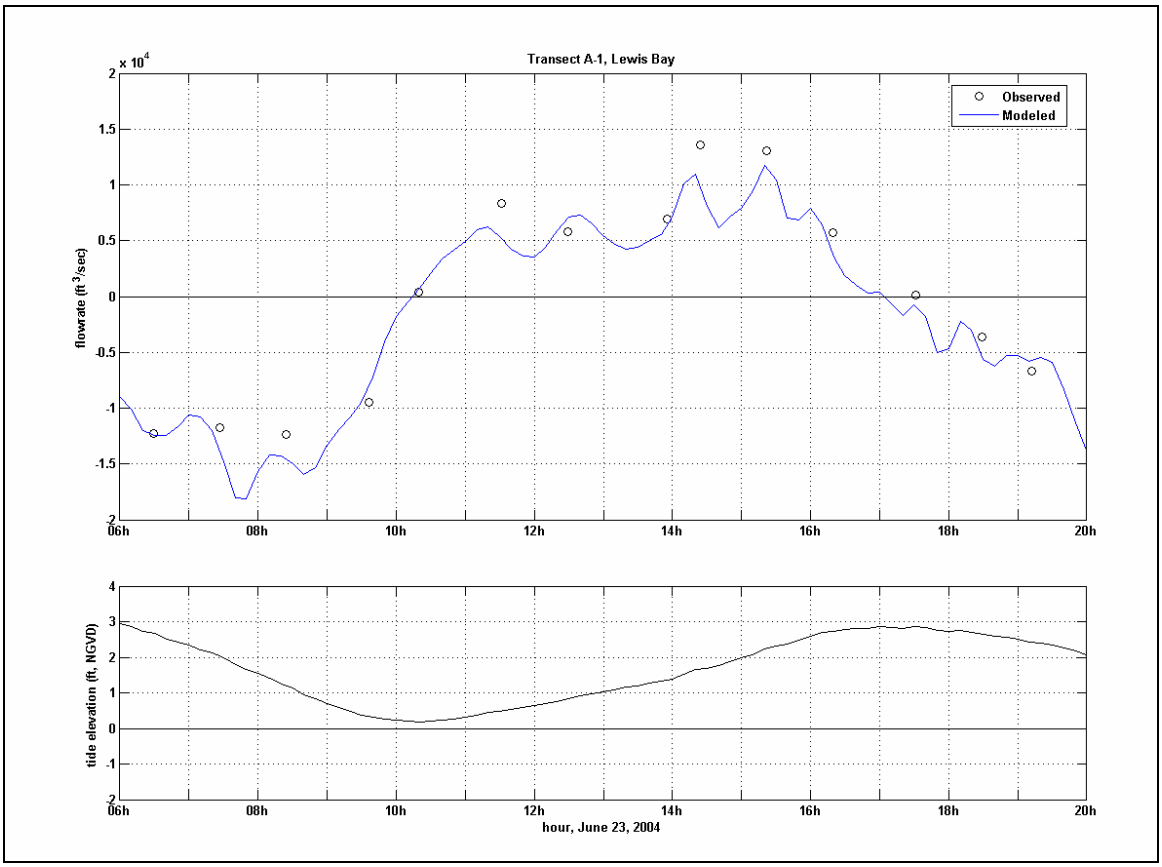


Figure V-28. Comparison of measured volume flow rates versus modeled flow rates (top plot) across the entrance to Lewis Bay (A-1), over a tidal cycle on June 23, 2004 (R^2 = 0.91). Flood flows into the inlet are positive (+), and ebb flows out of the inlet are negative (-). The bottom plot shows the tide elevation offshore, in Nantucket Sound.

V.3.5 Model Circulation Characteristics

The final calibrated and validated model serves as a useful tool for investigating the circulation characteristics of the Lewis Bay and Halls Creek estuarine systems. Using model inputs of bathymetry and tide data, current velocities and flow rates can be determined at any point in either model domain. This is a very useful feature of a hydrodynamic model, where a limited amount of collected data can be expanded to determine the physical attributes of the system in areas where no physical data record exists.

V.3.5.1 Lewis Bay

From the model run of Lewis Bay, maximum ebb velocities at the inlet are larger than velocities during the flood portion of the tide. Maximum depth-averaged velocities in the model are approximately 2.9 feet/sec for ebbing tides, and 1.7 ft/sec for flooding tides. A close-up of the model output is presented in Figure V-29, which shows contours of flow velocity, along with velocity vectors which indicate the direction and magnitude of flow, for a single model time-step, at the portion of the tide where maximum ebb velocities occur at the inlet.

The hydraulic model shows that the culverts conveying tidal flows into Stewarts Creek and Snows Creek represent restrictions to the natural flow. The limited size of the culverts restricts the full hydraulic exchange of tidal waters between the main basin and embayment. The

hydraulic efficiency of the existing culverts can be slightly improved by keep the openings and length of the culvert free of debris and any sediment buildup.

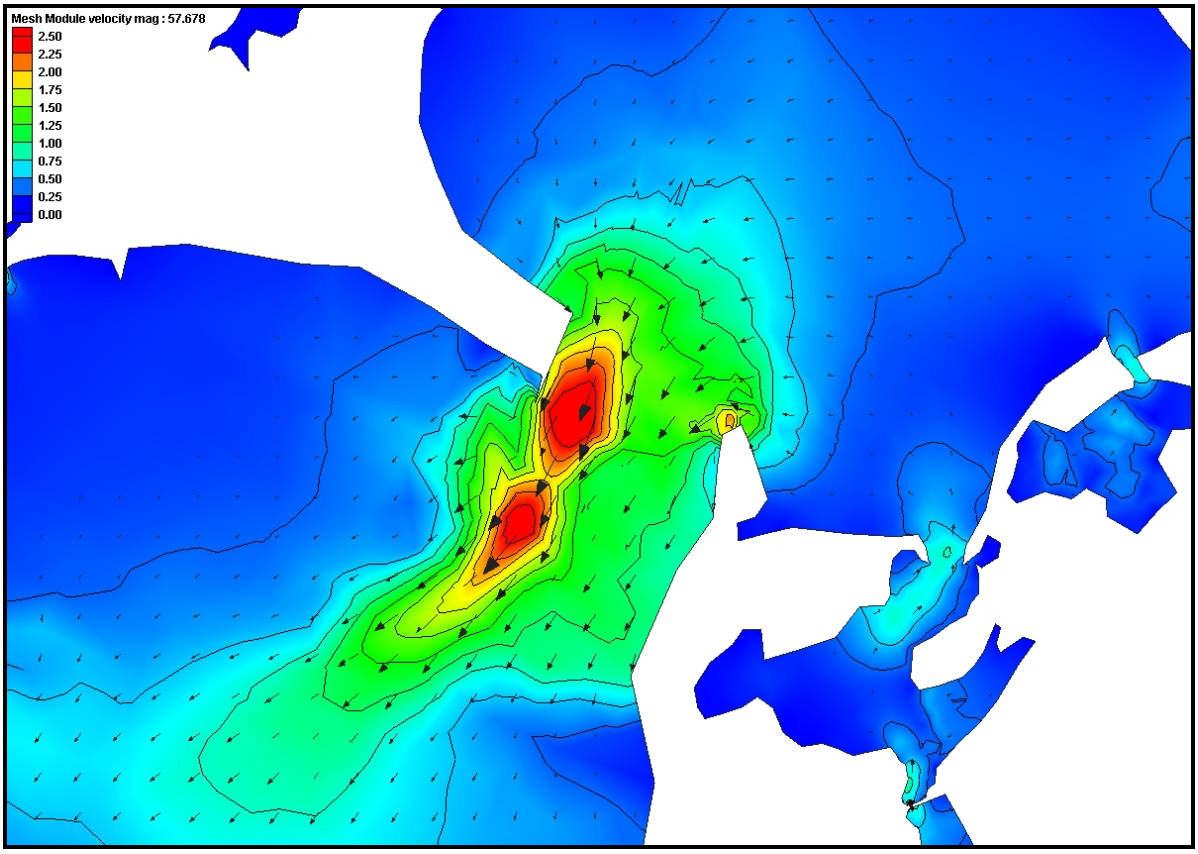


Figure V-29. Example of hydrodynamic model output in Lewis Bay for a single time step where maximum ebb velocities occur for this tide cycle. Color contours indicate flow velocity, and vectors indicate the direction and magnitude of flow.

V.3.5.2 Halls Creek

From the model run of Halls Creek, maximum ebb velocities in the inlet channels are slightly larger than velocities during maximum flood. Maximum depth-averaged flood velocities in the model are approximately 2.7 feet/sec in the inlet channel, while maximum ebb velocities are about 3.1 feet/sec. Close-up views of model output are presented in Figure V-30 which shows contours of velocity magnitude along with velocity vectors that indicate flow direction for a single model time-step, at the portion of the tide where maximum ebb velocities.

In addition to depth-averaged velocities, the total flow rate of water flowing through a channel can be computed with the hydrodynamic model. The variation of flow as the tide floods and ebbs at the two system inlets is seen in the plot of flow rates in Figure V-31. Maximum flow rates occur during flooding tides in this system. During spring tides, the maximum flood flow rates reach 1,300 ft^3/sec at the Creek inlet. Maximum ebb flow rates during spring tides are slightly smaller, at about 1,100 ft^3/sec. Minimum flood and ebb flows at the inlet during neap tides are both approximately 400 ft^3/sec.

Using the velocities computed in the model, an investigation of the flood or ebb dominance of different areas in the Halls Creek system can be performed. Marsh systems are

typically flood dominant, meaning that maximum flood tide velocities are greater than during the ebb portion of the tide. Flood dominance indicates a tendency to collect and trap sediment.

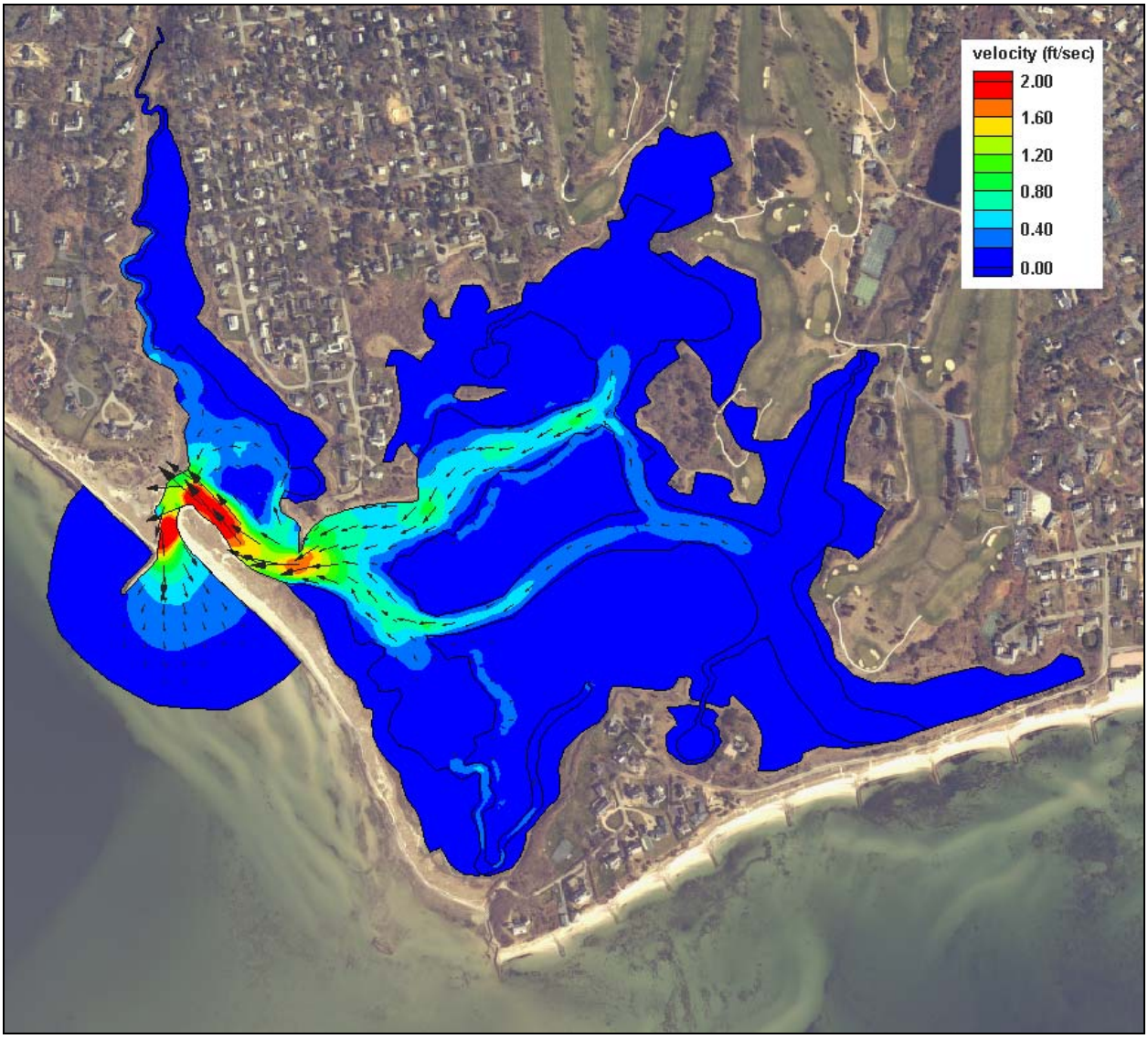


Figure V-30. Example of Halls Creek hydrodynamic model output for a single time step during an ebbing tide. Color contours indicate velocity magnitude, and vectors indicate the direction of flow. Material type boundaries are also shown as the solid black lines within the model domain.

Flood or ebb dominance in channels of a tidal system can be determined by performing a harmonic analysis of tidal currents. A discussion of the method of relative phase determination is presented in Friedrichs and Aubrey (1988). For this method, the M_2 and M_4 tidal constituents of a tidal velocity time series are computed, similar to the tidal elevation constituents presented in Section V.3.3.4.

The relative phase difference is computed as the difference between two times the M_2 phase and the phase of the M_4, expressed as $\Phi=2M_2-M_4$. If Φ is between 270 and 90 degrees

(-90<Φ<90), then the channel is characterized as being flood dominant, and peak flood velocities will be greater than for peak ebb. Alternately, if Φ were between 90 and 270 degrees (90<Φ<270), then the channel would be ebb dominant. If Φ is exactly 90 or 270 degrees, neither flood nor ebb dominance occurs. For Φ equal to exactly 0 or 180 degrees, maximum tidal distortion occurs and the velocity residuals of a channel are greatest. This relative phase relationship is presented graphically in Figure V-32.

Though this method of tidal constituent analysis provides similar results to a visual inspection of a velocity record (e.g., by comparing peak ebb and flood velocities), it allows a more exact characterization of the tidal processes. By this analysis technique, a channel can be characterized as being strongly, moderately, or weakly flood or ebb dominant.

Three points were selected for this velocity analysis: 1) the inlet, 2) in the lower portion of the Creek at the same location of the tide gauge station inside the Creek and 3) in the upper Creek at a location 1,300 feet upstream from the tide gauge station.

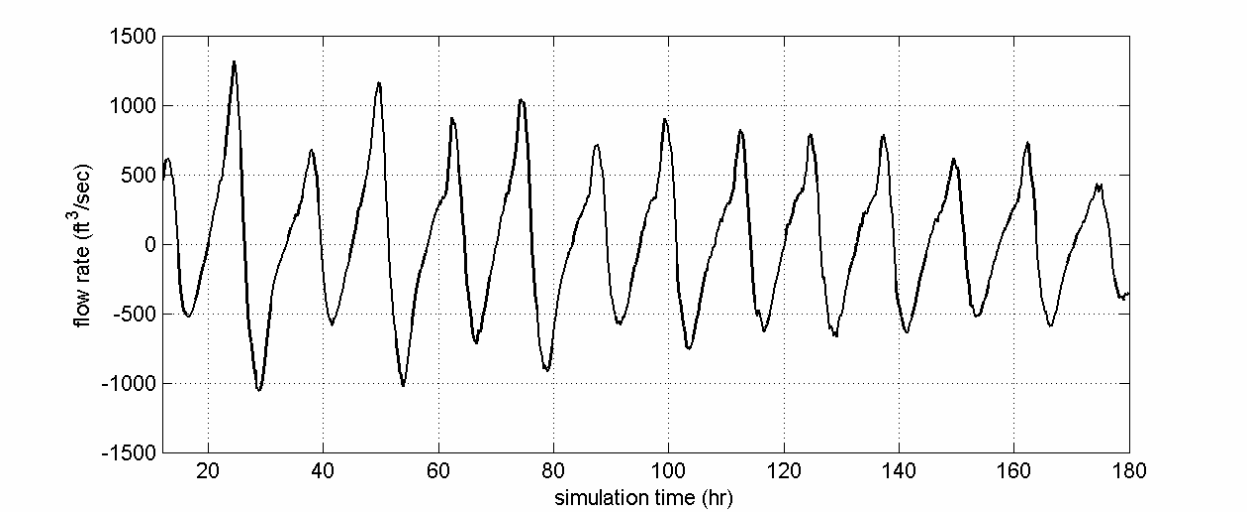


Figure V-31. Time variation of computed flow rates for Halls Creek. Plotted time period represents the seven-day period that includes the model calibration period. Positive flow indicated flooding tide, while negative flow indicates ebbing tide.

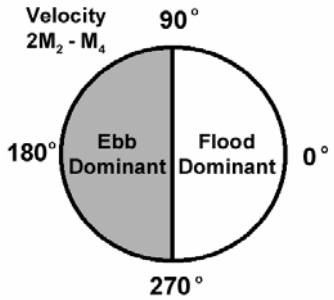


Figure V-32. Relative velocity phase relationship of M2 and M4 tidal velocity constituents and characteristic dominance, indicated on the unit circle. Relative phase is computed as the difference of two times the M_2 phase and the M_4 phase ($2M_2$-M_4). A relative phase of exactly 90 or 270 degrees indicates a symmetric tide, which is neither flood nor ebb dominant.

The results of this velocity analysis of the Halls Creek model output show that that, though the inlet area of the Creek is ebb dominant, upper portions of the system are indeed flood dominant, as is expected for a marsh. The computed values of $2M_2$-M_4 are presented in Table V-13. The first two locations, in the vicinity of the inlet, have a velocity constituent phase relationship that indicated that the tides in these areas are moderate ebb dominant. For the third location used in this analysis, which is farther into the system than the other two, the velocity constituent phase relationship indicates moderate flood dominance.

Table V-13. Halls Creek relative velocity phase differences of M_2 and M_4 tide constituents, determines using velocity records.

location	$2M_2$-M_4 relative phase (deg)	Characteristic dominance
Inlet	259.6	Moderate Ebb
Lower Halls Creek	113.3	Moderate Ebb
Upper Halls Creek	79.8	Moderate Flood

V.5 FLUSHING CHARACTERISTICS

Since the magnitude of freshwater inflow is much smaller in comparison to the tidal exchange through each inlet, the primary mechanism controlling estuarine water quality within Lewis Bay and Halls Creek is tidal exchange. A rising tide offshore in Nantucket Sound creates a slope in water surface from the ocean into the modeled systems. Consequently, water flows into (floods) the system. Similarly, the estuary drains into the open waters of the Sound on an ebbing tide. This exchange of water between each system and the ocean is defined as tidal flushing. The calibrated hydrodynamic model is a tool to evaluate quantitatively tidal flushing of each system, and was used to compute flushing rates (residence times) and tidal circulation patterns.

Flushing rate, or residence time, is defined as the average time required for a parcel of water to migrate out of an estuary from points within the system. For this study, **system residence times** were computed as the average time required for a water parcel to migrate from a point within the each embayment to the entrance of the system. System residence times are computed as follows:

$$T_{system} = \frac{V_{system}}{P} t_{cycle}$$

where T_{system} denotes the residence time for the system, V_{system} represents volume of the (entire) system at mean tide level, P equals the tidal prism (or volume entering the system through a single tidal cycle), and t_{cycle} the period of the tidal cycle, typically 12.42 hours (or 0.52 days). To compute system residence time for a sub-embayment, the tidal prism of the sub-embayment replaces the total system tidal prism value in the above equation.

In addition to system residence times, a second residence, the **local residence time**, was defined as the average time required for a water parcel to migrate from a location within a sub-

embayment to a point outside the sub-embayment. Using the head of Hyannis Inner Harbor as an example, the **system residence time** is the average time required for water to migrate from the inner harbor, through Lewis Bay, and finally into Hyannis Harbor, where the **local residence time** is the average time required for water to migrate from the head of the inner harbor to out into Lewis Bay (not all the way to through inlet and out of the system). Local residence times for each sub-embayment are computed as:

$$T_{local} = \frac{V_{local}}{P} t_{cycle}$$

where T_{local} denotes the residence time for the local sub-embayment, V_{local} represents the volume of the sub-embayment at mean tide level, P equals the tidal prism (or volume entering the local sub-embayment through a single tidal cycle), and t_{cycle} the period of the tidal cycle (again, 0.52 days).

Residence times are provided as a first order evaluation of estuarine water quality. Lower residence times generally correspond to higher water quality; however, residence times may be misleading depending upon pollutant/nutrient loading rates and the overall quality of the receiving waters. As a qualitative guide, **system residence times** are applicable for systems where the water quality within the entire estuary is degraded and higher quality waters provide the only means of reducing the high nutrient levels. For the modeled system, this approach is applicable, since it assumes the main system has relatively low quality water relative to Nantucket Sound.

The rate of pollutant/nutrient loading and the quality of water outside the estuary both must be evaluated in conjunction with residence times to obtain a clear picture of water quality. Efficient tidal flushing (low residence time) is not an indication of high water quality if pollutants and nutrients are loaded into the estuary faster than the tidal circulation can flush the system. Neither are low residence times an indicator of high water quality if the water flushed into the estuary is of poor quality. Advanced understanding of water quality is obtained from the calibrated hydrodynamic model by extending the model to include a total nitrogen dispersion model (Section VI). The water quality model will provide a valuable tool to evaluate the complex mechanisms governing estuarine water quality in the Lewis Bay and its component sub-embayments.

The volume of the each sub-embayment, as well as their respective tidal prisms, were computed as cubic feet (Table V-14). Model divisions used to define the system sub-embayments for the Lewis Bay system include 1) the whole of system, 2) all of Lewis Bay (including all sub-embayments), 3) Hyannis Inner Harbor, 4) Uncle Roberts Cove, 5) Mill Creek, 6) Snows Creek, and 7) Stewarts Creek. For Halls Creek, the flushing calculation was performed on the whole system only.

The model computed total volume of each sub-embayment (using the divisions shown in Figure V-12 and V-14, for Lewis Bay and Halls Creek, respectively), at every time step, and this output was used to calculate mean sub-embayment volume and average tide prism. Since the period used to compute the flushing rates of the system represent average tidal conditions, the measurements provide the most appropriate method for determining mean flushing rates for the system sub-embayments.

Computed residence times and are listed in Table V-15. Residence times were computed for the entire estuary, as well selected sub-embayments within the two systems. In addition, **system** and **local residence times** were computed to indicate the range of conditions possible for the system. Residence times were calculated as the volume of water (based on mean volumes computed for the simulation period) in the entire system divided by the average volume of water exchanged with each sub-embayment over a flood tidal cycle (tidal prism). Units then were converted to days.

The whole of Hyannis Harbor/Lewis Bay system has a low residence time (1.1 days) showing that the system has good flushing conditions. This is true of all the local residence times for the system. The only embayment with moderately high local residence time (3.7 days) is Snows Creek. The flow into and out of Snows Creek is restricted by the narrow channel and the culvert under Ocean Street. The longer residence times suggest that the water quality within the Snow Creek is highly sensitive to the combined nutrient load input from the system watersheds, benthic sediments and direct atmospheric deposition. The system residence time for Snows Creek does not provide a good indication of the water quality since the variation in basin volumes from Snows Creek to the system volume is considerable. The result is a very long system residence time which should not be considered an accurate characterization of the conditions occurring in the creek.

The computed flushing rate for the Halls Creek system show that as a whole, the system flushes very well, as is typical of marsh systems. A flushing time of 0.4 days for the entire estuary shows that on average, water is resident in the system less than one day.

Based on our knowledge of estuarine processes, we estimate that the combined errors associated with the method applied to compute residence times are within 10% to 15% of “true” residence times, for the Lewis Bay and Halls Creek estuary systems. Possible errors in computed residence times can be linked to two sources: the bathymetry information and simplifications employed to calculate residence time. In this study, the most significant errors associated with the bathymetry data result from the process of interpolating the data to the finite element mesh, which was the basis for all the flushing volumes used in the analysis. In addition, limited topographic measurements were available in some of the smaller sub-embayments of the system.

Minor errors may be introduced in residence time calculations by simplifying assumptions. Flushing rate calculations assume that water exiting an estuary or sub-embayment does not return on the following tidal cycle. For regions where a strong littoral drift exists, this assumption is valid. However, water exiting a small sub-embayment on a relatively calm day may not completely mix with estuarine waters. In this case, the “strong littoral drift” assumption would lead to an under-prediction of residence time. Since littoral drift in Nantucket Sound typically is strong because of the effects of the local winds, tidal induced mixing, the “strong littoral drift” assumption should cause only minor errors in residence time calculations.

Table V-14. Embayment mean volumes and average tidal prism of the Lewis Bay and Halls Creek system during the simulation periods.

Embayment	Mean Volume (ft^3)	Tide Prism Volume (ft^3)
Lewis Bay an Hyannis Harbor		
Entire System	1,368,016,852	645,052,581
Lewis Bay with sub-embayments	452,424,905	284,845,281
Hyannis Inner Harbor	23,711,223	11,275,304
Uncle Roberts Cove	18,052,002	18,972,946
Mill Creek	8,528,184	14,355,607
Snows Creek	3,017,376	421,485
Stewarts Creek	2,887,656	786,042
Halls Creek		
Halls Creek	6,969,000	9,203,000

Table V-15. Computed System and Local residence times for sub-embayments of the Lewis Bay estuary and Halls Creek marsh.

Embayment	System Residence Time (days)	Local Residence Time (days)
Lewis Bay an Hyannis Harbor		
Entire System	1.1	1.1
Lewis Bay with sub-embayments	0.8	0.8
Hyannis Inner Harbor	2.1	1.1
Uncle Roberts Cove	1.2	0.5
Mill Creek	1.6	0.3
Snows Creek	558.2	3.7
Stewarts Creek	---	1.9
Halls Creek		
Halls Creek	0.4	0.4

VI. WATER QUALITY MODELING

VI.1 DATA SOURCES FOR THE MODEL

Several different data types and calculations are required to support the water quality modeling effort for both the Lewis Bay and Halls Creeks systems. These include the output from the hydrodynamics model, calculations of external nitrogen loads from the watersheds, measurements of internal nitrogen loads from the sediment (benthic flux), and measurements of nitrogen in the water column.

VI.1.1 Hydrodynamics and Tidal Flushing in the Embayment

Extensive field measurements and hydrodynamic modeling of the embayment were an essential preparatory step to the development of the water quality model. The result of this work, among other things, was a calibrated model output representing the transport of water within the system embayment. Files of node locations and node connectivity for the RMA-2V model grid were transferred to the RMA-4 water quality model; therefore, the computational grid for the hydrodynamic model also was the computational grid for the water quality model. For Lewis Bay, the period of hydrodynamic output for the water quality model calibration was an 11-tidal cycle period in June 2004. For Halls Creek, the period of hydrodynamic output for the water quality model calibration was the 6 day period beginning July 3, 2004 1900 EST. Each modeled scenario executed for both systems (e.g., present conditions, build-out) required that each model be run for a 28-day spin-up period, to allow the model had reached a dynamic "steady state", and ensure that model spin-up would not affect the final model output.

VI.1.2 Nitrogen Loading to the Embayment

Three primary nitrogen loads to an embayment are recognized in this modeling study: external loads from the watersheds, nitrogen load from direct rainfall on the embayment surface, and internal loads from the sediments. Additionally, there is a fourth load to the Lewis Bay and Halls Creek systems, consisting of the background concentrations of total nitrogen in the waters entering from Nantucket Sound. This load is represented as a constant concentration along the seaward boundary of the model grids.

VI.1.3 Measured Nitrogen Concentrations in the Embayment

In order to create a model that realistically simulates the total nitrogen concentrations in a system in response to the existing flushing conditions and loadings, it is necessary to calibrate the model to actual measurements of water column nitrogen concentrations. The refined and approved data for each monitoring station used in the water quality modeling effort are presented in Table VI-1 and VI-2 for Lewis Bay and Halls Creek, respectively. Station locations are indicated in Figure VI-1 and VI-1 for the two separate systems. The multi-year averages present the "best" comparison to the water quality model output, since factors of tide, temperature and rainfall may exert short-term influences on the individual sampling dates and even cause inter-annual differences. Three years of baseline field data is the minimum required to provide a baseline for MEP an analysis. Six years of data (collected between 2001 and 2006) were available for stations monitored by SMAST in the Lewis Bay and Halls Creek systems.

VI.2 MODEL DESCRIPTION AND APPLICATION

A two-dimensional finite element water quality model, RMA-4 (King, 1990), was employed to study the effects of nitrogen loading in the Lewis Bay and Halls Creek estuarine systems.

The RMA-4 model has the capability for the simulation of advection-diffusion processes in aquatic environments. It is the constituent transport model counterpart of the RMA-2 hydrodynamic model used to simulate the fluid dynamics of both estuarine systems in this analysis. Like RMA-2 numerical code, RMA-4 is a two-dimensional, depth averaged finite element model capable of simulating time-dependent constituent transport. The RMA-4 model was developed with support from the US Army Corps of Engineers (USACE) Waterways Experiment Station (WES), and is widely accepted and tested. Applied Coastal staff have utilized this model in water quality studies of other Cape Cod embayments, including systems in Falmouth (Ramsey *et al*., 2000); Mashpee, MA (Howes *et al*., 2004) and Chatham, MA (Howes *et al*., 2003).

The overall approach involves modeling total nitrogen as a non-conservative constituent, where bottom sediments act as a source or sink of nitrogen, based on local biochemical characteristics. This modeling represents summertime conditions, when algal growth is at its maximum. Total nitrogen modeling is based upon various data collection efforts and analyses presented in previous sections of this report. Nitrogen loading information was derived from the Cape Cod Commission watershed loading analysis (based on the USGS watersheds), as well as the measured bottom sediment nitrogen fluxes. Water column nitrogen measurements were utilized as model boundaries and as calibration data. Hydrodynamic model output (discussed in Section V) provided the remaining information (tides, currents, and bathymetry) needed to parameterize the water quality model of each system.



Figure VI-1. Estuarine water quality monitoring station locations in the Lewis Bay system. Station labels correspond to those provided in Table VI-1.

Table VI-1. Towns of Barnstable and Yarmouth water quality monitoring data, and modeled Nitrogen concentrations for the Lewis Bay system used in the model calibration plots of Figure VI-2. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means.

Sub-Embayment	Hyannis Inner Harbor	Hyannis Inner Harbor	Hyannis Inner Harbor	Snows Creek	Lewis Bay	Lewis Bay	Stewarts Creek	Lewis Bay	Lewis Bay	Lewis Bay	Uncle Roberts Cove	Mill Creek	Mill Creek
Monitoring station	BH-1	BH-2	BH-3	BH-4	BH-5	BH-6	BH-7	BHY-1	BHY-2	BHY-3	BHY-4	MC-1	MC-2
2001 mean	0.422	0.327	0.351	1.422	0.298	0.308	--	0.270	0.329	0.333	--	--	--
2002 mean	0.634	0.535	0.483	1.459	0.399	0.415	1.257	0.358	0.420	0.369	--	0.469	0.476
2003 mean	0.676	0.494	0.491	1.873	0.420	0.349	1.411	0.351	0.420	0.405	--	0.555	0.510
2004 mean	0.580	0.492	0.368	1.295	0.372	0.353	1.023	0.445	0.496	0.424	0.469	0.594	0.523
2005 mean	0.526	0.413	0.400	1.450	0.325	0.349	1.016	0.326	0.373	0.371	0.364	0.500	0.463
2006 mean	0.585	0.468	0.416	1.917	0.344	0.421	1.606	0.435	0.476	0.461	0.391	0.749	0.638
mean	0.599	0.474	0.433	1.565	0.374	0.373	1.245	0.374	0.430	0.395	0.410	0.562	0.516
s.d. all data	0.140	0.100	0.097	0.442	0.089	0.095	0.399	0.115	0.111	0.095	0.091	0.162	0.128
N	55	58	55	33	57	61	31	63	59	60	8	27	26
model min	0.561	0.501	0.420	0.395	0.376	0.336	0.923	0.361	0.393	0.404	0.421	0.466	0.419
model max	0.585	0.537	0.488	2.022	0.401	0.399	1.643	0.406	0.475	0.412	0.442	0.665	0.608
model average	0.574	0.518	0.445	1.638	0.388	0.369	1.377	0.385	0.415	0.408	0.432	0.532	0.474

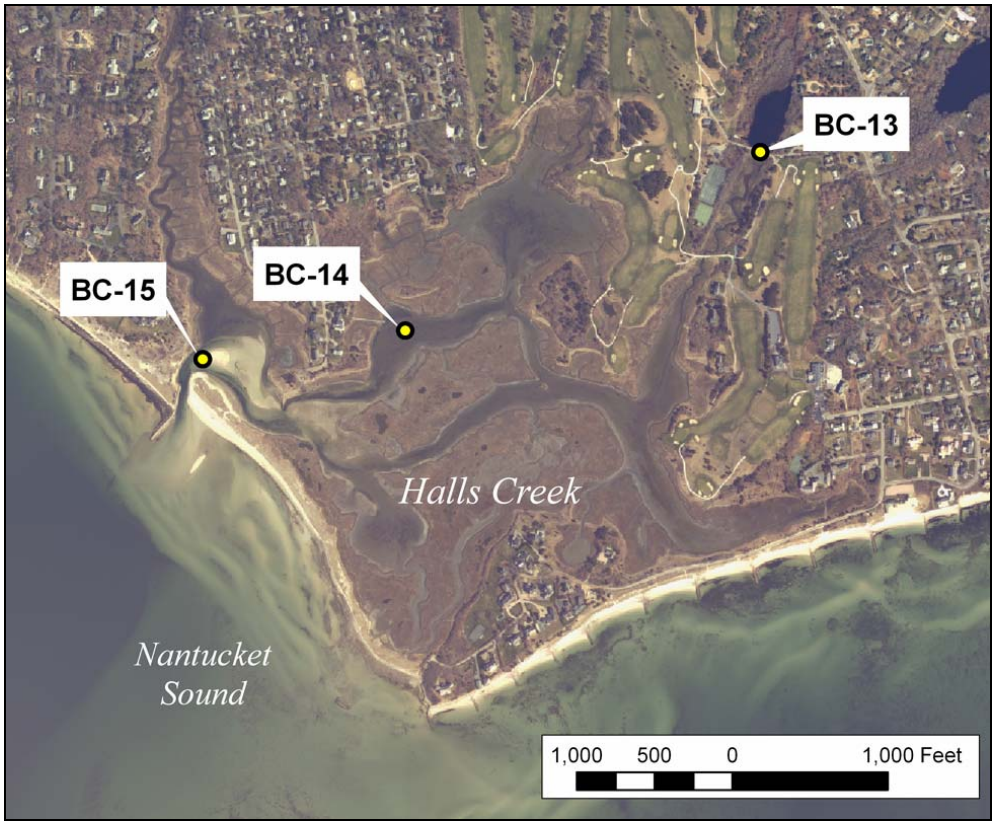


Figure VI-2. Estuarine water quality monitoring station locations in the Halls Creek estuary system. Station labels correspond to those provided in Table VI-2.

Table VI-2. Measured data and modeled nitrogen concentrations for the Halls Creek estuarine system used in the model calibration plots of Figures VI-2 and VI-3. All concentrations are given in mg/L N. "Data mean" values are calculated as the average all samples. Halls Creek data represented in this table were collected in the summers of 2001 through 2006.

Sub-Embayment	monitoring station	data mean	s.d. all data	N	model min	model max	model average	model target
Halls Creek Stream	BC-13	1.213	0.410	24	0.703	1.863	1.171	1.213
Halls Creek - middle	BC-14	0.454	0.083	26	0.302	0.685	0.433	0.454
Halls Creek - inlet	BC-15	0.431	0.083	28	0.293	0.568	0.349	0.431
Nantucket Sound	NTKS	0.294	0.062	4	-	-	-	0.294

VI.2.1 Model Formulation

The formulation of the model is for two-dimensional depth-averaged systems in which concentration in the vertical direction is assumed uniform. The depth-averaged assumption is justified since vertical mixing by wind and tidal processes prevent significant stratification in the modeled sub-embayments. The governing equation of the RMA-4 constituent model can be most simply expressed as a form of the transport equation, in two dimensions:

$$\left(\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y}\right) = \left(\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x} + \frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y} + \sigma\right)$$

where c in the water quality constituent concentration; t is time; u and v are the velocities in the x and y directions, respectively; D_x and D_y are the model dispersion coefficients in the x and y directions; and σ is the constituent source/sink term. Since the model utilizes input from the RMA-2 model, a similar implicit solution technique is employed for the RMA-4 model.

The model is therefore used to compute spatially and temporally varying concentrations c of the modeled constituent (i.e., total nitrogen), based on model inputs of 1) water depth and velocity computed using the RMA-2 hydrodynamic model; 2) mass loading input of the modeled constituent; and 3) user selected values of the model dispersion coefficients. Dispersion coefficients used for each system sub-embayment were developed during the calibration process. During the calibration procedure, the dispersion coefficients were incrementally changed until model concentration outputs matched measured data.

The RMA-4 model can be utilized to predict both spatial and temporal variations in total for a given embayment system. At each time step, the model computes constituent concentrations over the entire finite element grid and utilizes a continuity of mass equation to check these results. Similar to the hydrodynamic model, the water quality model evaluates model parameters at every element at 10-minute time intervals throughout the grid system. For this application, the RMA-4 model was used to predict tidally averaged total nitrogen concentrations throughout the two modeled systems.

VI.2.2 Water Quality Model Setup

Required inputs to the RMA-4 model include a computational mesh, computed water elevations and velocities at all nodes of the mesh, constituent mass loading, and spatially varying values of the dispersion coefficient. Because the RMA-4 model is part of a suite of integrated computer models, the finite-element meshes and the resulting hydrodynamic simulations previously developed for the Lewis Bay and Halls Creek systems was used for the water quality constituent modeling portion of this study.

Based on measured flow rates from SMAST and groundwater recharge rates from the USGS, the hydrodynamic model was set-up to include the latest estimate of surface water flows from Chase Brook, Mill Pond, Snows Creek, Stewarts Creek, and Hospital Creek/Hyannis Inner Harbor Creek along with ground water flowing into the system from watersheds. The Chase Brook has a measure flow rate of 1.33 ft^3/sec (3,255 m^3/day), Mill Pond has a measure flow rate of 6.40 ft^3/sec (15,655 m^3/day), Snows Creek has a measure flow rate of 2.17 ft^3/sec (5,298 m^3/day), Stewarts Creek has a measure flow rate of 5.71 ft^3/sec (13,966 m^3/day), and Hospital Creek/Hyannis Inner Harbor Creek has a measure flow rate of 0.54 ft^3/sec (1,318 m^3/day). The overall groundwater flow rate into the system is 6.38 ft^3/sec (15,614 m^3/day) distributed amongst the watersheds.

For Halls Creek, the hydrodynamic model was set-up to include the latest estimates of flows from the surface freshwater input to the marsh from Halls Creek stream (0.484 ft^3/sec), based on stream gauge measurements performed by SMAST. The groundwater inputs to the system are an additional 3.20 ft^3/sec (7,820 m^3/day).

For the model, an initial total N concentration equal to the concentration at the open boundary was applied to the entire model domain. The model was then run for a simulated month-long (28 day) spin-up period. At the end of the spin-up period, the model was run for an additional 7 tidal-day (174 hour) period. Model results were recorded only after the initial spin-up period. The time step used for the water quality computations was 10 minutes, which corresponds to the time step of the hydrodynamics input for both the Lewis Bay and Halls Creek systems.

VI.2.3 Boundary Condition Specification

Mass loading of nitrogen into each model included 1) sources developed from the results of the watershed analysis, 2) estimates of direct atmospheric deposition, 3) summer benthic regeneration, and 4) point source input developed from measurements of from Chase Brook, Mill Pond, and Hospital Creek/Hyannis Inner Harbor Creek for Lewis Bay, and Halls Creek stream for Halls Creek. Nitrogen loads from each separate sub-embayment watershed were distributed across the sub-embayment. For example, the combined watershed direct atmospheric deposition load for Uncle Roberts Cove was evenly distributed at grid cells that formed the perimeter of the embayment. Benthic regeneration load was distributed among another sub-set of grid cells which are in the interior portion of each basin.

The loadings used to model present conditions are given in Table VI-3 for Lewis Bay,and Figure VI-4 for Halls Creek. Watershed and depositional loads were taken from the results of the analysis of Section IV. Summertime benthic flux loads were computed based on the analysis of sediment cores in Section IV. The area rate ($g/sec/m^2$) of nitrogen flux from that analysis was applied to the surface area coverage computed for each sub-embayment (excluding marsh coverages, when present), resulting in a total flux for each embayment (as listed in Table VI-2). Due to the highly variable nature of bottom sediments and other estuarine characteristics of coastal embayments in general, the measured benthic flux for existing conditions also is variable. For present conditions, some sub-embayments have almost twice the loading rate from benthic regeneration as from watershed loads. For other sub-embayments, the benthic flux is relatively low or negative indicating a net uptake of nitrogen in the bottom sediments.

In addition to mass loading boundary conditions set within the model domain, concentrations along the model open boundary were specified. The model uses concentrations at the open boundary during the flooding tide periods of the model simulations. TN concentrations of the incoming water are set at the value designated for the open boundary. The boundary concentration in Nantucket Sound was set at 0.30 mg/L, based on SMAST data from the Sound. The open boundary total nitrogen concentration represents long-term average summer concentrations found within Nantucket Sound.

VI.2.4 Model Calibration

Calibration of the total nitrogen model proceeded by changing model dispersion coefficients so that model output of nitrogen concentrations matched measured data. Generally, several model runs of each system were required to match the water column measurements. Dispersion coefficient (E) values were varied through the modeled system by setting different values of E for each grid material type, as designated in Figure V-12 for Lewis Bay and V-14 for Halls Creek. Observed values of E (Fischer, *et al.*, 1979) vary between order 10 and order 1000 m^2/sec for riverine estuary systems characterized by relatively wide channels (compared to channel depth) with moderate currents (from tides or atmospheric forcing). Generally, the relatively quiescent areas of Lewis Bay and Halls Creek require values of E that

are lower compared to the riverine estuary systems evaluated by Fischer, *et al.*, (1979). Observed values of *E* in these calmer areas typically range between order 10 and order 0.001 m^2/sec (USACE, 2001). The final values of *E* used in each sub-embayment of the modeled systems are presented in Table VI-5. These values were used to develop the "best-fit" total nitrogen model calibration. For the case of TN modeling, "best fit" can be defined as minimizing the error between the model and data at all sampling locations, utilizing reasonable ranges of dispersion coefficients within each sub-embayment.

Table VI-3. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent **present loading conditions.**

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	30.855	13.507	25.999
Uncle Roberts Cove	0.540	0.759	12.771
Mill Creek	15.964	0.627	-15.355
Hyannis Inner Harbor	12.153	0.633	18.660
Snows Creek	15.115	-	-4.533
Stewarts Creek	38.992	0.236	-9.750
Surface Water Sources			
Chase Brook	3.345	-	-
Mill Pond	15.038	-	-
Hospital Creek/Hyannis Inner	1.907	-	-

Table VI-4. Sub-embayment and surface water loads used for total nitrogen modeling of the Halls Creek system, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent **present loading conditions** for the listed sub-embayments.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Halls Creek	21.534	0.630	5.252
Halls Creek Stream (freshwater)	1.597	-	-
System Total	23.132	0.630	5.252

Table VI-5. Values of longitudinal dispersion coefficient, E, used in calibrated RMA4 model runs of salinity and nitrogen concentration for the Lewis Bay and Halls Creek systems.

Embayment Division	E m^2/sec
Lewis Bay and Hyannis Harbor	
Hyannis Harbor	10.0
Lewis Bay	8.0
Uncle Roberts Cove	9.0
Uncle Roberts Cove (marsh)	1.0
Snows Creek	6.0
Pine Island Creek	3.0
Mill Creek	4.0
Mill Creek (marsh)	1.0
Mill Creek (creek on eastern edge)	10.0
Mill Creek (culvert)	4.0
Hyannis Inner Harbor	3.0
Snows Creek Inlet	1.0
Sweetheart Creek	3.0
Stewarts Creek	6.0
Stewarts Creek (culvert)	6.0
Halls Creek	
Inlet – Nantucket Sound	0.45
Halls Creek - east branch	0.45
Halls Creek - west branch	0.45
second order marsh channels	0.45
Marsh Plain	0.45

Comparisons between model output and measured nitrogen concentrations are shown in plots presented in Figures VI-3 and VI-4 for Lewis Bay and Halls Creek, respectively. In these plots, means of the water column data and a range of two standard deviations of the annual means at each individual station are plotted against the modeled maximum, mean, and minimum concentrations output from the model at locations which corresponds to the SMAST monitoring stations.

For model calibration, the mid-point between maximum modeled TN and average modeled TN was compared to mean measured TN data values, at each Pond-Watcher water-quality monitoring station. The calibration target would fall between the modeled mean and maximum TN because the monitoring data are collected, as a rule, during mid ebb tide.

Also presented in these figures are unity plot comparisons of measured data verses modeled target values for the system. The model of the Lewis Bay system shows good agreement with the measured data, with RMS error of 0.11 mg/L and an R^2 correlation coefficient of 0.91. The Halls Creek Model demonstrates similar skillful representation of the measured data, with a R^2 value of 0.99 and an RMS error of 0.03 mg/L.

Contour plots of calibrated model output are shown in Figure VI-5 for the Lewis Bay system and Figure V-6 for Halls Creek. In the figure, color contours indicate nitrogen

concentrations throughout the model domain. The output in the figure show average total nitrogen concentrations, computed using the full 5-tidal-day model simulation output period.

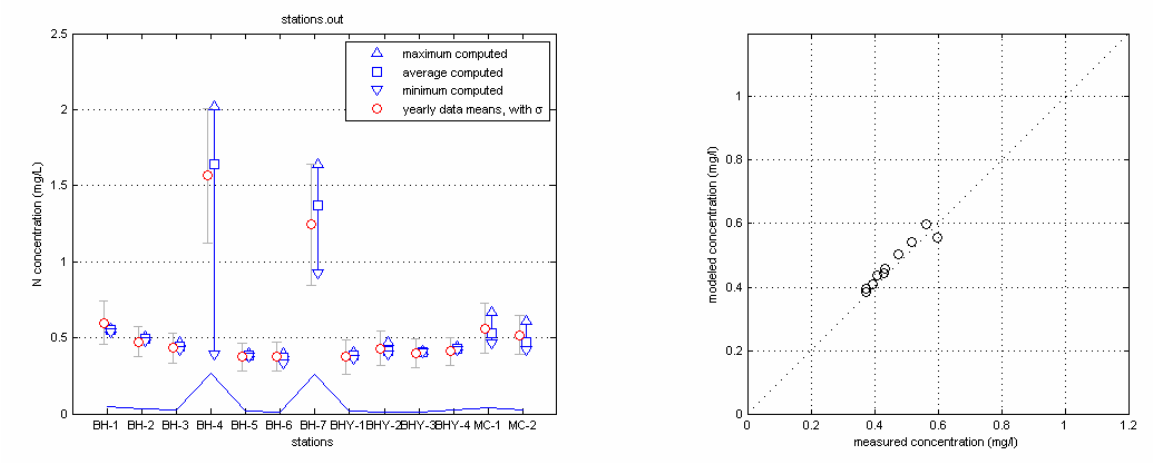


Figure VI-3. Comparison of measured total nitrogen concentrations and calibrated model output at stations in the Lewis Bay estuary system. For the left plot, station labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed concentration for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset. For the plots to the right, model calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for each model are also presented.

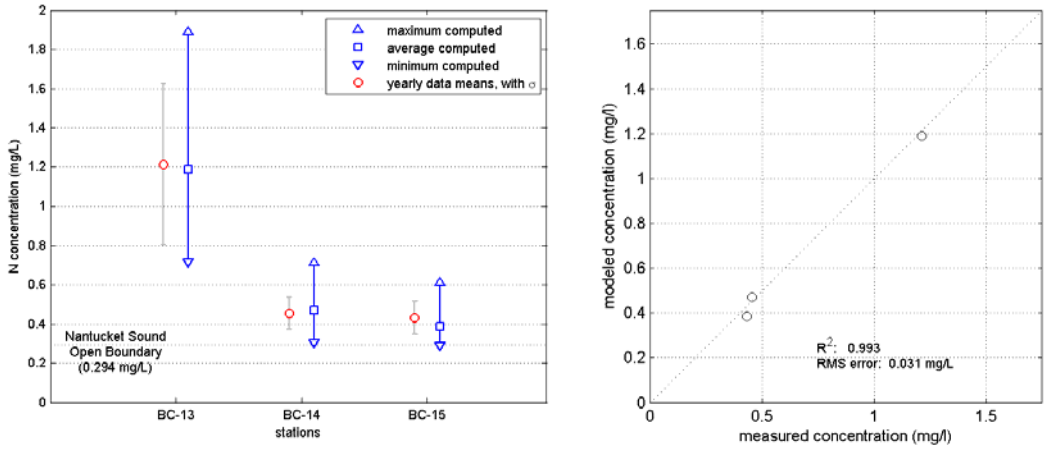


Figure VI-4. Comparison of measured total nitrogen concentrations and calibrated model output at stations in Halls Creek. Plots are interpreted similarly as those for Lewis Bay in Figure VI-3.

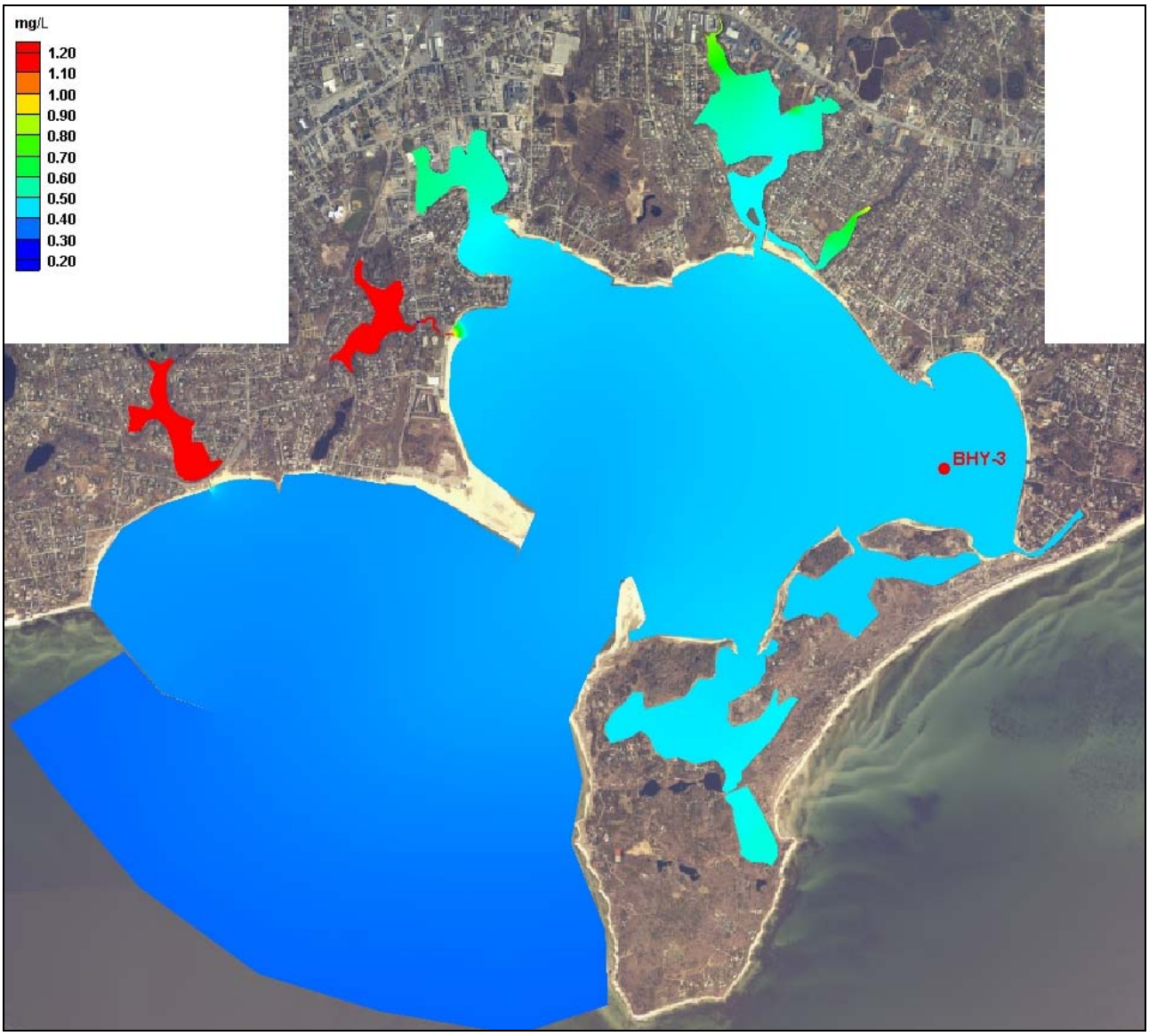


Figure VI-5 Contour plots of average total nitrogen concentrations from results of the present conditions loading scenario, for the Lewis Bay system. The approximate location of the sentinel threshold station for the Lewis Bay system (BHY-3) is shown.

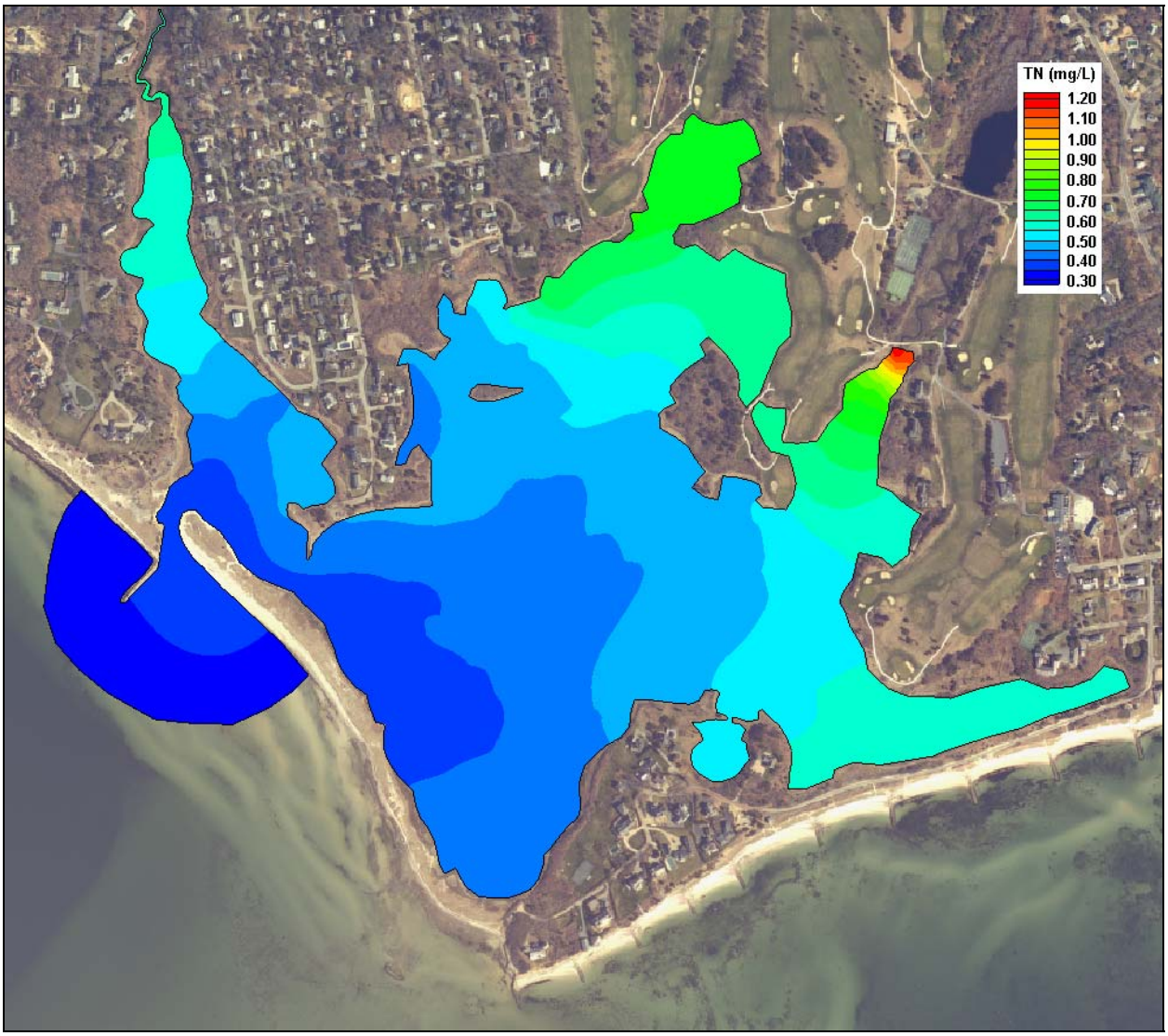


Figure VI-6. Contour plot of average total nitrogen concentrations from results of the present conditions loading scenario, for the Halls Creek system.

VI.2.5 Model Salinity Verification

In addition to the model calibration based on nitrogen loading and water column measurements, numerical water quality model performance is typically verified by modeling salinity. This step was performed for both the Lewis Bay and Halls Creek systems using salinity data collected at the same stations as the nitrogen data. The only required inputs into the RMA4 salinity model of each system, in addition to the RMA2 hydrodynamic model output, were salinities at the model open boundary, and groundwater inputs. The open boundary salinity was set at 30.8 ppt. For groundwater inputs salinities were set at 0 ppt. Groundwater input used for the model was a total of 6.38 ft^3/sec (15,614 m^3/day) for Lewis Bay and 3.20 ft^3/sec (7,820 m^3/day) for Halls Creek. Groundwater flows were distributed evenly in each model through the use of 1-D element input points positioned along each model's land boundary.

Comparisons of modeled and measured salinities are presented in Figure VI-7 and VI-8 for Lewis Bay and Halls Creek, respectively, with contour plots of model output shown in Figure

VI-9 and VI-10. Though model dispersion coefficients were not changed from those values selected through the nitrogen model calibration process, the modesl skillfully represents salinity gradients in both systems.

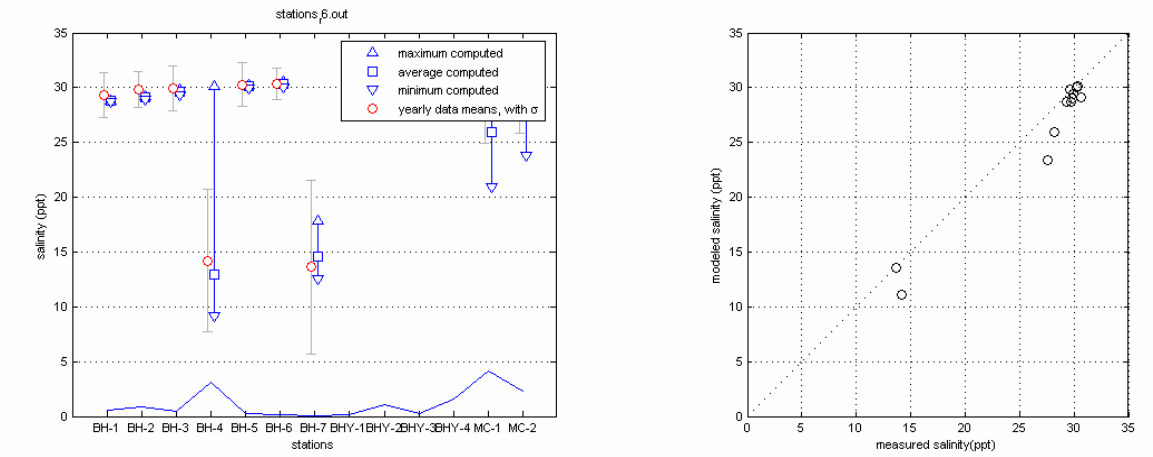


Figure VI-7. Comparison of measured and calibrated model output at stations in the Lewis Bay system. For the left plot, stations labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed salinity for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset. For the plot to the right, model calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for each model are also presented.

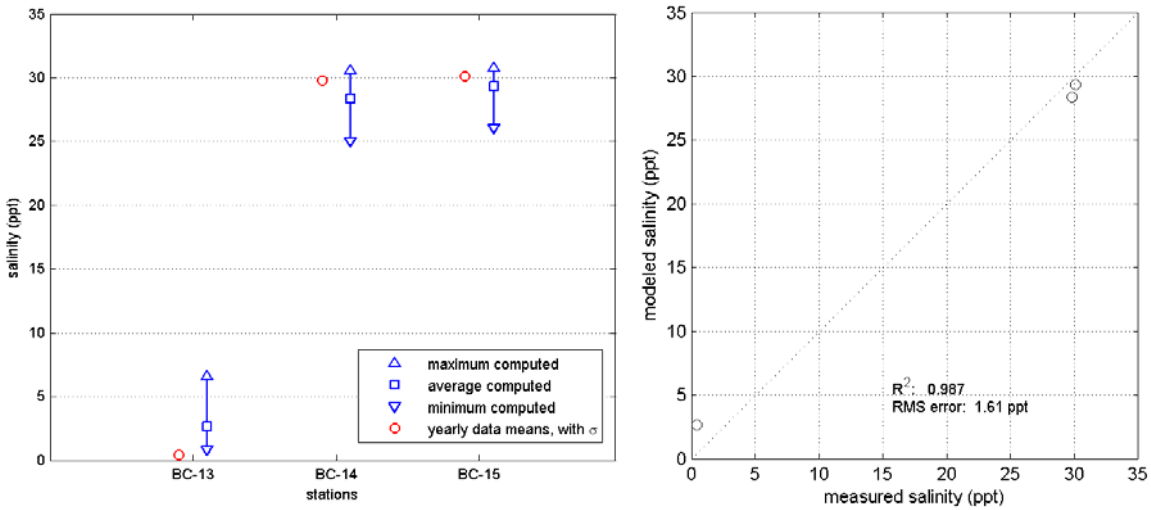


Figure VI-8. Comparison of measured salinity and calibrated model output at stations in Halls Creek. Plots are interpreted similarly as those for Lewis Bay in Figure VI-7.

For the Lewis Bay model, the RMS error of the models is 1.14 ppt, and correlation coefficient is 0.91. For Halls Creek, the RMS error of the model is less than 1.7 ppt, and the R^2 correlation coefficient of the model and measured salinity data is 0.987 The salinity verifications provide a further independent confirmation that model dispersion coefficients and represented freshwater inputs to the model correctly simulate the real physical systems.

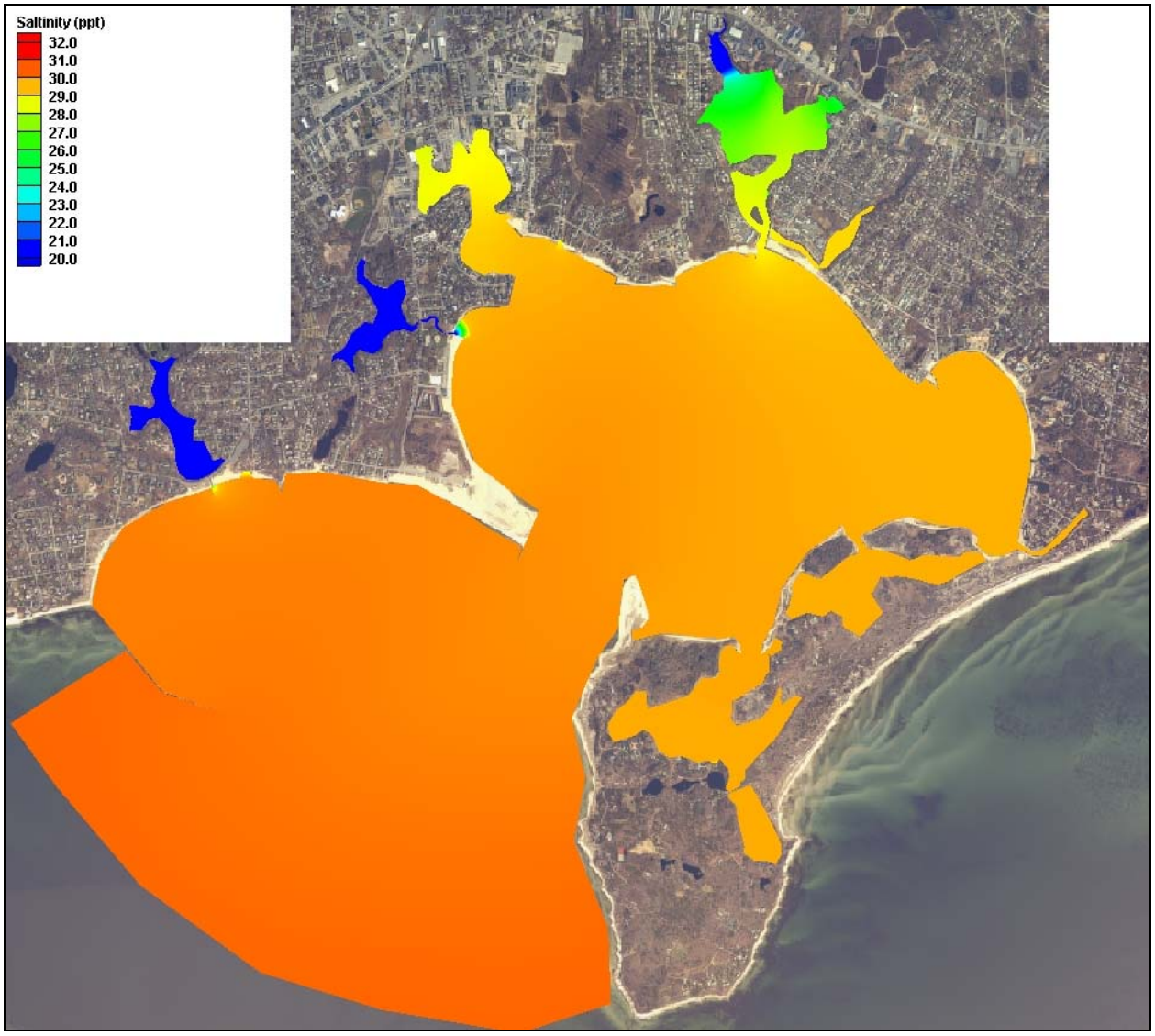


Figure VI-9. Contour plots of modeled salinity (ppt) in the Lewis Bay system.

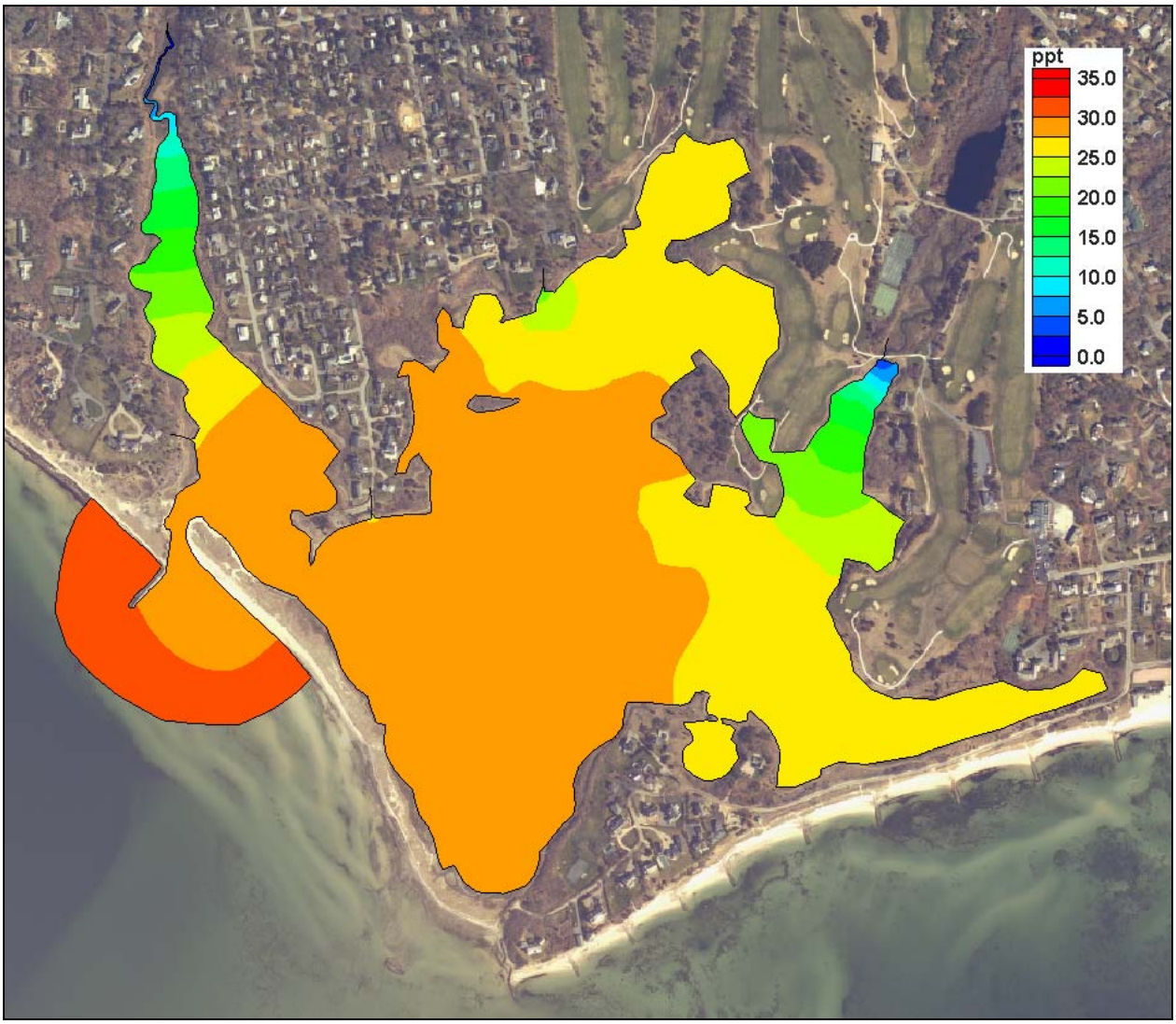


Figure VI-10. Contour Plot of modeled salinity (ppt) in the Halls Creek system.

VI.2.6 Build-Out and No Anthropogenic Load Scenarios

To assess the influence of nitrogen loading on total nitrogen concentrations within the embayment system, two standard water quality modeling scenarios were run: a "build-out" scenario based on potential development (described in more detail in Section IV) and a "no anthropogenic load" or "no load" scenario assuming only atmospheric deposition on the watershed and sub-embayment, as well as a natural forest within each watershed. Comparisons of the alternate watershed loading analyses are shown in Table VI-6 For Lewi s Bay and VI-7 for Halls Creek. Loads are presented in kilograms per day (kg/day) in this Section, since it is inappropriate to show benthic flux loads in kilograms per year due to seasonal variability.

In general, certain sub-embayments would be impacted more than others. The build-out scenario indicates that there would be more than a 12% increase in watershed nitrogen load to the Lewis Bay and a 17% increase for Halls Creek as a result of potential future development.

Other watershed areas would experience larger load increases, for example the loads to Mill Creek would increase 38% from the present day loading levels.

For the no load scenarios, a majority of the load entering the watersheds of the two separate systems is removed; therefore, the load is generally lower than existing conditions by over 90% overall and 95% in most areas.

Table VI-6. Comparison of sub-embayment watershed loads used for modeling of present, build-out, and no-anthropogenic ("no-load") loading scenarios of the Lewis Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	build out (kg/day)	build out % change	no load (kg/day)	no load % change
Lewis Bay	30.855	34.562	+12.0%	0.564	-98.2%
Uncle Roberts Cove	0.540	0.715	+32.5%	0.096	-82.2%
Mill Creek	15.964	22.066	+38.2%	0.405	-97.5%
Hyannis Inner Harbor	12.153	14.934	+22.9%	0.485	-96.0%
Snows Creek	15.115	21.532	+42.5%	0.293	-98.1%
Stewarts Creek	38.992	53.959	+38.4%	0.485	-98.8%
Surface Water Sources					
Chase Brook	3.345	4.066	+21.5%	0.140	-95.8%
Mill Pond	15.038	23.342	+55.2%	1.033	-93.1%
Hospital Creek/Hyannis Inner	1.907	1.956	+2.6%	0.060	-96.8%

Table VI-7. Comparison of sub-embayment watershed loads used for modeling of present, build-out, and no-anthropogenic ("no-load") loading scenarios of the Halls Creek system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	build out (kg/day)	build-out % change	no load (kg/day)	no load % change
Halls Creek	21.534	25.419	+18.0%	0.844	-96.1%
Halls Creek Stream (fresh)	1.597	1.649	+3.3%	0.060	-96.2%
System Total	23.132	27.068	+17.0%	0.904	-96.1%

VI.2.6.1 Build-Out

For the build-out scenario, a breakdown of the total nitrogen load entering the Lewis Bay system sub-embayments is shown in Table VI-8, and for Halls Creek the build-out load are shown in Table VI-9. The benthic flux for the build-out scenarios is assumed to vary proportional to the watershed load, where an increase in watershed load will result in an increase in benthic flux (i.e., a positive change in the absolute value of the flux), and *vise versa*.

Projected benthic fluxes (for both the build-out and no load scenarios) are based upon projected PON concentrations and watershed loads, determined as:

$$(\text{Projected N flux}) = (\text{Present N flux}) * [PON_{projected}]/[PON_{present}]$$

where the projected PON concentration is calculated by,

$$[PON_{projected}] = R_{load} * \Delta PON + [PON_{(present\ offshore)}],$$

using the watershed load ratio,

$$R_{load} = (Projected\ N\ load) / (Present\ N\ load),$$

and the present PON concentration above background,

$$\Delta PON = [PON_{(present\ flux\ core)}] - [PON_{(present\ offshore)}].$$

Table VI-8. **Build-out** sub-embayment and surface water loads used for total nitrogen modeling of the Lewis Bay system, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	34.562	13.507	28.153
Uncle Roberts Cove	0.715	0.759	14.431
Mill Creek	22.068	0.627	-1.927
Hyannis Inner Harbor	14.934	0.633	13.767
Snows Creek	21.532	-	-6.458
Stewarts Creek	53.959	0.236	-13.489
Surface Water Sources			
Chase Brook	4.066	-	-
Mill Pond	23.342	-	-
Hospital Creek/Hyannis Inner	1.956	-	-

Table VI-9. **Build-out** sub-embayment and surface water loads used for total nitrogen modeling of the Halls Creek system, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Halls Creek	25.419	0.630	5.679
Halls Creek Stream (freshwater)	1.649	-	-
System Total	27.068	0.630	5.679

Following development of the nitrogen loading estimates for the build-out scenario, the water quality model of the Lewis Bay and Halls Creek were run to determine nitrogen concentrations within across the sub-embayments of these systems (Table VI-10 for Lewis Bay and Table VI-11 for Halls Creek). Total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios.

For Lewis Bay, total N concentrations increased the most in the upper portion of the system, with the largest change occurring in Snows Creek (34%) and the least change occurring in Lewis Bay (3%). Color contours of model output for the build-out scenario for Lewis Bay are present in Figure VI-7. The range of nitrogen concentrations shown are the same as for the plot of present conditions in Figure VI-11, which allows direct comparison of nitrogen concentrations between loading scenarios.

For Halls Creek, total N concentrations increased the most in the mid creek monitoring station (BC-14), with an increase of 5.4%. The least change occurs in the creek inlet (3.4% BC-15) to Nantucket Sound (3.4% BC-15). Color contours of model output for the build-out scenario of Halls Creek are present in Figure VI-12.

Table VI-10. Comparison of model average total N concentrations from present loading and the build-out scenario, with percent change, for the Lewis Bay system. Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	build-out (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.591**	**+7.6%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.529**	**+6.7%**
Hyannis Inner Harbor	BH-3	0.440	0.464	+5.5%
Snows Creek	BH-4	1.638	2.186	+33.5%
Lewis Bay	BH-5	0.387	0.403	+4.1%
Lewis Bay	BH-6	0.368	0.380	+3.3%
Stewarts Creek	BH-7	1.374	1.772	+29.0%
Lewis Bay	BHY-1	0.384	0.399	+4.0%
Lewis Bay	BHY-2	0.414	0.440	+6.4%
Lewis Bay	**BHY-3**	**0.407**	**0.428**	**+5.1%**
Uncle Roberts Cove	BHY-4	0.431	0.453	+5.3%
Mill Creek	**MC-1**	**0.531**	**0.632**	**+19.0%**
Mill Creek	MC-2	0.473	0.529	+11.8%

Table VI-11. Comparison of model average total N concentrations from present loading and the build-out scenario, with percent change, for the Halls Creek system.

Sub-Embayment	monitoring station	present (mg/L)	build-out (mg/L)	% change
Halls Creek - stream	BC-13	1.189	1.239	+4.3%
Halls Creek - mid	BC-14	0.469	0.494	+5.4%
Halls Creek - inlet	BC-15	0.385	0.398	+3.4%

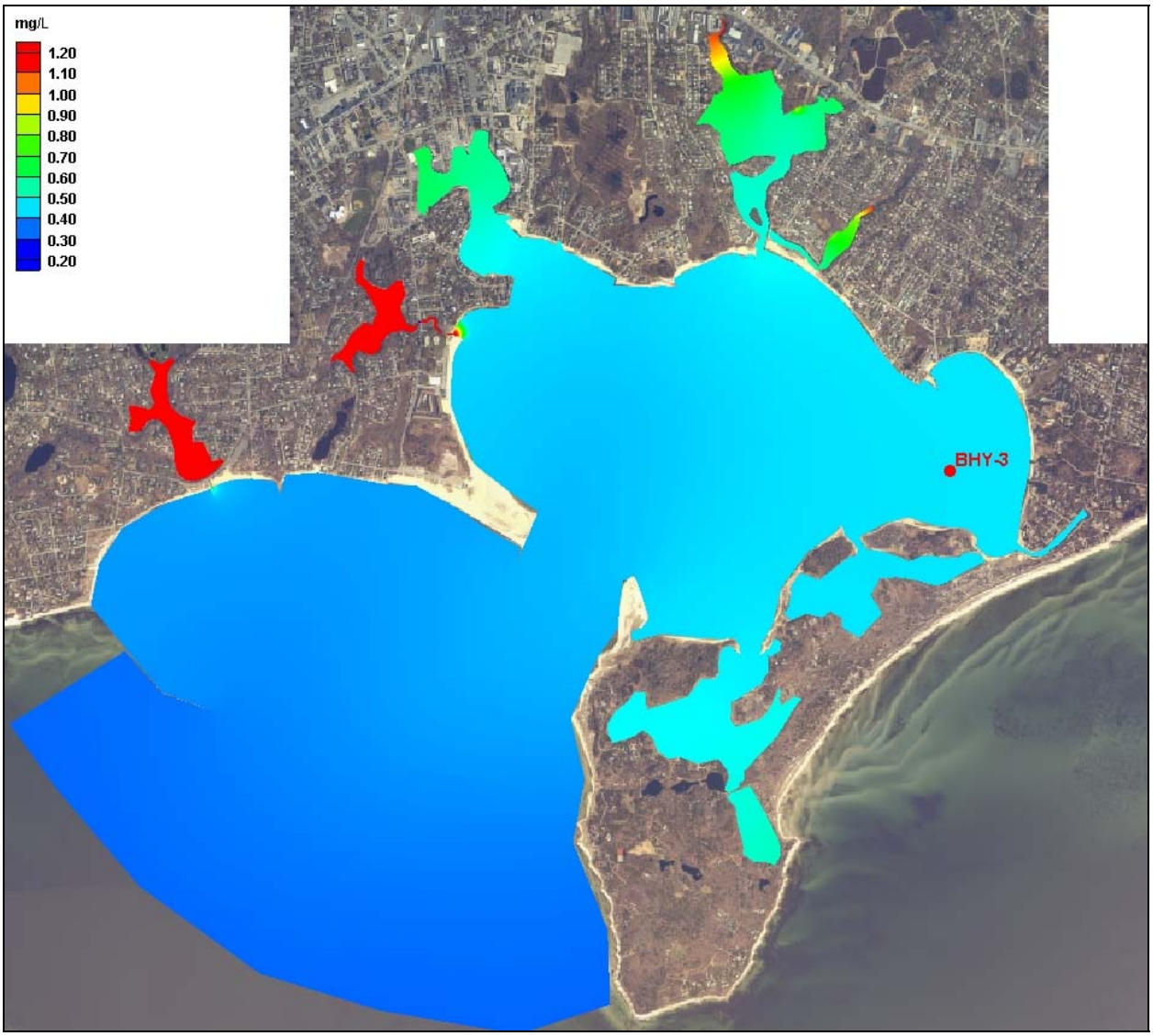


Figure VI-11. Contour plots of modeled total nitrogen concentrations (mg/L) in the Lewis Bay system, for projected build-out loading conditions, and bathymetry. The approximate location of the sentinel threshold station for the Lewis Bay system (BHY-3) is shown.

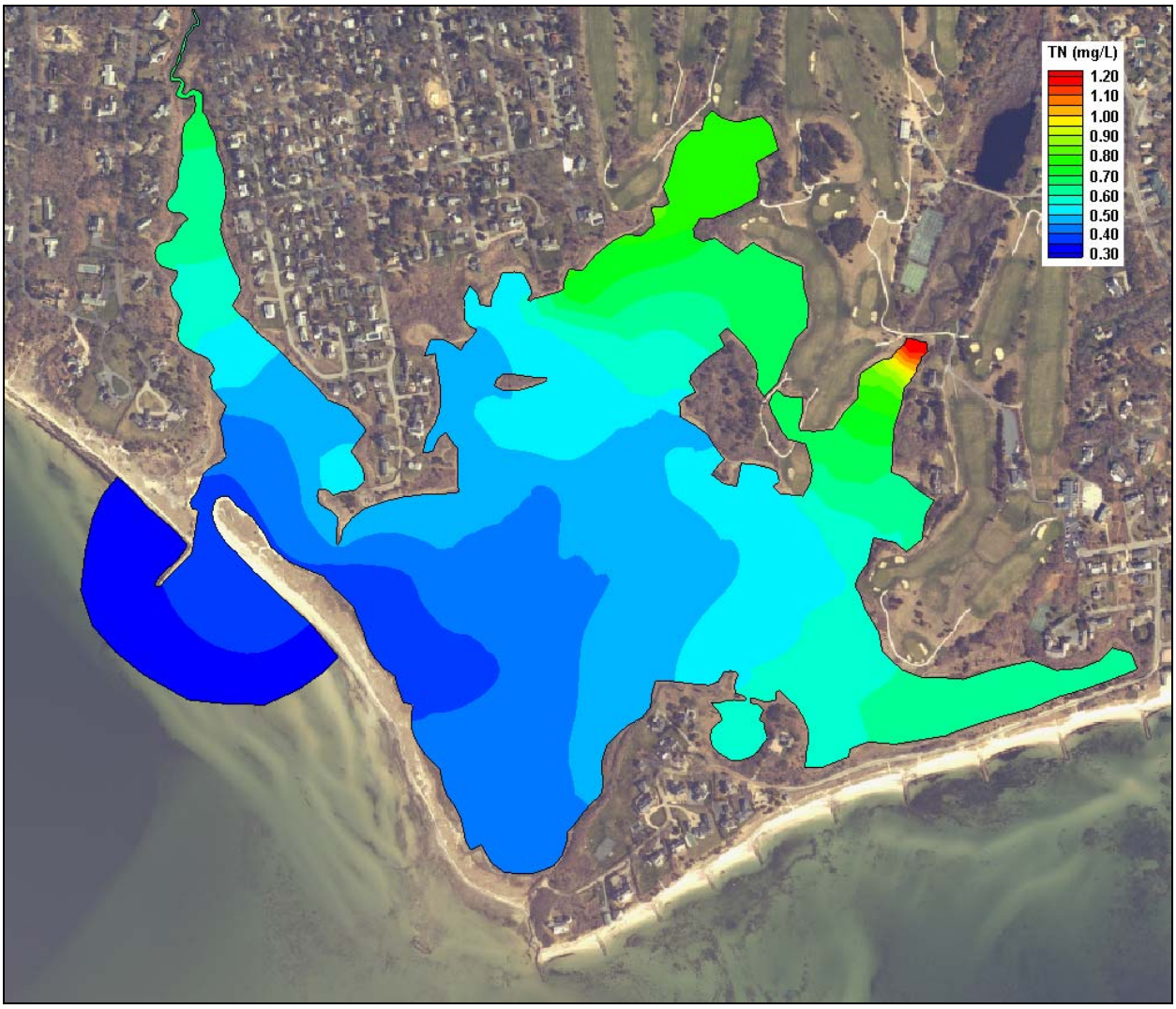


Figure VI-12 Contour plot of modeled total nitrogen concentrations (mg/L) in the Halls Creek system, for projected build-out loading conditions.

VI.2.6.2 No Anthropogenic Load

A breakdown of the total nitrogen load entering each system sub-embayment for the no anthropogenic load ("no load") scenario is shown in Table VI-12 for Lewis Bay and Table VI-13 for Halls Creek. The benthic flux input to each embayment was reduced (toward zero) based on the reduction in the watershed load (as discussed in §VI.2.6.1). Compared to the modeled present conditions and build-out scenario, atmospheric deposition directly to each sub-embayment becomes a greater percentage of the total nitrogen load as the watershed load and related benthic flux decrease.

Table VI-12. "No anthropogenic loading" ("no load") sub-embayment and surface water loads used for total nitrogen modeling of the Lewis Bay system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	0.564	13.507	20.418
Uncle Roberts Cove	0.096	0.759	8.184
Mill Creek	0.405	0.627	-0.653
Hyannis Inner Harbor	0.485	0.633	6.408
Snows Creek	0.293	-	-0.089
Stewarts Creek	0.485	0.236	-0.125
Surface Water Sources			
Chase Brook	0.140	-	-
Mill Pond	1.033	-	-
Hospital Creek/Hyannis Inner	0.060	-	-

Table VI-13. "**No anthropogenic loading**" ("no load") sub-embayment and surface water loads used for total nitrogen modeling of the Halls Creek system, with total watershed N loads, atmospheric N loads, and benthic flux

Sub-Embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Halls Creek	0.844	0.630	2.921
Halls Creek Stream (freshwater)	0.060	-	-
System Total	0.904	0.630	2.921

Similar to the build-out scenario, following development of the nitrogen loading estimates for the no load scenario, the water quality model was run to determine nitrogen concentrations within each sub-embayment. Again, total nitrogen concentrations in the receiving waters (i.e., Nantucket Sound) remained identical to the existing conditions modeling scenarios.

In Lewis Bay, the relative change in total nitrogen concentrations resulting from "no load" was significant as shown in Table VI-14, with reductions ranging from 10% occurring in Lewis Bay to greater than 70% within Snows and Stewarts Creek. Results for each system are shown pictorially in Figure VI-13.

From the model of Halls Creek, the change in total nitrogen concentrations was also large as shown in Table VI-15, with reductions greater than 59% occurring the upper portions of the system(at BC-13). Results for the system are shown pictorially in Figure VI-14.

Table VI-14. Comparison of model average total N concentrations from present loading and the no anthropogenic ("no load") scenario, with percent change, for the Lewis Bay system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	no-load (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.382**	**-30.4%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.365**	**-26.4%**
Hyannis Inner Harbor	BH-3	0.440	0.348	-20.8%
Snows Creek	BH-4	1.638	0.355	-78.4%
Lewis Bay	BH-5	0.387	0.332	-14.0%
Lewis Bay	BH-6	0.368	0.328	-10.8%
Stewarts Creek	BH-7	1.374	0.341	-75.2%
Lewis Bay	BHY-1	0.384	0.333	-13.3%
Lewis Bay	BHY-2	0.414	0.335	-19.2%
Lewis Bay	**BHY-3**	**0.407**	**0.338**	**-17.1%**
Uncle Roberts Cove	BHY-4	0.431	0.358	-17.0%
Mill Creek	**MC-1**	**0.531**	**0.308**	**-42.1%**
Mill Creek	MC-2	0.473	0.323	-31.7%

Table VI-15. Comparison of model average total N concentrations from present loading and the no anthropogenic ("no load") scenario, with percent change, for the Halls Creek system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). The sentinel threshold station is in bold print.

Sub-Embayment	monitoring station	present (mg/L)	no load (mg/L)	% change
Halls Creek - stream	BC-13	1.189	0.480	-59.6%
Halls Creek - mid	BC-14	0.469	0.329	-29.7%
Halls Creek - inlet	BC-15	0.385	0.313	-18.8%



Figure VI-13 Contour plots of modeled total nitrogen concentrations (mg/L) in the Lewis Bay system, for no anthropogenic loading conditions, and bathymetry. The approximate location of the sentinel threshold station for the Lewis Bay system (BHY-3) is shown.

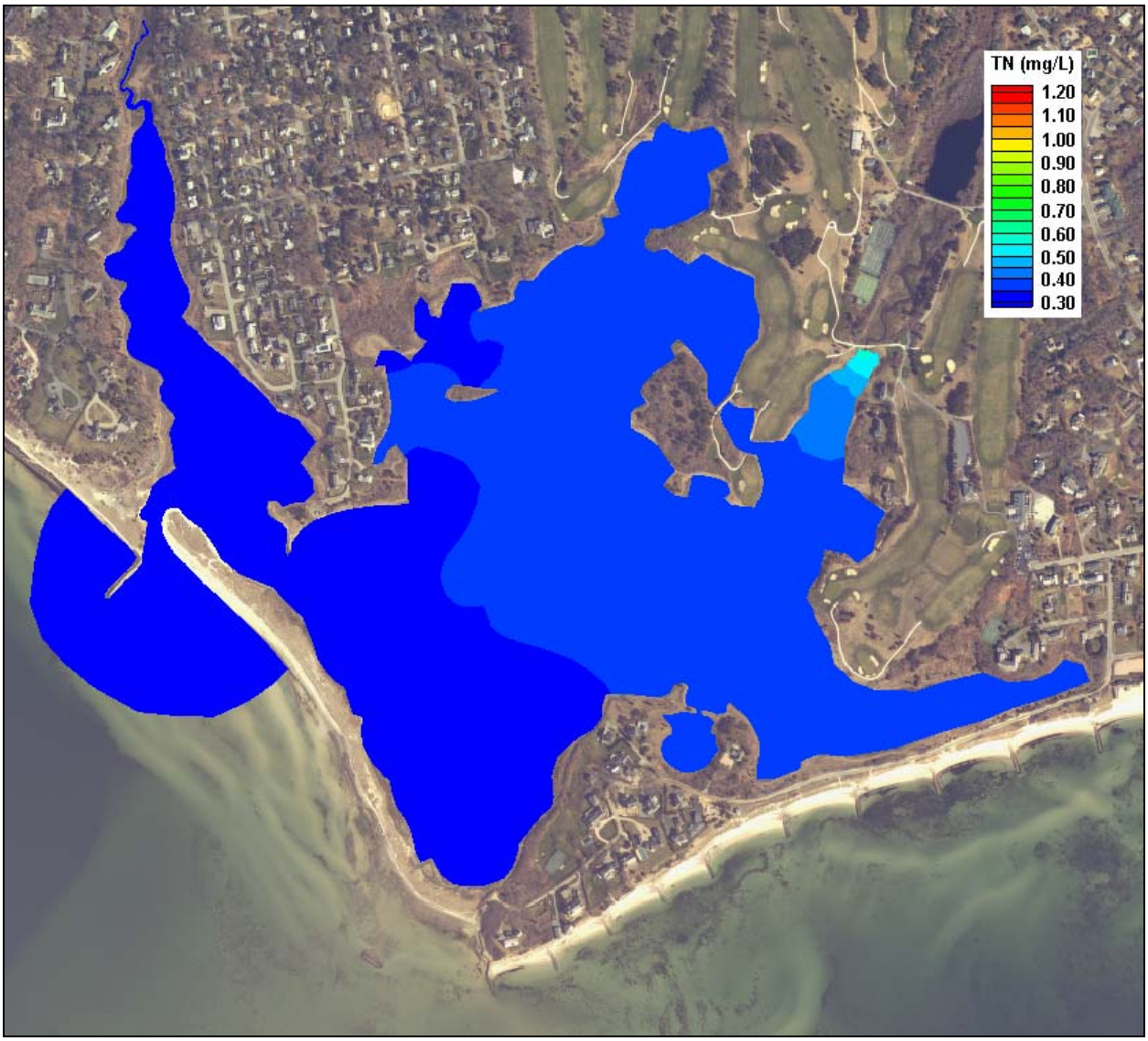


Figure VI-14. Contour plot of modeled total nitrogen concentrations (mg/L) in Halls Creek, for no anthropogenic loading conditions.

VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll, and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (fish, shellfish, infauna) which it supports. For the Lewis Bay embayment system (inclusive of Halls Creek) in the Town of Barnstable, MA, our assessment is based upon data from the water quality monitoring database developed by the Town of Barnstable and our surveys of eelgrass distribution, benthic animal communities and sediment characteristics, and dissolved oxygen records conducted during the summer and fall of 2004. These data form the basis of an assessment of this system's present health, and when coupled with a full water quality synthesis and projections of future conditions based upon the water quality modeling effort, will support complete nitrogen threshold development for these systems (Chapter VIII).

VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS

There are a variety of indicators that can be used in concert with water quality monitoring data for evaluating the ecological health of embayment systems. The best biological indicators are those species which are non-mobile and which persist over relatively long periods, if environmental conditions remain constant. The concept is to use species which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

As a basis for a nitrogen thresholds determination, MEP focused on major habitat quality indicators: (1) bottom water dissolved oxygen and chlorophyll a (Section VII.2), (2) eelgrass distribution over time (Section VII.3) and (3) benthic animal communities (Section VII.4). Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate cause being nitrogen loading). However, oxygen conditions can change rapidly and frequently show strong tidal and diurnal patterns. Even severe levels of oxygen depletion may occur only infrequently, yet have important effects on system health. To capture this variation, the MEP Technical Team deployed dissolved oxygen sensors within the Lewis Bay main basin (Inner and Outer Lewis Bay and its key tributary sub-embayments (Mill Creek, Uncle Roberts Cove, Hyannis Inner Harbor), to record the frequency and duration of low oxygen conditions during the critical summer period. The MEP habitat analysis uses eelgrass as a sentinel species for indicating nitrogen over-loading to coastal embayments. Eelgrass is a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. Mapping of the eelgrass beds within the Lewis Bay system was conducted for comparison to historic records (MassDEP Eelgrass Mapping Program, C. Costello). Temporal trends in the distribution of eelgrass beds are used by the MEP to assess the stability of the habitat and to determine trends potentially related to water quality. Eelgrass beds can decrease within embayments in response to a variety of causes, but throughout almost all of the embayments within southeastern Massachusetts, the primary cause appears to be related to increases in embayment nitrogen levels. Within the Lewis Bay system, temporal changes in eelgrass distribution provided a strong basis for evaluating recent increases (nitrogen loading) or decreases (increased flushing-new inlet) in nutrient enrichment.

In areas that do not support eelgrass beds, benthic animal indicators were used to assess the level of habitat health from "healthy" (low organic matter loading, high D.O.) to "highly stressed" (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment

samples were identified and the environments ranked based upon the fraction of healthy, transitional, and stressed indicator species. The analysis is based upon life-history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes *et al.* 1997). These data are coupled with the level of diversity (H') and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

VII.2 BOTTOM WATER DISSOLVED OXYGEN

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 3.8 mg L^{-1}, in open water estuarine environments.. Massachusetts State Water Quality Classifications indicate that SA (high quality) waters maintain oxygen levels above 6 mg L^{-1}. The tidal waters of the Lewis Bay system are currently listed under this Classification as SA. It should be noted that the Classification system represents the water quality that the embayment should support, not the existing level of water quality. It is through the MEP and TMDL processes that management actions are developed and implemented to keep or bring the existing conditions in line with the Classification.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates in summer than winter (Figure VII-1). It is not surprising that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute levels (mg L^{-1}) are found during the summer in southeastern Massachusetts embayments when water column respiration rates are greatest. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen conditions within shallow embayments (Taylor and Howes, 1994). To more accurately capture the degree of bottom water dissolved oxygen depletion during the critical summer period, autonomously recording oxygen sensors were moored 30 cm above the embayment bottom within key regions of the Lewis Bay system (Figure VII-2). The sensors (YSI 6600) were first calibrated in the laboratory and then checked with standard oxygen mixtures at the time of initial instrument mooring deployment. In addition periodic calibration samples were collected at the sensor depth and assayed by Winkler titration (potentiometric analysis, Radiometer) during each deployment. Each instrument mooring was serviced and calibration samples collected at least biweekly and sometimes weekly during a minimum deployment of 30 days within the interval from July through mid-September. All of the mooring data from the Lewis Bay system was collected during the summers of 2003, 2004, and 2006.

Similar to other embayments in southeastern Massachusetts, the Lewis Bay system evaluated in this assessment showed high frequency variation, apparently related to diurnal and sometimes tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site, underscores the need for continuous monitoring within these systems.

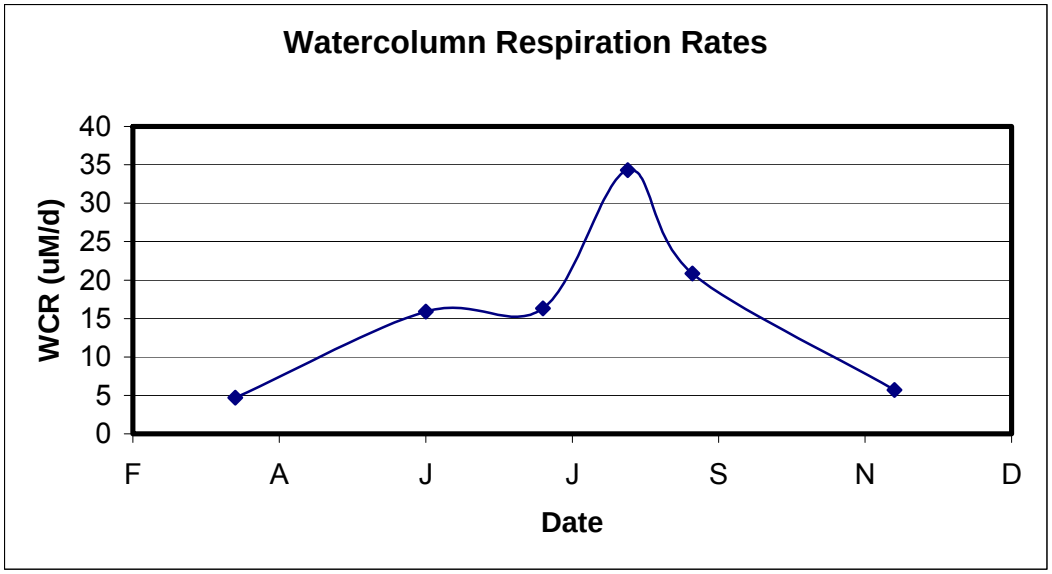


Figure VII-1. Average watercolumn respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System (Schlezinger and Howes, unpublished data). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Dissolved oxygen and chlorophyll a records were examined both for temporal trends and to determine the percent of the 33-52 day deployment period that these parameters were below/above various benchmark concentrations (Tables VII-1, VII-2). These data indicate both the temporal pattern of minimum or maximum levels of these critical nutrient related constituents, as well as the intensity of the oxygen depletion events and phytoplankton blooms. However, it should be noted that the frequency of oxygen depletion needs to be integrated with the actual temporal pattern of oxygen levels, specifically as it relates to daily oxygen excursions.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate moderately nutrient enriched waters within each sub-embayment basin (Figures VII-3 through VII-14). The oxygen data is consistent with organic matter enrichment, primarily from phytoplankton production as seen from the parallel measurements of chlorophyll a. The measured levels of oxygen depletion and enhanced chlorophyll a levels follows the spatial pattern of total nitrogen levels in this system (Chapter VI), and the parallel variation in these water quality parameters is consistent with watershed based nitrogen enrichment of this estuarine system.

The oxygen records show that the inner sub-embayments of Mill Creek and Hyannis Harbor, which receive significant watershed nitrogen loads, have the largest daily oxygen excursions, a nutrient related response. The use of only the duration of oxygen below, for example 4 mg L^{-1}, can underestimate the level of habitat impairment in these locations. The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). The clear evidence of oxygen levels above atmospheric equilibration indicates that the upper tidal reaches of the Lewis Bay system are nitrogen enriched.

Measured dissolved oxygen depletion indicate that sub-embayments to Lewis Bay, Uncle Robert's Cove and to a lesser extent, Hyannis Inner Harbor, show moderate and low levels of oxygen stress. The largest oxygen depletions were observed in Mill Creek, but this is primarily functioning as a salt marsh pond. As such this system is naturally nutrient and organic matter enriched, with oxygen depletions common. The observed spatial pattern indicated that the level of oxygen depletion (Table VII-1) and chlorophyll a (Table VII-2) and total nitrogen levels increased with increasing distance from the tidal inlet and into the smaller sub-embayments. The pattern of oxygen depletion, elevated chlorophyll a and nitrogen levels are consistent with the observed pattern of eelgrass loss (Section VII.3) and quality of infaunal habitats (Section VII.4) and are indicative of an estuarine system that is beyond its ability to assimilate nitrogen loads without impairment. The embayment specific results are as follows:

Hyannis Harbor (west and east) (Figures VII-3 and VII-9; Figures VII-4 and VII-10):

Both Hyannis Harbor moorings were placed in protected areas of the abundant finger piers. A deep channel provides access for ferries and less restriction of tidal water movement in the generally deep water (3-5 meters). The mooring records from the east and west side of the harbor were very similar where the mooring records overlap, however, dissolved oxygen in the west was slightly lower and had a smaller diurnal variation than observed in the east. A similar pattern was seen in the chlorophyll record. The records are consistent with a moderate enrichment of nitrogen and phytoplankton. Differences between the records appear to be a function of water depth and clarity at the two locations. The average depth of the West Hyannis Harbor was 0.75 m deeper than East Hyannis Harbor and while there was a 50% reduction in water column chlorophyll throughout the deployment secchi depths were less than 75 % of the total mooring depth in the west and less than 50% in the east. Deeper deployment depth and lower water clarity at Hyannis Harbor West, possibly influenced by sediment suspension by the ferries, explains the slightly lower DO and chlorophyll as well as less diurnal variation. The mooring records indicate moderate nutrient related impairment.

Mill Creek (Figures VII-5 and VII-11):

The Mill Creek mooring was placed in the middle of the west lobe of Mill Creek at a depth barely sufficient to keep the sensors submerged. Outside of the tidal channel accumulations of drift *Ulva* and *Codium* were moderate to high. It was not possible to ascertain the extent to which the macroalgae was produced within this basin versus that which was transported into the basin on the flood tide. However, as drift *Codium* was observed and it was not growing within the main basins of Mill Pond, it is clear that transport into the basin was occurring. In addition, high chlorophyll concentrations >20 ug L^{-1} (>25 ug L^{-1} 22% of the time) were observed during two weeks in August as a result of a phytoplankton bloom that was occurring system-wide. The bloom was most intense within this shallow basin, but was recorded within all basins. Coincident with this phytoplankton bloom were extreme diurnal variations in dissolved oxygen levels (10 mg L^{-1}). Macroalgal dark respiration resulting from self shading during daylight hours as well as surface water aeration may have been responsible for smaller diurnal variation during the remainder of the deployment. Oxygen concentrations rarely dropped below the benchmark level of 4 mg L^{-1} (2%). The oxygen and chlorophyll a data indicate that Mill Creek is a nutrient enriched salt marsh basin.

Inner Lewis Bay (Figures VII-6 and VII-12):

The Inner Lewis Bay mooring was located in 2.2 m of water within the mooring field 250 m offshore from Englewood Beach (Figure VII-2). Both the chlorophyll a and dissolved oxygen records indicate a moderately nutrient enriched estuarine area. Dissolved oxygen depletion was generally moderate, dropping below the 5 mg L^{-1} benchmark level for only 6% of the deployment interval (Table VII-1). However, the frequency of these short term events was

approximately every two days. Diurnal excursions in dissolved oxygen were typically 2-3 mg L^{-1}, but larger (>6 mg L^{-1}) during the senescing period of the phytoplankton bloom (August 10-22). Two of the lowest oxygen concentrations were associated with bloom collapse.. Both moderate to low sediment oxygen uptake rates and sparse to moderate macroalgae coverage at the bottom point to phytoplankton as a dominant contributor to the water column oxygen balance. The mooring data indicate that Inner Lewis Bay is moderately nutrient enriched and moderately impaired based upon these parameters.

Outer Lewis Bay (Figures VII-7 and VII-13)

The Outer Lewis Bay mooring was located in the main Lewis Bay basin towards the tidal inlet, east of the navigation channel (Figure VII-2). Oxygen depletions and chlorophyll enhancement were generally modest, with oxygen levels above 6 mg L^{-1} 82% of the time (Table VII-1) and chlorophyll a concentrations generally below 5 ug/L (75% of record) (Table VII-2). Diurnal variation in oxygen was small rarely exceeding 2 mg L^{-1}. Throughout the deployment air equilibration was ~7.1 mg L^{-1}. Phytoplankton (water column) respiration did not appear to significantly contribute to the oxygen balance at this location. Chlorophyll a levels were low (>5 ug L^{-1} for 25% of the time; Table VII-2) and dissolved oxygen response to blooms (Figure VII-13, Chlorophyll a>6 ug L^{-1}) was minimal. A combination of low to moderate sediment respiration and >80% coverage of macroalgae (*Codium*), was likely responsible for the observed low level of oxygen depletion. By these measures Lewis Bay at the location of the mooring was high quality habitat, without nitrogen related impairment through oxygen depletion. Measurements of Infaunal habitat quality at this location are fully supportive of this assessment (Section VII-4), as this site supports a rich and diverse productive benthic habitat and presently the only eelgrass "patch" inside of the tidal inlet.

Uncle Robert's Cove (Figures VII-8 and VII-14)

Uncle Robert's Cove is a shallow enclosed tributary embayment. The mooring, located in the top third of the embayment at a depth of 1.5 m, showed regular deficits in dissolved oxygen (54% of time <6 mg L^{-1}; 8% of time <5 mg L^{-1}; 1% of time <4 mg L^{-1}, Table VII-1). Diurnal fluctuations in dissolved oxygen were moderate ranging from 1-4 mg L^{-1}. Chlorophyll a levels were moderate to high usually averaging 10 ug L^{-1} with a peak of 30 ug L^{-1} during a bloom near the beginning of the deployment (97%>5 ug L^{-1}; 43%>10 ug L^{-1}, 9%>15 ug L^{-1}; Table VII-2). Dissolved oxygen response to changes in chlorophyll a levels was rapid and significant linking water column processes with changes in dissolved oxygen. Moderate sediment oxygen uptake and low coverage of macroalgae on the bottom (drift filamentous algae) substantiates the importance of water column over sediment processes. Data from Uncle Robert's Cove indicates a moderately to significantly impaired basin resulting from nutrient (and organic matter) enrichment.

Halls Creek

Halls Creek consists of a shallow basin with surrounding salt marsh. No moorings were placed in this basin due to the very low water at low tide. However, the Water Quality Monitoring Program data indicated that in the mid and inlet stations oxygen levels showed only modest levels of depletion with oxygen generally >6 mg L^{-1}, 90% of time, and only 1 record <4.5 mg L^{-1}. Chlorophyll a levels were generally <10 ug L-1 in the mid and inlet stations, 93% and 96% of records (N=30) and showed only moderate levels overall averaging 5.0 and 3.9 ug L^{-1}, respectively compared to 3.6 ug L^{-1} for the adjacent waters of Centerville Harbor. The low level of oxygen depletion for a salt marsh basin and the moderate chlorophyll a concentrations, Halls Creek coupled with the salt marsh structure of this system, is consistent with a high quality habitat.



Figure VII-2. Aerial Photograph of the Lewis Bay system in the Town of Barnstable showing locations of Dissolved Oxygen mooring deployments conducted in the Summer of 2003. No moorings were placed in Halls Creek, due to the near complete drainage of the creeks and basin at low tide.

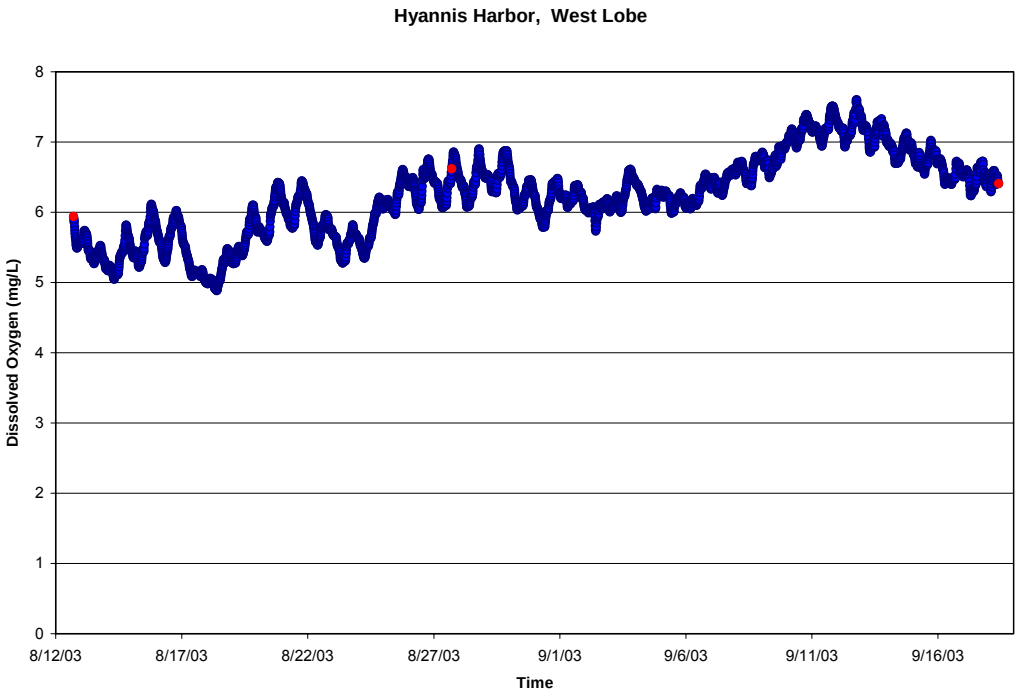


Figure VII-3. Bottom water record of dissolved oxygen at the Hyannis Harbor (west) station, Summer 2003. Calibration samples represented as red dots.

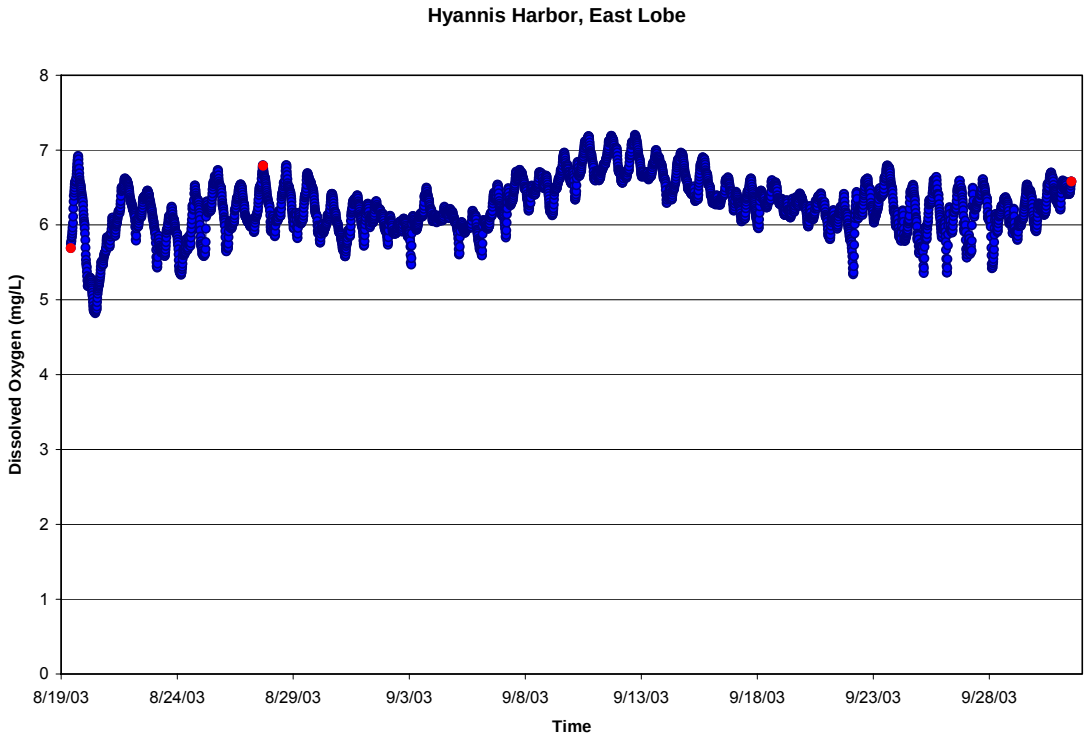


Figure VII-4. Bottom water record of dissolved oxygen at the Hyannis Harbor (east) station, Summer 2003. Calibration samples represented as red dots.

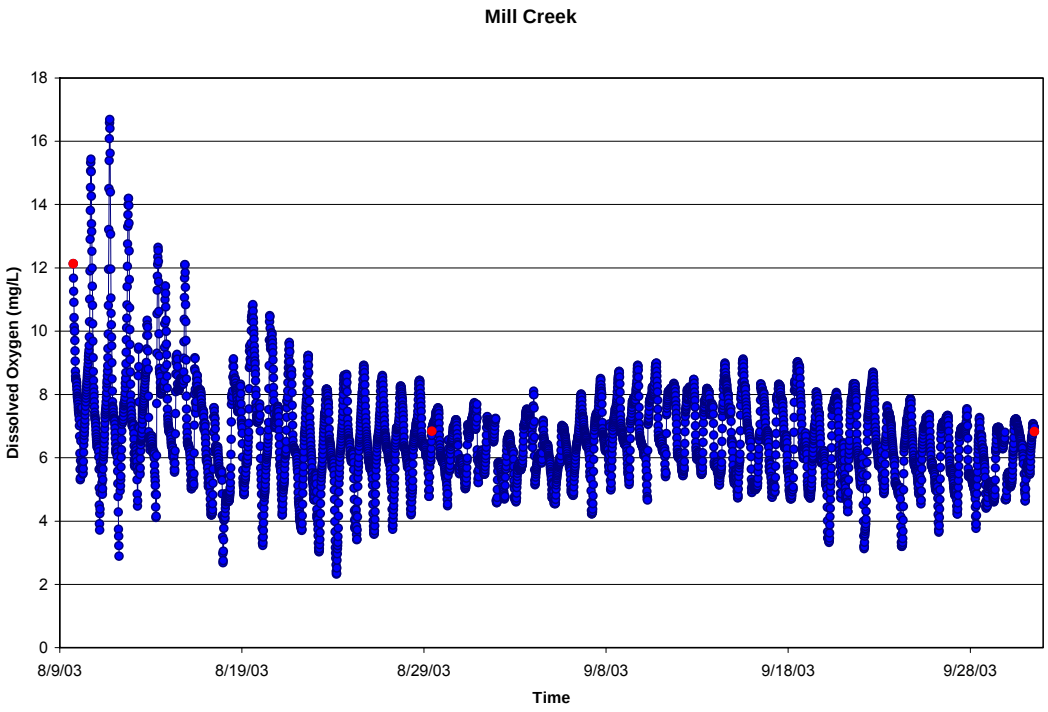


Figure VII-5. Bottom water record of dissolved oxygen at the Mill Creek station, Summer 2003. Calibration samples represented as red dots.

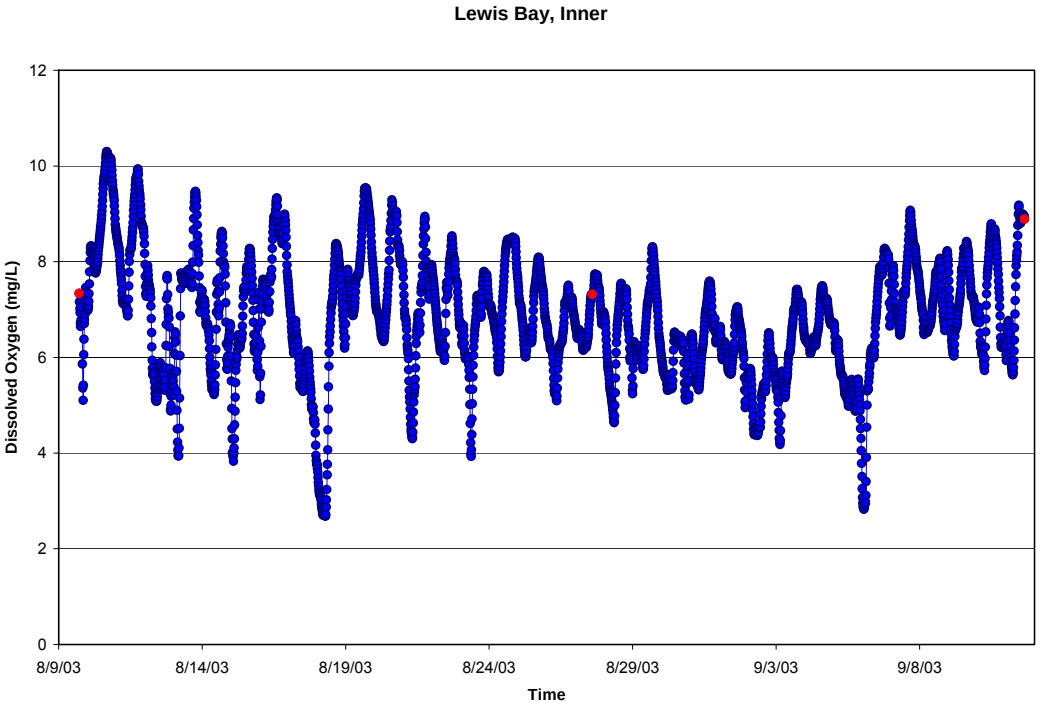


Figure VII-6. Bottom water record of dissolved oxygen at the Lewis Bay (inner) station, Summer 2003. Calibration samples represented as red dots.

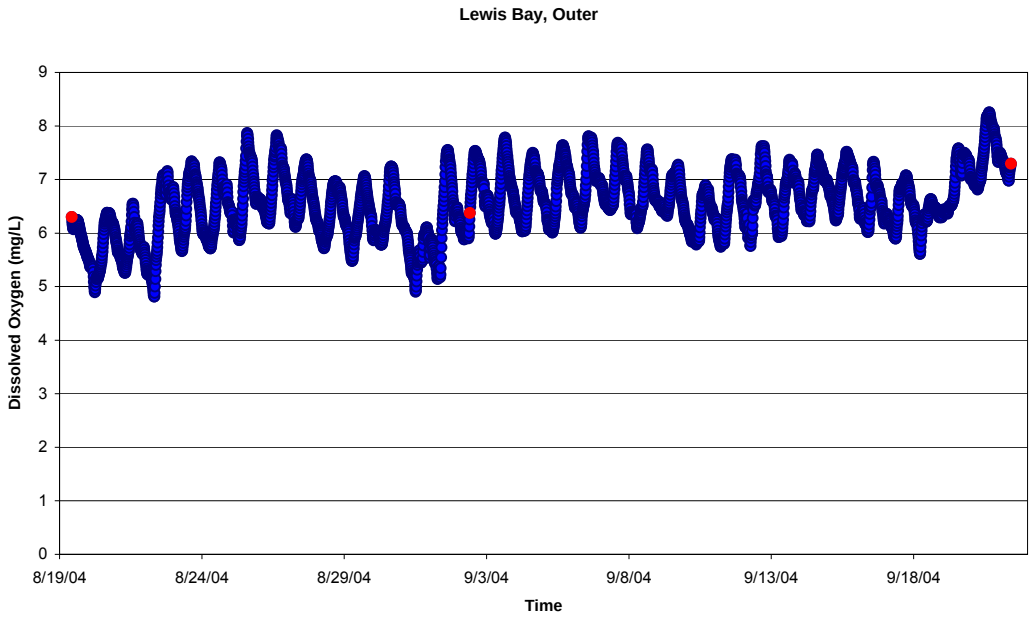


Figure VII-7. Bottom water record of dissolved oxygen at the Lewis Bay (outer) station, Summer 2003. Calibration samples represented as red dots.

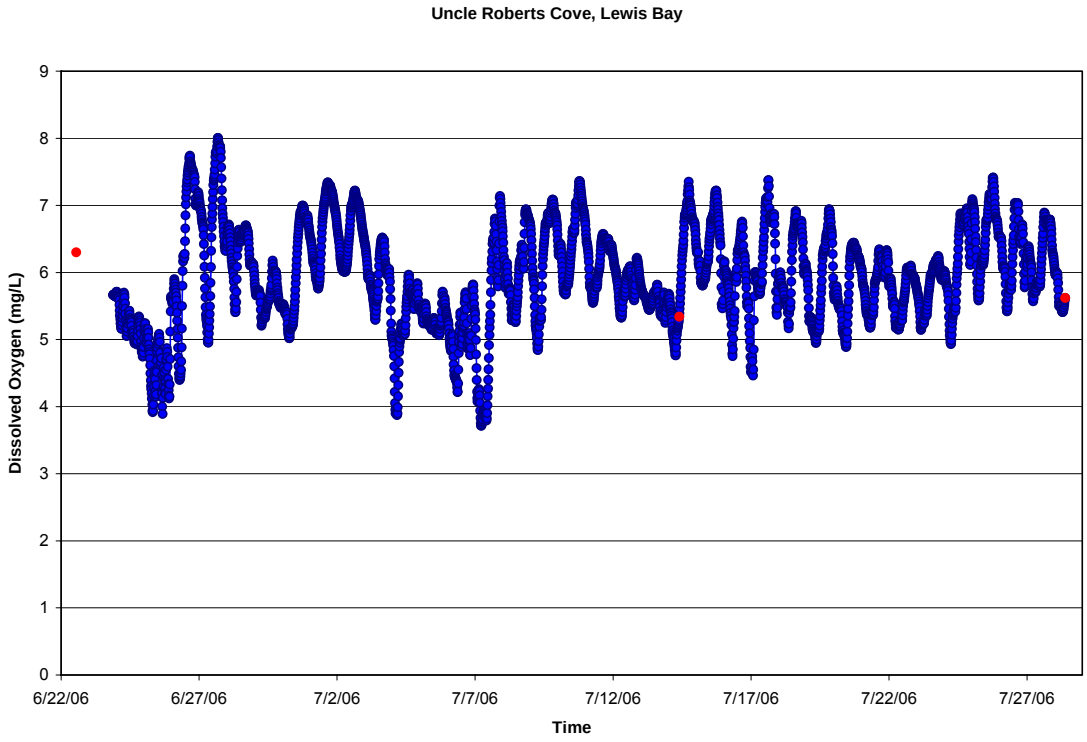


Figure VII-8. Bottom water record of dissolved oxygen at the Uncle Robert's Cove station, Summer 2003. Calibration samples represented as red dots .

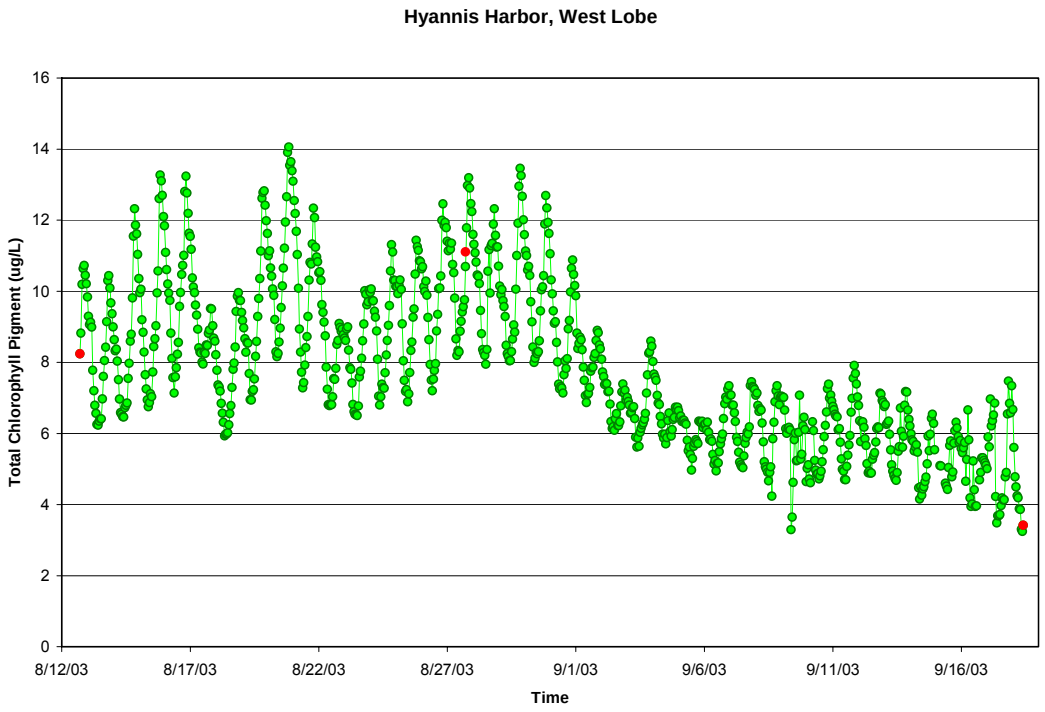


Figure VII-9. Bottom water record of Chlorophyll-*a* in Hyannis Harbor (west) station, Summer 2003. Calibration samples represented as red dots.

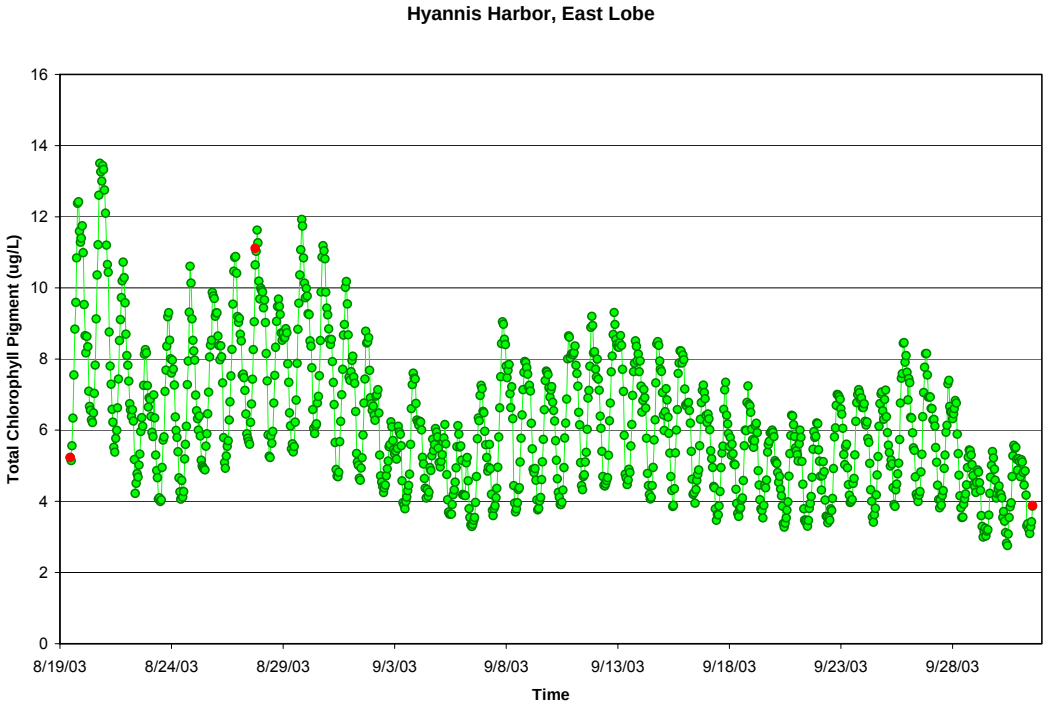


Figure VII-10. Bottom water record of Chlorophyll-*a* in Hyannis Harbor (east) station, Summer 2003. Calibration samples represented as red dots.

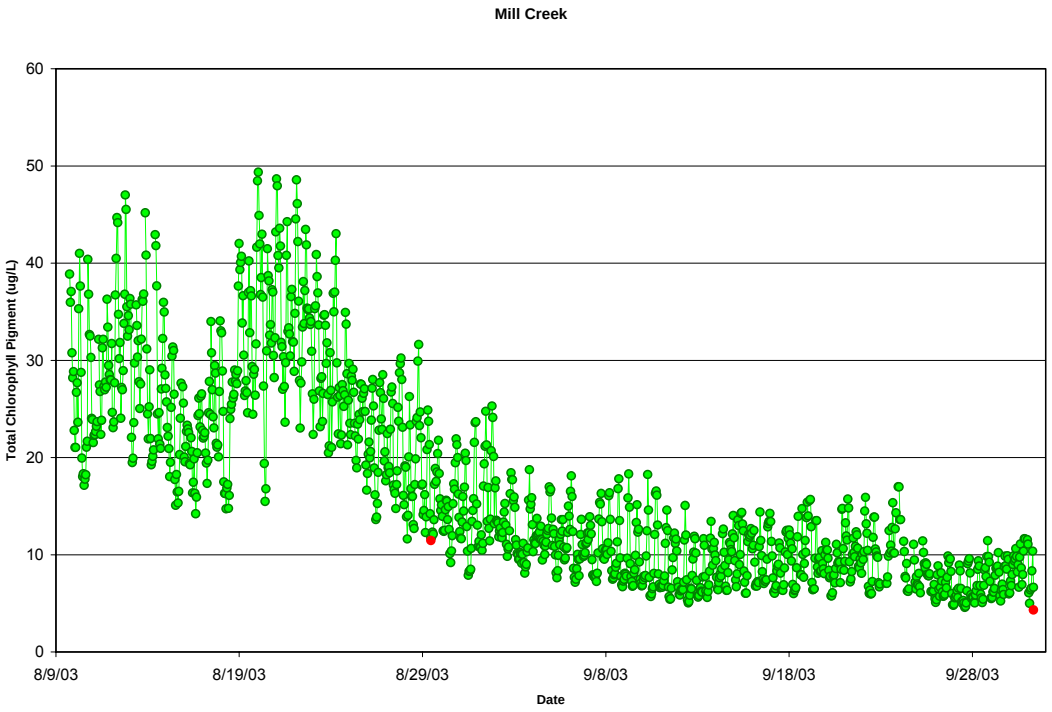


Figure VII-11. Bottom water record of Chlorophyll-*a* in Mill Creek station, Summer 2003. Calibration samples represented as red dots.

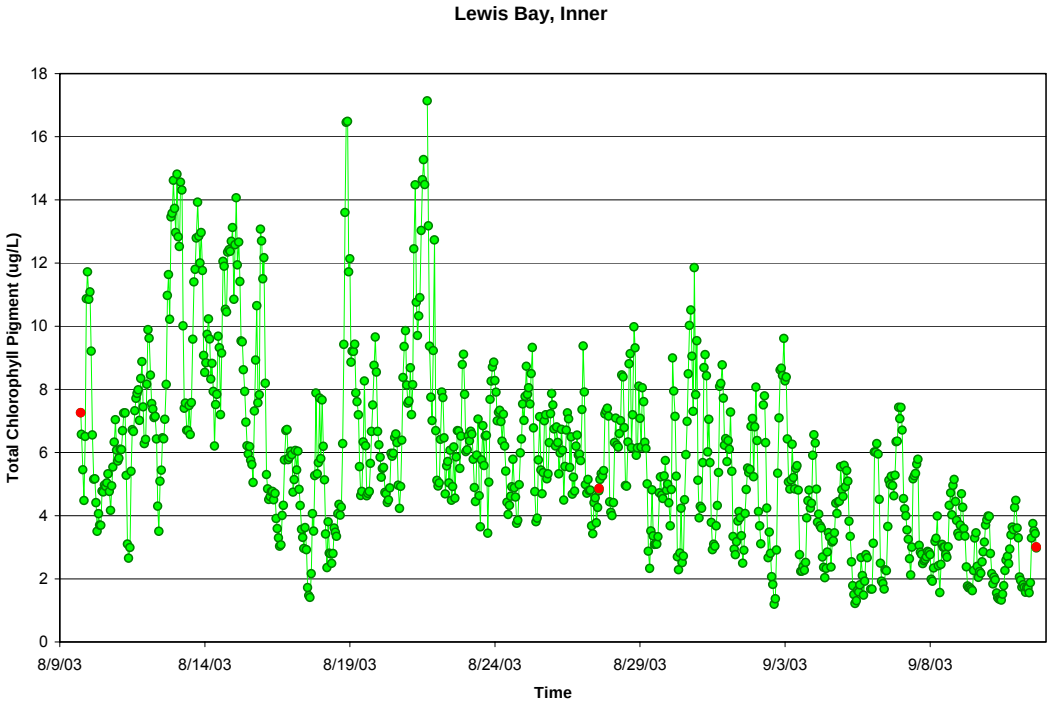


Figure VII-12. Bottom water record of Chlorophyll-*a* in Lewis Bay (inner) station, Summer 2003. Calibration samples represented as red dots.

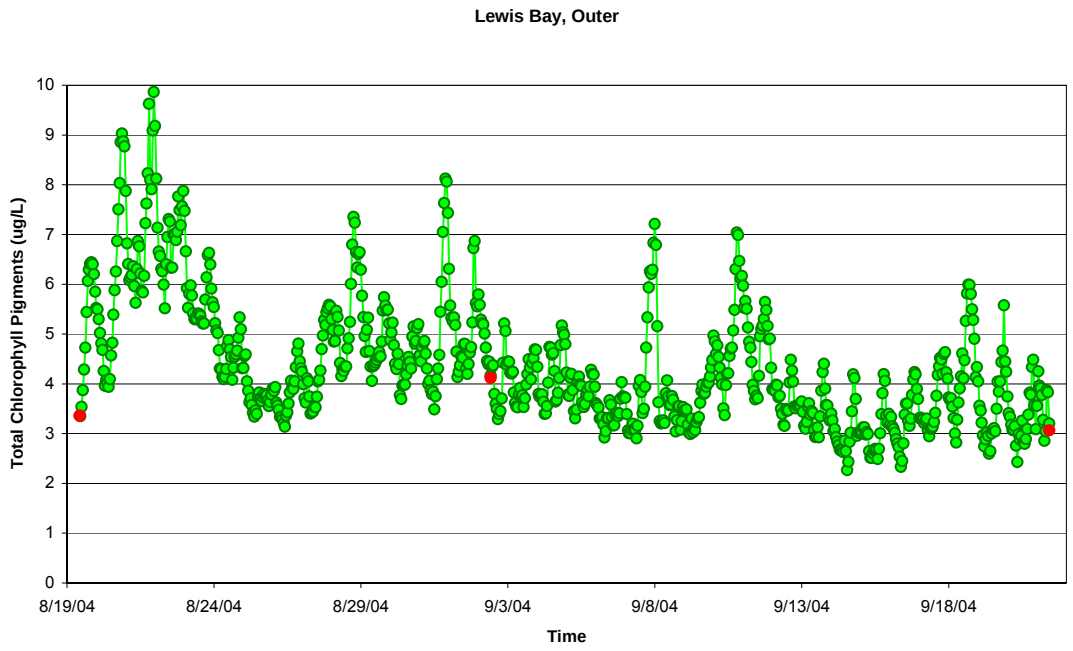


Figure VII-13. Bottom water record of Chlorophyll-*a* in Lewis Bay (outer) station, Summer 2003. Calibration samples represented as red dots.

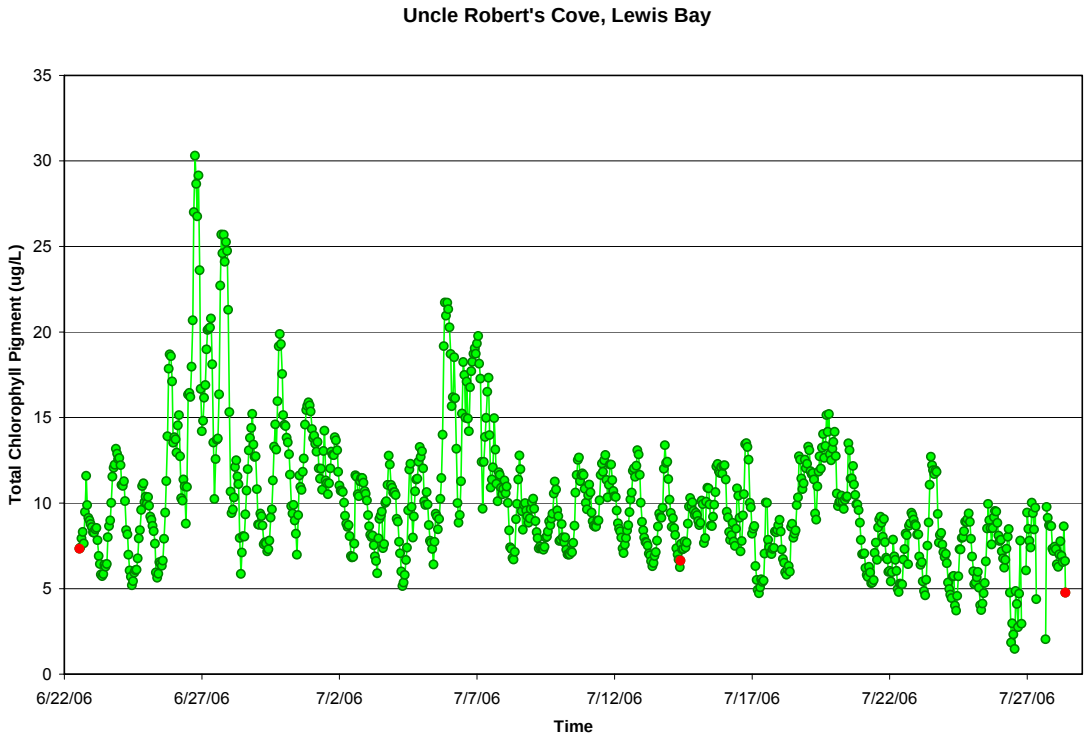


Figure VII-14. Bottom water record of Chlorophyll-*a* in Uncle Roberts Cove station, Summer 2003. Calibration samples represented as red dots.

Table VII-1. Percent of time during deployment of in situ sensors that bottom water oxygen levels were below various benchmark oxygen levels.

Massachusetts Estuaries Project Town of Barnstable: 2003-04	Dissolved Oxygen: Continuous Record, Summer 2003-04				
	Deployment Days	< 6 mg/L (% of days)	< 5 mg/L (% of days)	< 4 mg/L (% of days)	< 3 mg/L (% of days)
Hyannis Harbor (west)	36.7	30%	1%	0%	0%
Hyannis Harbor (east)	43.1	22%	0%	0%	0%
Mill Creek	52.7	36%	11%	2%	0%
Inner Lewis Bay	33.0	22%	6%	2%	1%
Outer Lewis Bay	33.0	18%	0%	0%	0%
Uncle Robert's Cove	34.5	54%	8%	1%	0%

Table VII-2. Duration (% of deployment time) that chlorophyll a levels exceed various benchmark levels within the embayment system. "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

Embayment System	Start Date	End Date	Total Deployment (Days)	> 5 ug/L Duration (Days)	> 10 ug/L Duration (Days)	> 15 ug/L Duration (Days)	> 20 ug/L Duration (Days)	> 25 ug/L Duration (Days)
Lewis Bay								
Hyannis Harbor (west)	8/12/03	9/18/03	36.7	92%	20%	0%	0%	0%
		Mean		1.66	0.30	NA	NA	NA
		S.D.		5.21	0.22	NA	NA	NA
Hyannis Harbor (east)	8/19/03	10/1/03	43.1	69%	5%	0%	0%	0%
		Mean		0.66	0.22	NA	NA	NA
		S.D.		0.78	0.15	NA	NA	NA
Mill Creek	8/9/03	10/1/03	52.7	99%	67%	43%	32%	22%
		Mean		8.51	0.56	0.52	0.55	0.24
		S.D.		18.86	2.61	1.55	0.98	0.24
Lewis Bay Inner	8/9/03	9/11/03	33.0	56%	9%	1%	0%	0%
		Mean		0.35	0.21	0.06	NA	NA
		S.D.		0.53	0.20	0.02	NA	NA

Table VII-2a. Duration (% of deployment time) that chlorophyll a levels exceed various benchmark levels within the embayment system. "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

Embayment System	Start Date	End Date	Total Deployment (Days)	> 5 ug/L Duration (Days)	> 10 ug/L Duration (Days)	> 15 ug/L Duration (Days)	> 20 ug/L Duration (Days)	> 25 ug/L Duration (Days)
Lewis Bay								
Lewis Bay Outer	8/19/04	9/21/04	33.0	25%	0%	0%	0%	
		Mean		0.42	NA	NA	NA	NA
		S.D.		0.77	NA	NA	NA	NA
Uncle Robert's Cove	6/22/06	7/28/06	34.5	97%	43%	9%	3%	1%
		Mean		3.12	0.38	0.21	0.25	0.08
		S.D.		7.27	0.39	0.17	0.08	0.08

VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS

Eelgrass surveys and analysis of historical data was conducted for the Lewis Bay Embayment System by the DEP Eelgrass Mapping Program as part of the MEP. Surveys were conducted in 1995 and 2001, as part of this program. Additional analysis of available aerial photos from 1951 was used to reconstruct the eelgrass distribution prior to any substantial development of the watershed. The 1951 data were only anecdotally validated, while the 1995 and 2001 maps were field validated. The primary use of the data is to indicate (a) if eelgrass once or currently colonizes a basin and (b) if large-scale system-wide shifts have occurred. Integration of these data sets provides a view of temporal trends in eelgrass distribution from 1951 to 1995 to 2001 (Figure VII-15 VII-16); the period in which watershed nitrogen loading significantly increased to its present level. This temporal information can be used to determine the stability of the eelgrass community.

At present, eelgrass exists only within a small portion of the system at the tidal inlet of Lewis Bay. Based on the 2001 eelgrass survey, the remaining eelgrass bed appears to be limited to a small area on the margin of the flood tidal delta, to the east of the inlet channel that exits to the man-made basin of Hyannis Harbor (formed by the long breakwater from the western shore). However, large eelgrass beds were observed in the 1951 analysis of aerial photographs, and the recent surveys in the outer basin, Hyannis Harbor. It should be noted that these beds have also declined near the outflow from Lewis Bay. The results of the DEP surveys have been confirmed by multiple MEP staff conducting infaunal animal and sediment sampling and mooring studies. The current decline of eelgrass beds relative to historical distributions is expected given the elevated nitrogen levels and resulting chlorophyll a and dissolved oxygen depletions within this embayment system.

The present absence of eelgrass throughout the Lewis Bay Embayment System is consistent with the observed moderate level of nutrient enrichment throughout each of the sub-embayments to this complex estuary. Total nitrogen levels (TN) within the lower basins that supported eelgrass in 1951, Lewis Bay and Uncle Roberts Cove, have mean summer-time levels of ~0.4 mg N L^{-1} compared to the levels at the outer beds in adjacent Hyannis Harbor of 0.30-0.35 mg N L^{-1} (monitoring data, Chapter VI). Other key water quality indicators, dissolved oxygen and chlorophyll a, show similar levels of moderate enrichment with periodic oxygen depletions below 5-4 mg/L and chlorophyll levels of 3-6 ug/l to 2-10 ug/l in the Lewis Bay basin and 5-15 ug/L in Uncle Roberts Cove. Given the sensitivity of eelgrass to declining light penetration resulting from nutrient enrichment and secondary effects of organic enrichment and oxygen depletion, the loss of eelgrass in these basins is expected.

Further evidence of nitrogen generated eelgrass decline can be seen in the stability of the eelgrass beds just outside of the tidal inlet to the Hyannis Harbor basin. In each of the MassDEP assessments (1951, 1995, 2001) the major beds along the western shore and outer portion of the eastern shore of Hyannis Harbor showed the same areal coverage. These beds are at the same depths as some of the areas of Lewis Bay that lost eelgrass during the same period. Equally important, the loss of beds nearest the outflow from Lewis Bay did lose coverage, suggesting that the nutrient enriched waters from Lewis Bay were influencing the beds within the ebb tide "plume".

The observed pattern of loss is consistent with nutrient enrichment and it appears that the major environmental differences between the Hyannis Harbor sites and Lewis Bay sites are related to nitrogen enrichment. In estuaries on Cape Cod, the general pattern is for highest

nitrogen levels to be found within the innermost basins, with concentrations declining moving toward the tidal inlet. This pattern is also observed in nutrient related habitat quality parameters, like phytoplankton, turbidity, oxygen depletion, etc. The consequence is that eelgrass bed decline typically follows a pattern of loss in the innermost basins (and sometimes also from the deeper waters of other basins) first. The temporal pattern is a "retreat" of beds toward the region of the tidal inlet. It appears from the eelgrass and water quality information that eelgrass beds within Lewis Bay and Uncle Roberts Cove have declined as a result of nitrogen enrichment and should be the target for restoration and that this habitat would be recovered with appropriate nitrogen management.

The other major sub-embayments to the Lewis Bay System do not have evidence of ever having supported eelgrass habitat. The basins of Mill Creek are strongly influenced by surrounding tidal salt marshes and as such do not typically support eelgrass habitat. Salt marsh basins are generally shallow, nutrient and organic matter enriched (as part of their structure and function) and generally show summertime oxygen depletion. All these factors together yields conditions not supportive of eelgrass. Basins like Hyannis Inner Harbor may support eelgrass habitat under low to moderate nitrogen loading conditions. However, this system is a busy working harbor, which is dredged for navigation, lacked eelgrass even in the 1951 analysis, and has no other evidence of eelgrass coverage within the past 75 years. Therefore, the necessary conclusion is that this small basin should not be considered for eelgrass restoration within Lewis Bay System.

Other factors which influence eelgrass bed loss in embayments can also be at play in the Lewis Bay Embayment System, though the recent loss appears completely in-line with nitrogen enrichment. However, a brief listing of non-nitrogen related factors is useful. Eelgrass bed loss does not seem to be directly related to mooring density, as loss in Lewis Bay and Uncle Roberts Cove was observed from both mooring and non-mooring areas. Moreover, much of the basin is not a boat mooring area. Similarly, pier construction and boating pressure may be adding additional stress in nutrient enriched areas, but do not seem to be the overarching factor, especially given structure of these basins and the distribution of docks. It is not possible at this time to determine the potential effect of shellfishing on eelgrass bed distribution, although it should be noted that given the extensive *Codium* beds that have colonized Lewis Bay, this would indicate that disturbance from shell fishing activity is not a major issue at this location.

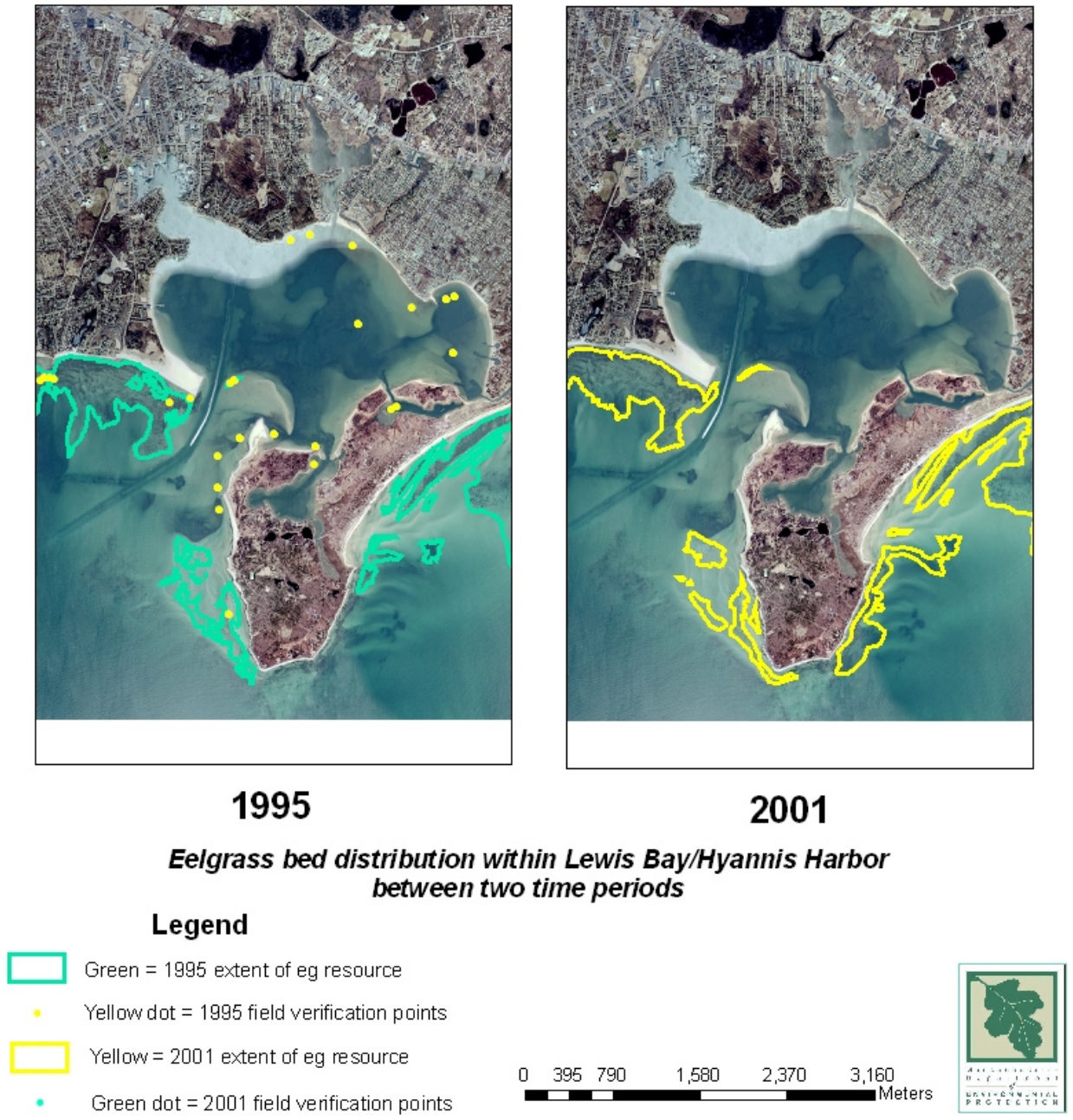


Figure VII-15. Eelgrass bed distribution within the Lewis Bay System. The 1995 coverage is depicted by the green outline inside of which circumscribes the eelgrass beds. The yellow (2001) areas were mapped by DEP. All data was provided by the DEP Eelgrass Mapping Program.

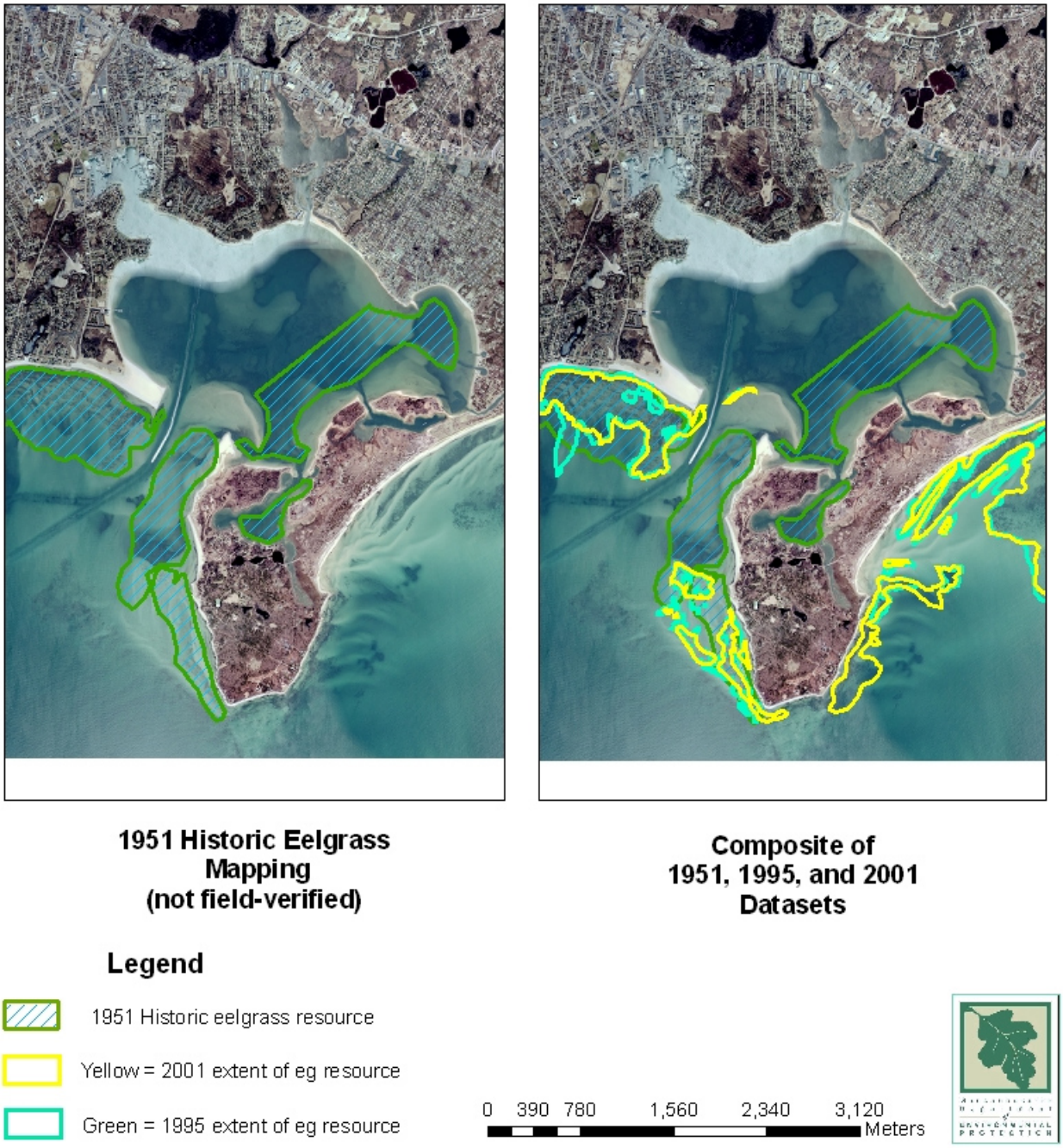


Figure VII-16. Eelgrass bed distribution within the Lewis Bay System. The 1951 coverage is depicted by the dark green outline (hatched area) inside of which circumscribes the eelgrass beds. In the composite photograph, the light green outline depicts the 1995 eelgrass coverage and the yellow outlined areas circumscribe the eelgrass coverage in 2001. The 1995 and 2001 areas were field verified. All data was provided by the MassDEP Eelgrass Mapping Program.

It is not possible to determine quantitative short- and long-term rates of change in eelgrass coverage from the mapping data, since there is only limited temporal data with virtually no eelgrass found in the recent surveys. However, it is possible to utilize the 1951 coverage data as an indication that a minimum eelgrass bed area that might be recovered (on the order of 200 acres) if nitrogen management alternatives were implemented (Table VII-3). It is likely that a greater area of eelgrass habitat would be restored, as the 1951 coverage is likely an underestimate as a result of mapping problems. Note that restoration of this eelgrass habitat will necessarily result in restoration of other resources throughout the Lewis Bay Embayment System, specifically the shallower eelgrass habitat in Uncle Roberts Cove and the infaunal habitat throughout Lewis Bay and within Hyannis Inner Harbor and Mill Creek. These latter sub-basins have traditionally only supported infaunal habitats (see below).

Table VII-3. Changes in eelgrass coverage in the Lewis Bay Embayment System within the Towns of Barnstable and Yarmouth over the past half century (MassDEP, C. Costello).

Lewis Bay Embayment System: Temporal Change in Eelgrass Coverage			
1951 Acreage	**1995 Acreage**	**2001 Acreage**	**% Loss 1951 to 2001**
216.22	**0.71**	**1.34**	**99%**

There is presently no eelgrass within the Halls Creek Estuary, nor historically. Based upon all available information, it appears that the Halls Creek Estuary is not structured to support eelgrass habitat, similar to Mill Creek and the salt marsh systems of Namskaket Marsh and Little Namskaket Creek in the Town of Orleans. This is typical for New England salt marshes, which are naturally organic and nutrient rich and generally contain little water in the creeks at low tide. This conclusion has been confirmed by the MEP Technical Team in a wide range of salt marsh dominated basins throughout southeastern Massachusetts. Therefore, threshold development for protection/restoration of this system will focus on infaunal habitat quality and the water quality data for this system (see below).

VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling was conducted at 14 locations throughout the Lewis Bay Embayment System and 4 locations within Halls Creek (Figure VII-17). In some cases multiple assays were conducted. In all areas and particularly those that do not support eelgrass beds, benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity and evenness of the community. It should be noted that, given the loss of eelgrass beds, the Lewis Bay System is clearly impaired by nutrient overloading. However, to the extent that it can still support healthy infaunal communities, the benthic infauna analysis is important for determining the level of impairment (moderately impaired→significantly impaired→severely

degraded). This assessment is also important for the establishment of site-specific nitrogen thresholds (Chapter VIII).

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas, as shown by the oxygen and chlorophyll records and eelgrass coverage, have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5.

Lewis Bay Estuary: Overall, the Infauna Survey indicated that most areas within the main Lewis Bay basin are supporting high to moderate quality infaunal habitat. The range of habitat quality within Lewis Bay results from a gradient in nutrient related habitat degradation from the inland reach to the high quality habitat near the tidal inlet. This gradient continues into Hyannis Harbor and Uncle Roberts Cove. While the basin of Mill Creek is naturally nutrient and organic matter enriched, the present conditions of macroalgae and high chlorophyll a levels suggest a moderate level of impairment for this system as well.

The outer stations within Lewis Bay currently support high numbers of individuals distributed among a large number of species (32). The community is composed of a variety of polychaete, crustacean and mollusk species, with high diversity and eveness. The data are clearly indicative of a high quality embayment habitat. Throughout the rest of the large basin of Lewis Bay, infaunal communities are indicative of a high to slightly impaired benthic habitat (in limited areas). The diversity and eveness are generally high, with numerous species and ones generally indicative of high habitat quality.

In contrast, Uncle Roberts Cove had depleted benthic communities (37 individuals/sample), although a moderate number of species were present. This pattern of high diversity, but impoverished numbers has been observed in systems with periodic oxygen stress. But whatever the cause, the benthic habitat quality in this tributary system is clearly significantly impaired. Hyannis Inner Harbor showed infauna typical of a moderately nitrogen enriched basin. The communities were highly spatially variable, with some species found in very high numbers (*Gemma*). However, the number of species remained moderate-high and stress indicator species were not prevalent, so only a moderate level of impairment was evident. The benthic habitat data was consistent with the levels of total nitrogen (0.518-0.574 mg N L^{-1}, tidally averaged) and chlorophyll a and oxygen depletion in this basin.

Mill Creek showed infaunal communities consistent with a salt marsh basin, with moderate numbers of species and individuals, and species indicative of an organic rich environment, but not contamination (i.e. not *Capitella*). Deposit and filter feeders were observed at these sites along with mollusks and crustaceans. The benthic habitat data suggests a high quality infaunal habitat, yet it did appear to be "patchy", potentially the result of drift algae. This variability is cause for concern as it suggests that this system may be moderately impaired. However, in general the habitat appeared typical of larger salt marsh basins in less developed watersheds

Overall, the infaunal habitat quality was consistent with the gradients in dissolved oxygen, chlorophyll, nutrients and organic matter enrichment in this system. Classification of habitat quality necessarily included the structure of the specific estuarine basin, specifically as to whether it was dominated by wetlands or more representative of a tidal embayment. Based upon this analysis it is clear that the tributary sub-embayment basins are presently supporting

moderately to significantly impaired benthic habitat, while the main basin of Lewis Bay is generally of high quality and the Mill Creek basin is supporting moderately impaired habitat for a salt marsh basin. Impairment in these basins is through nitrogen and organic matter enrichment.

The results of the Infauna Survey indicate that the nitrogen management threshold analysis (Chapter VIII) needs o include a lowering of the level of nitrogen enrichment in Hyannis Inner Harbor and Uncle Roberts Cove and potentially in Mill Creek to yield restoration of nitrogen impaired benthic habitats. However, it is important to note that in general the Lewis Bay Embayment System is supportive of high quality infauna habitat throughout much of basin area and that the level of impairment in the tributary sub-embayments is only moderate to low.

Halls Creek Estuary: Infauna communities within the central tidal creek of the Halls Creek Estuary are presently supporting infaunal habitat typical of the organic rich environment of New England salt marshes in summer. The communities are consistent with the observed levels of oxygen depletion and watercolumn TN. The communities within the upper reach had moderate to high numbers of individuals, and moderate species numbers. The communities generally contained some organic enrichment tolerant species. However, species like *Capitella* and tubificids did not dominate as in impaired habitats,, although *Streblospio* was among the dominant species. The diversity was moderate to high 2.14 – 3.41 and generally well distributed (Eveness >0.75). Equally important, the species present were typical of high quality salt marsh habitats, with some crustaceans and mollusks among the dominant polychaetes.

Overall, the Infauna Survey indicated that most areas within the creeks and basin of the Halls Creek Estuary are supporting infauna habitat typical of organic rich New England salt marshes, hence high quality relative to this estuarine ecosystem type. This is supported by the absence of macroalgal accumulations and algal mats within the creek bottoms which can result if there is "excessive" external nitrogen loading. The absence of macroalgal accumulations is consistent with the low total nitrogen levels within this system, 0.385-0.469 mg N L^{-1} (tidally averaged). This is in comparison to a similar marsh, Cockle Cove Creek (Chatham), which supports high quality habitats, both emergent marsh and creek bottom, at levels of 2 mg TN L^{-1}. Based upon all lines of evidence it appears that the Namskaket Estuary is presently supporting high quality infaunal habitat and has not exceeded its threshold nitrogen level for assimilating additional nitrogen without impairment.

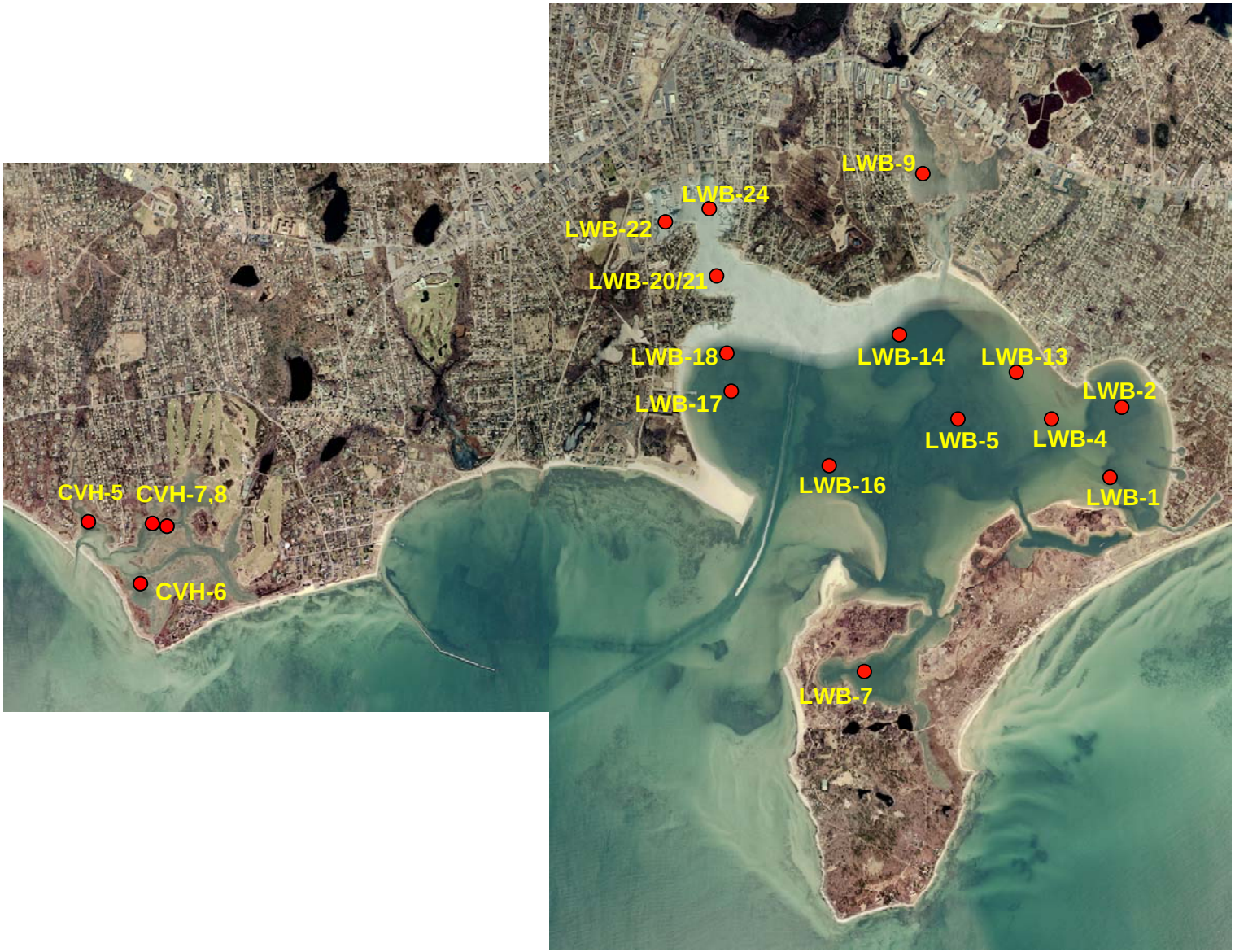


Figure VII-17. Aerial photograph of the Lewis Bay system showing location of benthic infaunal sampling stations (red symbol).

Table VII-4. Benthic infaunal community data for the Lewis Bay embayment system. Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations (Samples represent surface area of 0.018 m2). Stations refer to map in figure VII-17, (N) is the number of samples per site.

Location	Sta ID (N)	Total Actual Species	Total Actual Individuals	Species Calculated @75 Indiv.	Weiner Diversity (H')	Evenness (E)
Lewis Bay						
Eastern Basin	Sta. 1 (2)	6	248	4	1.02	0.33
	Sta. 2 (2)	21	97	19	3.96	0.90
	Sta. 4 (2)	19	185	16	3.45	0.82
Western Basin	Sta. 17 (1)	22	395	12	2.22	0.50
	Sta. 18 (2)	15	97	14	3.48	0.89
Central Basin	Sta. 13 (1)	15	84	14	2.93	0.75
	Sta. 5 (1)	12	64	NA	2.29	0.62
	Sta. 14 (1)	14	60	NA	2.99	0.79
Hyannis Inner Harbor						
	Sta. 22 (2)	16	147	12	2.76	0.70
	Sta. 24 (2)	12	81	15	2.83	0.80
	Sta. 20/21(2)	14	2061	6	1.77	0.52
Uncle Roberts Cove						
	Sta. 7 (2)	11	37	NA	3.05	0.88
Mill Creek						
	Sta. 9 (2)	14	93	14	3.04	0.83
Tidal Inlet						
	Sta. 16 (2)	32	502	18	3.69	0.74
Halls Creek						
	Sta 5	10	164	9.31	2.84	0.86
	Sta. 6	14	202	10.91	2.14	0.56
	Sta. 7	21	191	15.51	3.41	0.78
	Sta. 8	13	207	11.47	2.80	0.76

VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS

VIII.1. ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires integration of key habitat parameters (infauna and eelgrass), sediment characteristics, and nutrient related water quality information (particularly dissolved oxygen and chlorophyll) a). Additional information on temporal changes within each sub-embayment and its associated watershed nitrogen load further strengthens the analysis. These data were collected by the MEP to support threshold development for the Lewis Bay Embayment System and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels from the baseline Water Quality Monitoring Program coordinated between the Towns of Barnstable and Yarmouth (with technical and analytical support from the Coastal Systems Program at SMAST-UMass Dartmouth).

The Lewis Bay Embayment System is a complex estuary composed of 2 functional types of component basin types: embayments (Lewis Bay, Uncle Roberts Cove, Hyannis Inner Harbor) and a salt marsh pond/embayment (Mill Creek). In addition, associated with the Lewis Bay System is the adjacent Halls Creek Estuary, which like Mill Creek is primarily a salt marsh surrounding an open water basin. Halls Creek was included in the Lewis Bay MEP analysis as it receives nitrogen enriched groundwater resulting from discharge of treated effluent from the Hyannis WWTF. This discharge and almost all of the treated wastewater originates within the Lewis Bay watershed. Each of these 2 functional components (embayment and salt marsh) has different natural sensitivities to nitrogen enrichment and organic matter loading. Evaluation of eelgrass and infaunal habitat quality must consider the natural structure of each system and their ability to support eelgrass beds and specific types of infaunal communities.

At present, the Lewis Bay Embayment System is showing variations in nitrogen enrichment and habitat quality among its various component basins. In general the system is showing healthy to moderately impaired benthic habitat. However, the smaller tributary embayments and limited inner areas of Lewis Bay (e.g. Uncle Roberts Cove, Hyannis Inner Harbor) are presently moderately impaired based upon infaunal habitat criteria. Overall, the dominant habitat issue for this system is the significant impairment of the Lewis Bay basin and Uncle Roberts Cove, based on eelgrass criteria. Historical eelgrass beds have been lost in these areas and eelgrass is virtually non-existent within this system. These significantly impaired habitats comprise ca. 90% of the estuarine area of the Lewis Bay Embayment System. In contrast, the Halls Creek System is presently supporting high quality habitat, representative of a New England salt marsh system. As there is no record of eelgrass within this system, typical of salt marshes, the primary resource within the basin relates to infaunal animal communities.

Eelgrass: The present virtual absence of eelgrass throughout the Lewis Bay Embayment System is consistent with the observed nitrogen and the chlorophyll levels and functional basin types comprising this estuary. Lewis Bay and Uncle Roberts Cove supported extensive eelgrass beds in 1951 under lower nitrogen loading conditions.

Currently, eelgrass exists only within a small portion at the tidal inlet of Lewis Bay. The absence of eelgrass throughout the Lewis Bay Embayment System is consistent with the observed moderate level of nutrient enrichment throughout each of the sub-embayments to this complex estuary. Total nitrogen levels (TN) within the lower basins that supported eelgrass in

1951 (Lewis Bay and Uncle Roberts Cove) have mean summertime levels of ~0.4 mg N L^{-1} compared to the levels at the outer beds in adjacent Hyannis Harbor of 0.30-0.35 mg N L^{-1} (monitoring data, Chapter VI). Other key water quality indicators, dissolved oxygen and chlorophyll a, show similar levels of moderate enrichment with periodic oxygen depletions below 5-4 mg/L and chlorophyll levels of 3-6 ug/l to 2-10 ug/l in the Lewis Bay basin and 5-15 ug/L in Uncle Roberts Cove. Given the sensitivity of eelgrass to declining light penetration resulting from nutrient enrichment and secondary effects of organic enrichment and oxygen depletion, the loss of eelgrass in these basins is expected.

The observed pattern of loss is consistent with nutrient enrichment and it appears that the major environmental differences between the Hyannis Harbor sites and Lewis Bay sites are related to nitrogen enrichment. In estuaries on Cape Cod, the general pattern is for highest nitrogen levels to be found within the innermost basins, with concentrations declining moving toward the tidal inlet. This pattern is also observed in nutrient related habitat quality parameters, like phytoplankton, turbidity, oxygen depletion, etc. The consequence is that eelgrass bed decline typically follows a pattern of initial loss in the innermost basins (and sometimes also from the deeper waters of other basins). The temporal pattern is a “retreat” of beds toward the region of the tidal inlet. It appears from the eelgrass and water quality information that eelgrass beds within Lewis Bay and Uncle Roberts Cove have declined as a result of nitrogen enrichment and should be the target for restoration and that this habitat would be recovered with appropriate nitrogen management. Recovery generally follows the reverse pattern of eelgrass loss, with colonization first in the outer and shallow basin areas and later within the inner basin and tributaries.

The other sub-embayments to the Lewis Bay System do not have evidence of ever having supported eelgrass habitat. The basins of Mill Creek are strongly influenced by surrounding tidal salt marshes and as such, do not typically support eelgrass habitat. Salt marsh basins are generally shallow, nutrient and organic matter enriched based on their structure and function and generally show summertime oxygen depletion, conditions not supportive of eelgrass. Basins like Hyannis Inner Harbor may support eelgrass habitat under low to moderate nitrogen loading conditions. However, this sub-basin to the Lewis Bay system is a busy working harbor, which is dredged for navigation, lacked eelgrass even in the 1951 analysis, and has no other evidence of eelgrass coverage within the past 75 years. The necessary conclusion is therefore that this small basin should not be considered for eelgrass restoration within Lewis Bay System.

It appears from the eelgrass and water quality information that eelgrass beds within the Lewis Bay main basin and Uncle Roberts Cove should be the target for restoration and that this habitat should be recovered with appropriate nitrogen management. From the historical analysis, it appears that more than 212 acres of eelgrass habitat could be recovered, if nitrogen management alternatives were implemented. More acreage recovered is likely, as the analysis of the 1951 aerial photography is likely to have underestimated the acreage of eelgrass habitat within Lewis Bay. Note that restoration of this habitat will necessarily result in restoration of other resources throughout the Lewis Bay Embayment System. Since Uncle Roberts Cove, Hyannis Inner Harbor and Mill Creek all receive flood tidal waters from Lewis Bay, nitrogen management focused on lowering nitrogen levels within this large lagoon will de facto result in a lowering of nitrogen levels throughout the estuarine system. Therefore, an improvement of infaunal habitats in each of the 3 tributary sub-embayments will result. It appears that only limited nitrogen reduction is required as Hyannis Inner Harbor and Mill Creek have traditionally only supported infaunal habitat and are only moderately impaired. Similarly, though Uncle Roberts Cove is considered significantly impaired as a result of losing its eelgrass coverage, its

nitrogen levels are presently only 0.4 mg N L^{-1} (tidally averaged) and are controlled primarily by nitrogen levels in flood waters from Lewis Bay and rates of flushing.

Based upon the above analysis, eelgrass habitat was selected as the primary nitrogen management goal for Lewis Bay and Uncle Roberts Cove while infaunal habitat quality was selected as the management target for Hyannis Inner Harbor and possibly Mill Creek. These goals are the focus of the MEP management alternatives analysis presented in Chapter IX.

Water Quality: Overall, the oxygen levels within the major sub-basins to the Lewis Bay Embayment System are indicative of relatively healthy or only moderately impaired conditions. This is based on the definition of the Hyannis Inner Harbor and Mill Pond basins as infaunal habitats (e.g. historically have not supported eelgrass) and consideration of each sub-basins physical structure and natural biogeochemical cycling. Similar to other embayments in southeastern Massachusetts, the inner basins evaluated in this assessment showed high frequency variation, apparently related to diurnal and tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site underscores the need for continuous monitoring within these systems.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate moderately nutrient enriched waters within each sub-embayment basin to Lewis Bay. The oxygen data is consistent with organic matter enrichment, primarily from phytoplankton production, as seen from the parallel measurements of chlorophyll a. The measured levels of oxygen depletion and enhanced chlorophyll a levels match the spatial pattern of total nitrogen concentrations in this system. The parallel variation in these water quality parameters is consistent with watershed based nitrogen enrichment of this estuarine system.

The oxygen records show that the inner sub-embayments of Mill Creek and Hyannis Harbor, which receive significant watershed nitrogen loads, have the largest daily oxygen excursions (a nutrient related response). The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). The clear evidence of oxygen levels above atmospheric equilibration indicates that the upper tidal reaches of the Lewis Bay system are nitrogen enriched. In contrast, oxygen levels within Lewis Bay were generally high and chlorophyll a and total nitrogen showed a low level of enrichment, consistent with the generally high level of infaunal habitat quality and the recent loss of the eelgrass that is more sensitive to nutrient enrichment.

Measured dissolved oxygen depletion indicates that the Lewis Bay sub-embayments, Uncle Robert's Cove and to a lesser extent, Hyannis Inner Harbor, exhibit moderate levels of oxygen stress. The largest oxygen depletions were observed in Mill Creek, but this is primarily functioning as a salt marsh pond. As such this system is naturally nutrient and organic matter enriched, with oxygen depletions common. The observed spatial pattern indicated increasing levels of oxygen depletion (Table VII-1) and chlorophyll a (Table VII-2), and increased total nitrogen levels with increasing distance from the tidal inlet and into the smaller sub-embayments. The pattern of oxygen depletion, elevated chlorophyll a and nitrogen levels is consistent with the observed pattern of eelgrass loss (Section VII.3) and quality of infaunal

habitats (Section VII.4). All the information put together reflects an estuarine system that is beyond its ability to assimilate nitrogen loads without impairment.

Infaunal Communities: The infaunal study indicated an overall system supporting generally healthy to only moderately impaired infaunal habitat relative to the ecosystem types represented (i.e. embayment versus salt marsh creek/pond). The range of habitat quality within Lewis Bay, results from a gradient in nutrient related habitat degradation from the inland reaches to the high quality habitat near the tidal inlet. This gradient continues into Hyannis Harbor and Uncle Roberts Cove. While the basin of Mill Creek is naturally nutrient and organic matter enriched, the present conditions of macroalgae and high chlorophyll a levels suggest a moderate level of impairment for this system as well.

The outer stations within Lewis Bay currently support high numbers of individuals distributed among a large number of species (32). The community is composed of a variety of polychaete, crustacean and mollusk species, with high diversity and eveness. The data are clearly indicative of a high quality embayment habitat. Throughout the rest of the large basin of Lewis Bay, infaunal communities are indicative of a high to slightly impaired benthic habitat (in limited areas). In contrast, Uncle Roberts Cove had depleted benthic communities, a pattern observed in systems with periodic oxygen stress. The benthic habitat in this tributary system is clearly significantly impaired. Hyannis Inner Harbor showed infauna typical of a moderately nitrogen enriched basin. The communities showed high spatial variability, with some species found in very high numbers (*Gemma*). However, the number of species remained moderate-high and stress indicator species were not prevalent, so only a moderate level of impairment was evident. The benthic habitat data was consistent with the levels of total nitrogen (0.518-0.574 mg N L^{-1}, tidally averaged) and chlorophyll a and oxygen depletion in this basin.

Mill Creek showed infaunal communities consistent with a salt marsh basin, with moderate numbers of species and individuals, and species indicative of a nutrient and organic rich environment, but not nutrient contamination (i.e. not Capitella). Deposit and filter feeders were observed at these sites with mollusks and crustaceans. The benthic habitat data suggests a high quality infaunal habitat, but did appear to be "patchy", potentially the result of drift algae. This variability is cause for concern as it suggests that this system may be moderately impaired. However, in general the habitat appeared typical of larger salt marsh basins in less developed watersheds

Overall, the infaunal habitat quality was consistent with the gradients in dissolved oxygen, chlorophyll, nutrients and organic matter enrichment in this system. Classification of habitat quality necessarily included the structure of the specific estuarine basin, specifically as to it being dominated by wetlands versus being more characteristic of a tidal embayment. Based upon this analysis it is clear that the tributary sub-embayment basins are presently supporting moderately to significantly impaired benthic habitat, while the main basin of Lewis Bay is generally of high quality. The Mill Creek basin is supporting moderately impaired habitat for a salt marsh basin. Impairment in these basins is through nitrogen and organic matter enrichment.

Table VIII-1. Summary of Nutrient Related Habitat Health within the Lewis Bay Embayment System on Nantucket Sound within the Towns of Barnstable and Yarmouth, MA., based upon assessment data presented in Chapter VII. The main basin of Lewis Bay and its tributary sub-embayments of Hyannis Inner Harbor and Uncle Roberts Cove are typical coastal embayment basins. In contrast, Mill Creek is primarily a salt marsh basin.

Health Indicator	Lewis Bay Embayment System					
	Lewis Bay		Uncle Roberts Cove	Hyannis Inner Harbor	Mill Creek	Halls Creek
	Outer	Inner				
Dissolved Oxygen	H-MI[2]	MI-SI[3]	MI-SI[4]	H-MI[2]	H-MI[1, 15]	H[24]
Chlorophyll	H-MI[5]	MI[6]	MI-SI[7]	MI[6]	MI[8]	H[5]
Macroalgae	MI[9]	MI[9]	MI[10]	--[11]	MI[12]	--[11]
Eelgrass	SI[13]	SI[13]	SI[13]	--[14]	--[14]	--[14]
Infaunal Animals	H[16]	H-MI[17]	SI[18]	MI[19]	H[20]	H[20]
Overall:	**SI[21]**	**SI[21]**	**SI[21]**	**MI[22]**	**MI[23]**	**H**

1 – primarily a salt marsh pond, periodic oxygen depletions to <4 mg/L, very rarely to 3-2 mg/L.
2 – oxygen levels generally >6 mg/L, with periodic depletions 6-5 mg/L.
3 – oxygen depletions periodically 4-3 mg/L, generally >5 mg DO/L.
4 -- oxygen depletions periodically to 4-4.5 mg/L, with infrequent declines to 3.7 mg/L.
5 – low to moderate chlorophyll a levels generally 3-6 ug/L, generally <5 ug/L 73% of time.
6 – moderate chlorophyll a levels generally ~3-10 ug/L, generally >5 ug/L frequently >10 ug/L
7 – elevated chlorophyll a levels generally 5-15 ug/L, frequently >13 ug/L
8 – high chlorophyll a levels generally >10 ug/L, frequently >20 ug/L
9 – extensive attached dense bed of *Codium* throughout basin, serving as SAV.
10 -- moderate amounts of filamentous drift algae
11 -- drift algae sparse or absent, little surface microphyte mat.
12 -- moderate to high levels of drift algae, Ulva and Codium some in situ, some transported in
13 -- eelgrass lost from this system between 1951-1995.
14 – no evidence this basin is supportive of eelgrass.
15 -- basin supports fringing salt marsh areas.
16 -- Inlet: high numbers, diversity, eveness, large #'s polychaete, crustacean, mollusk species
17 -- moderate numbers of species and high-moderate number individuals; high-moderate diversity and eveness; with polychaetes, mollusks and crustaceans
18 -- low numbers of species and individuals, organic enrichment indicators
19 -- moderate-high (*Gemma*) numbers of individuals, moderate species, moderate H' & Eveness
20 -- Infauna: moderate numbers of individuals, moderate species, high diversity and Eveness; organic enrichment indicators typical of salt marsh ponds, some deep burrowers.
21 -- Significant Impairment based upon loss of eelgrass from system, 1951-1995.
22 -- Moderate Impairment based upon moderate oxygen depletion, elevated chlorophyll; variable infaunal communities, with wide range of numbers, moderate numbers of species with organic enrichment indicators (*Spionids, Gemma, Mullinia*).
23 -- Moderate Impairment based primarily on the high sustained chlorophyll levels.
24 – No moorings were deployed, monitoring data showed moderate depletion of oxygen.

H = healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment; SD = Severe Degradation; -- = not applicable to this estuarine reach

The results of the infauna survey indicate that the nitrogen management threshold analysis (Section VIII.2) needs to include a lowering of the level of nitrogen enrichment in Hyannis Inner Harbor and Uncle Roberts Cove and potentially in Mill Creek thereby leading to restoration of nitrogen impaired benthic habitats. However, it is important to note that in general the Lewis Bay Embayment System is supportive of high quality infauna habitat throughout much basin area. Although there are some moderately impaired infaunal habitats within the Lewis Bay Embayment System, restoration needs to also target eelgrass habitat. While most of Lewis Bay shows high quality infauna habitat, it is clearly significantly impaired based on eelgrass criteria, since historical eelgrass beds have been recently lost. As a result, both eelgrass and infaunal animal habitats are impaired in this estuary, and nitrogen management is required for their restoration.

All of the key habitat indicators are consistent within the Halls Creek Estuary, and particularly its tidal creeks, supporting high quality habitat in line with the system's salt marsh structure and function (Chapter VII). Similar to other salt marshes throughout the region, Halls Creek does not appear structured to support eelgrass beds. In contrast, the systems is presently supporting high quality infaunal animal habitat typical of organic rich New England salt marshes, hence high quality relative to this estuarine ecosystem type. This is consistent with the absence of significant accumulations of drift macroalgae within the creek bottoms which can result if there is "excessive" external nitrogen loading. The absence of macroalgal accumulations is consistent with the low levels of total nitrogen within this system, 0.385-0.469 mg N $L^{-1}$$_{-1}$ (tidally averaged). Based upon all lines of evidence it appears that the Halls Creek Estuary is presently supporting high quality infaunal habitat and has not exceeded its threshold nitrogen level for assimilating additional nitrogen without impairment.

VIII.2. THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout an embayment system, is to first identify a sentinel location within the embayment and second to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality. The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level are determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

Determination of the critical nitrogen thresholds for maintaining high quality habitat within Lewis Bay Embayment System and Halls Creek are based primarily upon the nutrient and oxygen levels, temporal trends in eelgrass distribution and current benthic community indicators. Given such a database, it is possible to develop a site-specific threshold, which is a refinement upon more general threshold analyses frequently employed.

Lewis Bay Estuary: The Lewis Bay Embayment System presently supports a range of infaunal habitat quality. Within Lewis Bay, a gradient in nutrient related habitat degradation was observed from the inland reach to the high quality habitat near the tidal inlet. This gradient continues into Hyannis Harbor and Uncle Roberts Cove. While the basin of Mill Creek is naturally nutrient and organic matter enriched, the present conditions of macroalgae and high chlorophyll a levels suggest a moderate level of impairment for this system as well. However, the primary habitat issue within the Lewis Bay Embayment System relates to the loss of the extensive eelgrass beds from Lewis Bay and the shallow marginal beds from Uncle Roberts Cove. This loss of eelgrass classifies these areas as "significantly impaired", although Lewis

Bay presently supports generally high quality infaunal communities. The impairments to both the infaunal habitat and the eelgrass habitat within the component basins of the Lewis Bay Embayment System are supported by the variety of other indicators, oxygen depletion, chlorophyll, and TN levels, all of which support the conclusion that these impairments are the result of nitrogen enrichment, primarily from watershed nitrogen loading.

The habitat assessment data are also internally consistent. For example, the observed loss of eelgrass, and continuing presence of SAV (*Codium*) within the Lewis Bay basin, suggests a system not far above its nitrogen threshold level supportive of eelgrass. The tidally averaged nitrogen levels throughout Lewis Bay were found to range from 0.385-0.415 mg N L^{-1}, compared to the inlet station (adjacent existing beds) that supported a TN concentration of 0.369 mg N L^{-1} (tidally averaged). Similarly, the moderate impairment of infaunal habitat in the inner basins of Hyannis Inner Harbor is consistent with the moderate levels of oxygen depletion, chlorophyll a enhancement and tidally averaged total nitrogen levels of 0.518-0.574 mg N L^{-1}.

Only Uncle Roberts Cove can be classified as having both significantly impaired eelgrass and infaunal habitats. The observed loss of eelgrass is consistent with the observed oxygen depletions and elevated chlorophyll and total nitrogen levels (0.432 mg N L^{-1}). The impairment to infauna appears to be related to structural features of the inner basin that provide for a depositional environment and supports periodic stratification and oxygen depletion. The effect of the sedimentation of the inlet to the Cove in enhancing the impacts of nitrogen enrichment in this basin needs to be evaluated. However, as the infaunal community is presently diverse, small reductions in organic matter deposition to reduce the level of oxygen depletion will likely be sufficient to restore this habitat.

The results of the water quality and infaunal data, coupled with the temporal trends in eelgrass coverage, clearly support the need to lower nitrogen levels within Lewis Bay and Uncle Roberts Cove in order to restore eelgrass habitat. Lesser loading reductions would be necessary within Hyannis Inner Harbor and potentially in Mill Creek for restoration of nitrogen impaired benthic habitats. Restoration of the limited areas of moderately impaired and areas of significantly impaired infaunal habitats within Lewis Bay and Uncle Roberts Cove, respectively, will be achieved with the restoration of eelgrass habitat within these basins.

Considering the eelgrass and water quality information it is clear that eelgrass beds within the Lewis Bay basin should be the primary target for restoration of the Lewis Bay Embayment System and that restoration would require appropriate nitrogen management. From the historical analysis, it appears that at least 200 acres of eelgrass habitat could be recovered, if nitrogen management alternatives are implemented. Therefore, the sentinel station (BHY-3) for the Lewis Bay Embayment System was selected based upon its location within the inner region of documented eelgrass coverage in this estuary. The sentinel station is within the mid basin of the easternmost basin of Lewis Bay (sometimes called Little Lewis Bay), between Pine Island and Englewood Beach and is a long-term sampling station of the Yarmouth/Barnstable Water Quality Monitoring Program.

The target nitrogen concentration (tidally averaged TN) for restoration of eelgrass at the sentinel location within Lewis Bay was determined to be 0.38 mg TN L^{-1}. As there is not high quality eelgrass habitat within the Lewis Bay Embayment System, this threshold was based upon comparison to other local embayments of similar depths and structure under MEP analysis as well as conditions near the eelgrass areas adjacent the tidal inlet to Hyannis Harbor. A well studied eelgrass bed within the lower Oyster River (Chatham) has been stable at a tidally averaged water column TN concentration of 0.37 mg N L^{-1}, while eelgrass was lost within the

Lower Centerville River at a tidally averaged TN concentration of 0.395 mg N L^{-1}, and also lost within Waquoit Bay at 0.39 mg N L^{-1}. The nitrogen threshold for the lower main basin of Popponesset Bay and for the complex Stage Harbor System was 0.38 mg N L^{-1}. These latter 2 systems have a similarly complex multiple component structure to the Lewis Bay System. These values from other Cape Cod embayments are consistent with the data from Lewis Bay. Eelgrass beds still exist to the west of the inlet to Lewis Bay within Hyannis Harbor. These beds are exposed to tidally averaged nitrogen levels of 0.37 mg N L^{-1}, similar to that in the Oyster River (Chatham). In addition, extensive SAV (*Codium*) persists within the main basin of Lewis Bay which has a basin-wide tidally averaged TN concentration of 0.393 mg N L^{-1} (range 0.385-0.408 mg N L^{-1}). These site specific data indicate that the threshold for eelgrass in this system is between 0.370 and 0.393 (or 0.385) mg N L^{-1}, tidally averaged TN. This is strong support for the 0.380 mg N L^{-1} value determined for the sentinel station (BHY-3). Restoration of the shallow marginal eelgrass habitat within Uncle Roberts Cove allows a higher TN threshold than within the deeper habitat of Lewis Bay.

The selection of the TN level for the shallow marginal bed within Uncle Roberts Cove followed the process noted above for the sentinel station. Since water depth is important in determining the criteria for eelgrass restoration, as the same phytoplankton concentration that results in shading of eelgrass in deep water will allow sufficient light to support eelgrass in shallow water, the shallower water at the upper basin site allows for a higher TN level compared to the sentinel station. Analysis of comparable beds within the Green Pond Estuary (Falmouth) recommends the secondary criteria for this site to be 0.40 mg TN L^{-1} for stability. The target nitrogen concentration for restoration of eelgrass within the lower basin of Green Pond, was determined to be 0.40 mg TN L^{-1} based in part upon the findings that: (1) eelgrass beds have been lost in that basin at 0.41 mg TN L^{-1}, although sparse eelgrass were observed adjacent the inlet, (2) eelgrass beds in Bournes Pond in very shallow water persisted at 0.42 mg TN L^{-1}. It should be noted that 0.40 mg N L^{-1} within Uncle Roberts Cove is a secondary criteria to ensure restoration of eelgrass habitat within this sub-embayment and should be met when the threshold is met at the sentinel station in Lewis Bay. Nitrogen management specific to the watershed of Uncle Roberts Cove will likely not be required, although it will be important to maintain unrestricted tidal exchange to this basin. The sentinel station under present loading conditions supports a tidally averaged concentration of 0.408 mg TN L^{-1}, so watershed nitrogen management will be required for restoration of the estuarine habitats within this system.

Although the nitrogen management target is restoration of eelgrass habitat (and associated water clarity, shellfish and fisheries resources), benthic infaunal habitat quality must also be supported as a secondary condition. At present, the regions with moderately impaired infaunal habitat within the Hyannis Inner Harbor and the potentially impaired habitat within Mill Creek have total nitrogen (TN) levels in the range of 0.518 - 0.574 mg N L^{-1}. The observed moderate impairment at these sites is consistent with observations by the MEP Technical Team in other enclosed basins along Nantucket Sound (e.g. Perch Pond, Bournes Pond, Popponesset Bay) where levels <0.5 mg N L^{-1} were found to be supportive of healthy infaunal habitat and in deeper enclosed basins in Buzzards Bay (e.g. Eel Pond in Bourne) where healthy infaunal habitat had a slightly lower threshold level, 0.45 mg N L^{-1}, due to it being a "deep" depositional basin. Similarly, the Centerville River system showed moderate impairment at tidally averaged TN levels of 0.526 mg N L^{-1} in Scudder Bay (analogous to Mill Creek) and at 0.543 mg TN L^{-1} in the middle reach of the Centerville River. Additionally, moderate impairment was also observed at the same TN levels (0.535-0.600 mg N L^{-1}) within the Wareham River, with high quality infaunal animal habitat at TN levels of 0.444-0.463 mg TN L^{-1}. Based upon these observations, the MEP Technical Team concluded that an upper limit of 0.50 mg N L^{-1} tidally averaged TN would support healthy infaunal habitat in the Lewis Bay System.

For restoration of the Lewis Bay Embayment System, both the primary nitrogen threshold at the sentinel station and the secondary criteria within the sub-embayments need to be achieved. However, the secondary criteria established by the MEP are to merely provide a check on the acceptability of conditions within the tributary basins at the point that the threshold level is attained at the sentinel station. Three secondary criteria were established for the Lewis Bay Embayment System: (1) a TN level of 0.40 mg N L^{-1} was set to restore the shallow marginal eelgrass bed within Uncle Roberts Cove (tidal average at BHY-4), this will also ensure restoration of infaunal habitat throughout that basin; (2) a tidally averaged TN level of <0.5 mg N L^{-1} with the Hyannis Inner Harbor basin (average of BH-1 and BH-2) and (3) a tidally averaged TN level of <0.5 mg N L^{-1} within the salt marsh basin of Mill Creek to reduce the magnitude of the phytoplankton blooms and improve infaunal habitat in the lower basin.

It should be emphasized that these secondary criteria values were not used for setting nitrogen thresholds in this embayment system. These values merely provide a check on the acceptability of conditions within the tributary basins at the point that the threshold level is attained at the sentinel station. The results of the Linked Watershed-Embayment modeling are used to ascertain that when the nitrogen threshold is attained, TN levels in these regions are within the acceptable range. The goal is to achieve the nitrogen target at the sentinel location and restore eelgrass habitat throughout Lewis Bay and Uncle Roberts Cove as well as infaunal habitat throughout the System. The nitrogen loads associated with the threshold concentration at the sentinel location and secondary infaunal check stations are discussed in Section VIII.3, below and depicted in Figure VIII-1.

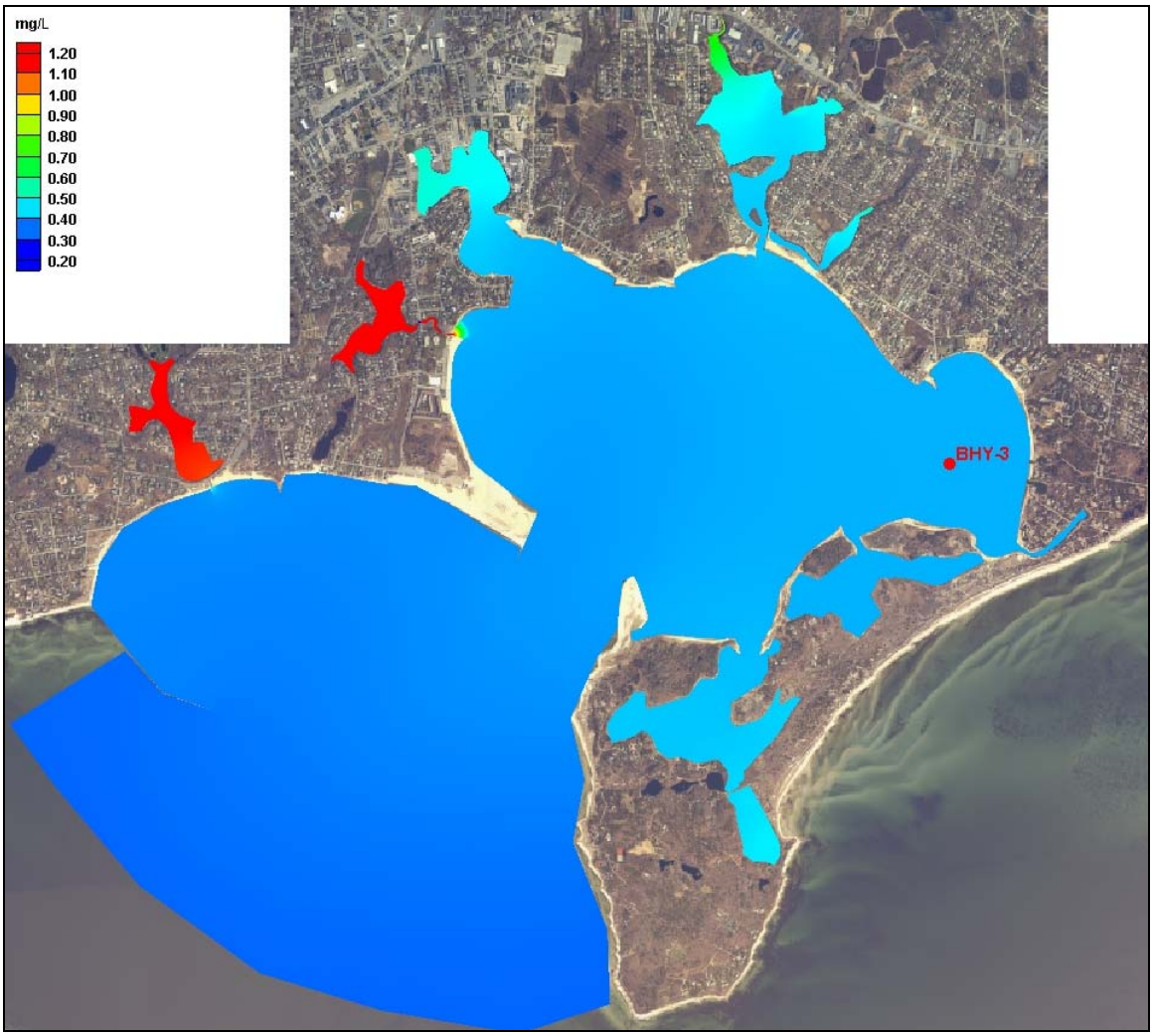


Figure VIII-1. Contour plot of modeled average total nitrogen concentrations (mg/L) in the Lewis Bay system, for threshold conditions (0.38 mg/L at water quality monitoring station BHY-3, and less than 0.5 at water quality monitoring station MC-1 and the average of stations BH-1 and BH-2). The approximate location of the sentinel threshold station for Lewis Bay (BHY-3) is shown.

Halls Creek Estuary: All of the key habitat indicators are consistent within the Halls Creek Estuary, and particularly its tidal creeks, supporting high quality habitat in line with the salt marsh structure and function of this system (Chapter VII). Given that Halls Creek does not appear to be a system structured to support eelgrass habitat, its nitrogen threshold needs to focus on infaunal animal communities. Overall, the infauna survey described in Chapter VII indicated that most areas within the creeks and basin of the Halls Creek Estuary are supporting infauna habitat typical of organic rich New England salt marshes, hence high quality relative to this estuarine ecosystem type. This is supported by the absence of macroalgal accumulations and algal mats within the creek bottoms which can result if there is "excessive" external nitrogen loading. The absence of macroalgal accumulations is consistent with the low total nitrogen levels within this system, 0.385-0.469 mg N L^{-1} (tidally averaged). This is in comparison to a similar marsh, Cockle Cove Creek (Chatham), which supports high quality habitats, both emergent marsh and creek bottom, at levels of 2 mg N L^{-1}. Based upon all lines of evidence it appears that the Halls Creek Estuary is presently supporting high quality infaunal habitat and

has not exceeded its threshold nitrogen level for assimilating additional nitrogen without impairment.

A principal component of the high tolerance of salt marsh systems to nitrogen inputs from groundwater and surface water inflows is that unlike embayments, creek waters cannot accumulate nutrients over multiple tidal cycles as embayments do. In addition, increasing the nitrogen concentration in the tidal waters that flood the marsh plain will have a negligible or possibly a stimulatory effect on marsh primary and likely secondary production (i.e. an enhancement of habitat). In addition, since the inflowing fresh waters flow down gradient through the marsh creek and out to the Centerville Harbor and Nantucket Sound, the nitrogen level in estuarine waters will never exceed the inflowing freshwater nitrogen level. As was the case for the Cockle Cove Creek system (similar in structure to the Halls Creek system), it was determined that a highly conservative nitrogen threshold would yield a total nitrogen level of <2 mg N L^{-1} throughout the salt marsh (e.g. from headwaters to tidal inlet). As this system closely resembles the structure and hydrodynamics of Halls Creek, this threshold level appears to be appropriate for Halls Creek marsh as well. It should be noted that the upper most marsh reach of Cockle Cove is currently exposed to 2-3 mg N L^{-1} without discernable habitat impairment. Also, it is important to note that since the creek bottom sediments remove nitrate during transport, the TN concentration declines along the tidal reach. As such, the lower tidal reach has a significantly lower tidally averaged concentration compared to the headwaters. This can be seen in the existing TN gradient, where the tidally averaged TN concentration in Halls Creek is 0.469 mg N L^{-1} and 0.385 mg N L^{-1} at the inlet.

Putting all the assessment elements together, it appears that for Halls Creek, the critical values are a total nitrogen level of 2 mg N L^{-1} in the headwaters (Station BC-13) and a level of 1 mg N L^{-1} at the border of the upper and lower reach (Station BC-14). As this upper/lower boundary station is the uppermost long-term marine water quality sampling site and integrates all of the watershed and upper marsh nitrogen inputs and removals, it was selected as the sentinel station for this system (BC-14). The threshold (tidally averaged) total nitrogen level of 1 mg N L^{-1} was determined to be appropriate for the sentinel station (BC-14). It should be noted that the tidally averaged total nitrogen level at the middle marsh station in Cockle Cove Creek is currently 1.378 mg N L^{-1} and the tidal inlet station shows concentrations of 0.472 mg N L^{-1}, consistent with the 1 mg N L^{-1} at the sentinel station in Halls Creek. This threshold applies as long as the tidal creek maintains its present hydrodynamic characteristics (flushing and velocity). The nitrogen threshold for Halls Creek salt marsh is intentionally conservative based upon all available data from comparable systems. However, it indicates that additional nitrogen may enter this system without impairment of its habitat quality throughout the estuary. The nitrogen loads associated with the threshold concentration at the sentinel location are discussed in Section VIII.3, below. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-2.

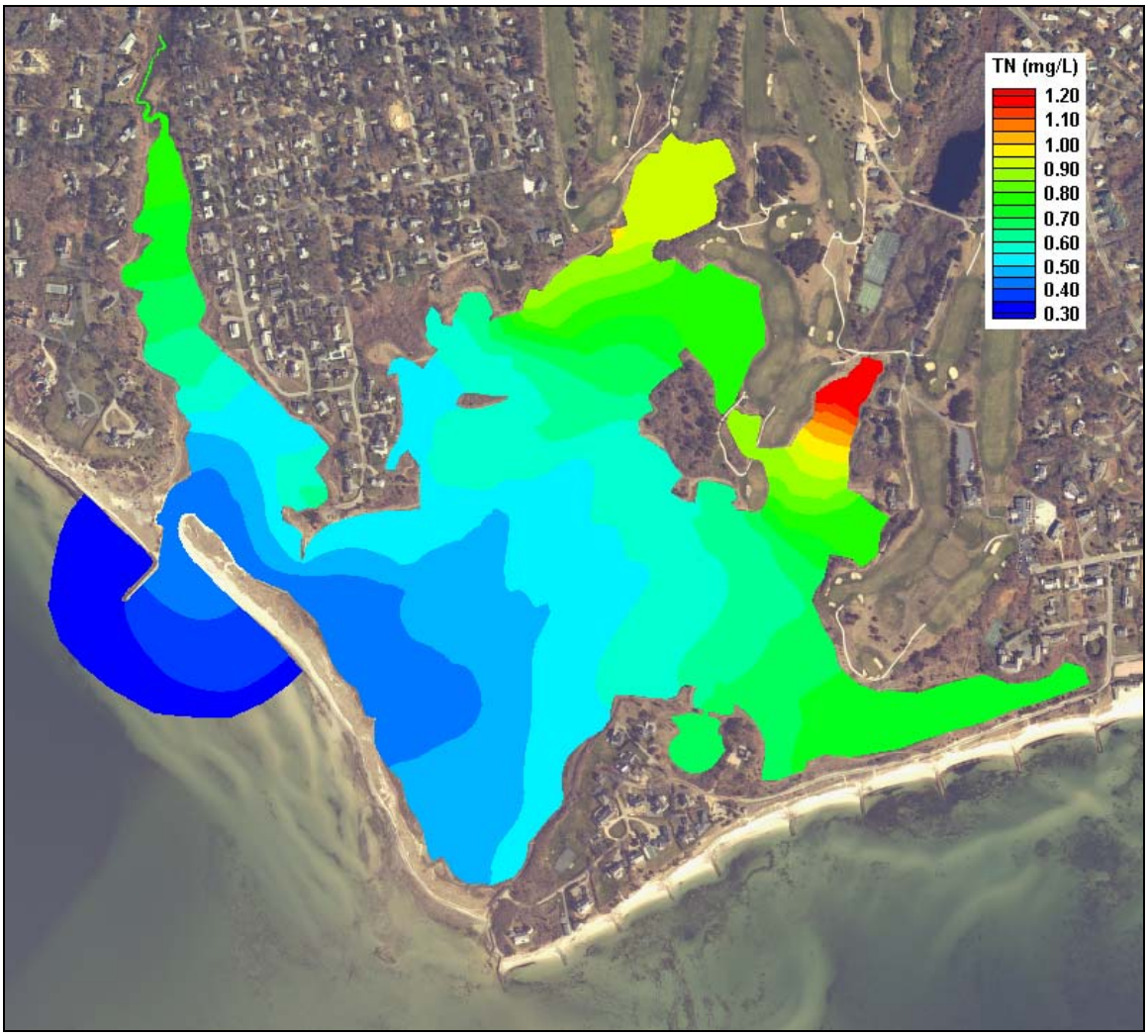


Figure VIII-2. Contour plot of tidally averaged modeled total nitrogen concentrations (mg/L) in the Halls Creek system, for threshold conditions (maximum concentration of 2.0 mg/L at monitoring station BC-13 and 1.0 mg/L at BC-14).

VIII.3. DEVELOPMENT OF TARGET NITROGEN LOADS

The nitrogen thresholds developed in the previous section were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Lewis Bay Embayment System and the level of additional nitrogen loading to Halls Creek which will still sustain high quality habitat in that system. Tidally averaged total nitrogen thresholds derived in Section VIII.1 and VIII.2 were used to adjust the calibrated constituent transport model developed in Section VI.

It should be noted, one approach to achieving the nitrogen load reductions within the Lewis Bay Embayment System necessary to achieve the threshold nitrogen concentrations built upon the "Existing Removal Scenario B", presented to the MEP Technical Team by the Towns of Yarmouth and Barnstable and described in Chapter IX. Since this version of Scenario B did not achieve the threshold targets (Chapter IX), additional removal of septic N loading was necessary. The threshold nitrogen level at the sentinel station and at the secondary stations was achieved when removal of septic N loading was increased to produce an 80% total

reduction in loading from this source to the main basin of Lewis Bay (Watershed 16) and an 80% reduction from this source to Hyannis Inner Harbor (Watershed 13). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Lewis Bay Estuary: Watershed nitrogen loads to Lewis Bay were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel station chosen for the Lewis Bay Embayment System (BHY-3 located in the eastern basin of Lewis Bay), and at the secondary stations in Uncle Roberts Cove, Hyannis Inner Harbor and Mill Creek. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

As shown in Table VIII-2, the nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations required using: 1) Existing Removal Scenario B (as requested by the Towns of Yarmouth and Barnstable) with 2) additional removal of septic N loading to produce an 80% total reduction in loading from this source to the main basin of Lewis Bay (Watershed 16) and 3) an 80% reduction from septic N Loading to Hyannis Inner Harbor (Watershed 13). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Lewis Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	5.299	-80.0%
Uncle Roberts Cove	0.214	0.214	0.0%
Mill Creek	13.570	1.926	-85.8%
Hyannis Inner Harbor	6.847	1.808	-73.6%[1]
Snows Creek	7.970	9.088	+14.0%
Stewarts Creek	21.564	24.178	+12.1%
Surface Water Sources			
Chase Brook	2.488	2.479	-0.3%
Mill Pond	10.425	10.068	-3.4%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

[1] Hyannis Inner Harbor is a combination of Hyannis Inner Harbor watershed (13), and Wells Mary Dunn watershed (6) thus the 80% reduction in septic loading for the threshold does not result in a direct 80% reduction in septic loading.

Tables VIII-3 and VIII-4 provide additional loading information associated with the thresholds analysis. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. Removal of septic loads from Existing

Removal Scenario B along with the additional septic removals from Lewis Bay and Hyannis Inner Harbor results in the total nitrogen loads presented in Table VIII-4. Table VIII-4 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-4, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound.

Table VIII-3. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Lewis Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Lewis Bay	30.855	9.663	-68.7%
Uncle Roberts Cove	0.540	0.540	0.0%
Mill Creek	15.964	4.321	-72.9%
Hyannis Inner Harbor	12.153	7.115	-41.5%
Snows Creek	15.115	16.233	+7.4%
Stewarts Creek	38.992	41.605	+6.7%
Surface Water Sources			
Chase Brook	3.345	3.337	-0.2%
Mill Pond	15.038	14.682	-2.4%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table VIII-4. Threshold sub-embayment loads and attenuated surface water loads used for total nitrogen modeling of the Lewis Bay system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	threshold load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	9.663	13.507	23.916
Uncle Roberts Cove	0.540	0.759	10.991
Mill Creek	4.321	0.627	-1.208
Hyannis Inner Harbor	7.115	0.633	9.780
Snows Creek	16.233	-	-4.533
Stewarts Creek	41.605	0.236	-10.402
Surface Water Sources			
Chase Brook	3.337	-	-
Mill Pond	14.682	-	-
Hospital Creek/Hyannis Inner	0.326	-	-

Comparison of model results between existing loading conditions and the selected loading scenario to achieve the target TN concentrations at the sentinel station is shown in Table VIII-5. To achieve the threshold nitrogen concentrations at the sentinel station, a reduction in TN concentration of approximately 7% is required at station BHY-3. To meet the secondary threshold requirement for stations BHY-4 (Uncle Roberts Cove), MC-1 (Mill Creek) and the average of BH-1 and BH-2 (Hyannis Inner Harbor), a reduction in TN concentration of approximately 7.0%, 13% and 12% were required, respectively.

The basis for the watershed nitrogen removal strategy utilized to achieve the embayment thresholds may have merit, since this example nitrogen remediation effort is focused on watersheds where groundwater is flowing directly into the estuary. For nutrient loads entering the systems through surface flow, natural attenuation in freshwater bodies (i.e., streams and ponds) can significantly reduce the load that finally reaches the estuary. Presently, this attenuation is occurring due to natural ecosystem processes and the extent of attenuation being determined by the mass of nitrogen which discharges to these systems. The nitrogen reaching these systems is currently "unplanned", resulting primarily from the widely distributed non-point nitrogen sources (e.g. septic systems, lawns, etc.). Future nitrogen management should take advantage of natural nitrogen attenuation, where possible, to ensure the most cost-effective nitrogen reduction strategies. However, "planned" use of natural systems has to be done carefully and with the full analysis to ensure that degradation of these systems will not occur. One clear finding of the MEP has been the need for analysis of the potential associated with restored wetlands or ecologically engineered ponds/wetlands to enhance nitrogen attenuation. Attenuation by ponds in agricultural systems has also been found to work in some cranberry bog systems, as well. Cranberry bogs, other freshwater wetland resources, and freshwater ponds provide opportunities for enhancing natural attenuation of their nitrogen loads. Restoration or enhancement of wetlands and ponds associated with the lower ends of rivers and/or streams discharging to estuaries are seen as providing a dual service of lowering infrastructure costs associated with wastewater management and increasing aquatic resources associated within the watershed and upper estuarine reaches.

Table VIII-5. Comparison of model average total N concentrations from present loading and the modeled threshold scenario, with percent change, for the Lewis Bay system. Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.477**	**-13.1%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.440**	**-11.4%**
Hyannis Inner Harbor	BH-3	0.440	0.400	-9.0%
Snows Creek	BH-4	1.638	1.745	+6.6%
Lewis Bay	BH-5	0.387	0.365	-5.5%
Lewis Bay	BH-6	0.368	0.353	-4.2%
Stuarts Creek	BH-7	1.374	1.435	+4.4%
Lewis Bay	BHY-1	0.384	0.364	-5.3%
Lewis Bay	BHY-2	0.414	0.383	-7.5%
Lewis Bay	**BHY-3**	**0.407**	**0.378**	**-7.2%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.400**	**-7.0%**
Mill Creek	**MC-1**	**0.531**	**0.462**	**-13.0%**
Mill Creek	MC-2	0.473	0.421	-11.0%

Although the above modeling results provide one manner of achieving the selected threshold level for the sentinel site within the estuarine system, the specific example does not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment.

Halls Creek Estuary: The nitrogen thresholds developed in Section VIII.2 were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Halls Creek system. Total nitrogen thresholds derived in Section VIII.1 and VIII.2 were used to adjust the calibrated constituent transport model developed in Section VI. Contrary to most other estuarine systems evaluated as part MEP, the threshold concentration was set higher than present conditions, meaning that the system would be allowed to have a higher load than present to meat the threshold. Therefore, watershed nitrogen loads were sequentially raised in the model until the nitrogen levels either reached the 1.0 mg/L threshold level at the sentinel station (BC-14) chosen for Halls Creek, or reached a tidally averaged maximum of 2.00 mg/L at the headwaters of the system. It is important to note that load increases could be produced by increasing any or all sources of nitrogen to the system. The load increases presented below represent only one of a suite of potential approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of loading that will be allowable for this system. A comparison between present watershed loading and the loadings for the modeled threshold scenario is provided in Tables VIII-6, 7 and 8.

As shown in Table VIII-6, the threshold scenario run for this system would allow up to 1.57 times (57% increase) the present watershed loading. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-2.

Table VIII-7 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-7, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is modified from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound, as discussed in Section VI.2.6.1.

Comparison of model results between existing loading conditions and the selected loading scenario to achieve the target TN concentrations at the sentinel station is shown in Table VIII-8. To achieve the threshold nitrogen concentrations at the sentinel station, increases in average TN concentrations of typically greater than 19% occur in the system, between the main harbor basin and the marsh.

Although the above modeling results provide one manner of achieving the selected threshold level for the sentinel site within the estuarine system, the specific example does not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment.

Table VIII-6. Comparison of sub-embayment ***total watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Halls Creek system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Halls Creek	21.534	32.918	+52.9%
Halls Creek Stream (freshwater)	1.597	3.345	+109.4%
System Total	23.132	36.263	+56.8%

Table VIII-7. Threshold sub-embayment loads used for total nitrogen modeling of the Halls Creek system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Halls marsh	32.918	0.630	6.649
Halls Creek (freshwater)	3.345	-	-
System Total	36.263	0.630	6.649

Table VIII-8. Comparison of model average total N concentrations from present loading and the threshold scenario, with percent change, for the Halls Creek system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Halls Creek - stream	BC-13	1.189	2.037	+71.4%
Halls Creek - mid	**BC-14**	**0.469**	**0.557**	**+18.9%**
Halls Creek - inlet	BC-15	0.385	0.432	+12.1%

IX. ALTERNATIVES TO IMPROVE WATER QUALITY

At the request of Town of Barnstable and Town of Yarmouth staff, MEP staff completed six additional scenarios in July of 2007. Through a current Comprehensive Wastewater Management Planning process, the Town of Yarmouth delineated a potential sewer district (Section IV, Figure IV-6). Both town staffs agreed to the following scenarios: A) collection of wastewater within the proposed district and removal of wastewater loads from Lewis Bay watershed, B) collection of wastewater within the proposed district and treatment and discharge at the Hyannis WPCF, and C) collection of wastewater within the proposed district, treatment at the Hyannis WPCF, and discharge within an abandoned bog system to the east of Cape Cod Hospital. Wastewater flows were developed under both current and buildout conditions. It should be noted that in subsequent 18-months since the original six scenarios were run, the water quality models have been further developed and improved upon, thus there may be slight changes in the base loading for the watersheds. However, since these scenarios did not meet the threshold requirements, they were not revisited.

MEP staff developed a separate "sewershed" module for the proposed district, which cuts across six sub-watersheds. The sewershed module contains all the properties in the proposed district according to their current sub-watershed assignments. Just as in the standard nitrogen loading analysis, staff determined water use for all developed properties within the sewershed and potential future water use at buildout based on a review of developable land and additional development on existing developed properties. Total existing wastewater load within the whole sewershed is 7,792 kg/yr and buildout will add 2,486 kg/yr.

Under scenario A, the existing and buildout loads from the sewershed are removed from the respective sub-watersheds. Under scenario B, wastewater flows are assumed to be discharged at the Hyannis WPCF and redistributed to various sub-watersheds based on the analyses described above. Under scenario C, the WPCF-treated effluent from the sewershed is discharged at the abandoned bogs in the Inner Harbor Creek sub-watershed. The scenario C loads receive an additional 30% attenuation from the bog system. Overall impacts on all loads are shown in Table IV-5.

Six additional scenarios were provided to the MEP in the Fall of 2008, by Town of Barnstable and Town of Yarmouth staff. The new scenarios evolved out of the water quality results from the original six scenarios (A through C). Both town staffs agreed to the following scenarios: D) collection of wastewater within the proposed district and removal of wastewater loads from Lewis Bay watershed and discharge outside the watershed, E) collection of wastewater within the proposed district and treatment and discharge at the Hyannis WPCF, and F) collection of wastewater within the proposed district, treatment at the Hyannis WPCF, and discharge within an abandoned bog system to the east of Cape Cod Hospital. Wastewater flows were developed under both current and buildout conditions.

Under scenario D, the existing and buildout loads from the sewershed are removed from the respective sub-watersheds. Under scenario E, wastewater flows are assumed to be discharged at the Hyannis WPCF and redistributed to various sub-watersheds based on the analyses described above. Under scenario F, the WPCF-treated effluent from the sewershed is discharged at the abandoned bogs in the Inner Harbor Creek sub-watershed. The scenario F loads receive an additional 30% attenuation from the bog system.

IX.1 EXISTING LOADING SCENARIO A

Based on the potential sewer district developed by the Town of Yarmouth under their ongoing CWMP process, a set of scenarios were developed to be modeled by the MEP. Both the Towns of Barnstable and Yarmouth were in agreement about the types of scenarios to be modeled and worked together to develop them. Scenario A as developed jointly by the two Towns is based on collection of wastewater within the proposed district and removal of wastewater loads from Lewis Bay watershed. Wastewater flows were developed under both current as presented herein and buildout conditions provided below (Section IX.4). Table IX-1 and Table IX-2 illustrate the overall change to septic and watershed loads resulting from this alternative. Septic removal from potential Lewis Bay sewer district results in significant reductions in the watershed loads in specific sub-embayments, particularly the Mill Creek and Hyannis Inner Harbor sub-watersheds. Based on the assumptions developed for this alternative, Table IX-3 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the modeled sewer district, the threshold target (0.38 mg/L TN at BHY-3) is approached (0.391 mg/L TN at BHY-3) but not reached at the sentinel station. The load reduction associated with this scenario did yield water column concentrations that were <0.5 mg/L TN (infaunal threshold) at 2 of 3 locations selected as check stations. Concentrations at MC-1 and BH-2 were 0.472 mg/L and 0.486 mg/L respectively, slightly less than the 0.5 mg/L infaunal target.

Table IX-1. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Existing Scenario A. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	21.647	-18.3%
Uncle Roberts Cove	0.214	0.214	+0.0%
Mill Creek	13.570	1.923	-85.8%
Hyannis Inner Harbor	6.847	4.663	-31.9%
Snows Creek	7.970	7.970	+0.0%
Stewarts Creek	21.564	21.564	+0.0%
Surface Water Sources			
Chase Brook	2.488	2.463	-1.0%
Mill Pond	10.425	10.003	-4.0%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table IX-2. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Existing Scenario A. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	26.011	-15.7%
Uncle Roberts Cove	0.540	0.540	+0.0%
Mill Creek	15.964	4.318	-73.0%
Hyannis Inner Harbor	12.153	9.970	-18.0%
Snows Creek	15.115	15.115	+0.0%
Stewarts Creek	38.992	38.992	+0.0%
Surface Water Sources			
Chase Brook	3.345	3.321	-0.7%
Mill Pond	15.038	14.616	-2.8%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table IX-3. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Existing Scenario A, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	scenario load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	26.011	13.507	24.872
Uncle Roberts Cove	0.540	0.759	11.940
Mill Creek	4.318	0.627	-1.208
Hyannis Inner Harbor	9.970	0.633	18.990
Snows Creek	15.115	-	-4.533
Stewarts Creek	38.992	0.236	-9.683
Surface Water Sources			
Chase Brook	3.321	-	-
Mill Pond	14.616	-	-
Hospital Creek/Hyannis Inner	0.326	-	-

Table IX-4. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Existing Scenario A), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.535**	**-2.5%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.486**	**-2.0%**
Hyannis Inner Harbor	BH-3	0.440	0.422	-4.1%
Snows Creek	BH-4	1.638	1.626	-0.7%
Lewis Bay	BH-5	0.387	0.375	-3.1%
Lewis Bay	BH-6	0.368	0.359	-2.4%
Stewarts Creek	BH-7	1.374	1.372	-0.1%
Lewis Bay	BHY-1	0.384	0.372	-3.0%
Lewis Bay	BHY-2	0.414	0.394	-4.8%
Lewis Bay	**BHY-3**	**0.407**	**0.391**	**-4.0%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.414**	**-3.9%**
Mill Creek	**MC-1**	**0.531**	**0.472**	**-11.1%**
Mill Creek	MC-2	0.473	0.433	-8.6%

IX.2 EXISTING LOADING SCENARIO B

Scenario B as developed jointly by the two Towns is based on collection of wastewater within the proposed district and treatment and discharge at the Hyannis WPCF. Wastewater flows were developed under both current conditions presented herein and buildout conditions provided below (Section IX.5). Table IX-5 and Table IX-6 illustrate the overall change to septic and watershed loads resulting from this alternative. Septic removal from potential Lewis Bay sewer district results in significant reductions in the watershed loads in specific sub-embayments, particularly the Mill Creek and Hyannis Inner Harbor sub-watersheds. Unlike Scenario A that showed no change in the septic loads (present vs. scenario) for the Snows Creek and Stewarts Creek sub-watershed, under Scenario B septic loads increase in Snows Creek and decrease in Stewarts Creek. Based on the assumptions developed for this alternative, Table IX-7 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the modeled sewer district, the threshold target (0.38 mg/L TN at BHY-3) is approached (0.391 mg/L TN at BHY-3) but not reached at the sentinel station. The load reduction associated with this scenario did yield water column concentrations that were <0.5 mg/L TN (infaunal threshold) at 2 of 3 locations selected as check stations. Concentrations at MC-1 and BH-2 were 0.472 mg/L and 0.488 mg/L respectively, slightly less than the 0.5 mg/L infaunal target.

Table IX-5. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Existing Scenario B. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	21.647	-18.3%
Uncle Roberts Cove	0.214	0.214	0.0%
Mill Creek	13.570	1.923	-85.8%
Hyannis Inner Harbor	6.847	4.899	-28.5%
Snows Creek	7.970	9.088	+14.0%
Stewarts Creek	21.564	13.775	-36.1%
Surface Water Sources			
Chase Brook	2.488	2.463	-1.0%
Mill Pond	10.425	10.003	-4.0%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table IX-6. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Existing Scenario B. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	26.011	-15.7%
Uncle Roberts Cove	0.540	0.540	0.0%
Mill Creek	15.964	4.318	-73.0%
Hyannis Inner Harbor	12.153	10.205	-16.0%
Snows Creek	15.115	16.233	+7.4%
Stewarts Creek	38.992	31.203	-20.0%
Surface Water Sources			
Chase Brook	3.345	3.321	-0.7%
Mill Pond	15.038	14.616	-2.8%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table IX-7. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Existing Scenario B, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	26.011	13.507	25.067
Uncle Roberts Cove	0.540	0.759	11.980
Mill Creek	4.318	0.627	-1.208
Hyannis Inner Harbor	10.205	0.633	19.173
Snows Creek	16.233	-	-4.533
Stewarts Creek	31.233	0.236	-10.402
Surface Water Sources			
Chase Brook	3.321	-	-
Mill Pond	14.616	-	-
Hospital Creek/Hyannis Inner	0.326	-	-

Table IX-8. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Existing Scenario B), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.538**	**-2.1%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.488**	**-1.7%**
Hyannis Inner Harbor	BH-3	0.440	0.422	-3.9%
Snows Creek	BH-4	1.638	1.754	+7.1%
Lewis Bay	BH-5	0.387	0.375	-3.1%
Lewis Bay	BH-6	0.368	0.359	-2.5%
Stewarts Creek	BH-7	1.374	1.074	-21.9%
Lewis Bay	BHY-1	0.384	0.372	-3.1%
Lewis Bay	BHY-2	0.414	0.394	-4.9%
Lewis Bay	**BHY-3**	**0.407**	**0.391**	**-4.1%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.414**	**-4.0%**
Mill Creek	**MC-1**	**0.531**	**0.472**	**-11.2%**
Mill Creek	MC-2	0.473	0.432	-8.7%

IX.3 EXISTING LOADING SCENARIO C

Scenario C as developed jointly by the two Towns is based on Collection of wastewater within the proposed district, treatment at the Hyannis WPCF, and discharge within an abandoned bog system to the east of Cape Cod Hospital. Wastewater flows were developed under both current conditions presented herein and buildout conditions provided below (Section IX.6). Table IX-9 and Table IX-10 illustrate the overall change to septic and watershed loads resulting from this alternative. Septic removal from potential Lewis Bay sewer district results in significant reductions in the watershed loads in specific sub-embayments, particularly the Mill Creek and Hyannis Inner Harbor sub-watersheds. Unlike Scenario B that showed change in the septic loads (present vs. scenario) for the Snows Creek and Stewarts Creek sub-watershed,

under Scenario C septic loads did not change from present conditions for both Snows Creek and Stewarts Creek (similar to Scenario A results). As would be expected, loads to Hospital Creek/Hyannis Inner Harbor go up dramatically over present conditions. Based on the assumptions developed for this alternative, Table IX-11 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the modeled sewer district, the threshold target (0.38 mg/L TN at BHY-3) is approached less so than under Scenario A and B (0.399 mg/L TN at BHY-3) but not reached at the sentinel station. The load reduction associated with this scenario did yield water column concentrations that were <0.5 mg/L TN (infaunal threshold) at 1 of 3 locations selected as check stations. Concentrations at MC-1 was 0.480 mg/L, slightly less than the 0.5 mg/L infaunal target but not as low as under Scenario A and B.

Table IX-9. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Existing Scenario C. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	21.647	-18.3%
Uncle Roberts Cove	0.214	0.214	+0.0%
Mill Creek	13.570	1.923	-85.8%
Hyannis Inner Harbor	6.847	4.663	-31.9%
Snows Creek	7.970	7.970	0.0%
Stewarts Creek	21.564	21.564	0.0%
Surface Water Sources			
Chase Brook	2.488	2.463	-1.0%
Mill Pond	10.425	10.003	-4.0%
Hospital Creek/Hyannis Inner	1.907	3.753	+96.8%

Table IX-10. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Existing Scenario C. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	26.011	-15.7%
Uncle Roberts Cove	0.540	0.540	0.0%
Mill Creek	15.964	4.318	-73.0%
Hyannis Inner Harbor	12.153	9.970	-18.0%
Snows Creek	15.115	15.115	0.0%
Stewarts Creek	38.992	38.992	0.0%
Surface Water Sources			
Chase Brook	3.345	3.321	-0.7%
Mill Pond	15.038	14.616	-2.8%
Hospital Creek/Hyannis Inner	1.907	3.753	+96.8%

Table IX-11. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Existing Scenario C, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	26.011	13.507	25.176
Uncle Roberts Cove	0.540	0.759	12.098
Mill Creek	4.318	0.627	-1.208
Hyannis Inner Harbor	9.970	0.633	18.990
Snows Creek	15.115	-	-4.533
Stewarts Creek	38.992	0.236	-9.683
Surface Water Sources			
Chase Brook	3.321	-	-
Mill Pond	14.616	-	-
Hospital Creek/Hyannis Inner	3.753	-	-

Table IX-12. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Existing Scenario C), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.552**	**+0.5%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.503**	**+1.5%**
Hyannis Inner Harbor	BH-3	0.440	0.438	-0.3%
Snows Creek	BH-4	1.638	1.635	-0.2%
Lewis Bay	BH-5	0.387	0.384	-0.8%
Lewis Bay	BH-6	0.368	0.365	-0.9%
Stewarts Creek	BH-7	1.374	1.375	+0.1%
Lewis Bay	BHY-1	0.384	0.379	-1.2%
Lewis Bay	BHY-2	0.414	0.403	-2.8%
Lewis Bay	**BHY-3**	**0.407**	**0.399**	**-2.0%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.422**	**-2.1%**
Mill Creek	**MC-1**	**0.531**	**0.480**	**-9.7%**
Mill Creek	MC-2	0.473	0.441	-6.9%

IX.4 BUILD-OUT LOADING SCENARIO A

Scenario A (buildout) as developed jointly by the two Towns is based on collection of wastewater within the proposed district and removal of wastewater loads from Lewis Bay watershed. Wastewater flows were developed under both current conditions as presented above (Section IX.1) and buildout conditions herein. Table IX-13 and Table IX-14 illustrate the overall change to septic and watershed loads resulting from this alternative. Based on the assumptions developed for this alternative, Table IX-15 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the

modeled sewer district, the threshold target (0.38 mg/L TN at BHY-3) is exceeded at the sentinel station and infaunal check stations under build out conditions.

Table IX-13. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Build-Out Scenario A. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	20.603	-22.2%
Uncle Roberts Cove	0.214	0.340	+59.0%
Mill Creek	13.570	-2.775	-120.5%
Hyannis Inner Harbor	6.847	4.616	-32.6%
Snows Creek	7.970	9.893	+24.1%
Stewarts Creek	21.564	25.307	+17.4%
Surface Water Sources			
Chase Brook	2.488	2.318	-6.8%
Mill Pond	10.425	8.986	-13.8%
Hospital Creek/Hyannis Inner	1.907	0.332	-82.6%

Table IX-14. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Build-Out Scenario A. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	29.049	-5.9%
Uncle Roberts Cove	0.540	0.715	+32.5%
Mill Creek	15.964	5.721	-64.2%
Hyannis Inner Harbor	12.153	12.690	+4.4%
Snows Creek	15.115	21.529	+42.4%
Stewarts Creek	38.992	53.959	+38.4%
Surface Water Sources			
Chase Brook	3.345	3.896	+16.5%
Mill Pond	15.038	21.074	+40.1%
Hospital Creek/Hyannis Inner	1.907	0.332	-82.6%

Table IX-15. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Build-Out Scenario A, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	29.049	13.507	26.482
Uncle Roberts Cove	0.715	0.759	13.008
Mill Creek	5.721	0.627	-1.437
Hyannis Inner Harbor	12.690	0.633	21.238
Snows Creek	21.529	-	-6.458
Stewarts Creek	53.959	0.236	-13.489
Surface Water Sources			
Chase Brook	3.896	-	-
Mill Pond	21.074	-	-
Hospital Creek/Hyannis Inner	0.332	-	-

Table IX-16. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Build-Out Scenario A), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.575**	**+4.6%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.518**	**+4.3%**
Hyannis Inner Harbor	BH-3	0.440	0.442	+0.5%
Snows Creek	BH-4	1.638	2.171	+32.6%
Lewis Bay	BH-5	0.387	0.387	+0.1%
Lewis Bay	BH-6	0.368	0.368	+0.1%
Stewarts Creek	BH-7	1.374	1.767	+28.6%
Lewis Bay	BHY-1	0.384	0.384	-0.1%
Lewis Bay	BHY-2	0.414	0.412	-0.4%
Lewis Bay	**BHY-3**	**0.407**	**0.406**	**-0.3%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.430**	**-0.2%**
Mill Creek	**MC-1**	**0.531**	**0.538**	**+1.2%**
Mill Creek	MC-2	0.473	0.468	-1.2%

IX.5 BUILD-OUT LOADING SCENARIO B

Scenario B (buildout) as developed jointly by the two Towns is based on collection of wastewater within the proposed district and treatment and discharge at the Hyannis WPCF. Wastewater flows were developed under both current conditions as presented above (Section IX.2) and buildout conditions herein. Table IX-17 and Table IX-18 illustrate the overall change to septic and watershed loads resulting from this alternative. Based on the assumptions developed for this alternative, Table IX-19 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the modeled sewer district,

the threshold target (0.38 mg/L TN at BHY-3) is exceeded at the sentinel station and infaunal check stations under build out conditions.

Table IX-17. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Build-Out Scenario B. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	20.603	-22.2%
Uncle Roberts Cove	0.214	0.340	+59.0%
Mill Creek	13.570	-2.775	-120.5%
Hyannis Inner Harbor	6.847	4.904	-28.4%
Snows Creek	7.970	11.255	+41.2%
Stewarts Creek	21.564	14.203	-34.1%
Surface Water Sources			
Chase Brook	2.488	2.318	-6.8%
Mill Pond	10.425	8.986	-13.8%
Hospital Creek/Hyannis Inner	1.907	0.332	-82.6%

Table IX-18. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Build-Out Scenario B. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	29.049	-5.9%
Uncle Roberts Cove	0.540	0.715	+32.5%
Mill Creek	15.964	5.721	-64.2%
Hyannis Inner Harbor	12.153	12.978	+6.8%
Snows Creek	15.115	22.890	+51.4%
Stewarts Creek	38.992	42.855	+9.9%
Surface Water Sources			
Chase Brook	3.345	3.896	+16.5%
Mill Pond	15.038	21.074	+40.1%
Hospital Creek/Hyannis Inner	1.907	0.332	-82.6%

Table IX -19. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Build-Out Scenario B, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	29.049	13.507	26.326
Uncle Roberts Cove	0.715	0.759	13.087
Mill Creek	5.721	0.627	-1.437
Hyannis Inner Harbor	12.978	0.633	21.463
Snows Creek	22.890	-	-6.458
Stewarts Creek	42.855	0.236	-14.288
Surface Water Sources			
Chase Brook	3.896	-	-
Mill Pond	21.074	-	-
Hospital Creek/Hyannis Inner	0.332	-	-

Table IX-20. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Build-Out Scenario B), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.577**	**+5.0%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.519**	**+4.6%**
Hyannis Inner Harbor	BH-3	0.440	0.442	+0.6%
Snows Creek	BH-4	1.638	2.325	+42.0%
Lewis Bay	BH-5	0.387	0.386	-0.1%
Lewis Bay	BH-6	0.368	0.367	-0.2%
Stewarts Creek	BH-7	1.374	1.349	-1.8%
Lewis Bay	BHY-1	0.384	0.383	-0.3%
Lewis Bay	BHY-2	0.414	0.411	-0.7%
Lewis Bay	**BHY-3**	**0.407**	**0.405**	**-0.6%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.429**	**-0.4%**
Mill Creek	**MC-1**	**0.531**	**0.537**	**+1.0%**
Mill Creek	MC-2	0.473	0.467	-1.4%

IX.6 BUILD-OUT LOADING SCENARIO C

Scenario C (buildout) as developed jointly by the two Towns is based on collection of wastewater within the proposed district, treatment at the Hyannis WPCF, and discharge within an abandoned bog system to the east of Cape Cod Hospital. Wastewater flows were developed under both current conditions as presented above (Section IX.3) and buildout conditions herein. Table IX-21 and Table IX-22 illustrate the overall change to septic and watershed loads resulting from this alternative. Based on the assumptions developed for this alternative, Table IX-23 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the modeled sewer district, the threshold target (0.38 mg/L TN

at BHY-3) is exceeded at the sentinel station and infaunal check stations under build out conditions.

Table IX-21. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Build-Out Scenario C. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	20.603	-22.2%
Uncle Roberts Cove	0.214	0.340	+59.0%
Mill Creek	13.570	-2.775	-120.5%
Hyannis Inner Harbor	6.847	4.616	-32.6%
Snows Creek	7.970	9.896	+24.2%
Stewarts Creek	21.564	14.203	-34.1%
Surface Water Sources			
Chase Brook	2.488	2.318	-6.8%
Mill Pond	10.425	8.986	-13.8%
Hospital Creek/Hyannis Inner	1.907	4.507	+136.4%

Table IX-22. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Build-Out Scenario C. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	29.049	-5.9%
Uncle Roberts Cove	0.540	0.715	+32.5%
Mill Creek	15.964	5.721	-64.2%
Hyannis Inner Harbor	12.153	12.690	+4.4%
Snows Creek	15.115	21.532	+42.5%
Stewarts Creek	38.992	42.855	+9.9%
Surface Water Sources			
Chase Brook	3.345	3.896	+16.5%
Mill Pond	15.038	21.074	+40.1%
Hospital Creek/Hyannis Inner	1.907	4.507	+136.4%

Table IX-23. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Build-Out Scenario C, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	29.049	13.507	26.699
Uncle Roberts Cove	0.715	0.759	13.245
Mill Creek	5.721	0.627	-1.437
Hyannis Inner Harbor	12.690	0.633	21.238
Snows Creek	21.532	-	-6.458
Stewarts Creek	42.855	0.236	-14.288
Surface Water Sources			
Chase Brook	3.896	-	-
Mill Pond	21.074	-	-
Hospital Creek/Hyannis Inner	4.507	-	-

Table IX-24. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Build-Out Scenario C), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.594**	**+8.1%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.537**	**+8.2%**
Hyannis Inner Harbor	BH-3	0.440	0.461	+4.8%
Snows Creek	BH-4	1.638	2.181	+33.2%
Lewis Bay	BH-5	0.387	0.396	+2.5%
Lewis Bay	BH-6	0.368	0.373	+1.5%
Stewarts Creek	BH-7	1.374	1.352	-1.6%
Lewis Bay	BHY-1	0.384	0.391	+1.7%
Lewis Bay	BHY-2	0.414	0.421	+1.6%
Lewis Bay	**BHY-3**	**0.407**	**0.414**	**+1.6%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.438**	**+1.7%**
Mill Creek	**MC-1**	**0.531**	**0.545**	**+2.6%**
Mill Creek	MC-2	0.473	0.476	+0.6%

IX.7 EXISTING LOADING SCENARIO D

Based on the potential sewer district developed by the Town of Yarmouth under their ongoing CWMP process, a second set of six scenarios were developed to be modeled by the MEP. Scenario D as developed jointly by the two Towns is based on collection of wastewater within the proposed district and removal of wastewater loads from Lewis Bay watershed. Wastewater flows were developed under both current as presented herein and buildout conditions provided below (Section IX.10). Table IX-25 and Table IX-26 illustrate the overall change to septic and watershed loads resulting from this alternative. Septic removal from potential Lewis Bay sewer district results in significant reductions in the watershed loads in

specific sub-embayments, particularly the Mill Creek and Hyannis Inner Harbor sub-watersheds. Based on the assumptions developed for this alternative, Table IX-27 presents the various components of nitrogen loading for the Lewis Bay system. The reductions in load related to the modeled sewer district, meet the threshold target (0.38 mg/L TN at BHY-3) at the sentinel station (0.373 mg/L TN at BHY-3). The load reduction associated with this scenario did yield water column concentrations that were <0.5 mg/L TN (infaunal threshold) at all 3 locations selected as check stations. Concentrations at MC-1 and BH-2 were 0.495 mg/L and 0.454 mg/L respectively, for an average concentration of 0.475 mg/L, which is below the 0.5 mg/L infaunal target. At stations BHY-4 and MC-1 concentrations were 0.396 mg/L and 0.449 mg/L respectively, which are below the 0.4 mg/L and 0.5 mg/L infaunal targets.

Table IX-25. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Existing Scenario D. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	0.351	-98.7%
Uncle Roberts Cove	0.214	0.214	0.0%
Mill Creek	13.570	1.614	-88.1%
Hyannis Inner Harbor	6.847	4.723	-31.0%
Snows Creek	7.970	7.970	0.0%
Stewarts Creek	21.564	21.564	0.0%
Surface Water Sources			
Chase Brook	2.488	1.077	-56.7%
Mill Pond	10.425	9.427	-9.6%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table IX-26. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Existing Scenario D. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	4.715	-84.7%
Uncle Roberts Cove	0.540	0.540	0.0%
Mill Creek	15.964	4.008	-74.9%
Hyannis Inner Harbor	12.153	10.030	-17.5%
Snows Creek	15.115	15.115	0.0%
Stewarts Creek	38.992	38.992	0.0%
Surface Water Sources			
Chase Brook	3.345	1.934	-42.2%
Mill Pond	15.038	14.041	-6.6%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table IX-27. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Existing Scenario D, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	scenario load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	4.715	13.507	23.396
Uncle Roberts Cove	0.540	0.759	10.556
Mill Creek	4.008	0.627	-1.143
Hyannis Inner Harbor	10.030	0.633	11.261
Snows Creek	15.115	-	-4.533
Stewarts Creek	38.992	0.236	-9.750
Surface Water Sources			
Chase Brook	1.934	-	-
Mill Pond	14.041	-	-
Hospital Creek/Hyannis Inner	0.326	-	-

Table IX-28. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Existing Scenario D), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.495**	**-9.8%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.454**	**-8.5%**
Hyannis Inner Harbor	BH-3	0.440	0.405	-7.9%
Snows Creek	BH-4	1.638	1.615	-1.4%
Lewis Bay	BH-5	0.387	0.363	-6.1%
Lewis Bay	BH-6	0.368	0.350	-4.8%
Stewarts Creek	BH-7	1.374	1.365	-0.6%
Lewis Bay	BHY-1	0.384	0.361	-6.0%
Lewis Bay	BHY-2	0.414	0.378	-8.8%
Lewis Bay	**BHY-3**	**0.407**	**0.373**	**-8.4%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.396**	**-8.1%**
Mill Creek	**MC-1**	**0.531**	**0.449**	**-15.5%**
Mill Creek	MC-2	0.473	0.406	-14.3%

IX.8 EXISTING LOADING SCENARIO E

Scenario E as developed jointly by the two Towns is based on collection of wastewater within the proposed district and treatment and discharge at the Hyannis WPCF. Wastewater flows were developed under both current conditions presented herein and buildout conditions provided below (Section IX.11). Table IX-29 and Table IX-30 illustrate the overall change to septic and watershed loads resulting from this alternative. Septic removal from potential Lewis Bay sewer district results in significant reductions in the watershed loads in specific sub-embayments, particularly the Mill Creek and Hyannis Inner Harbor sub-watersheds. Unlike Scenario D that showed no change in the septic loads (present vs. scenario) for the Snows

Creek and Stewarts Creek sub-watershed, under Scenario E septic loads increase in Snows Creek and Stewarts Creek. Based on the assumptions developed for this alternative, Table IX-31 presents the various components of nitrogen loading for the Lewis Bay system. The reductions in load related to the modeled sewer district, meet the threshold target (0.38 mg/L TN at BHY-3) at the sentinel station (0.374 mg/L TN at BHY-3). In addition, the load reduction associated with this scenario did yield water column concentrations that were <0.5 mg/L TN (infaunal threshold) at all 3 locations selected as check stations. Concentrations at MC-1 and average of BH-1 and BH-2 were 0.450 mg/L and 0.480 mg/L respectively, slightly less than the 0.5 mg/L infaunal target.

Table IX-29. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Existing Scenario E. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	0.351	-98.7%
Uncle Roberts Cove	0.214	0.214	0.0%
Mill Creek	13.570	1.614	-88.1%
Hyannis Inner Harbor	6.847	5.244	-23.4%
Snows Creek	7.970	10.427	+30.8%
Stewarts Creek	21.564	27.310	+26.6%
Surface Water Sources			
Chase Brook	2.488	1.077	-56.7%
Mill Pond	10.425	9.427	-9.6%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table IX-30. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Existing Scenario E. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	4.715	-84.7%
Uncle Roberts Cove	0.540	0.540	0.0%
Mill Creek	15.964	4.008	-74.9%
Hyannis Inner Harbor	12.153	10.551	-13.2%
Snows Creek	15.115	17.573	+16.3%
Stewarts Creek	38.992	44.737	+14.7%
Surface Water Sources			
Chase Brook	3.345	1.934	-42.2%
Mill Pond	15.038	14.041	-6.6%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

Table IX-31. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Existing Scenario E, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	4.715	13.507	23.434
Uncle Roberts Cove	0.540	0.759	10.715
Mill Creek	4.008	0.627	-1.143
Hyannis Inner Harbor	10.551	0.633	11.538
Snows Creek	17.573	-	-5.272
Stewarts Creek	44.737	0.236	-11.188
Surface Water Sources			
Chase Brook	1.934	-	-
Mill Pond	14.041	-	-
Hospital Creek/Hyannis Inner	0.326	-	-

Table IX-32. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Existing Scenario E), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.502**	**-8.6%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.459**	**-7.5%**
Hyannis Inner Harbor	BH-3	0.440	0.408	-7.2%
Snows Creek	BH-4	1.638	1.821	+11.2%
Lewis Bay	BH-5	0.387	0.365	-5.6%
Lewis Bay	BH-6	0.368	0.352	-4.4%
Stewarts Creek	BH-7	1.374	1.516	+10.4%
Lewis Bay	BHY-1	0.384	0.362	-5.6%
Lewis Bay	BHY-2	0.414	0.379	-8.4%
Lewis Bay	**BHY-3**	**0.407**	**0.374**	**-8.0%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.398**	**-7.7%**
Mill Creek	**MC-1**	**0.531**	**0.450**	**-15.2%**
Mill Creek	MC-2	0.473	0.407	-13.9%

IX.9 EXISTING LOADING SCENARIO F

Scenario F as developed jointly by the two Towns is based on Collection of wastewater within the proposed district, treatment at the Hyannis WPCF, and discharge within an abandoned bog system to the east of Cape Cod Hospital. Wastewater flows were developed under both current conditions presented herein and buildout conditions provided below (Section IX.12). Table IX-33 and Table IX-34 illustrate the overall change to septic and watershed loads resulting from this alternative. Septic removal from potential Lewis Bay sewer district results in significant reductions in the watershed loads in specific sub-embayments, particularly the Mill Creek and Lewis Bay sub-watersheds. Unlike Scenario E that showed change in the septic loads (present vs. scenario) for the Snows Creek and Stewarts Creek sub-watershed, under

Scenario F septic loads did not change from present conditions for both Snows Creek and Stewarts Creek (similar to Scenario D results). As would be expected, loads to Hospital Creek/Hyannis Inner Harbor go up dramatically over present conditions. Based on the assumptions developed for this alternative, Table IX-35 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the modeled sewer district, the threshold target (0.38 mg/L TN at BHY-3) is approached (0.390 mg/L TN at BHY-3) but not reached at the sentinel station. The load reduction associated with this scenario did yield water column concentrations that were <0.5 mg/L TN (infaunal threshold) at 1 of 3 locations selected as check stations. Concentrations at MC-1 was 0.465 mg/L, slightly less than the 0.5 mg/L infaunal target.

Table IX-33. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Existing Scenario F. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	0.351	-98.7%
Uncle Roberts Cove	0.214	0.214	0.0%
Mill Creek	13.570	1.614	-88.1%
Hyannis Inner Harbor	6.847	4.723	-31.0%
Snows Creek	7.970	7.970	0.0%
Stewarts Creek	21.564	21.564	0.0%
Surface Water Sources			
Chase Brook	2.488	1.077	-56.7%
Mill Pond	10.425	9.427	-9.6%
Hospital Creek/Hyannis Inner	1.907	7.863	+312.4%

Table IX-34. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Existing Scenario F. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	4.715	-84.7%
Uncle Roberts Cove	0.540	0.540	0.0%
Mill Creek	15.964	4.008	-74.9%
Hyannis Inner Harbor	12.153	10.030	-17.5%
Snows Creek	15.115	15.115	0.0%
Stewarts Creek	38.992	38.992	0.0%
Surface Water Sources			
Chase Brook	3.345	1.934	-42.2%
Mill Pond	15.038	14.041	-6.6%
Hospital Creek/Hyannis Inner	1.907	7.863	+312.4%

Table IX-35. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Existing Scenario F, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	4.715	13.507	23.652
Uncle Roberts Cove	0.540	0.759	10.912
Mill Creek	4.008	0.627	-1.143
Hyannis Inner Harbor	10.030	0.633	11.261
Snows Creek	15.115	-	-4.533
Stewarts Creek	38.992	0.236	-9.750
Surface Water Sources			
Chase Brook	1.934	-	-
Mill Pond	14.041	-	-
Hospital Creek/Hyannis Inner	7.863	-	-

Table IX-36. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Existing Scenario F), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.532**	**-3.1%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.491**	**-1.1%**
Hyannis Inner Harbor	BH-3	0.440	0.441	+0.4%
Snows Creek	BH-4	1.638	1.634	-0.2%
Lewis Bay	BH-5	0.387	0.383	-1.0%
Lewis Bay	BH-6	0.368	0.362	-1.6%
Stewarts Creek	BH-7	1.374	1.371	-0.2%
Lewis Bay	BHY-1	0.384	0.376	-2.1%
Lewis Bay	BHY-2	0.414	0.396	-4.5%
Lewis Bay	**BHY-3**	**0.407**	**0.390**	**-4.2%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.413**	**-4.2%**
Mill Creek	**MC-1**	**0.531**	**0.465**	**-12.5%**
Mill Creek	MC-2	0.473	0.423	-10.6%

IX.10 BUILD-OUT LOADING SCENARIO D

Scenario D (buildout) as developed jointly by the two Towns is based on collection of wastewater within the proposed district and removal of wastewater loads from Lewis Bay watershed. Wastewater flows were developed under both current conditions as presented above (Section IX.7) and buildout conditions herein. Table IX-37 and Table IX-38 illustrate the overall change to septic and watershed loads resulting from this alternative. Based on the assumptions developed for this alternative, Table IX-39 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the

modeled sewer district, the threshold target (0.38 mg/L TN at BHY-3) is exceeded at the sentinel station and infaunal check stations under build out conditions.

Table IX-37. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Build-Out Scenario D. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	-3.266	-112.3%
Uncle Roberts Cove	0.214	0.340	+59.0%
Mill Creek	13.570	-2.814	-120.7%
Hyannis Inner Harbor	6.847	4.688	-31.5%
Snows Creek	7.970	9.896	+24.2%
Stewarts Creek	21.564	25.307	+17.4%
Surface Water Sources			
Chase Brook	2.488	0.534	-78.5%
Mill Pond	10.425	9.726	-6.7%
Hospital Creek/Hyannis Inner	1.907	0.332	-82.6%

Table IX-38. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Build-Out Scenario D. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	5.181	-83.2%
Uncle Roberts Cove	0.540	0.715	+32.5%
Mill Creek	15.964	5.682	-64.4%
Hyannis Inner Harbor	12.153	12.762	+5.0%
Snows Creek	15.115	21.532	+42.5%
Stewarts Creek	38.992	53.959	+38.4%
Surface Water Sources			
Chase Brook	3.345	2.112	-36.9%
Mill Pond	15.038	21.814	+45.1%
Hospital Creek/Hyannis Inner	1.907	0.332	-82.6%

Table IX-39. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Build-Out Scenario D, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	5.181	13.507	24.546
Uncle Roberts Cove	0.715	0.759	11.505
Mill Creek	5.682	0.627	-1.404
Hyannis Inner Harbor	12.762	0.633	12.659
Snows Creek	21.532	-	-6.458
Stewarts Creek	53.959	0.236	-13.489
Surface Water Sources			
Chase Brook	2.112	-	-
Mill Pond	21.814	-	-
Hospital Creek/Hyannis Inner	0.332	-	-

Table IX-40. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Build-Out Scenario D), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.531**	**-3.4%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.482**	**-2.9%**
Hyannis Inner Harbor	BH-3	0.440	0.423	-3.7%
Snows Creek	BH-4	1.638	2.160	+31.9%
Lewis Bay	BH-5	0.387	0.374	-3.2%
Lewis Bay	BH-6	0.368	0.359	-2.5%
Stewarts Creek	BH-7	1.374	1.762	+28.2%
Lewis Bay	BHY-1	0.384	0.371	-3.3%
Lewis Bay	BHY-2	0.414	0.395	-4.7%
Lewis Bay	**BHY-3**	**0.407**	**0.386**	**-5.1%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.410**	**-4.8%**
Mill Creek	**MC-1**	**0.531**	**0.522**	**-1.7%**
Mill Creek	MC-2	0.473	0.441	-6.9%

IX.11 BUILD-OUT LOADING SCENARIO E

Scenario E (buildout) as developed jointly by the two Towns is based on collection of wastewater within the proposed district and treatment and discharge at the Hyannis WPCF. Wastewater flows were developed under both current conditions as presented above (Section IX.8) and buildout conditions herein. Table IX-41 and Table IX-42 illustrate the overall change to septic and watershed loads resulting from this alternative. Based on the assumptions developed for this alternative, Table IX-43 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the modeled sewer district, the threshold target (0.38 mg/L TN at BHY-3) is exceeded at the sentinel station and infaunal check stations under build out conditions.

Table IX-41. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Build-Out Scenario E. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	-3.266	-112.3%
Uncle Roberts Cove	0.214	0.340	+59.0%
Mill Creek	13.570	-2.814	-120.7%
Hyannis Inner Harbor	6.847	5.315	-22.4%
Snows Creek	7.970	12.847	+61.2%
Stewarts Creek	21.564	32.205	+49.3%
Surface Water Sources			
Chase Brook	2.488	0.534	-78.5%
Mill Pond	10.425	9.726	-6.7%
Hospital Creek/Hyannis Inner	1.907	0.332	-82.6%

Table IX-42. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Build-Out Scenario E. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	5.181	-83.2%
Uncle Roberts Cove	0.540	0.715	+32.5%
Mill Creek	15.964	5.682	-64.4%
Hyannis Inner Harbor	12.153	13.389	+10.2%
Snows Creek	15.115	24.482	+62.0%
Stewarts Creek	38.992	60.858	+56.1%
Surface Water Sources			
Chase Brook	3.345	2.112	-36.9%
Mill Pond	15.038	21.814	+45.1%
Hospital Creek/Hyannis Inner	1.907	0.332	-82.6%

Table IX -43. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Build-Out Scenario E, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	5.181	13.507	24.585
Uncle Roberts Cove	0.715	0.759	11.703
Mill Creek	5.682	0.627	-1.404
Hyannis Inner Harbor	13.389	0.633	12.972
Snows Creek	24.482	-	-7.343
Stewarts Creek	60.858	0.236	-15.215
Surface Water Sources			
Chase Brook	2.112	-	-
Mill Pond	21.814	-	-
Hospital Creek/Hyannis Inner	0.332	-	-

Table IX-44. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Build-Out Scenario E), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.538**	**-2.0%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.488**	**-1.7%**
Hyannis Inner Harbor	BH-3	0.440	0.427	-2.8%
Snows Creek	BH-4	1.638	2.408	+47.0%
Lewis Bay	BH-5	0.387	0.377	-2.6%
Lewis Bay	BH-6	0.368	0.360	-2.1%
Stewarts Creek	BH-7	1.374	1.943	+41.5%
Lewis Bay	BHY-1	0.384	0.373	-2.9%
Lewis Bay	BHY-2	0.414	0.397	-4.2%
Lewis Bay	**BHY-3**	**0.407**	**0.388**	**-4.7%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.412**	**-4.3%**
Mill Creek	**MC-1**	**0.531**	**0.524**	**-1.4%**
Mill Creek	MC-2	0.473	0.443	-6.5%

IX.12 BUILD-OUT LOADING SCENARIO F

Scenario F (buildout) as developed jointly by the two Towns is based on collection of wastewater within the proposed district, treatment at the Hyannis WPCF, and discharge within an abandoned bog system to the east of Cape Cod Hospital. Wastewater flows were developed under both current conditions as presented above (Section IX.9) and buildout conditions herein. Table IX-45 and Table IX-46 illustrate the overall change to septic and watershed loads resulting from this alternative. Based on the assumptions developed for this alternative, Table IX-47 presents the various components of nitrogen loading for the Lewis Bay system. Despite the reductions in load related to the modeled sewer district, the threshold target (0.38 mg/L TN

at BHY-3) is exceeded at the sentinel station and infaunal check stations under build out conditions.

Table IX-45. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling present loading conditions for Build-Out Scenario F. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	scenario septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	-3.266	-112.3%
Uncle Roberts Cove	0.214	0.340	+59.0%
Mill Creek	13.570	-2.814	-120.7%
Hyannis Inner Harbor	6.847	4.688	-31.5%
Snows Creek	7.970	9.896	+24.2%
Stewarts Creek	21.564	25.307	+17.4%
Surface Water Sources			
Chase Brook	2.488	0.534	-78.5%
Mill Pond	10.425	9.726	-6.7%
Hospital Creek/Hyannis Inner	1.907	9.384	+392.1%

Table IX-46. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present conditions for Build-Out Scenario F. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	scenario load (kg/day)	threshold % change
Lewis Bay	30.855	5.181	-83.2%
Uncle Roberts Cove	0.540	0.715	+32.5%
Mill Creek	15.964	5.682	-64.4%
Hyannis Inner Harbor	12.153	12.762	+5.0%
Snows Creek	15.115	21.532	+42.5%
Stewarts Creek	38.992	53.959	+38.4%
Surface Water Sources			
Chase Brook	3.345	2.112	-36.9%
Mill Pond	15.038	21.814	+45.1%
Hospital Creek/Hyannis Inner	1.907	9.384	+392.1%

Table IX-47. Sub-embayment loads used for total nitrogen modeling of the Lewis Bay system for present loading scenario with present loading conditions for Build-Out Scenario F, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Lewis Bay	5.181	13.507	25.067
Uncle Roberts Cove	0.715	0.759	11.980
Mill Creek	5.682	0.627	-1.404
Hyannis Inner Harbor	12.762	0.633	6.937
Snows Creek	21.532	-	-6.458
Stewarts Creek	53.959	0.236	-13.489
Surface Water Sources			
Chase Brook	2.112	-	-
Mill Pond	21.814	-	-
Hospital Creek/Hyannis Inner	9.384	-	-

Table IX-48. Comparison of model average total N concentrations from present loading scenarios (with and without the reduction of septic loads for Build-Out Scenario F), with percent change, for the Lewis Bay system. The threshold station is shown in bold print.

Sub-Embayment	monitoring station	present (mg/L)	scenario (mg/L)	% change
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.540**	**-1.8%**
Hyannis Inner Harbor	**BH-2**	**0.496**	**0.502**	**+1.3%**
Hyannis Inner Harbor	BH-3	0.440	0.456	+3.8%
Snows Creek	BH-4	1.638	2.180	+33.1%
Lewis Bay	BH-5	0.387	0.395	+2.3%
Lewis Bay	BH-6	0.368	0.371	+1.0%
Stewarts Creek	BH-7	1.374	1.768	+28.7%
Lewis Bay	BHY-1	0.384	0.387	+0.9%
Lewis Bay	BHY-2	0.414	0.414	+0.0%
Lewis Bay	**BHY-3**	**0.407**	**0.405**	**-0.6%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.429**	**-0.5%**
Mill Creek	**MC-1**	**0.531**	**0.540**	**+1.6%**
Mill Creek	MC-2	0.473	0.460	-2.9%

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Appendix BB

MassDEP TMDL Report for Lewis Bay System and Halls Creek, March 2015

FINAL
Lewis Bay System and Halls Creek
Total Maximum Daily Loads
For Total Nitrogen

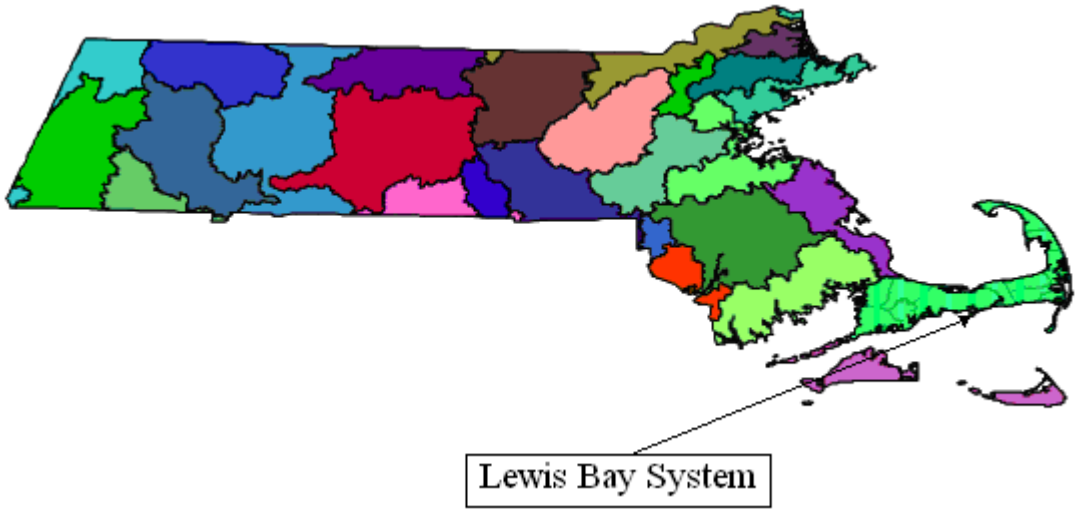
(Report # 96-TMDL-18 Control #314)



COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
MATTHEW A. BEATON, SECRETARY
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
MARTIN SUUBERG, COMMISSIONER
BUREAU OF WATER RESOURCES
BETHANY CARD, ASSISTANT COMMISSIONER

March 3, 2015

Lewis Bay System
Total Maximum Daily Loads
For Total Nitrogen



Key Feature:	Total Nitrogen TMDL for Barnstable and Yarmouth
Location:	EPA Region 1
Land Type:	New England Coastal
303d Listing:	The waterbody segments impaired and on the Category 5 list include Lewis Bay (MA96-36), Hyannis Inner Harbor (MA96-82), Mill Creek (MA96-80)
Data Sources:	University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Cape Cod Commission, Towns of Barnstable and Yarmouth
Data Mechanism:	Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model
Monitoring Plan:	Barnstable Town wide Monitoring Program and Yarmouth Town wide Monitoring Program, both with technical assistance by SMAST
Control Measures:	Sewering, Storm Water Management, Attenuation by Impoundments and Wetlands, Fertilizer Use By-laws

Executive Summary

Problem Statement

Excessive nitrogen (N) originating from a variety of sources, has impaired the environmental quality of the Lewis Bay System. In general, excessive N in theses waters are indicated by:

- Loss of eelgrass beds, which are critical habitats for macroinvertebrates and fish
- Undesirable increases in macro algae, which are much less beneficial than eelgrass
- Periodic extreme decreases in dissolved oxygen concentrations that threaten aquatic life
- Reductions in the diversity of benthic animal populations
- Periodic algae blooms

With proper management of N inputs these trends can be reversed.

Studies within the Halls Creek system, included in this document, indicate a "healthy" environment relative to dissolved oxygen, algae, and benthic animal populations; indicating that the Halls Creek estuary can assimilate the existing N loads.

Without proper management of N loads to Lewis Bay, on the other hand, more severe problems might develop, including:

- Periodic fish kills
- Unpleasant odors and scum
- Benthic communities reduced to the most stress-tolerant species, or in the worst cases, near loss of the benthic animal communities

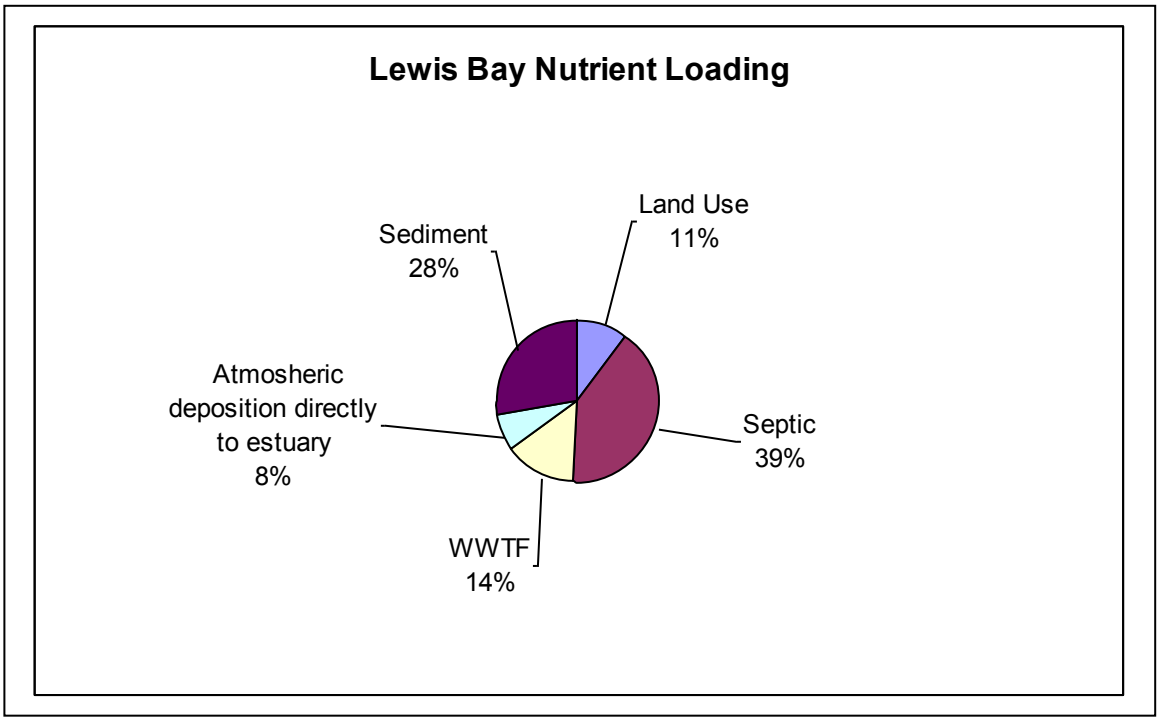
Coastal communities, including Barnstable and Yarmouth rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings could result in complete replacement of eelgrass by macro-algae, a higher frequency of extreme decreases in dissolved oxygen concentrations and fish kills, widespread occurrence of unpleasant odors and visible scum, and a complete loss of benthic macroinvertebrates throughout most of the system. As a result of these environmental impacts, commercial and recreational uses of Lewis Bay waters will be greatly reduced, and could cease altogether.

Sources of Nitrogen

Nitrogen enters the waters of coastal embayments/ponds from the following sources:

- The watershed
    - On-site subsurface wastewater disposal systems
    - Wastewater treatment facilities
    - Natural background
    - Runoff
    - Fertilizers
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments/ponds

Most of the present controllable N load originates from individual subsurface wastewater disposal (septic) systems, primarily serving individual residences, as seen in the following figure.



Target Threshold N Concentrations and Loadings

The groundwater N loadings to the Lewis Bay system (the quantity of N) range from 14.07 kg/day in Uncle Roberts Cove, to 70.37 kg/day in Lewis Bay. The resultant concentrations of N in the system range from 0.42 mg/L (milligrams per liter of N) in Lewis Bay and 0.47 mg/L in Uncle Roberts Cove, to 1.92 mg/L in Snows Creek. The N loading to Halls Creek is 29 kg/day, with N concentrations up to 1.21 mg/L. These concentrations are taken from Tables ES-1, ES-2, and VI-1 of the Massachusetts Estuaries Project (MEP) Technical Report (Linked Watershed Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Lewis Bay Embayment System. Dec. 2008. UMass Dartmouth, School of Marine Science and Technology).

In order to restore and protect the Lewis Bay system, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below the thresholds that cause the observed environmental impacts. This concentration will be referred to as the target threshold N concentration. The goal of the implementation of this TMDL is to reach this target threshold N concentration, as it has been determined for each impaired waterbody segment. The MEP has determined that, for the Lewis Bay system, a N concentration of 0.38 mg/L, in the area of the Eastern end of Lewis Bay (Sentinel Station, Figures 4a and 4b), will protect water quality and habitat throughout the embayment system. The mechanism for achieving this target threshold N concentration is to reduce the N loadings to various portions of the system. Based on the MEP modeling efforts, presented in their Technical Report, the MassDEP has adopted a range of Total Maximum Daily Loads (TMDL) of N throughout the system. Values of TMDLs range from 5 - 47 kg/day in the Lewis Bay System, and 44 kg/day for Halls Creek.

As a function of various aspects of the sub-embayment systems (size, current N loading rates, hydrodynamics, and land uses in the watersheds) N loading reductions will not be necessary in the watersheds of Snows Creek, Stewarts Creek, Uncle Roberts Cove, Chase Brook, or Halls Creek. The TMDLs for these subembayments are set at existing N loads. Snows Creek and Stewarts Creek have among the highest N concentrations in the Lewis Bay system. They are also projected to be heavily

impacted by future growth as seen in the build-out scenario described in Table IV-6 of the MEP Technical Report. Reductions in N loadings in the watersheds of adjacent embayments will result in reductions in the N concentrations in all of the embayments as needed to meet the target threshold N concentrations.

Implementation

The primary goal of implementation will be lowering the concentrations of N by reducing the loadings from on-site subsurface wastewater disposal systems through a variety of centralized or decentralized methods such as sewering and treatment with N removal technology, advanced treatment of septage, and/or installation of N-reducing on-site systems.

These strategies, plus methods of reducing N loadings from stormwater runoff and fertilizers, are explained in detail in the "MEP Embayment Restoration Guidance for Implementation Strategies", that is available on the MassDEP website http://www.mass.gov/eea/agencies/massdep/water/watersheds/coastal-resources-and-estuaries.html. The appropriateness of any of the alternatives will depend on local conditions, and will have to be determined on a case-by-case basis, using an adaptive management approach. This adaptive management approach will incorporate the priorities and concepts included in the updated area wide management plan established under the Clean Water Act Section 208.

Finally, growth within the communities of Barnstable and Yarmouth that would exacerbate the problems associated with N loadings should be guided by considerations of water quality-associated impacts.

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Introduction

Section 303(d) of the Federal Clean Water Act requires each state (1) to identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. The TMDL allocation establishes the maximum loadings (of pollutants of concern), from all contributing sources, that a water body may receive and still meet and maintain its water quality standards and designated uses, including compliance with numeric and narrative standards. The TMDL development process may be described in four steps, as follows:

1. Determination and documentation of whether or not a water body is presently meeting its water quality standards and designated uses.

2. Assessment of present water quality conditions in the water body, including estimation of present loadings of pollutants of concern from both point sources (discernable, confined, and concrete sources such as pipes) and non-point sources (diffuse sources that carry pollutants to surface waters through runoff or groundwater).

3. Determination of the loading capacity of the water body. EPA regulations define the loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. If the water body is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings.

4. Specification of load allocations, based on the loading capacity determination, for non-point sources and point sources, that will ensure that the water body will not violate water quality standards.

After public comment and final approval by the EPA, the TMDL will serve as a guide for future implementation activities. The MassDEP will work with the Towns to develop specific implementation strategies to reduce N loadings, and will assist in developing a monitoring plan for assessing the success of the nutrient reduction strategies.

In the Lewis Bay System and Halls Creek, as with other coastal systems, the pollutant of concern is the nutrient N. Nitrogen is the limiting nutrient in coastal and marine waters, which means that as its concentration is increased, so is the amount of plant matter. This leads to nuisance populations of macro-algae and increased concentrations of phytoplankton and epiphyton that imperil the healthy ecology of the affected water bodies.

The TMDLs for N for the Lewis Bay System and Halls Creek are based primarily on data collected, compiled, and analyzed by University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Barnstable/Yarmouth Lewis Bay Water Quality Monitoring Program, and others, as part of the Massachusetts Estuaries Project (MEP). The data were collected over a study period from 2001 to 2006 (see Appendix A). This study period will be referred to as the "Present Conditions" in the TMDL since it contains the most recent data available. The MEP Technical Report can be found at http://www.oceanscience.net/estuaries/reports.htm. The Technical Report presents the results of the analyses of this embayment system using the MEP Linked Watershed-Embayment Nitrogen Management Model (Linked Model). The analyses were performed to assist Barnstable and Yarmouth with decisions on current and future wastewater planning, wetland restoration, anadromous fish runs, shellfisheries, open-space, and harbor maintenance programs. A critical element of this approach is the assessment of water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic

community structure that was conducted on this embayment. These assessments served as the basis for generating an N loading threshold for use as a goal for watershed N management. The TMDL is based on the site- specific target threshold N concentration generated for this embayment. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision making process in the Towns of Barnstable and Yarmouth.

Description of Water Bodies and Priority Ranking

The Lewis Bay System is a complex estuary located within the Towns of Barnstable and Yarmouth on Cape Cod Massachusetts and its southern shore is bordered by Nantucket Sound (See Figure 1). It is comprised of the primarily lagoonal Lewis Bay and three tributary sub-embayments: Hyannis Inner Harbor, Mill Creek and Uncle Roberts Cove. Other groundwater sources included in the analyses included Snow's Creek, Stewarts Creek, and Halls Creek estuaries. Surface water sources from Chase Brook, Mill Pond Creek, and Inner Harbor Creek, were also analyzed. The Lewis Bay watershed lies completely within the Towns of Barnstable and Yarmouth. This embayment system constitutes an important component of both Towns' natural and cultural resources.

The nature of enclosed embayments in populous regions brings two opposing elements to bear: 1) as protected marine shoreline they are popular regions for boating, recreation, and land development and 2) as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the Lewis Bay System is at risk of further eutrophication from high nutrient loads in the groundwater and runoff from their watersheds. The segments listed below are already listed as waters requiring a TMDL (Category 5) for pathogens and estuarine bioassessments in the MA 2012 Integrated List of Waters, as summarized in Table 1A.

Table 1A: The Lewis Bay System Water Body Segments in Category 5 of the Massachusetts 2012 Integrated List

Name	Waterbody Segment	Description	Size	Pollutant Listed
Lewis Bay	MA96-36_2008	Includes portion of Pine Island Creek and Uncle Roberts Cove to confluence with Nantucket Sound, Barnstable/Yarmouth (excluding Hyannis Inner Harbor, Barnstable/Yarmouth and Mill Creek, Yarmouth	1.8 sq mi	-Pathogens -estuarine bioassessments
Hyannis Inner Harbor	MA96-82_2010	Waters inland of an imaginary line drawn from Harbor Bluff, Barnstable to Hyannis Park, Yarmouth	0.3 sq mi	-Fecal coliform -Nitrogen (total)
Mill Creek	MA96-80_2010	Headwaters, outlet Mill Pond, Yarmouth to confluence with Lewis Bay, Yarmouth	0.07 sq mi	-Fecal coliform -Nitrogen (total)

A complete description of this embayment system is presented in Chapters I and IV of the MEP Technical Report. A majority of the information on this embayment system is drawn from this report. Chapter VI and VII of the MEP Technical Report provide assessment data that show that various portions of the Lewis Bay System are impaired because of nutrients, low dissolved oxygen levels, elevated chlorophyll *a* levels, eelgrass loss, and/or decreased quality of benthic fauna habitat. Please note that pathogens are listed in Tables 1A and 1B for completeness. Further discussion of pathogens is beyond the scope of this TMDL.

Table 1B. Comparison of Impaired Parameters for the Lewis Bay System

Name	DEP Listed Impaired Parameter	SMAST Impaired Parameter
Lewis Bay (includes Uncle Roberts Cove)	Pathogens, estuarine bioassessments	Nutrients, DO, Chlorophyll, Eelgrass loss, Benthic fauna
Hyannis Inner Harbor	Fecal coliform, Total Nitrogen	Nutrients, DO, Chlorophyll, Benthic fauna
Mill Creek	Fecal coliform, Total Nitrogen	Nutrients, DO, Chlorophyll, Benthic fauna
Mill Pond Creek	--	Nutrients
Inner Harbor Creek	--	Nutrients

FIGURE 1: Overview of Lewis Bay



The embayments addressed by this document is determined to be a high priority based on three significant factors: (1) the initiative that the Towns have taken to assess the conditions of the entire embayment system, (2) the commitment made by the Towns to restore and preserve the embayment, and (3) the need to halt further degradation to prevent the existing "moderate" impairments from becoming "significant". In particular, portions of the Lewis Bay system are at risk of further degradation from increased N loads entering through groundwater and surface water from their increasingly developed watersheds. In both marine and freshwater systems, an excess of nutrients results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources. Observations are summarized in the Problem Assessment section below and detailed in Chapter VII, Assessment of Embayment Nutrient Related Ecological Health, of the MEP Technical Report.

Table 1C: General Summary of Conditions Related to the Major Indicators of Habitat Impairment Observed in the Lewis Bay System

Embayment System	Dissolved Oxygen Depletion	Chlorophyll *a*[1]	Eelgrass Loss	Benthic Fauna[2]
Hyannis Inner Harbor	Oxygen levels <6 mg/L 20-30% of time, but <5 mg/L only 1% H-MI	Moderate levels (5–10 µg/L) MI	No historical beds	Moderate reduced numbers of species and individuals MI
Lewis Bay (outer)	Oxygen levels <6 mg/L 18%, with no depletions of <5 mg/L H	Low levels (approx. 5 µg/L) H	Eelgrass present in 1951 in lower main basin only, now very sparse SI	High number of species and individuals H
Lewis Bay (inner)	Oxygen levels <6 mg/L 22%, with depletions rarely 5-3 mg/L MI-SI	Moderate levels (5 – 10 µg/L) MI	Eelgrass beds lost between 1951 and 1995 SI	Moderate to high number of species and individuals H-MI
Uncle Robert's Cove	Oxygen levels <6 mg/L 54%, with depletions <5 mg/L 8 % MI - SI	High levels (>10 µg/L) 43% occasional bloom conditions SI	Eelgrass beds lost between 1951 and 1995 SI	Moderate number of species but very low numbers of individuals SI
Mill Creek	Oxygen levels <6 mg/L 36%, depletions < 5 mg/L 11 % H-MI	High levels >25 µg/L 22% of the time MI	No historical beds	Typical of salt marsh, but with signs of possible moderate impairment H-MI
Hall's Creek	Oxygen levels >6 mg/L 90% H	Levels Consistently < 10 µg/L H	No historical beds	Typical of salt marsh H

1 Algal blooms are consistent with chlorophyll *a* levels above 20 µg/L

2 Based on observations of the types of species, number of species, and number of individuals

H - Healthy habitat conditions

MI – Moderately Impaired

SI – Significantly Impaired - considerably and appreciably changed from normal conditions*

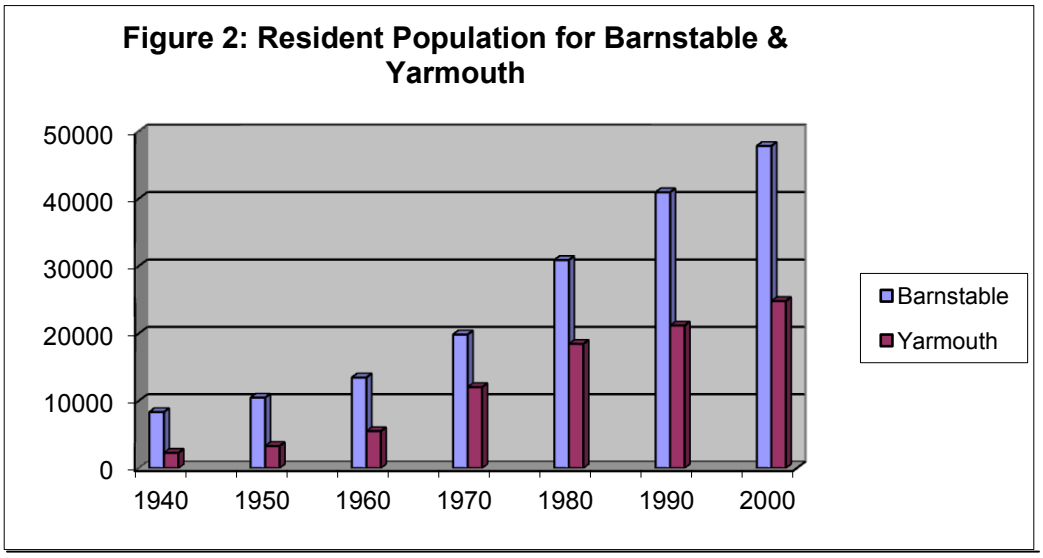
* - These terms are more fully described in MEP report "Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators" December 22, 2003. http://www.mass.gov/eea/agencies/massdep/water/watersheds/coastal-resources-and-estuaries.html

Problem Assessment

The primary ecological threat to the Lewis Bay embayment system as a coastal resource is degradation resulting from nutrient enrichment. The N loading to this system, like almost all embayments in southeastern Massachusetts including the Islands, results primarily from on-site disposal of wastewater and WWTF discharges. Wastewater effluents (from septic systems and from wastewater treatment facilities) discharge to the ground, enter the groundwater system and eventually enter the surface water bodies. In the sandy soils of Cape Cod, effluent that has entered the groundwater travel towards the coastal waters at an average rate of one foot per day.

The nutrient load to the groundwater system is primarily a function of the human population. The towns of Barnstable and Yarmouth have been among the fastest growing towns in the Commonwealth over the past two decades. In the period from 1940 to 2000 the number of year round residents in Barnstable and Yarmouth has almost quadrupled (Figure 2). The watershed of Lewis Bay embayment has had rapid and extensive development of single-family homes and the conversion of

seasonal into full time residences. This is reflected in a substantial transformation of land from forest to suburban use between the years 1940 to 2000. Water quality problems associated with this development result primarily from wastewater, and to a lesser extent, from runoff - including fertilizers - from these developed areas.



Prior to the 1940's there were few homes and many of those were seasonal. During these times water quality was not a problem and eelgrass beds were plentiful. Dramatic declines in water quality and the quality of the estuarine habitats throughout Cape Cod and the Islands have paralleled its population growth since these times. The problems in this particular embayment generally include periodic decreases of dissolved oxygen, decreased diversity and quantity of benthic animals, loss of eelgrass habitat, and periodic algal blooms. In the most severe cases habitat degradation could lead to periodic fish kills, unpleasant odors and scums, and near loss of the benthic community and/or presence of only the most stress-tolerant species of benthic animals.

Coastal communities, including Barnstable and Yarmouth, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as commercial fin fishing and shellfishing. The continued degradation of this coastal embayment, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources.

Habitat and water quality assessments were conducted on each of the these embayment systems based upon six years of water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present, the Lewis Bay Embayment System is showing variations in N enrichment and habitat quality among its various component basins. In general the system is showing healthy to moderately impaired benthic habitat. However, the smaller tributary embayments and limited inner areas of Lewis Bay (e.g. Uncle Roberts Cove, Hyannis Inner Harbor) are presently moderately impaired based upon infaunal habitat criteria. However, the dominant habitat issue for this system is the significant impairment of the Lewis Bay basin and Uncle Roberts Cove, based on eelgrass criteria. Historical eelgrass beds have been lost in these areas and eelgrass is virtually non-existent within this system.

Halls Creek continues to function as a healthy salt marsh-dominated system that is assimilating its current N loadings.

Pollutant of Concern, Sources and Controllability

Target Threshold N Concentrations and Loadings

The total N loadings to the Lewis Bay system (the quantity of N) range from 14.07 kg/day in Uncle Roberts Cove, to 70.37 kg/day in Lewis Bay. The resultant concentrations of N in the system range from 0.42 mg/L (milligrams per liter of N) in Lewis Bay and 0.47 mg/L in Uncle Roberts Cove to 1.92 mg/L in Snows Creek. The N loading to Halls Creek is 29 kg/day, with N concentrations up to 1.21 mg/L. These concentrations are taken from Tables ES-1, ES-2, and VI-1 of the MEP Technical Report.

In order to restore and protect the Lewis Bay system, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below the thresholds that cause the observed environmental impacts. This concentration will be referred to as the target threshold N concentration. The goal of the implementation of this TMDL is to reach this target threshold N concentration, as it has been determined for each impaired waterbody segment. The MEP has determined that, for the Lewis Bay system, a N concentration of 0.38 mg/L, in the area of the eastern end of Lewis Bay (sentinel Station, Figures 4a), will protect water quality and habitat throughout the embayment system. The mechanism for achieving this target threshold N concentration is to reduce the N loadings to various portions of the system. Based on the MEP modeling efforts, presented in their Technical Report, the MassDEP has adopted a range of Total Maximum Daily Loads (TMDL) of N throughout the system. Values of TMDLs range from <1 - 47 kg/day in the Lewis Bay System, and 30 kg/day in Halls Creek.

As a function of various aspects of the sub-embayment systems (size, current N loading rates, hydrodynamics, and land uses in the watersheds) N loading reductions will not be necessary in the watersheds of Snows Creek, Stewarts Creek, Uncle Roberts Cove, and Chase Brook. Reductions in N loadings in the watersheds of adjacent embayments will result in reductions in the N concentrations in all of the embayments as needed to meet the target threshold N concentrations.

Implementation

The primary goal of implementation will be lowering the concentrations of N by reducing the loadings from on-site subsurface wastewater disposal systems through a variety of centralized or decentralized methods such as sewering and treatment with N removal technology, advanced treatment of septage, and/or installation of N-reducing on-site systems.

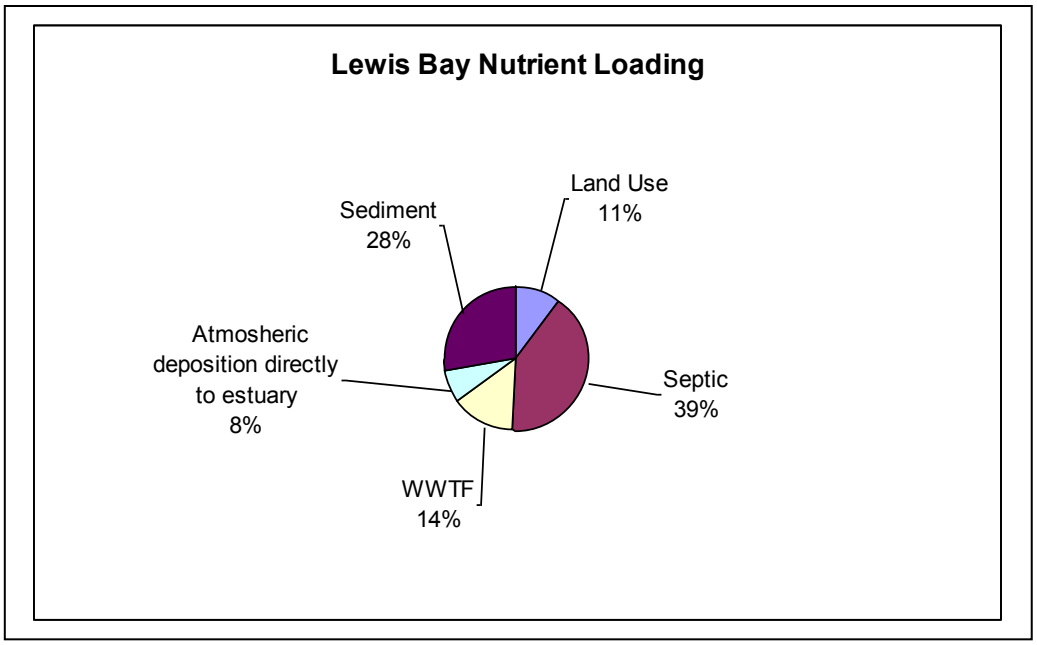
In the coastal embayments of the Towns of Barnstable and Yarmouth, as in most marine and coastal waters, the limiting nutrient is N. Nitrogen concentrations beyond those expected naturally contribute to undesirable conditions, including the impacts described above, through the promotion of excessive growth of plants and algae, including nuisance vegetation.

The embayment system covered in this TMDL has had extensive data collected and analyzed through the MEP and with the cooperation and assistance from the Towns of Barnstable and Yarmouth. Data collection included both water quality and hydrodynamics as described in Chapters I, IV, V, and VII of the MEP Technical Report.

These investigations revealed that loadings of nutrients, especially N, are much larger than they would be under natural conditions, and as a result the water quality has deteriorated.

The sources of N and their percent contributions are illustrated in Figure 3.

Figure 3: Lewis Bay Nutrient Loading



The level of "controllability" of each source, however, varies widely:

Atmospheric N – local control efforts are helpful, but are not adequate to significantly reduce N - it is only through region- and nation-wide air pollution control initiatives that significant reductions are feasible;

Sediment N- control by such measures as dredging is not feasible on a large scale. However, the concentrations of N in sediments, and thus the loadings from the sediments, will decline over time if sources in the watershed are removed, or reduced to the target levels discussed later in this document. Increased dissolved oxygen will help keep N from fluxing;

Stormwater Runoff – related N loadings can be reduced through best management practices (BMPs), bylaws, stormwater infrastructure improvements and public education;

Fertilizer – related N loadings can be reduced through bylaws and public education;

WWTF – related N loadings can be reduced by upgrading the treatment process to include N removal.

Septic system - sources of N are the largest controllable sources. These can be controlled by a variety of case-specific methods including: sewering and treatment at centralized or decentralized locations, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing N-reducing on-site wastewater treatment systems.

Atmospheric deposition to natural surfaces (forests, fields, etc.) and lakes in the watershed – atmospheric deposition (loadings) to these areas cannot adequately be controlled locally; however the N from these sources might be subjected to enhanced natural attenuation as it moves towards the estuary.

Cost/benefit analyses will have to be conducted on all of the possible N loading reduction methodologies in order to select the optimal control strategies, priorities, and schedules.

Description of the Applicable Water Quality Standards

The water bodies addressed in this report are classified as SA. Water quality standards of particular interest to the issues of cultural eutrophication are dissolved oxygen, nutrients, aesthetics, excess plant biomass, and nuisance vegetation. The Massachusetts water quality standards (314 CMR 4.0) contain numeric criteria for dissolved oxygen, but have only narrative standards that relate to the other variables, as described below:

314 CMR 4.05(5)(a) states "Aesthetics – All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances; produce objectionable odor, color, taste, or turbidity; or produce undesirable or nuisance species of aquatic life."

314 CMR 4.05(5)(c) states, "Nutrients. Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established…"

314 CMR 4.05(b) 1:

(a) Class SA

1. Dissolved Oxygen -
a. Shall not be less than 6.0 mg/L unless background conditions are lower;
b. natural seasonal and daily variations above this level shall be maintained.

Thus, the assessment of eutrophication is based on site-specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is recommended by the US Environmental Protection Agency in their draft Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (EPA-822-B-01-003, Oct 2001). The guidance Manual notes that lakes, reservoirs, streams, and rivers may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management. However, individual estuarine and coastal marine waters tend to have unique characteristics, and development of individual water body criteria is typically required.

It is this framework, coupled with an extensive outreach effort that the Department, with the technical support of SMAST, is employing to develop nutrient TMDLs for coastal waters.

Methodology - Linking Water Quality and Pollutant Sources

Extensive data collection and analyses have been described in detail in the MEP Technical Report. Those data were used by SMAST to assess the loading capacity of each sub-embayment. Physical (Chapter V), chemical, and biological (Chapters IV, VII, and VIII) data were collected and evaluated. The primary water quality objective was represented by conditions that:

1) Restore the natural distribution of eelgrass because it provides valuable habitat for shellfish and finfish
2) Prevent algal blooms
3) Protect benthic communities from impairment or loss
4) Maintain dissolved oxygen concentrations that are protective of the estuarine communities.

The details of the data collection, modeling and evaluation are presented and discussed in Chapters IV, V, VI, VII and VIII of the MEP Technical Report. The main aspects of the data evaluation and modeling approach are summarized below, taken from pages 6 through 8 of that report.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. It fully links watershed inputs with embayment circulation and N characteristics, and is characterized as follows:

• Requires site specific measurements within the watershed and each sub-embayment;

• Uses realistic "best-estimates" of N loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);

• Spatially distributes the watershed N loading to the embayment;

• Accounts for N attenuation during transport to the embayment;

• Includes a 2D or 3D embayment circulation model depending on embayment structure;

• Accounts for basin structure, tidal variations, and dispersion within the embayment;

• Includes N regenerated within the embayment;

• Is validated by both independent hydrodynamic, N concentration, and ecological data;

• Is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied previously to watershed N management in over 15 embayments throughout Southeastern Massachusetts. In these applications it became clear that the model can be calibrated and validated, and has use as a management tool for evaluating watershed N management options.

The Linked Model, when properly calibrated and validated for a given embayment, becomes a N management planning tool as described in the model overview below. The model can assess solutions for the protection or restoration of nutrient-related water quality and allows testing of management scenarios to support cost/benefit evaluations. In addition, once a model is fully functional it can be refined for changes in land-use or embayment characteristics at minimal cost. In addition, since the Linked Model uses a holistic approach that incorporates the entire watershed, embayment, and tidal source waters, it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries. It should be noted that this approach includes high-order, watershed and sub-watershed scale modeling necessary to develop critical nitrogen targets for each major sub-embayment. The models, data and assumptions used in this process are specifically intended for the purposes stated in the MEP Technical Report, upon

which this TMDL is based. As such, the Linked Model process does not contain the type of data or level and scale of analysis necessary to predict the fate and transport of nitrogen through groundwater from specific sources. In addition, any determinations related to direct and immediate hydrologic connection to surface waters are beyond the scope of the MEP's Linked Model process.

The Linked Model provides a quantitative approach for determining an embayment's: (1) N sensitivity, (2) N threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-3 of the MEP Technical Report). This methodology integrates a variety of field data and models, specifically:

• Monitoring - multi-year embayment nutrient sampling

• Hydrodynamics -

- Embayment bathymetry (depth contours throughout the embayment)
- Site specific tidal record (timing and height of tides)
- Water velocity records (in complex systems only)
- Hydrodynamic model

• Watershed N Loading

- Watershed delineation
- Stream flow (Q) and N load
- Land-use analysis (GIS)
- Watershed N model

• Embayment TMDL - Synthesis

- Linked Watershed-Embayment Nitrogen Model
- Salinity surveys (for linked model validation)
- Rate of N recycling within embayment
- Dissolved oxygen record
- Macrophyte survey
- Infaunal survey (in complex systems)

Application of the Linked Watershed-Embayment Model
The approach developed by the MEP for applying the linked model to specific embayments, for the purpose of developing target N loading rates, includes:

1) Selecting one or two sub-embayments within the embayment system, located close to the inland-most reach or reaches, which typically has the poorest water quality within the system. These are called "sentinel" stations;

2) Using site-specific information and a minimum of three years of sub-embayment-specific data to select target threshold N concentrations for each sub-embayment. This is done by refining the draft target threshold N concentrations that were developed as the initial step of the MEP process. The target threshold N concentrations that were selected generally occur in higher quality waters near the mouth of the embayment system;

3) Running the calibrated water quality model using different watershed N loading rates, to determine the loading rate which will achieve the target threshold N concentration at the sentinel station. Differences between the modeled N load required to achieve the target threshold N concentration, and the present watershed N load, represent N management goals for restoration and protection of the embayment system as a whole.

Previous sampling and data analyses, and the modeling activities described above, resulted in four major outputs that were critical to the development of the TMDL. Two outputs are related to N **concentration**:

- the present N concentrations in the sub-embayments
- site-specific target threshold N concentrations

And, two outputs are related to N **loadings:**

- the present N loads to the sub-embayments
- load reductions necessary to meet the site specific target threshold N concentrations

In summary: meeting the water quality standards by reducing the N concentration (and thus the N load) at the sentinel station(s), the water quality goals will be met throughout the entire system. A brief overview of each of the outputs follows:

Nitrogen concentrations in the embayment

a) Observed "present" conditions:
Table 2 presents the average concentrations of N measured in this system from six years of data collection (during the period 2001 through 2006). The concentrations of N in this embayment system range from 0.41 mg/L (milligrams per liter of N) in Lewis Bay to 1.57 mg/L in Snows Creek. The overall means and standard deviations of the averages are presented in Appendix A (reprinted from Table VI-1 of the MEP Technical Report). The water quality sampling stations are shown in Figures 4a and 4b.

b) Modeled site-specific target threshold N concentrations:
A major component of TMDL development is the determination of the maximum concentrations of N (based on field data) that can occur without causing unacceptable impacts to the aquatic environment. Prior to conducting the analytical and modeling activities described above, SMAST selected appropriate nutrient-related environmental indicators and tested the qualitative and quantitative relationship between those indicators and N concentrations. The Linked Model was then used to determine site-specific target threshold N concentrations by using the specific physical, chemical, and biological characteristics of each sub-embayment.

As listed in Table 2, the site-specific target threshold N concentration for Lewis Bay is 0.38 mg/L (at the sentinel station BHY-3 at 41°38'5.5"N, 70°14'43.5"W), and is 1.0 mg/L in the Halls Creek system (at station BC-14 at 41°37'56"N, 70°9'3"W). See Figures 4a and 4b.

TABLE 2: Observed Present Nitrogen Concentrations and Target Threshold Nitrogen Concentrations for the Major Sub-Embayments of the Lewis Bay System and Halls Creek

Lewis Bay System	Observed N Concentration (mg/L) [1]	Target Threshold N Concentration (mg/L)
Hyannis Inner Harbor	0.43 – 0.60[2]	
Snows Creek	1.57	
Lewis Bay (BHY-3)	0.41	0.38
Stewarts Creek	1.25	
Uncle Roberts Cove	0.41	
Mill Creek	0.52-0.56[2]	
Halls Creek System (BC-14)	0.45	1.0

[1] Ranges represent the upper to lower regions (highest – lowest) of a sub-embayment, calculated as the average of the separate yearly means of 2001-2006 data. Individual yearly means and standard deviations of the average are presented in Appendix A

[2] Listed as a range since it was sampled at more than one station (Appendix A)

The findings of the analytical and modeling investigations for these embayment systems are discussed and explained below:

The target threshold N concentration for an embayment represents the average water column concentration of N that will support the habitat quality or dissolved oxygen conditions being sought. The water column N concentration is ultimately controlled by the integration of the watershed N load, the N concentration in the inflowing tidal waters (boundary condition) and dilution due to ground or surface water flows. The water column N concentration is also modified by the extent of sediment regeneration and by direct atmospheric deposition.

Target threshold N concentrations in this study were developed to restore or maintain SA waters or high habitat quality. In this system, high habitat quality was defined as diverse benthic animal communities and dissolved oxygen levels that would support Class SA waters.

Nitrogen loadings to the embayment

a) Present loading rates:

In the Lewis Bay System overall, the highest N loading from controllable sources is from on-site wastewater treatment systems, which is almost always the highest N loading source in other coastal embayments as well. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) is significant in portions of these embayments. As discussed previously, however, the direct control of N from sediments is not considered feasible. However, the magnitude of the benthic contribution is related to the watershed load. Therefore, reducing the incoming load should reduce the benthic flux over time. A breakdown of N loading, by source, is presented in Table 3. This table is based on data from Tables ES-1and ES-2 of the MEP Technical Report.

As previously indicated, the present N loadings to Lewis Bay System must be reduced in order to restore conditions and to avoid further nutrient-related adverse environmental impacts. The critical final step in the development of the TMDL is modeling and analysis to determine the loadings required to achieve the target threshold N concentrations.

Figure 4a. Water Quality Sampling Stations within the Lewis Bay System.
Station BHY-3 is the sentinel station.



Figure 4b. Water Quality Sampling Stations Within the Halls Creek System.
Station BC-14 is the sentinel station.



TABLE 3: Nitrogen Loadings to the Lewis Bay System and Halls Creek

Embayment	Present Non-Wastewater Watershed Load[1] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load (kg/day)	Present Sediment Load (kg/day)	Present Atmospheric Deposition[2] (kg/day)	Total Load (kg/day)
Hyannis Inner Harbor	3.60	6.84	1.72	18.66	0.63	31.45
Snow's Creek	2.12	4.91	8.09	0[3]	Not Measured	15.12
Lewis Bay	4.36	26.49	0	26.00	13.51	70.37
Stewart's Creek	4.31	15.76	18.92	0[3]	0.24	39.23
Uncle Robert's Cove	0.15	0.39	0	12.77	0.76	14.07
Mill Creek	1.75	13.57	0.65	0[3]	0.63	16.60
Chase Brook	1.08	2.27	0	Not Measured	Not Measured	3.35
Mill Pond Creek	4.23	10.39	0.43	Not Measured	Not Measured	15.05
Inner Harbor Creek	0.33	1.58	0	Not Measured	Not Measured	1.91
Halls Creek	6.38	15.62	1.14	5.25	0.63	29.02

[1]Composed of fertilizer, runoff, and atmospheric deposition to freshwater and natural surfaces
[2]Atmospheric deposition directly to the estuary surface only, any atmospheric deposition to other water bodies that run into the estuary are considered in the present watershed load.
[3]Represented as 0, not a nitrogen load.

b) Nitrogen loads necessary for meeting the site-specific target N concentrations:

Table 4 (based on data from Tables ES-1 and ES-2 of the MEP Technical Report) lists the present watershed N loadings from the Lewis Bay System, and one scenario of the reduced loads and percentage reductions that could achieve the target threshold N concentration at the sentinel station (see following section). It is important to note that load reductions can be produced through reduction of any or all sources of N. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated the Towns of Barnstable and Yarmouth. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this N impaired embayment. Other alternatives may also achieve the desired target threshold N concentration as well and can be explored using the MEP modeling approach. Table VIII-2 of the MEP Technical Report (and rewritten as Appendix B of this document) summarizes the present loadings from on-site subsurface wastewater disposal systems and the reduced loads that would be necessary to achieve the target threshold N concentration in the Lewis Bay System. In the scenario presented in Table 4 the percentage reductions in N loadings to meet target threshold N concentration ranged from 2% in Mill Pond Creek up to 83 % in Inner Harbor Creek. However, Snow's Creek, Stewart's Creek, Uncle Roberts Cove, Chase Brook, and Halls Creek will not need N loading reductions (under this scenario) in order for the remainder of the system to be restored. There

can be variations depending on the chosen sub-watershed and which controllable source is selected for reduction. Alternate scenarios will result in different amounts of N being reduced in different sub-watersheds. For example, taking out additional N "upstream" will impact how much N has to be taken out "downstream". The municipalities should take any reasonable actions to reduce the controllable N sources.

TABLE 4: Present Watershed Nitrogen Loading Rates, Calculated Loading Rates that are Necessary to Achieve Target Threshold Nitrogen Concentrations, and the Percent Reductions of the Existing Loads Necessary to Achieve the Target Threshold Loadings

Embayment	Present Total Watershed Load [1] (kg/day)	Target Threshold Watershed Load[2] (kg/day)	Percent Watershed Load Reductions Needed to Achieve Threshold Loads
Hyannis Inner Harbor	12.15	7.12	42%
Snow's Creek	15.12	15.12	0
Lewis Bay	30.86	9.66	69%
Stewart's Creek	38.99	38.99	0
Uncle Robert's Cove	0.54	0.54	0
Mill Creek	15.96	4.32	73%
Chase Brook	3.35	3.35	0
Mill Pond Creek	15.04	14.68	2%
Inner Harbor Creek	1.91	0.33	83%
Halls Creek System	23.14	23.14	0

[1] Composed of fertilizer, runoff from impervious surfaces, septic systems and atmospheric deposition to natural surfaces.
[2] Target threshold watershed load is the load from the watershed needed to meet the embayment target threshold N concentration identified in Table 2 above. Includes natural background.

Total Maximum Daily Loads

As described in EPA guidance, a total maximum daily load (TMDL) identifies the loading capacity of a water body for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. The TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass, the leading indicator of ecological health, thus meeting water quality goals for aquatic life support. Because there are no "numerical" water quality standards for N, the TMDL for the Lewis Bay System is aimed at determining the loads that would correspond to specific N concentrations determined to be protective of the water quality and ecosystems.

The effort includes detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time), for each sub-embayment. The results of the mathematical model are correlated with estimates of impacts on water quality, including negative impacts on eelgrass (the primary indicator), as well as dissolved oxygen, chlorophyll, and benthic infauna.

The TMDL can be defined by the equation:

TMDL = BG + WLAs + LAs + MOS

Where

TMDL = loading capacity of receiving water
BG = natural background
WLAs = portion allotted to point sources
LAs = portion allotted to (cultural) non-point sources
MOS = margin of safety

Background Loading

Natural background N loading is included in the loading estimates, but is neither quantified nor presented separately.

Wasteload Allocations

Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of storm water be included in the waste load component of the TMDL. For purposes of the Lewis Bay/Halls Creek TMDL, MassDEP also considered the nitrogen load reductions from regulated MS4 sources necessary to meet the target nitrogen concentrations.

In estimating the nitrogen loadings from regulated stormwater sources, MassDEP considered that most stormwater runoff in the MS4 communities is not discharged directly into surface waters, but, rather, percolates into the ground. The geology on Cape Cod and the Islands consists primarily of glacial outwash sands and gravels, and water moves rapidly through this type of soil profile. A systematic survey of stormwater conveyances on Cape Cod and the Islands has never been undertaken. Nevertheless, most catch basins on Cape Cod and the Islands are known to MassDEP to have been designed as leaching catch basins in light of the permeable overburden. MassDEP, therefore, recognized that most stormwater that enters a catch basin in the regulated area will percolate into the local groundwater table rather than directly discharge to a surface waterbody.

As described in the Methodology Section (above), the Linked Model accounts for storm water loadings and groundwater loading in one aggregate allocation as a non-point source. However, MassDEP also considered that some stormwater collected in regulated area is discharged directly to surface waters through outfalls. In the absence of specific data or other information to accurately quantify stormwater discharged directly to surface waters, MassDEP assumed that all impervious surfaces within 200 ft of the shoreline, as calculated from MassGIS data layers, would discharge directly to surface waters, whether or not it in fact did so. MassDEP selected this approach because it considered it unlikely that any stormwater collected farther than 200 ft. from the shoreline would be directly discharged into surface waters. Although the 200 ft. approach provided a gross estimate, MassDEP considered it a reasonable and conservative approach given the lack of pertinent data and information

about MS4 systems on Cape Cod. For Lewis Bay/Halls Creek this calculated stormwater WLA based on the 200" buffer is 1.11% of the total N load or 704.1 kg/yr as compared to the overall N load of 63,482 kg/yr to the embayment (see Appendix C for details). This conservative load is a negligible amount of the total nitrogen load to the embayment when compared to other sources.

Load Allocations

Load allocations identify the portion of loading capacity allocated to existing and future nonpoint sources. In the case of the Lewis Bay System, the nonpoint source loadings are primarily from on-site subsurface wastewater disposal systems. Additional N sources include: WWTF's, fertilizer, stormwater runoff (including N from fertilizers), atmospheric deposition, and nutrient-rich sediments.

Generally, stormwater that is subject to the EPA Phase II Program would be considered a part of the wasteload allocation, rather than the load allocation. As presented in Chapter IV, V, and VI, of the MEP Technical Report, on Cape Cod and the Islands the vast majority of stormwater percolates into the aquifer and enters the embayment system through groundwater. Given this, the TMDL accounts for stormwater loadings and groundwater loadings in one aggregate allocation as a non-point source. As the Phase II Program is implemented in Barnstable and Yarmouth, new studies, and possibly further modeling, will identify what portion of the stormwater load may be controllable through the application of Best Management Practices (BMPs).

The sediment loading rates for Lewis Bay which are incorporated into the TMDL are lower than the existing sediment flux rates listed in Table 3 above because projected reductions of N loadings from the watershed will result in reductions of nutrient concentrations in the sediments, and therefore, over time, reductions in loadings from the sediments will occur. Benthic N flux is a function of N loading and particulate organic N (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed N loads, and are calculated by multiplying the present N flux by the ratio of projected PON to present PON, using the following formulae:

Projected N flux = (present N flux) (PON projected / PON present)

When: $PON\ projected = (R_{load})\ (D_{PON}) + PON_{present\ offshore}$

When R_{load} = *(projected N load) / (Present N load)*

And D_{PON} is the PON concentration above background determined by:

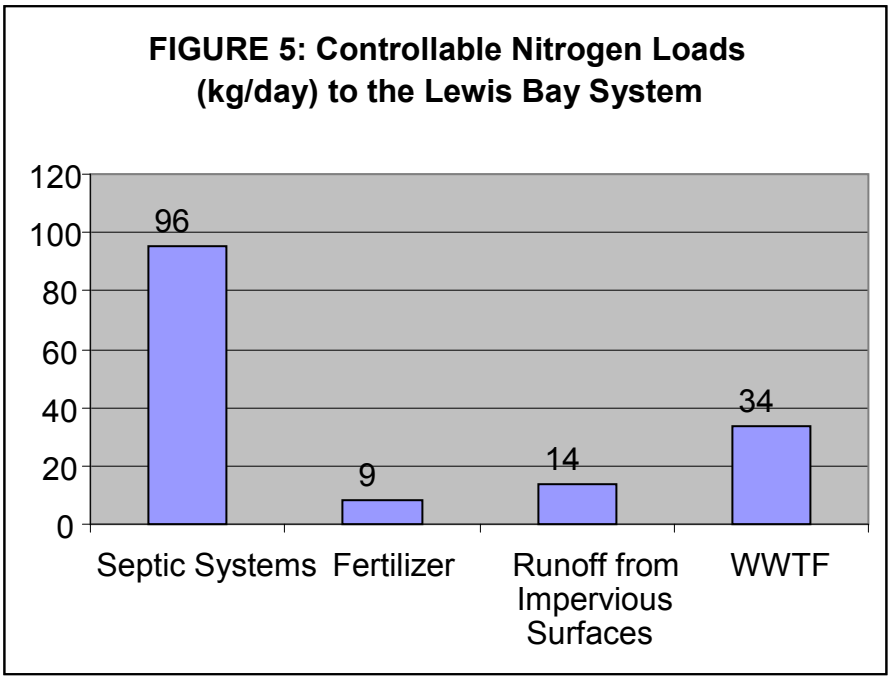
$D_{PON} = (PON_{present\ embayment} - PON_{present\ offshore})$

Benthic loading is affected by the change in watershed load. The benthic flux modeled for the Lewis Bay system is reduced from existing conditions based on the load reduction from controllable sources.

The loadings from atmospheric sources incorporated into the TMDL, however, are the same rates presently occurring, because, as discussed above, local control of atmospheric loadings is not considered feasible.

Locally controllable sources of N within the watersheds are categorized as on-site subsurface wastewater disposal system wastes, the effluent plume from the WWTF's, and land use (which includes agriculture, stormwater runoff and fertilizers). The following figure emphasizes the fact

that the overwhelming majority of locally controllable N comes from on-site subsurface wastewater disposal systems.



Margin of Safety

Statutes and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA para 303 (d)(20C, 40C.G.R. para 130.7C(1)]. The EPA's 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. The MOS for the Lewis Bay System TMDL is implicit, and the conservative assumptions in the analyses that account for the MOS are described below.

1. Use of conservative data in the linked model

The watershed N model provides conservative estimates of N loads to the embayment. Nitrogen transfer through direct groundwater discharge to estuarine waters is based upon studies indicating negligible aquifer attenuation and dilution, i.e. 100% of load enters embayment. This is a conservative estimate of loading because studies have also shown that in some areas less than 100% of the load enters the estuary. In this context, "direct groundwater discharge" refers to the portion of fresh water that enters an estuary as groundwater seepage into the estuary itself, as opposed to the portion of fresh water that enters as surface water inflow from streams, which receive much of their water from groundwater flow. Nitrogen from the upper watershed regions, which travel through ponds or wetlands, almost always enter the embayment via streamflow, are directly measured (over 12-16 months) to determine attenuation. In these cases the land-use model has shown a slightly higher predicted N load than the measured discharges in the streams/rivers that have been assessed to date. Therefore, the watershed model as applied to the surface water watershed areas again presents a conservative estimate of N loads because the actual measured N in streams was lower than the modeled concentrations.

The hydrodynamic and water quality models have been assessed directly. In the many instances where the hydrodynamic model predictions of volumetric exchange (flushing) have also been directly

measured by field measurements of instantaneous discharge, the agreement between modeled and observed values has been ≥95%. Field measurement of instantaneous discharge was performed using acoustic doppler current profilers (ADCP) at key locations within the embayment (with regards to the water quality model, it was possible to conduct a quantitative assessment of the model results as fitted to a baseline dataset - a least squares fit of the modeled versus observed data showed an R^2>0.95, indicating that the model accounted for 95% of the variation in the field data). Since the water quality model incorporates all of the outputs from the other models, this excellent fit indicates a high degree of certainty in the final result. The high level of accuracy of the model provides a high degree of confidence in the output, therefore less of a margin of safety is required.

Similarly, the water column N validation dataset was also conservative. The model is validated to measured water column N. However, the model predicts average summer N concentrations. The very high or low measurements are marked as outliers. The effect is to make the N threshold more accurate and scientifically defensible. If a single measurement two times higher than the next highest data point in the series raises the average 0.05 mg N/L, this would allow for a higher "acceptable" load to the embayment. Marking the very high outlier is a way of preventing a single and rare bloom event from changing the N threshold for a system. This effectively strengthens the data set so that a higher margin of safety is not required.

Finally, the reductions in benthic regeneration of N are most likely underestimates, i.e. conservative. The reduction is based solely on a reduced deposition of PON, due to lower primary production rates under the reduced N loading in these systems. As the N loading decreases and organic inputs are reduced, it is likely that rates of coupled remineralization-nitrification, denitrification and sediment oxidation will increase.

Benthic regeneration of N is dependant upon the amount of PON deposited to the sediments and the percentage that is regenerated to the water column versus being denitrified or buried. The regeneration rate projected under reduced N loading conditions was based upon two assumptions:(1) PON in the embayment in excess of that of inflowing tidal water (boundary condition) results from production supported by watershed N inputs and (2) Presently enhanced production will decrease in proportion to the reduction in the sum of watershed N inputs and direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON levels if watershed N loading and direct atmospheric deposition could be reduced to zero (an impossibility of course). This proportional reduction assumes that the proportion of remineralized N will be the same as under present conditions, which is almost certainly an underestimate. As a result, future N regeneration rates are overestimated which adds to the margin of safety.

2. Conservative sentinel station/target threshold N concentration

Conservatism was used in the selection of the sentinel station and target threshold N concentration. The site was chosen that had stable eelgrass or benthic animal (infaunal) communities, and not those just starting to show impairment, which would have slightly higher N concentration. Meeting the target threshold N concentration at the sentinel station will result in reductions of N concentrations in the rest of the system.

3 Conservative approach

The linked model accounted for all stormwater loadings and groundwater loadings in one aggregate allocation as a non point source and this aggregate load is accounted for in the load allocation. The method of calculating the WLA in the TMDL for regulated stormwater was conservative as it did not disaggregate this negligible load from the modeled stormwater LA, hence this approach further enhances the MOS.

The target loads were based on tidally averaged N concentrations on the outgoing tide, which is the worst case condition because that is when the N concentrations are the highest. The N concentrations will be lower on the flood tides, therefore this approach is conservative.

In addition to the margin of safety within the context of setting the N threshold levels, described above, a programmatic margin of safety also derives from continued monitoring of this embayment to support adaptive management. This continuous monitoring effort provides the ongoing data to evaluate the improvements that occur over the multi-year implementation of the N management plan. This will allow refinements to the plan to ensure that the desired level of restoration is achieved.

TABLE 5: The Total Maximum Daily Loads (TMDLs) for the Lewis Bay System and Halls Creek

Sub-embayment	Target Threshold Watershed Load [1] (kg/day)	Atmospheric Deposition (kg/day)	Sediment Load (kg/day)	TMDL [2] (kg/day)
Hyannis Inner Harbor	7.12	0.63	9.78	17.53
Snow's Creek	15.12	Not Measured	0	15.12
Lewis Bay	9.66	13.51	23.92	47.09
Stewart's Creek	38.99	0.24	0	39.23
Uncle Robert's Cove	0.54	0.76	10.99	12.29
Mill Creek	4.32	0.63	0	4.95
Chase Brook	3.35	Not Measured	Not Measured	3.35
Mill Pond Creek	14.68	Not Measured	Not Measured	14.68
Inner Harbor Creek	0.33	Not Measured	Not Measured	0.33
Halls Creek System	23.14	0.63	6.65	30.42

[1] Target threshold watershed load is the load from the watershed needed to meet the embayment target threshold nitrogen concentration identified in Table 2.

[2] Sum of target threshold watershed load, atmospheric deposition, and sediment load.

Seasonal Variation

Since the TMDLs for the waterbody segments are based on the most critical time period, i.e. the summer growing season, the TMDLs are protective for all seasons. The daily loads can be converted to annual loads by multiplying by 365 (the number of days in a year). Nutrient loads to the embayment are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Second, as a practical matter, the types of controls necessary to control the N load, the nutrient of primary concern, by their very nature do not lend themselves to intra-annual manipulation since a considerable portion of the N is from non-point sources. Thus, the annual loads make sense, since it is difficult to control non-point sources of N on a seasonal basis and N sources can take considerable time to migrate to impacted waters.

TMDL Values for the Lewis Bay System and Halls Creek

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of the embayment were calculated by considering all sources of N grouped by natural background, point sources, and non-point sources. A more meaningful way of presenting the loadings data, from an implementation perspective, is presented in Table 5. This table is based on data from Tables ES-3 and ES-4 of the MEP Technical Report.

In this table the N loadings from the atmosphere is listed separately from the target watershed threshold loads, which are composed of natural background N along with locally controllable N from the on-site subsurface wastewater disposal systems, stormwater runoff, and fertilizer sources. In the case of the Lewis Bay System the TMDL was calculated by projecting reductions in locally controllable on-site subsurface wastewater disposal system, stormwater runoff, and fertilizer sources. Once again the goal of this TMDL is to achieve the identified target threshold N concentration at the identified sentinel station. The target load identified in this table represents one alternative loading scenario to achieve that goal but other scenarios may be possible and approvable as well.

Implementation Plans

The critical element of this TMDL process is achieving the sentinel station specific target threshold N concentration presented in Table 2 above, that are necessary for the restoration and protection of water quality and eelgrass habitat within the Lewis Bay System. In order to achieve this target threshold N concentration, N loading rates must be reduced throughout this embayment. Table 5, above, lists the target watershed threshold loads for this embayment. If this threshold load is achieved, this embayment will be protected.

As previously noted, this loading reduction scenario is not the only way to achieve the target threshold N concentrations. Barnstable and Yarmouth are free to explore other loading reduction scenarios through additional modeling as part of the Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated, however, that any alternative implementation strategies will be protective of Lewis Bay, and that none of the embayment will be negatively impacted. To this end, additional linked model runs can be performed by the MEP at a nominal cost to assist the planning efforts of the Towns in achieving target N loads that will result in the desired target threshold N concentration.

The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, the MassDEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results. This adaptive management approach will incorporate the priorities and concepts included in the updated area wide management plan established under the Clean Water Act Section 208.

Because the vast majority of controllable N load is from individual on-site subsurface wastewater disposal systems for private residences, the CWMP should assess the most cost-effective options for achieving the target N watershed loads, including but not limited to, sewering and treatment for N control of sewage and septage at either centralized or de-centralized locations, and denitrifying systems for all private residences.

Barnstable and Yarmouth are urged to meet the target threshold N concentrations by reducing N loadings from any and all sources, through whatever means are available and practical, including reductions in stormwater runoff and/or fertilizer use within the watershed through the establishment

of local by-laws and/or the implementation of stormwater BMPs, in addition to reductions in on-site subsurface wastewater disposal system loadings.

MassDEP's MEP Implementation Guidance report http://www.mass.gov/eea/agencies/massdep/water/watersheds/coastal-resources-and-estuaries.html provides N loading reduction strategies that are available to Barnstable and Yarmouth and that could be incorporated into the implementation plans. The following topics related to N reduction are discussed in the Guidance:

- Wastewater Treatment
    - On-Site Treatment and Disposal Systems
    - Cluster Systems with Enhanced Treatment
    - Community Treatment Plants
    - Municipal Treatment Plants and Sewers
- Tidal Flushing
    - Channel Dredging
    - Inlet Alteration
    - Culvert Design and Improvements
- Stormwater Control and Treatment *
    - Source Control and Pollution Prevention
    - Stormwater Treatment
- Attenuation via Wetlands and Ponds
- Water Conservation and Water Reuse
- Management Districts
- Land Use Planning and Controls
    - Smart Growth
    - Open Space Acquisition
    - Zoning and Related Tools
- Nutrient Trading

* The Towns of Barnstable and Yarmouth are two of the 237 communities in Massachusetts covered by the Phase II stormwater program requirements.

Monitoring Plan

MassDEP is of the opinion that there are two forms of monitoring that are useful to determine progress towards achieving compliance with the TMDL keeping in mind that MassDEP's position is that implementation will be conducted through an iterative process where adjustments may be needed along the way. The two forms of monitoring include 1) tracking implementation progress as approved in the Town CWMP plan and 2) monitoring ambient water quality conditions at the sentinel stations identified in the MEP Technical Report, and listed in Table 2 and the related discussion in this report.

The CWMP will evaluate various options to achieve the goals set out in the TMDL and Technical Report. It will also make a final recommendation based on existing or additional modeling runs, set out required activities, and identify a schedule to achieve the most cost effective solution that will result in compliance with the TMDL. Once approved by the Department tracking progress on the agreed upon plan will, in effect, also be tracking progress towards water quality improvements in conformance with the TMDL.

Relative to water quality, MassDEP believes that an ambient monitoring program, much reduced from the data collection activities needed to properly assess conditions and to populate the model,

will be important to determine actual compliance with water quality standards. Although the TMDL load values are not fixed, the target threshold N concentrations at the sentinel stations are fixed. In addition, there are target threshold N concentrations that are provided for many other non-sentinel locations in subembayments to protect nearshore benthic habitat. These are the water quality targets, and a monitoring program should encompass these stations at a minimum. Through discussions amongst the MEP it is generally agreed that existing monitoring programs, which were designed to thoroughly assess conditions and populate water quality models, can be substantially reduced for compliance monitoring purposes. Although more specific details need to be developed on a case by case basis MassDEP's current thinking is that about half the current effort (using the same data collection procedures) would be sufficient to monitor compliance over time and to observe trends in water quality changes. In addition, the benthic habitat and communities would require periodic monitoring on a frequency of about every 3-5 years. Finally, in addition to the above, existing monitoring conducted by MassDEP for eelgrass should continue into the future to observe any changes that may occur to eelgrass populations as a result of restoration efforts.

The MEP will continue working with the Towns to develop and refine monitoring plans that remain consistent with the goals of the TMDL. It must be recognized however that development and implementation of a monitoring plan will take some time, but it is more important at this point to focus efforts on reducing existing watershed loads to achieve water quality goals.

Reasonable Assurances

MassDEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act (CWA), to implement and enforce the provisions of the TMDL through its many permitting programs, including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Barnstable and Yarmouth have demonstrated this commitment through the comprehensive wastewater planning that they initiated well before the generation of the TMDL. The Towns expect to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers), and to prevent any future degradation of these valuable resources. Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations, availability of financial incentives and local, state and federal programs for pollution control. Storm water NPDES permit coverage will address discharges from municipally owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act; Title 5 regulations for on-site subsurface wastewater disposal systems, and other local regulations such as the Town of Rehoboth's stable regulations. Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement between MassDEP and EPA. Other potential funds and assistance are available through Massachusetts' Department of Agriculture's Enhancement Program and the United States Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

As the towns implement this TMDL the loading values (kg/day of N) will be used by MassDEP as guidelines for permitting activities, and may be used by local communities as a management tool.

Public Participation

Public meetings to present the results of and answer questions on this TMDL were held on September 15, 2010 in the Barnstable Selectman's meeting room and September 23, 2010 at the Yarmouth Town Hall. Mike Ackerman (MassDEP) summarized the Mass Estuaries Project and described the Draft Nitrogen TMDL Report findings. Public comments received at the public meetings and comments received in writing within a 30-day comment period following the public meeting were considered by the Department. This final version of the TMDL report includes both a summary of the public comments together with the Department's response to the comments and scanned images of the attendance sheets from the meetings (Appendix E). MEP representatives at the public meetings included MassDEP (Michael Ackerman, Rick Dunn, Chris Duerring, Brian Dudley, Dave Delorenzo, Cathy Vakalopoulos) and SMAST (Brian Howes).

Appendix A

Summarizes the Nitrogen Concentrations for Lewis Bay System (from Chapter VI of the MEP Technical Report)

Table VI-1. Towns of Barnstable and Yarmouth water quality monitoring data, and modeled Nitrogen concentrations for the Lewis Bay System used in the model calibration plots of Figure VI-2. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means.

Sub-Embayment	Hyannis Inner Harbor	Hyannis Inner Harbor	Hyannis Inner Harbor	Snows Creek	Lewis Bay	Lewis Bay	Stewarts Creek	Lewis Bay	Lewis Bay	Lewis Bay	Uncle Roberts Cove	Mill Creek	Mill Creek
Monitoring station	BH-1	BH-2	BH-3	BH-4	BH-5	BH-6	BH-7	BHY-1	BHY-2	BHY-3	BHY-4	MC-1	MC-2
2001 mean	0.422	0.327	0.351	1.422	0.298	0.308	--	0.270	0.329	0.333	--	--	--
2002 mean	0.634	0.535	0.483	1.459	0.399	0.415	1.257	0.358	0.420	0.369	--	0.469	0.476
2003 mean	0.676	0.494	0.491	1.873	0.420	0.349	1.411	0.351	0.420	0.405	--	0.555	0.510
2004 mean	0.580	0.492	0.368	1.295	0.372	0.353	1.023	0.445	0.496	0.424	0.469	0.594	0.523
2005 mean	0.526	0.413	0.400	1.450	0.325	0.349	1.016	0.326	0.373	0.371	0.364	0.500	0.463
2006 mean	0.585	0.468	0.416	1.917	0.344	0.421	1.606	0.435	0.476	0.461	0.391	0.749	0.638
mean	0.599	0.474	0.433	1.565	0.374	0.373	1.245	0.374	0.430	0.395	0.410	0.562	0.516
s.d. all data	0.140	0.100	0.097	0.442	0.089	0.095	0.399	0.115	0.111	0.095	0.091	0.162	0.128
N	55	58	55	33	57	61	31	63	59	60	8	27	26
model min	0.561	0.501	0.420	0.395	0.376	0.336	0.923	0.361	0.393	0.404	0.421	0.466	0.419
model max	0.585	0.537	0.488	2.022	0.401	0.399	1.643	0.406	0.475	0.412	0.442	0.665	0.608
model average	0.574	0.518	0.445	1.638	0.388	0.369	1.377	0.385	0.415	0.408	0.432	0.532	0.474

Appendix B

Summarizes the Present On-Site Subsurface Wastewater Disposal System Loads, and the Loading Reductions that would be Necessary to Achieve the TMDL by Reducing On-Site Subsurface Wastewater Disposal System Loads, Ignoring All Other Sources

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Lewis Bay system. These loads do not include direct atmospheric deposition (onto the subembayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	5.299	-80.0%
Uncle Roberts Cove	0.214	0.214	0.0%
Mill Creek	13.570	1.926	-85.8%
Hyannis Inner Harbor	6.847	1.808	-73.6%[1]
Snows Creek	7.970	9.088	+14.0%
Stewarts Creek	21.564	24.178	+12.1%
Surface Water Sources			
Chase Brook	2.488	2.479	-0.3%
Mill Pond	10.425	10.068	-3.4%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

[1] Hyannis Inner Harbor is a combination of Hyannis Inner Harbor watershed (13), and Wells Mary Dunn watershed (6) thus the 80% reduction in septic loading for the threshold does not result in a direct 80% reduction in septic loading.

Appendix C

The Lewis Bay Embayment System estimated wasteload allocation (WLA) from runoff of all impervious areas within 200 feet of waterbodies.

Watershed Name	Impervious subwatershed buffer areas[1]		Total subwatershed Impervious areas		Total Impervious subwatershed load	Total subwatershed load	Impervious watershed buffer area WLA	
	Acres	%	Acres	%	Kg/year	Kg/year	Kg/year[2]	%[3]
Lewis Bay	43.1	12.2	321.1	7.6	3895	40490	522.8	1.29
Stewarts Creek	5.4	10.5	85.6	9.2	749	14318	47.2	0.32
Halls Creek	14.8	5.7	76.5	9.0	731	8674	9.6	0.11
Total	63.3	10.7	483.2	9.1	5375	63482	704.1	1.11

[1]The entire impervious area within a 200 foot buffer zone around all waterbodies as calculated from GIS. Due to the soils and geology of Cape Cod it is unlikely that runoff would be channeled as a point source directly to a waterbody from areas more than 200 feet away. Some impervious areas within approximately 200 feet of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of the wasteload allocation (WLA) it was assumed that all impervious surfaces within 200feet of the shoreline discharge directly to the waterbody.

[2]The impervious subwatershed buffer area (acres) divided by total subwatershed impervious area (acres) then multiplied by total impervious subwatershed load (kg/year).

[3]The impervious subwatershed buffer area WLA (kg/year) divided by the total subwatershed load (kg/year) then multiplied by 100.

Appendix D

6 Total Nitrogen TMDLs, 4 Pollution Prevention TMDLs

Embayment System and Sub-embayment	Segment ID	Impairment/TMDL Status	TMDL (kg/day)
Lewis Bay System			
Hyannis Inner Harbor	MA96-82_2010	Determined to be impaired for nutrients during the development of this TMDL.	17.53
Snow's Creek	MA96-81_2008	Not impaired for total nitrogen, but TMDL needed since embayments are linked. (Pollution Prevention TMDL)	15.12
Lewis Bay	MA96-36_2008	Determined to be impaired for nutrients during the development of this TMDL.	47.09
Stewart's Creek	MA96-94_2012	Not impaired for total nitrogen, but TMDL needed since embayments are linked. (Pollution Prevention TMDL)	39.23
Uncle Robert's Cove	Part of MA96-36_2008	Determined to be impaired for nutrients during the development of this TMDL.	12.29
Mill Creek	MA96-80_2010	Determined to be impaired for nutrients during the development of this TMDL.	4.95
Chase Brook		Not impaired for total nitrogen, but TMDL needed since embayments are linked. (Pollution Prevention TMDL)	3.35
Mill Pond Creek		Determined to be impaired for nutrients during the development of this TMDL.	14.68
Inner Harbor Creek		Determined to be impaired for nutrients during the development of this TMDL.	0.33
Lewis Bay System Total			154.57
Halls Creek System	MA96-93_2012	Not impaired for total nitrogen, but TMDL needed since embayments are linked. (Pollution Prevention TMDL)	30.42

Appendix E

MEP
Response to Comments
DRAFT TMDL REPORT FOR THE LEWIS BAY SYSTEM AND HALLS CREEK
(Report Dated August 12, 2010)

Verbal Questions and Responses from Public Hearings for Draft Nitrogen TMDLs
September 23, 2010, 4:00-6:00 PM, Yarmouth Town Hall and September 15, 2010, 4:00–6:00 PM, Barnstable Selectman's Meeting Room

Mike Ackerman (MassDEP) summarized the Mass Estuaries Project and described the Draft Nitrogen TMDL Report findings. The public was able to ask questions and provide comments during and after the presentation. The following is a summary of the public comments prepared by Cathy Vakalopoulos (MassDEP). Also commenting are Brian Dudley (MassDEP), Christine Duerring (MassDEP), and Brian Howes (SMAST). Scanned images of the attendance sheets from these public meetings and the public meeting held in Barnstable (September 15, 2010 4:00-6:00 PM) / Barnstable Selectman's Meeting Room.

Audience: What percent [nitrogen] is from cesspools and hotels near the water, jet fuel deposition, and road runoff?
M. Ackerman: Various sources have been differentiated but I do not have the details available here today. Information on nitrogen sources presented here was separated into two groups: controllable sources and non-controllable sources (e.g. atmospheric deposition and nitrogen from the sediments). Dredging the sediments would not reduce the nitrogen coming from the sediments because that nitrogen is originally from decaying algae. To control this, nitrogen must be controlled from the original source and sources of nitrogen will be discussed later in the presentation. Jet fuel was not considered in this analysis.

Audience: Why wasn't fertilizer addressed?
M. Ackerman: Fertilizer use is considered in the analysis (lawn care, golf courses, and cranberry bogs).

Audience: Though the stench of jet fuel is a problem, people need to understand that we need sewers.

Audience: The Maritime Provinces of Canada, as well as Quebec have banned inorganic fertilizers and weed killers so Canada is way ahead of us. It's better to have homeowners reduce nitrogen use by using organic fertilizers instead of digging up the streets [for sewers].

Audience: Flushing improvements would be good because Nantucket Sound is a much larger area that can handle algae. Shoaling has been a problem and is making areas shallower so dredging would have a significant effect. We are looking at opening the old Hyannis Channel down the road. These ideas are much cheaper than sewering although dredging is not the complete solution.
Audience: Please discuss the other "non-traditional" approaches some more.
[M. Ackerman did]

Audience: Can we get a better geographic idea of septic use, i.e. is it mostly near the shore?
M. Ackerman: Septic information is based on water use data.
B. Dudley: We could look at septic information more carefully to some degree by looking at the subwatersheds. Nitrogen loads in the upper reaches have more potential to be attenuated.

Audience: These data are great but they are not specific to our town. Residents are concerned about money. Yarmouth had a meeting this past Tuesday evening that discussed cost.
Audience: How do you account for seasonal vs. year round septic use?
B. Howes: It is impossible to count people. We use water use meter data.
Audience: How come some areas are allowed to have a higher threshold?
M. Ackerman: There are a lot of factors such as groundwater load, hydrodynamics, flushing, septic load, and sediment flux. What was presented here was just one example that only looked at septic load.

Audience: Early on, what standards were held when deciding where you wanted to end up?
M. Ackerman: There were both subjective and objective standards [CV missed something here in her notes].

Audience: Please explain the acronyms we have never heard of before.

Audience: If we are now close to 0.38 mg/L N, why do we need a 69% reduction?
M. Ackerman: Though the concentration is low, after converting it to load (from mg/L to kg/day), it is a lot of nitrogen.

Audience: Over what period of time and what part of year is this?
M. Ackerman: A town needs three years of data to enter the Mass Estuaries Program, then three years of intensive data collection occurs during the summer months. The summer months are the most crucial when it comes to things like dissolved oxygen.
B. Howes: One important piece of information is that at 0.37 mg/L nitrogen, there is eelgrass. Though there is a 69% reduction needed in one subembayment, if you look at all of the subembayments, then it is not as much. We are not trying to go back to pristine conditions but we want the water to be clear and the bottom to be sandy. This is good for the environment, the economy, and the people that live here.

Audience: Why are fertilizers, runoff from impervious surfaces, and WWTFs not included on the TMDL chart on page 9?
M. Ackerman: We are only presenting one scenario as an example.

Audience: Please add those columns so we can discuss them further.
M. Ackerman: We can certainly discuss this. I'm not telling you how to solve this. For example, perhaps the airport should be looked at. What I showed was just one example.
C. Duerring: The total load is from all sources, not just septic.
M. Ackerman: Load reductions in this case only look at septic.

Audience: There is a high percent contribution from the sediments in Lewis Bay. Explain why this is the case here and not in the other embayments.
B. Howes: Perhaps it is because Lewis Bay is deep and there is a lot of *Codium* (invasive attached macroalgae). This may cause particles in the water column to fall out because they found fine materials over a sandy base. But the fix to Lewis Bay does not require the town to do anything to the sediments. As nitrogen is reduced in the watershed, the sediments will improve. We look at the sediments because they interact with the overall nitrogen balance. Just dredging will not solve the problem, fine sediments will be deposited again.

Audience: So phytoplankton settling is causing this?
B. Howes: 2 mm of sediments settles per year (both organic and inorganic).

Audience: In some areas, the fine sediments get flushed out but in some areas there are deep pockets. I'm concerned about using eelgrass as an indicator for improvement because it won't grow in these areas with fine sediments. If eelgrass is what we hang our hat on, I'm not sure that we will see a recovery.
B. Howes: We have tracked sediment type and eelgrass and in these waters, fine sediments will support eelgrass. If we are limited by a lack of seed source or propagation then we would have to help things along with some plantings.

Audience: There are issues of decomposing *Codium* which will smother the eelgrass. *Codium* is growing because of the nitrogen.

Audience: You will get the best cooperation if the government mandates it and pays for it. [Sewering] is a tax, and we don't like it. If our town can't pay for it, how can residents pay $10-80K per household? It's going to kill the homeowners.
B. Dudley: There are programs (e.g. state revolving loan fund) that can help towns. The O'Leary Bill provides 0% loans and there are USDA and rural development grants (Provincetown and Chatham has benefited from these). There are avenues to pursue that would help funding.

Audience: Yarmouth is applying for SRF. The O'Leary Bill provides 0% loans but only for 10 years and two years have already passed. [Sewering] is an unfunded mandate from the state. But we will pursue all grants available to us. Now that there is no money available from the federal government, we are on our own. [Yarmouth's] elected officials will try to make this as manageable as possible. We are required to remove nitrogen but our eye is on the homeowners.

Audience: What is the timeline for all of this?
M. Ackerman: This TMDL is guidance and not an enforcement document.
B. Dudley: We do have "ways", but we would prefer to work together though the CWMP process so that we can compromise on a workable plan. If we are forced to take an enforcement action, we would prefer a mutually agreed upon consent order but this would take away all flexibility. So far we are satisfied with Yarmouth's progress and we feel that it's better to work together to solve this problem.

Audience: Has the lawsuit been filed [by the Conservation Law Foundation]?
B. Dudley: The notice of intent has been filed. If [the regulatory agencies] show progress, it may prevent the lawsuit.

Audience: This lawsuit echoes of the Boston Harbor case.
G. Allaire: They are going after the regulatory agencies because they want them to work more quickly.

Audience: Who is going to force us to start digging? If we don't do it, then will the feds come in and do it? This feels like extortion. We should force the feds to fund these mandates.

Audience: No, it's in our local interest to fix our problems. When our water quality is exceeded, then our tax base and our revenues will suffer. That's the driving force.

Audience: But we cannot afford this!

Audience: What does this cost?
G. Allaire: There are five phases at $55 million each south of Route 6.

Audience: Schools are run in the same way – unfunded mandates.
Audience: In a sense we are paying now for poor decisions in the 1970's. Anecdotally, Lewis Bay has slime and oil, and in my opinion, is not swimmable. It is sad to see tourists coming to Englewood Beach and not being able to swim. We are already "over the edge". Let's not stonewall and dig in our heels.

Audience: Let's say we go ahead with this and it takes 25 years to do the work. Once the project is completed, and Lewis Bay is cleaner, when can it be considered "cleaned"?
B. Howes: Lewis Bay already has significant sewering and is not as impaired as Seine Pond in the Parkers River watershed. Things would improve with each year with a ~95% improvement within 3-5 years. We come up with plans that limit sewering. Here we recommended 30% sewering. Delaying and having to go through a court case could make us have to sewer 100%.

Audience: Would it be prudent to ban the use of inorganic fertilizers?
M. Ackerman: That makes sense but we are not telling what the towns to do.

Audience: Will the technology improve if we delay?
Yarmouth official: No, the cost to dig sewers or build treatment plants does not go down.

Written comments

Comment (1):

FROM: Zabelle D'Amico
53 Lewis Bay Boulevard, West Yarmouth, MA 02673
1355 Main St., Holden, MA 01520

TO: Mass DEP, Division of Watershed Management
627 Main St., Worcester, MA 01608
Attn: Mr. Michael Ackerman:

I read with concern the article on Lewis Bay contamination that appeared in the Cape Cod Times last week. When I looked up the website you noted to find more details on the estuaries report on Lewis Bay, I could find no specific mention of the work done on Lewis Bay. Can you help me? **[Comment 1]**

My husband and I have owned a home on Lewis Bay (specifically in the Englewood Beach corner) for over 30 years. Last year, my husband and I donated to a report funded by the Springer Beach Association, also carried out by UMA-Dartmouth researchers, that was specifically targeted from the tip of the Englewood dock to Sweetheart Creek. I would be interested in reviewing the two reports again. I'm also wondering if the two research projects are one and the same. **[Comment 2]**

Meanwhile, my level of concern for Lewis Bay went on high alert in August when my granddaughter took part in a Knockabout Sailboat race sponsored by the Yarmouth Recreation Department. All of the participants were given a bright yellow t-shirt with a detailed mariner's map of the entire bay showing in detail the various depths of the water. I was astounded to see a graphic presentation showing just how shallow much of the bay now is. We who live along the water, have expressed concern about the depth to one another, but his was the first time I'd seen a reliable visual that made the reality so shocking. Have you looked at this issue? Certainly that too must be a contributing factor to the negative quality of the water. **[Comment 3]**

I believe the issue is especially urgent as Cape Wind is nearing final approval of 130 windmills on Nantucket Sound that will be connected by huge underground cables that will run from the wind farm site along the floor of Lewis Bay to the Englewood area, then proceed by land to connect to the power plant on Higgins Crowell Road. The bay is already shallow and I fear that the upshot of all of the work will be to further compromise both the depth and the water quality.

I am not concerned about the appearance of the wind farm; rather, I am concerned about the further negative impact it will have on this very fragile resource. The loss of Lewis Bay would have a huge impact not just on tourism, but on the entire economy of Hyannis and Yarmouth.

Also, have you thought of actively enlisting the participation of homeowners who live on Lewis Bay, perhaps on the entire south side of 28, to use organic fertilizers that will at minimum stabilize the amount of nitrogen levels? It isn't sewers, but every effort counts. **[Comment 4]**

I appreciate your time in this matter. I look forward to hearing back from you.

Sincerely,

Zabelle D'Amico

Response:
Comment (1) The MassDEP TMDLs are available at http://www.mass.gov/dep/water/resources/tmdls.htm

Comment (2) It appears that the two research projects are not the same.

Comment (3) The issue of waterbody depth, the rate of sedimentation, and the shape of the waterbody (bathymetry) are all issues that have been reviewed as part of the TMDL process.

Comment (4) MassDEP does not get involved directly in modifying individual homeowner behavior over this type of issue (fertilizer use). MassDEP does however encourage local communities (and individuals) to look at every source of nutrients which it is able to control. In this particular system fertilizer use accounts for approximately 6% of the total controllable nitrogen load and is the smallest of the four controllable sources.

From: Tom Cambareri [tcambareri@capecodcommission.org]
Sent: Friday, October 01, 2010 11:24 AM
To: BhowesCapecod@verizon.net; Ackerman, Michael (DEP)
Cc: Ed Eichner; Saad, Dale
Subject: LEWIS BAY PERCENT REMOVAL FOR STEWARDS CREEK
Attachments: DraftTMDLlewisbay.pdf

Hi,

I noted an alarming difference in the percent removal required for Stewarts Creek between the Tech Report and the Draft TMDL.

The Tech report indicates Stewards Creek has assimilative capacity to increase nitrogen loading by 12%, but the Draft TMDL show that there is a requirement for 36.1% removal. Given the ultimate discharge of the Hyannis WPCF into Stewarts Creek, this is a BIG difference. **[Comment 5]**
Please review and advise. The comparison can be seen on the attached

-Tom

Tom Cambareri, CGWP, LSP
Water Resources Program Manager
Cape Cod Commission
3225 Main Street
Barnstable, MA 02630
www.capecodcommission.org
Main: (508) 362-3828
Fax: (508) 362-3136

Attachment:

DRAFT
Lewis Bay System and Halls Creek
Total Maximum Daily Loads
For Total Nitrogen

(Report # 96-TMDL-18 Control #314)



COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS

IAN A. BOWLES, SECRETARY
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
LAURIE BURT, COMMISSIONER
BUREAU OF RESOURCE PROTECTION
GLENN HAAS, ACTING ASSISTANT COMMISSIONER

August 12, 2010

Appendix B

Summarizes the Present On-Site Subsurface Wastewater Disposal System Loads, and the Loading Reductions that would be Necessary to Achieve the TMDL by Reducing On-Site Subsurface Wastewater Disposal System Loads, Ignoring All Other Source

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Lewis Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	5.299	-80.0%
Uncle Roberts Cove	0.214	0.214	+0.0%
Mill Creek	13.570	1.923	-85.8%
Hyannis Inner Harbor	6.827	1.792	-73.8%
Snows Creek	7.970	9.088	+14.0%
Stewarts Creek	21.564	13.775	-36.1%
Surface Water Sources			
Chase Brook	2.488	2.463	-1.0%
Mill Pond	10.359	10.003	-3.4%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

reduction in loading from this source to the main basin of Lewis Bay (Watershed 16) and an 80% reduction from this source to Hyannis Inner Harbor (Watershed 13). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Lewis Bay Estuary: Watershed nitrogen loads to Lewis Bay were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel station chosen for the Lewis Bay Embayment System (BHY-3 located in the eastern basin of Lewis Bay), and at the secondary stations in Uncle Roberts Cove, Hyannis Inner Harbor and Mill Creek. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

As shown in Table VIII-2, the nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations required using: 1) Existing Removal Scenario B (as requested by the Towns of Yarmouth and Barnstable) with 2) additional removal of septic N loading to produce an 80% total reduction in loading from this source to the main basin of Lewis Bay (Watershed 16) and 3) an 80% reduction from septic N Loading to Hyannis Inner Harbor (Watershed 13). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Tables VIII-3 and VIII-4 provide additional loading information associated with the thresholds analysis. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. Removal of septic loads from Existing

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Lewis Bay system. These loads do not include direct atmospheric deposition (onto the subembayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Lewis Bay	26.490	5.299	-80.0%
Uncle Roberts Cove	0.214	0.214	0.0%
Mill Creek	13.570	1.926	-85.8%
Hyannis Inner Harbor	6.847	1.808	-73.6%[1]
Snows Creek	7.970	9.088	+14.0%
Stewarts Creek	21.564	24.178	+12.1%
Surface Water Sources			
Chase Brook	2.488	2.479	-0.3%
Mill Pond	10.425	10.068	-3.4%
Hospital Creek/Hyannis Inner	1.907	0.326	-82.9%

[1] Hyannis Inner Harbor is a combination of Hyannis Inner Harbor watershed (13), and Wells Mary Dunn watershed (6) thus the 80% reduction in septic loading for the threshold does not result in a direct 80% reduction in septic loading.

Response:
Comment (5) MassDEP was unaware of the revision which you supplied as part of your comment (see attachment) at the time the public meetings for this project were advertised and conducted. Revisions have been made to the TMDL document (Appendix B) based on the information in the attachment.

From: Charles Spooner [spooner.charles@gmail.com]
Sent: Friday, October 22, 2010 3:39 PM
To: Ackerman, Michael (DEP); Charles Spooner
Subject: Lewis Bay TMDL Comments

Michael T. Ackerman
Massachusetts Department of Environmental Protection
Basin Planning Section
627 Main Street
Worcester MA 01608

Dear Mr. Ackerman:

Thank you for the opportunity to review the DRAFT Lewis Bay System and Halls Creek Total Maximum Daily Loads For Total Nitrogen (Report #96-TMDL-18 Control #314) dated August 12, 2010.
My comments follow. I hope that they may help establish the TMDL as the basis for future planning and state oversight, and local response.

First, the draft report is clear, representing what appears in the December, 2008 final report "Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Lewis Bay Embayment System, Barnstable/Yarmouth, MA". The one exception: I found no tables in the MEP Technical Report labeled either ES-1 or ES-2. These are cited in the draft document. **[Comment 6]**

One regulatory linkage might be clarified in the TMDL. How and when the pathogen TMDL that is noted as being outside the scope of this report will be addressed is part of the overall water quality picture and, I believe, should be noted. **[Comment 7]**

The third paragraph on page iii states that "… N loading reductions will not be necessary in the watersheds of Snows Creek, Stewarts Creek, Uncle Roberts Cove, and Chase Brook." I suggest also noting that the TMDLs for these embayments are set at existing N load levels. This might also be the place to underscore that both Snows Creek and Stewarts Creek have among the highest N concentrations in the Lewis Bay system. They are also projected to be heavily impacted by future growth as seen in the build-out scenario described in Table IV-6. **[Comment 8]**

In contrast to TMDLs for Snows Creek, Stewarts Creek, Uncle Roberts Cove, and Chase Brook, Halls Creek has an allowable N load that is set higher than the current loading. This feature of the TMDL seems unwise. The Technical Report (section VII .3 on page 186) notes that allowing load increases is the exception in the estuaries the MEP has addressed and specifically notes that the load increases presented "… represent only one of a suite of potential approaches that need to be evaluated by the community." I recommend that Halls Creek be capped at the existing N load level. If it is not, then it might be interpreted as a special backsliding privilege for Hyannisport, so the logic for an increased N load should at least be explained. **[Comment 9]**

The TMDL allocates substantial reduced loads to the benthic nitrogen flux in three specific areas, Hyannis Inner Harbor, Lewis Bay, and Uncle Roberts Cove. The discussion of this in the Technical Report is skimpy and curiously embedded in the discussion of the build-out scenario. The draft document replicates this text. Neither document presents a very compelling understanding of how well or how quickly these reductions will become apparent. The draft TMDL report might emphasize that the TMDL for this N load represents a 20% reduction in sediment loads and that the TMDL target accounts for 25% of the allowed N load in the Lewis Bay system. This means that it is an important source to reduce. I recommend that special monitoring and even research should be put in place to better understand how appropriate the assumptions on its dissipation are. It should be

stressed that if this load does not reduce, then additional pollution controls in other areas will be needed. **[Comment 10]**

I am pleased to see that you have noted the need for an implementation-monitoring program in the TMDL. I find the absence of monitoring data to be the single biggest defect in the Technical Report, and a TMDL monitoring program can be a good place to make both older data and the planned new data available. The proposed language in the draft could be strengthened by tightly referencing the measures that will be used to gauge the success of implementation. This section of the draft could also be strengthened by noting that the monitoring may be needed to update the current conditions should implementation be delayed and growth in the loads in the watershed begin to increase the load reductions that are needed. Rather than suggest that this monitoring will take time to implement, I would suggest phrasing it in such a way that it adds urgency to the undertaking and reminds everyone that DEP is serious about the TMDL's implementation.

There are several aspects of the TMDL that are the opportunities and responsibilities of the town governments. Perhaps they should be emphasized under a special heading

• Page 22 notes that the TMDL "loading reduction scenario is not the only way to achieve the target threshold N concentrations. Barnstable and Yarmouth are free to explore other loading reduction scenarios through additional modeling as part of the Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated, however, that any alternative implementation strategies will be protective of Lewis Bay…"

• The draft notes that both Barnstable and Yarmouth have been among the fastest growing towns in the Commonwealth. This is particularly important because, as the Technical Report makes clear, the land use plans of the two towns will increase N loads from watershed sources on average, by 30% above current levels used to plan the TMDL. Given the load increases that are likely with planned growth and the role that sewers often play in sparking growth, a further description of the interplay between the TMDL, the expected CWMP, and state permits would be in order in this document.

• The list of other programs noted under the reasonable assurance section of the draft does not describe that the towns are responsible for coordinated efforts to harness them to meet the load reduction challenge. At least, I am not aware of any other planning vehicle.

• The application of many of these programs may be unknowable, and the list of them as opportunities on pages 22 and 23 of the draft may have to suffice. There is a note on page 23 of the draft, however that confirms that the two towns are covered by Phase II stormwater (MS4) control program requirements, but it does not describe the potential role of that program in quantifying and in controlling N loads in the Lewis Bay System. There appears to be no expectation in the draft document that the CWMP or any other planning program in response to the MEP Implementation Guidance will (or should) consider stormwater quality beyond the impervious surfaces at the facilities they require. Given the inevitable problems towns will face in funding the WWTF systems implied by this TMDL and the 25-YEAR implementation suggested (on page 10-1) in the draft CWMP, it would appear to be an opportunity for DEP to outline opportunities and obligations stemming from the MS4 program.

Sincerely,
Charles S. Spooner, P.E.
176 Thacher Shore Rd
Yarmouth Port MA 02675

Response:
Comment (6) The draft MEP Technical Report does not contain an Executive Summary (no tables ES-1 or ES-2). The final MEP Technical Report does contain them and can be found at http://www.oceanscience.net/estuaries/reports.htm. Please note that in the case of this MEP Technical Report the above referenced ES-1 would apply to ES-1 and 2 and ES-2 would apply to ES-3 and 4.

Comment (7) MassDEP (for a variety of reasons) has no current plans to write a bacteria TMDL for Lewis Bay specifically. There is an EPA approved basin wide Pathogen TMDL for the Cape Cod Basin (96).

Comment (8) The suggested language has been added to the TMDL.

Comment (9) The Target Threshold Watershed Load (Tables 4 and 5) and the TMDL (Table 5) for Halls Creek have been adjusted to Present Total Watershed Load levels.

Comment (10) In most cases (but certainly not all) when comparing existing benthic flux loads (ES-1 and 2) to post TMDL benthic flux loads (ES-3 and 4), the flux approaches zero. Also, please note in the Implementation Plans section "The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, the MassDEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results."

October 29, 2010

Michael Ackerman
Department of Environmental Protection
Division of Watershed Management
627 Main Street 2 Floor
Worcester, MA 01608

Subject: Lewis Bay Draft TMDL – Comments from the Town of Yarmouth

Dear Mr. Ackerman:

The Town of Yarmouth recently submitted their Expanded Environmental Notification Form (ENF) and Draft Comprehensive Wastewater Management Plan (CWMP) in accordance with the Massachusetts Environmental Policy Act (MEPA) regulations. The expanded ENF and Draft CWMP were also filed with the Cape Cod Commission (CCC) for joint review with their Determination of Regional Impact (DRI) process.

The town is pursuing a long-term, multi-phased wastewater management program with centralized treatment to reduce nutrient loading to coastal estuariess, to meet the anticipated total maximum daily loads (TMDL's) for those estuaries, to protect the towns drinking water sources, and to support viable business centers along Route 28. The Lewis Bay Watershed is one of three estuary systems located within the town boundaries and has been studied by the Massachusetts Estuaries Project(MEP). At this time, the Town of Yarmouth has reviewed the Final Lewis Bay Draft TMDL Report and has concluded that Yarmouth's CWMPwill meet the threshold nitrogen loadin Lewis Bayand therefore meet the proposed TMDL.

In section eight of the Expanded ENF/Draft CWMP, the town summarizes the nitrogen threshold loads for Lewis Bay which it shares with the Town of Barnstable and Yarmouth's proposed sewer service area in that watershed. It discusses the results of the threshold nitrogen loads found in the MEP report and runs a scenario to determine if the proposed sewer service area will remove sufficient nitrogen to meet those threshold loads. In the preferred scenario, the threshold loads are exceeded by 0.01mg/l to 0.02mg/l total nitrogen in the sentinel and check stations for the bay. The table below shows the results of the total nitrogen threshold concentrations and the result of the preferred scenario.

Sentinel and Check Stations – Lewis Bay, Build-out Flow – Total Nitrogen Concentrations

Sub-Embayment	*Monitoring Station*	*Threshold Concentration (mg/l)*	*-Preferred Scenario-Scenario D Concentration (mg/l)*	*Result*
Lewis Bay – **Sentinel Station**	BHY – 3	0.38	0.39	**0.01 mg/l Over**
Hyannis Inner Harbor – Check Station	BH-1	0.50 (average)	0.51	**0.01 mg/l Over**
Hyannis Inner Harbor– Check Station	BH-2			
Uncle Roberts Cove– Check Station	BHY – 4	0.40	0.41	**0.01 mg/l Over**
Mill Creek– Check Station	MC-1	0.50	0.52	**0.02 mg/l Over**

Source: Lewis Bay MEP Report, Table IX-40

As shown in the above table, Scenario D for the Lewis Bay watershed misses by a slight margin. Based on discussions with the MEP team and MassDEP, it is believed that the Yarmouth sewershed described in Scenario D will meet the nitrogen removal targets once the proposed sewer services areas in theBarnstable

portion of Lewis Bay are included in this model scenario. To date, only the *existing* sewers in Barnstable are part of Scenario D MEP model. Barnstable is proposing to update these model runs with their proposed sewer areas.

Since the town has created a sewer scenario that removes almost all of the wastewater load in the Yarmouth portion of Lewis Bay and elected to recharge the treated effluent in another watershed outside of the Lewis Bay, the town feels that it has accounted for more than its share of the wastewater load. As a result, the town would like to request that the MEP model be re-run to include all of Barnstable's proposed Lewis Bay sewer areas.

The town of Yarmouth would like to request that this updated model scenario be conducted prior to the "final" TMDL being set so that both communities can demonstrate that they have recommended programs to meet these loadings. It is important for Yarmouth and the success of their wastewater management program that this final scenario be run so the town can present a model scenario that meets the TMDL. **[Comment 13]**

Very truly yours,

George Allaire, P.E.
Director of Public Works

cc: Robert C. Lawton, Jr., Town Administrator

Response:
Comment (13) MassDEP realizes that the towns of Barnstable and Yarmouth need to work this out. However, MassDEP needs to keep this project moving forward.

SIGN IN SHEET 9/15/2010
Lewis Bay System and Halls Creek
Draft TMDL Public Meeting

Signature	Print Name	Affiliation / E-Mail
Rick Dunn	RICK DUNN	MASS DEP / Dennis.Dunn@state.ma.us
Mike Ackerman	Mike Ackerman	MASS DEP / Michael.Ackerman@state.ma.us
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Nate Weeks	"	S&W GHD.
R. Ciolek	R. CIOLEK	NONE
Phil Boudreau	Phil Boudreau	Barnstable CAC
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Draft TMDL Public Meeting, 9/15/2010

Signature	Print Name	Affiliation
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Gail Maguire	Gail Maguire — WZPA	Kinsella@capenews.net
Alison McCall	Alison McCall	The Register

SIGN IN SHEET 9/23/2010
Lewis Bay System and Halls Creek
Draft TMDL Public Meeting

Signature	Print Name	Affiliation
	J. Ravalese, Jr	Self - Property Owner on LB.
	Jean Ravalese	Self - " " " "
	Rachel A Youngling	Hyannis Park Civic Association
	Rob Musci	CDM, Cambridge MA
	Paul O'Sullivan	CWO & 638 Main St W/Yar.
	TOM DURKIN	YAR. CONSERVATION COMM. AOP INC.
	Ron Gramzow	OWNER
	Donna Hill	h.o
	Charles S Spooner	HO
	Barbara S. Vessuer	HPCA
	Barbara Shine	HPCA W. Yarmouth Resident

Yarmouth

~~Edgartown Great Pond Draft~~ TMDL Public Meeting, 9/23/2010

Signature	Print Name	Affiliation
R. Sands	Renate Sands	LWVCCA
~~George Allis~~		
George Allis	George R Allis	Yarmouth DPW
Bob Brown	Robert Brown	W. Yarm
John Bark	John Bark	W Yarm.
Maryanne Morse	Maryanne Morse	W. Yarmouth
Karen O'Donnell	Karen O'Donnell	W. Yarmouth
Bruce Murphy	Bruce Murphy	Town Health
Tom Cambrea	Tom Cambrea	CCC
Loren Charle		W. Yarmouth
Sheila Charle	Sheila Charle	
Bob DeBarr	Bob DeBarr	Yarmouth
Chris Dawering		MassDEP

Yarmouth

~~Edgartown Great Pond Draft~~ **TMDL Public Meeting, 9/23/2010**

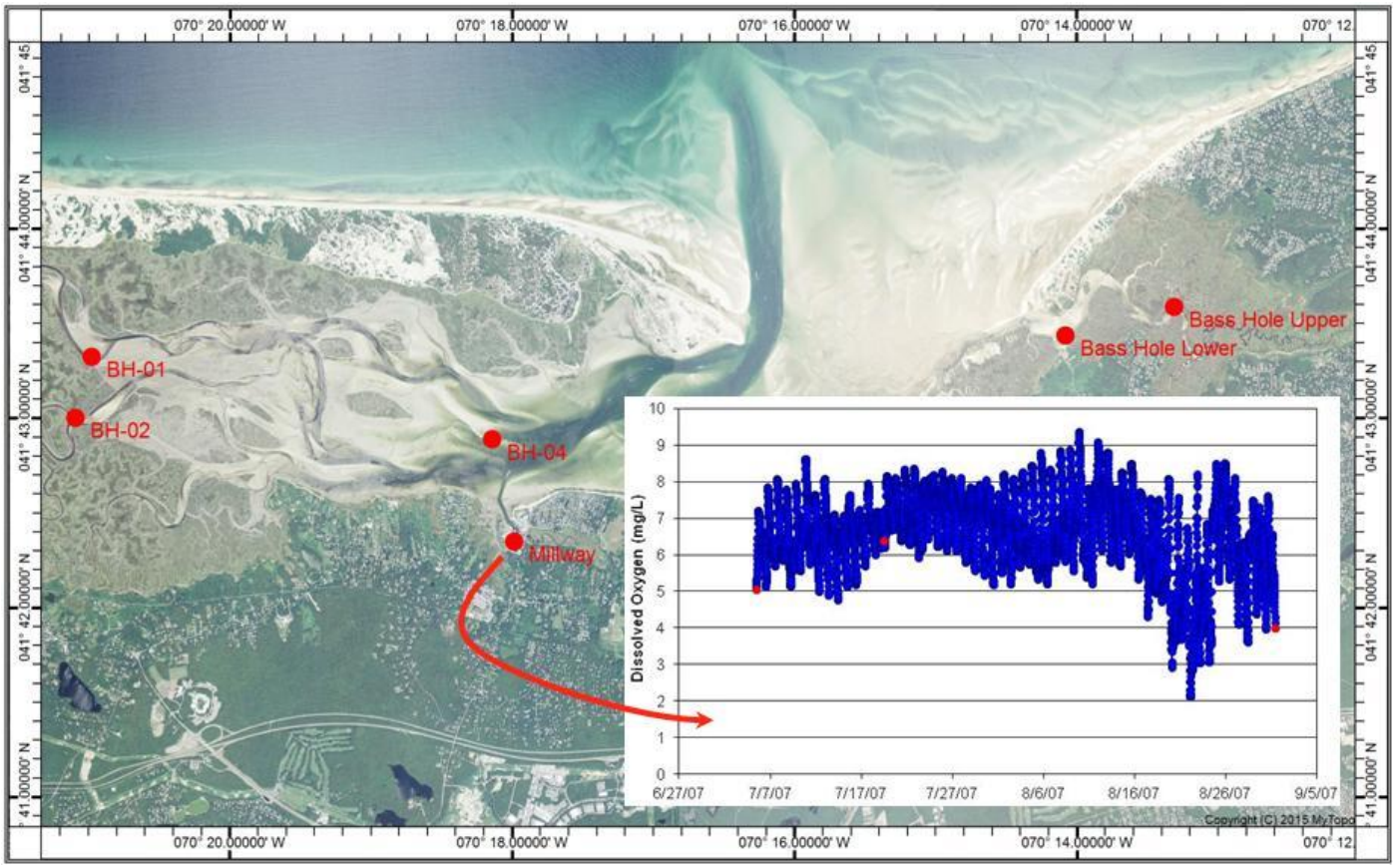
Signature	Print Name	Affiliation
	Dale Saad	Barnstable DPW.
	DAVE DeCORATO	DEP/BOSTON
Dorothy Cleaveland	Dorothy Cleaveland	Yarmouth resident

Appendix CC

MEP Draft Technical Report for Barnstable Harbor, June 2017

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Barnstable Great Marshes-Bass Hole Estuarine System Town of Barnstable & Dennis, Massachusetts



University of Massachusetts Dartmouth
School of Marine Science and Technology

Massachusetts Department of Environmental Protection

DRAFT REPORT – June 2017

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Barnstable Great Marshes -Bass Hole Estuarine System Town of Barnstable & Dennis, Massachusetts

DRAFT REPORT – June 2017

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Don Walters and John Masterson

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Massachusetts Department of Environmental Protection
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SMAST Coastal Systems Program
Jennifer Benson, Michael Bartlett, Sara Sampieri

Cape Cod Commission
Tom Cambareri

ACKNOWLEDGMENTS

The Massachusetts Estuaries Project Technical Team would like to acknowledge the contributions of the many individuals who have worked tirelessly for the restoration and protection of the critical coastal resources of Barnstable and Dennis and drove for the completion of the Linked Watershed-Embayment Model to Determine the Critical Nitrogen Loading Threshold for the Barnstable Great Marshes - Bass Hole Estuarine System. Without these stewards and their efforts, this project would not have been possible.

First and foremost we would like to recognize and applaud the commitment shown by both the Town of Dennis and the Town of Barnstable in carrying forward with the Massachusetts Estuaries Project and the protection/restoration of all the estuaries of the Towns. Significant time and attention has been dedicated to this effort by Mr. David Larkowski, whose efforts were instrumental to completion of this report. Mr. Larkowski, Director of the Dennis Water District was critical to establishing the Town of Dennis Estuarine Water Quality Monitoring Program and dedicated much personal time and effort towards organizing and participating in sample collection to determine the nutrient related water quality for Bass Hole and other estuaries in the Town of Dennis. Without this baseline water quality data the present analysis would not have been possible.

The MEP Technical Team would also like to recognize and applaud the significant time and effort in data collection and discussion spent by members of the Town of Barnstable Water Quality Monitoring Program and SMAST “volunteers”. The Monitoring of Barnstable Harbor was truly a coordinated joint effort between the Town staff, citizens and Coastal Systems Program scientific staff. These individuals gave of their time to collect nutrient related water quality from this system, without which the present analysis would not have been possible. Of particular note are Dale Saad for her energy and perseverance in the stewardship of one of the regions key coastal resources and John Jacobsen of the Town of Barnstable, both of whom have coordinated the Barnstable Town-wide Monitoring Program since its inception. Additionally, many in the Town of Barnstable helped in this effort, the Barnstable Department of Public Works and the Barnstable Shellfish Department, as well as the Barnstable Nutrient Management Committee. The technical team would like to specifically acknowledge the early efforts of Mark Els for helping to move this effort forward from its inception. In addition, the Three Bays Preservation Inc served as the major NGO promoting estuarine restoration and monitoring within the Town of Barnstable including the Barnstable Great Marshes.

In addition to local contributions, technical, policy and regulatory support has been freely and graciously provided by Paul Niedzwiecki and Tom Cambareri of the Cape Cod Commission. We are also thankful for the long hours in the field and laboratory spent by technical staff (Jen Benson, Michael Bartlett, Sara Sampieri and Dahlia Medieros), interns and students within the Coastal Systems Program at SMAST-UMD.

Support for this project was provided by the Town of Barnstable, Town of Dennis, Barnstable County and the MassDEP.

PROPER CITATION

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I. INTRODUCTION

The Barnstable Great Marsh estuary system (inclusive of Bass Hole) is located within the Towns of Barnstable, Yarmouth, and Dennis on Cape Cod Massachusetts. The system has a northern shore bounded by a narrow barrier beach (Sandy Neck) separating the Harbor from Cape Cod Bay, with which it exchanges tidal waters. The Barnstable Harbor Estuary is one of the largest embayments on Cape Cod and is comprised of large open water areas (namely Barnstable Harbor) as well as a large salt marsh system (Great Marshes) in the western portion of the overall embayment. Barnstable Harbor also supports small salt marsh dominated tributary sub-embayments such as Bass Hole-Chase Garden Creek near to the inlet to the system as well as the Millway which supports an active marina and is the discharge point for the Maraspin Creek salt marsh (Figure I-1). The watershed contributing nitrogen to the waters of the Barnstable Harbor Estuary contains portions of the Towns of Barnstable, Yarmouth, Sandwich, and Dennis. The sub-watershed to Bass Hole-Chase Garden Creek, which is a large subsystem on the eastern side of the Barnstable Great Marsh estuary system, is located in the Towns of Dennis and Yarmouth. Protection/Restoration of healthy or degraded habitats within the estuary will depend mainly upon the efforts of the Town of Barnstable and its citizens, however, depending on the level of nutrient management there may be the need for some coordination of efforts with the Towns of Dennis and Yarmouth.

The present configuration of the Barnstable Harbor embayment system results from a combination of glacially dominated geologic processes including the deposition of glacial outwash deposits and tidal flooding of drowned river valleys (Alder Creek, Bridge Creek, Boat Cove Creek, Marapsin Creek, Chase Garden Creek, Whites Brook) formed primarily by post-glacial rivers and enhancements to support human uses (e.g. tidal channel to Millway). The major drowned-river valley components are found in the Great Marshes and associated tributary salt marshes such as Bass Hole-Chase Garden Creek. Overall, the Barnstable Great Marsh estuary system is a composite or complex estuary comprised of the aforementioned drowned river valley sub-estuaries exchanging tidal waters with a large lagoonal estuary, Barnstable Harbor, which is flushed by Cape Cod Bay. The large open water basin that is regarded as Barnstable Harbor is oriented in an east-west manner with a central axis that runs parallel to the shore line and is bounded to the north by barrier beach and to the south by the uplands of Cape Cod. The lagoon represents more than 1/2 of the estuarine area and habitat. The lagoon was mainly formed by the depression created by the overlying Cape Cod Lobe of the continental glacier that formed Cape Cod and occupied Cape Cod Bay during the last glacial period. The wetland shield that generally surrounds the lagoon was enhanced by sediments deposited in a lake that occupied most of the southern portion of the current Cape Cod Bay during the retreat of the glacier. Following the retreat of the glaciers, sea level gradually rose and drove erosion and sediment transport along the shores of Cape Cod. Sediment from the eroding Cape Cod Bay-side uplands to the west of Barnstable supplied sand to the bay side beaches by long shore drift. The sand moving east formed a spit of land off of the Barnstable mainland and an open water lagoon with associated salt marsh formation along the edges of the lagoon. The spit (Sandy Neck) formed through steady longshore transport of sand to the west and provided protection from the waves of Cape Cod Bay thus forming the sheltered environment of Barnstable Harbor with its associated salt marshes. The Barnstable Great Marsh estuary system is a relatively “young” estuary and coastal feature that required significant post glaciation sea-level rise and the formation of the barrier beach, occurring on the order of 2500-4000 years b.p.



Figure I-1. Study region proximal to the Barnstable Harbor embayment system for the Massachusetts Estuaries Project nitrogen thresholds analysis. Tidal waters enter the system through one wide "inlet" to Cape Cod Bay. Freshwaters enter from the watershed primarily through 6 notable surface water discharges: Alder Creek, Bridge Creek, Boat Cove Creek, Maraspin Creek Chase Garden Creek and White Brook, as well as direct groundwater discharge. The main basin constitutes Barnstable Harbor.

Although erosional processes associated with post-glacial streams and rivers were fundamental to the formation of portions of this system, at present the streams are relatively small and discharge only a small portion of the aquifer recharge to the estuary. The biggest of the streams is the Boat Cove Creek which discharges to the innermost portion of the Great Marshes portion of the overall system. The other five small freshwater creeks discharge at various points along salt marsh that fringes the southern side of the harbor. Most freshwater from the watershed enters the embayment through direct groundwater seepage along the southern shore after passing through seeps along the edges of the system's wetland shield.

As is typical of many other Cape Cod embayments (Nauset System, Pleasant Bay, Wellfleet Harbor), Barnstable Harbor is separated from Cape Cod Bay by a barrier beach, which is heavily influenced by coastal storms. Within portions of Barnstable Harbor, mainly Boat Cove Creek and Maraspin Creek, the tide propagating through the wide opening of the Harbor is attenuated by culverts which reduce tidal flow into the interior portions of these sub-systems. Generally, all other areas of the Barnstable Great Marsh estuary system experience an undampened tide and are relatively well flushed.

The barrier beach (Sandy Neck) that protects Barnstable Harbor to the north is a very dynamic geomorphic feature, due to the strong influence of littoral transport processes. While the formation of the Barnstable Great Marsh estuary system was dependent upon coastal processes which formed the barrier beach to form the lagoon, the estuary continues to be affected by these same coastal processes as they alter both the length of the spit extending eastward towards the inlet and the location of the tidal flats at the inlet. The effect of these processes is no longer to significantly affect the geomorphology of the estuary and its basins, but to partially control the quality of the habitats within the estuary given how they may be influenced by activities in the contributing watershed. Changes in hydrodynamics wrought by inlet and shoal dynamics is a key factor in determining the effects of watershed nitrogen loading on estuarine health (see Sections V & VI). To the extent that the small inlets to the sub-components of Barnstable Harbor become restricted due to shifting shoals and tidal flushing is reduced, nitrogen loading impacts will be magnified over present conditions. This effect is moderated by the fact that large sections of the western and southern portions of the overall system are dominated by salt marsh.

Similar to the Wellfleet Harbor, Nauset Harbor and Pleasant Bay embayment systems, Barnstable Harbor is a shallow coastal estuary dominated by salt marsh and tidal flats, as well as being located within a watershed that includes lake deposits, beach/dune and marsh deposits as well as moraine deposits, generally laid down after the retreat of the Cape Cod Lobe of the Laurentide Ice sheet ~15,000 years ago (Figure I-2, Oldale, 1992). The upper portions of the watershed are generally composed of both younger and older outwash deposits. The outwash material is highly permeable and varies in composition from well sorted medium sands to course pebble sands and gravels. As such, direct rainwater run-off is typically rather low for these coastal systems and therefore, most freshwater inflow to these estuarine systems is via groundwater discharge or groundwater fed surface water flow (e.g. Alder Creek, Boat Cove Creek, Maraspin Creek). Barnstable Harbor acts as a large mixing zone for terrestrial freshwater inflow and saline tidal flow from Cape Cod Bay, however, the salinity characteristics of the embayment system are mainly dominated by that of Cape Cod Bay with the exception of the uppermost reaches of the salt marsh tidal creeks that receive fresh surface water discharges. Given the large tidal flows and volumetric exchange, there is presently only minor dilution of salinity throughout most of the estuary.

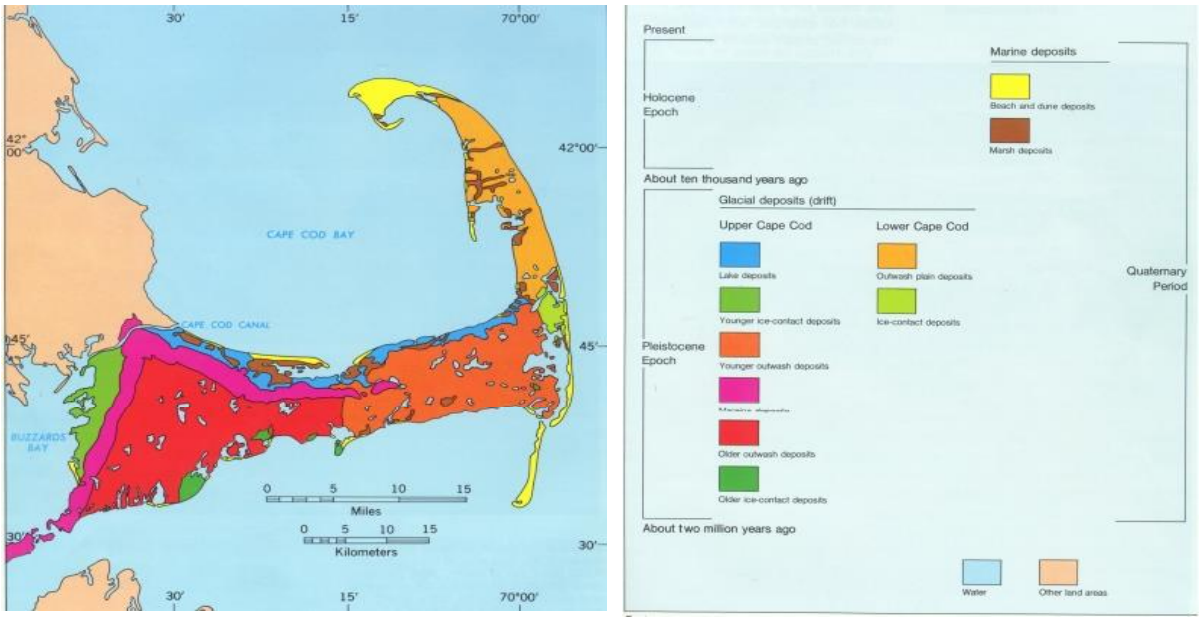


Figure I-2. Geologic map of Cape Cod (generalized from detailed mapping by K. F. Mather, R. P. Goldthwait, L. R. Theismeyer, J. H. Hartshorn, Carl Koteff, and R. N. Oldale).

Barnstable Harbor, along with its associated terminal sub-embayments which are dominated by salt marshes, constitutes an important component of the natural and cultural resources of Cape Cod and the Towns of Barnstable, Yarmouth, and Dennis. As such the Towns of Barnstable and Dennis, working with the Coastal Systems Program at the University of Massachusetts School for Marine Science and Technology, have undertaken comprehensive water quality monitoring of the Barnstable Great Marsh estuary system.

The primary ecological threat to Barnstable Harbor resources is degradation resulting from nutrient enrichment. Loading of the critical eutrophying nutrient, nitrogen, to the embayment waters has been greatly increased over the past few decades with further increases certain unless nitrogen management is implemented. The nitrogen loading to this and other outer Cape embayment systems such as Pleasant Bay, Wellfleet Harbor and Nauset Harbor, like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater. The Towns of Barnstable, Yarmouth, and Dennis have been steadily growing over the past two to three decades and Barnstable does have limited centralized wastewater treatment to process the increasing levels of nutrients resulting from the increased development. As existing and probable increasing levels of nutrients impact the coastal embayments of Barnstable Harbor, the potential for water quality degradation will increase, with further harm to invaluable environmental resources of the Towns.

The large shoreline and numerous streams greatly increases the potential for direct discharges from homes situated on the shore and decreases the travel time of groundwater from areas removed from the shoreline and close to the watershed boundary. The nature of enclosed embayments in populous regions brings two opposing elements to bear: as protected marine shoreline they are popular regions for boating, recreation, and land development; as semi-enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the more enclosed portions of the basin (like the Millway) and portions furthest from the inlet are at risk of

eutrophication from high nitrogen loads entering via direct groundwater seepage in addition to surface water inflows from adjacent sub-watersheds.

Given the value of the resource and concern over the problems associated with nutrient over-enrichment, in 1978 the Massachusetts Secretary of Environmental Affairs designated part of Barnstable Harbor as an Area of Critical Environmental Concern (ACEC). The ACEC boundary generally follows the 100-year floodplain elevation on the landward side and mean low water on the seaward side of the Harbor. Almost half of the land within the ACEC boundary is covered by salt marsh habitat, and over 75% of the area is located within the 100-year floodplain. The majority of the 4,335 acres of protected open space in the ACEC are owned by the Town of Barnstable - located on Sandy Neck and in the adjacent expanse of salt marsh, locally known as the Great Marsh. Approximately 90% of the ACEC exists within the Town of Barnstable and ~10% exists in the Town of Sandwich. There are also several private in-holdings, including two small (< 20 acre) tracts owned by The Nature Conservancy and cottages at the end of the Neck, which are leased by the town to private individuals. The purpose of the ACEC program is to preserve, restore, and enhance critical environmental resource areas in the state. The designation is intended to encourage communities to steward the area's natural resources, but in practical terms it provides little regulatory oversight. It has therefore been necessary for the Town of Barnstable and Sandwich to take the initiative to provide such oversight and clarity through amendments and revisions to town Environmental By-Laws and take necessary steps to protect the Barnstable Harbor resource consistent with the ACEC designation.

As the primary stakeholder to the Barnstable Harbor embayment system, the Town of Barnstable was among the first communities to become concerned over perceived degradation of embayment health. The Town of Barnstable (via the Town of Barnstable Department of Public Works) has long recognized the potential threat of nutrient over-enrichment of the Town's coastal embayments. As such, a comprehensive water quality monitoring program was developed to establish the current water quality conditions in the harbor and monitor for gradual changes in water quality over time. The common focus of the water quality monitoring efforts undertaken by the Town of Barnstable has been to gather site-specific data on the current nitrogen related water quality throughout the Barnstable Great Marsh estuary system to ultimately determine the relationship between observed water quality and watershed nitrogen loads. This multi-year effort has provided the baseline information required for determining the link between upland loading, tidal flushing, and estuarine water quality. The water quality data set developed by the Town of Barnstable Water Quality Monitoring Program over the past 5+ years forms a baseline from which to gauge long-term changes as watershed nitrogen management moves forward. The quality of these data allowed the MEP to prioritize the Barnstable Great Marsh estuary system for this next step in the protection and management of the harbor.

The MEP effort builds upon the efforts of the water quality monitoring programs, and previous hydrodynamic and water quality analyses, and includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for the Barnstable Great Marsh estuary system, including all sub-embayments such as the Millway and Bass Hole in addition to specific consideration of the Great Marshes portion of the overall embayment.

The critical nitrogen targets and the link to specific ecological criteria form the basis for the nitrogen threshold limits necessary to undertake wastewater master planning and nitrogen management alternatives development which may be currently needed by the Town of Barnstable, Yarmouth, and Dennis. While the completion of this complex multi-step process of rigorous scientific investigation to support watershed based nitrogen management has taken

place under the programmatic umbrella of the Massachusetts Estuaries Project, the results stem directly from the efforts of large number of Town staff, committees, and volunteers over many years. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns to develop and evaluate the most cost effective nitrogen management alternatives to protect/restore this valuable coastal resource which is currently being degraded by nitrogen overloading.

I.1 THE MASSACHUSETTS ESTUARIES PROJECT APPROACH

Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The nutrients are primarily related to changes in watershed land-use associated with increasing population within the coastal zone over the past half century. Many of Massachusetts' embayments have nutrient levels that are approaching or are currently over this assimilative capacity, which begins to cause declines in their ecological health. The result is the loss of fisheries habitat, eelgrass beds, and a general disruption of benthic communities and the food chain which they support. At higher levels, nitrogen loading from surrounding watersheds causes aesthetic degradation and inhibits even recreational uses of coastal waters. In addition to nutrient related ecological declines, an increasing number of embayments are being closed to swimming, shellfishing and other activities as a result of bacterial contamination. While bacterial contamination does not generally degrade the habitat, it restricts human uses. However like nutrients, bacterial contamination is frequently related to changes in land-use as watersheds become more developed. The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities. This is particularly the case across Cape Cod and in the Town of Barnstable considering the significant embayments of Barnstable Harbor, Three Bays, Lewis Bay and Centerville Harbor.

The primary nutrient causing the increasing impairment of the Commonwealth's coastal embayments is nitrogen and the primary sources of this nitrogen are wastewater disposal, fertilizers, and changes in the freshwater hydrology associated with development. At present there is a critical need for state-of-the-art approaches for evaluating and restoring nitrogen sensitive and impaired embayments. Within southeastern Massachusetts alone, almost all of the municipalities (as is the case with the Town of Wellfleet) are grappling with Comprehensive Wastewater Planning and/or environmental management issues related to the declining health of their estuaries.

Municipalities are seeking guidance on the assessment of nitrogen sensitive embayments, as well as available options for meeting nitrogen goals and approaches for restoring impaired systems. Many of the communities have encountered problems with "first generation" watershed based approaches, which do not incorporate estuarine processes. The appropriate method must be quantitative and directly link watershed and embayment nitrogen conditions. This "Linked" Modeling approach must also be readily calibrated, validated, and implemented to support planning. Although it may be technically complex to implement, results must be understandable to the regulatory community, town officials, and the general public.

The Massachusetts Estuaries Project represents the next generation of watershed based nitrogen management approaches. The Massachusetts Department of Environmental Protection (MassDEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool for watershed-embayment management for communities

throughout Southeastern Massachusetts. The MEP approach was selected after extensive review by the MassDEP and USEPA and associated scientists and engineers. It has subsequently been applied to more than 60 estuaries and reviewed by other state agencies, municipalities, non-profit environmental organizations, engineering firms, scientists and private citizens. Over the course of the extensive reviews, the MEP approach has proven to be robust and capable of yielding quantitative results to support management of a wide variety of estuaries.

The Massachusetts Estuary Project is founded upon science-based management. The Project is using a consistent, state-of-the-art approach throughout the region's coastal waters and providing technical expertise and guidance to the municipalities and regulatory agencies tasked with their management, protection, and restoration. The overall goal of the Massachusetts Estuaries Project is to provide the DEP and municipalities with technical guidance to support policies on nitrogen loading to embayments. In addition, the technical reports prepared for each embayment system in the MEP study region is serving as the basis for the development of Total Maximum Daily Loads (TMDLs). Development of TMDLs is required pursuant to Section 303(d) of the Federal Clean Water Act. TMDLs must identify sources of the pollutant of concern (in this case nitrogen) from both point and non-point sources, the allowable load to meet the state water quality standards and then allocate that load to all sources taking into consideration a margin of safety, seasonal variations, and several other factors. In addition, each TMDL must contain an outline of an implementation plan. For this project, the DEP recognizes that there are likely to be multiple ways to achieve the desired goals, some of which are more cost effective than others and therefore, it is extremely important for each Town to further evaluate potential options suitable to their community. As such, DEP will likely be recommending that specific activities and timelines be further evaluated and developed by the Towns (sometimes jointly) through the Comprehensive Wastewater Management Planning process.

The MEP nitrogen threshold analysis includes site-specific habitat assessments and watershed/embayment modeling approaches to develop and assess various nitrogen management alternatives for meeting selected nitrogen goals supportive of restoration/protection of embayment health.

The major MEP nitrogen management goals are to:

- provide technical analysis and supporting documentation to Towns as a basis for sound nutrient management decision making towards embayment restoration
- develop a coastal TMDL working group for coordination and rapid transfer of results,
- determine the nutrient sensitivity of each of 70 embayments in Southeastern MA
- provide necessary data collection and analysis required for quantitative modeling,
- conduct quantitative TMDL analysis, outreach, and planning,
- keep each embayment's model "alive" to address future municipal needs.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach (Figure I-3). This approach represents the "next generation" of nitrogen management strategies. It fully links watershed inputs with embayment circulation and nitrogen characteristics. The Linked Model builds on and refines well accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site specific measurements within each watershed and embayment;

- uses realistic "best-estimates" of nitrogen loads from each land-use within the watershed (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for watershed nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated from sediments within the embayment;
- is validated by both independent hydrodynamic, nitrogen and salinity concentrations, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied for watershed nitrogen management of more than 60 embayments throughout southeastern Massachusetts. In these applications it has become clear that the Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options. The MEP Technical Team, through SMAST-UMD, has conducted more than 200 scenarios to date.

The Linked Watershed-Embayment Model when properly parameterized, calibrated and validated for a given embayment becomes a nitrogen management planning tool, which fully supports TMDL analysis. The Model facilitates the evaluation of nitrogen management alternatives relative to meeting water quality targets within a specific embayment. The Linked Watershed-Embayment Model also enables Towns to evaluate improvements in water quality relative to the associated cost. In addition, once a model is fully functional it can be "kept alive" and updated for continuing changes in land-use or embayment characteristics (at minimal cost). In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries.

Linked Watershed-Embayment Model Overview: The Model provides a quantitative approach for determining an embayment's: (1) nitrogen sensitivity, (2) nitrogen threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is both calibrated and fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-3). This methodology integrates a variety of collected field data and models, specifically:

- Water column Monitoring - multi-year embayment nutrient sampling
- Hydrodynamics -
  - embayment bathymetry
  - site specific tidal record
  - current records (in complex systems only)
  - hydrodynamic model
- Watershed Nitrogen Loading
  - watershed delineation
  - stream flow (Q) and nitrogen load
  - land-use analysis (GIS)
  - watershed N model built from individual parcels
- Embayment TMDL - Synthesis
  - linked Watershed-Embayment N Model
  - salinity surveys (for linked model validation)

- rate of N recycling within embayment
- continuous dissolved oxygen record
- Macrophyte survey
- Infaunal survey

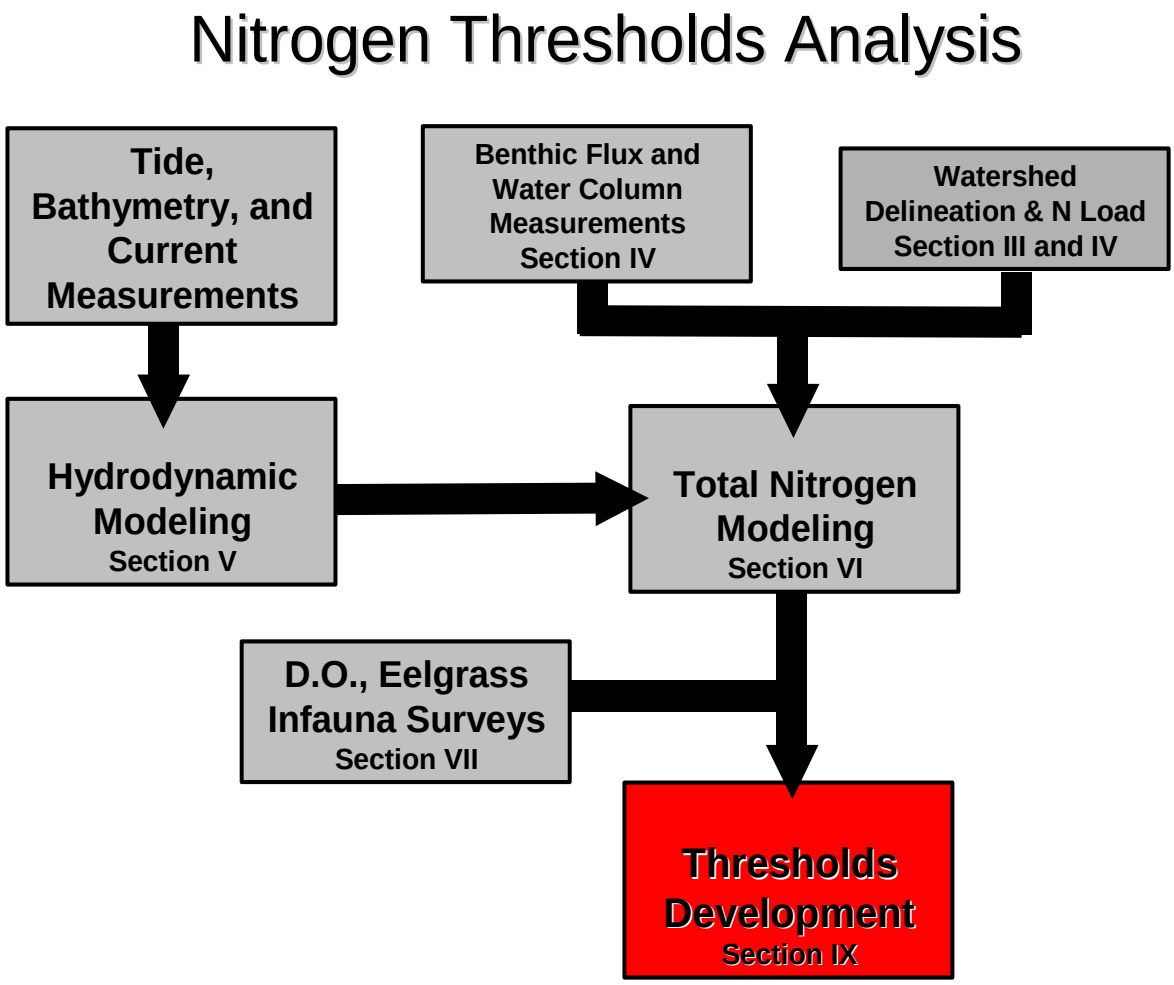


Figure I-3. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

As management alternatives are being developed and evaluated, it is important to note that nitrogen loading and tidal exchange within each sub-embayment is the primary factor controlling habitat health in that sub-basin. The quality of the inflowing waters from Barnstable Harbor to tributary sub-embayments is the other, although a slightly less critical controlling factor given the connectivity to low nutrient water from Cape Cod Bay. In addition the nitrogen loading to each sub-embayment affects the health of the receiving main basin of the System. Much of the nitrogen entering the lagoonal component first passes through a sub-embayment. The result is that the restoration of potentially nitrogen impaired sub-embayments to the Barnstable Great Marsh estuary system require both “local” or contributing area specific nitrogen management, as well as management of nitrogen levels within the watershed of the larger “regional” main basin.

I.2 NITROGEN LOADING

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the Barnstable Harbor embayment system, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer mineral (Weiskel and Howes 1992). Since even Cape Cod "rivers" are primarily groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant-available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1998, Weiskel and Howes 1992, Smith *et al.* 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within Barnstable Great Marsh estuary system follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. As nearshore coastal salt ponds, marshes and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 and in press, Ramsey et al., 1995, Howes and Taylor, 1990, the Falmouth Coastal Overlay Bylaw). While each approach may be different, they all focus on changes in nitrogen loading from watershed to embayment, and aim at projecting the level of increase in nitrogen concentration within the receiving waters. Each approach depends upon estimates of circulation within the embayment; however, few directly link the watershed and hydrodynamic models, and virtually none include internal recycling of nitrogen (as was done in the present effort). However, determination of the "allowable N concentration increase" or "threshold nitrogen concentration" used in previous studies had a significant uncertainty due to the need for direct linkage of watershed and embayment models and site-specific data. In the present effort we have integrated site-specific data on nitrogen levels and the gradient in N concentration throughout the Barnstable Great Marsh estuary system monitored by the Town of Barnstable and the Town of Dennis Water Quality Monitoring Programs with site-specific habitat quality data (D.O., eelgrass, phytoplankton blooms, benthic animals) to "tune" general nitrogen thresholds typically used by the Cape Cod Commission, Buzzards Bay Project, and Massachusetts State Regulatory Agencies.

In general, nutrient over-fertilization is termed “eutrophication” and when the nutrient loading is primarily from human activities, “cultural eutrophication”. Although the influence of human-induced changes has increased nitrogen loading to the Barnstable Great Marsh estuary system and potentially contributed to the degradation in ecological health, it is sometimes possible that eutrophication within portions of the Barnstable Great Marsh estuary system could potentially occur without anthropogenic influence and this must always be considered in the nutrient threshold analysis. While this finding would not change the need for protection or restoration, it would change the approach and potential targets for management. As part of future restoration efforts, it is important to understand that it may not be possible to turn each embayment into a “pristine” system.

I.3 WATER QUALITY MODELING

Evaluation of upland nitrogen loading provides important “boundary conditions” for water quality modeling of the Barnstable Harbor-Great Marshes system; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within the system. Therefore, water quality modeling of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. The spread of pollutants may be analyzed from tidal current information developed by the numerical models.

The MEP water quality evaluation examined the potential impacts of nitrogen loading into the Barnstable Great Marsh estuary system and all of its component sub-embayments (e.g. Bass Hole). A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for the system. Once the hydrodynamic properties of the estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates.

Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic models were then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis defined by MEP watershed delineations based on USGS recharge area outputs from the regional West Cape model. Almost all nitrogen entering the Barnstable Great Marsh estuary system is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Cape Cod Bay source waters and throughout the Barnstable Great Marsh estuary system was taken from the water quality monitoring program run by the Town of Barnstable (associated with the Coastal Systems Program at SMAST). Measurements of current salinity and nitrogen and salinity distributions throughout estuarine waters of the system were used to calibrate and validate the water quality model (under existing loading conditions).

I.4 REPORT DESCRIPTION

This report presents the results generated from the implementation of the Massachusetts Estuaries Project linked watershed-embayment approach to the Barnstable Great Marsh estuary

system (inclusive of Bass Hole) for the Towns of Barnstable and Dennis. A review of existing studies related to habitat health or nutrient related water quality is provided in Section II with a more detailed review of prior hydrodynamic investigations in Section V. The development of the watershed delineations and associated detailed land use analysis for watershed based nitrogen loading to the coastal system is described in Sections III and IV. In addition, nitrogen input parameters to the water quality model are described, along with streamflow measurements and loads. Since nitrogen recycling associated with the bottom sediments is a critical (but often overlooked) component of nitrogen loading to shallow estuarine systems, determination of the site-specific magnitude of this component was also summarized in Section IV. Nitrogen loads from the watershed and sub-watershed surrounding the estuary were derived from town-supplied data and offshore water column nitrogen values were derived from an analysis of monitoring station data for an offshore station proximal to the "inlet" of the Harbor (Section IV and VI). Intrinsic to the calibration and validation of the linked-watershed embayment modeling approach is the collection of background water quality monitoring data (conducted by the municipality) as discussed in Section VI. Results of hydrodynamic modeling of embayment circulation are discussed in Section V and nitrogen (water quality) modeling, as well as an analysis of how the measured nitrogen levels correlate to observed estuarine water quality are described in Section VI. This analysis includes modeling of current conditions, conditions at watershed build-out, and with removal of anthropogenic nitrogen sources. In addition, an ecological assessment of each embayment was performed that included a review of existing water quality information and the results of a benthic analysis (Section VII). The modeling and assessment information is synthesized and nitrogen threshold levels developed for restoration of each embayment in Section VIII.

II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

Nutrient additions to aquatic systems cause shifts in a series of biological processes that can result in impaired nutrient-related habitat quality. Effects include excessive plankton and macrophyte growth, which in turn lead to reduced water clarity, organic matter enrichment of waters and sediments with concomitant increased rates of oxygen consumption and periodic depletion of dissolved oxygen, especially in bottom waters, and the limitation of the growth of desirable species such as eelgrass. Even without changes to water clarity and bottom water dissolved oxygen, the increased organic matter deposition to the sediments generally results in a decline in habitat quality for benthic animal communities (e.g. "infauna", animals living in the sediments). This habitat change causes a shift in infaunal communities from high diversity, deep burrowing forms (which include economically important species), to low diversity shallow dwelling organisms. This shift alone causes significant degradation of the resource and a loss of productivity important for local shell fisherman and sport and offshore fin fisheries, which are dependent upon these highly productive estuarine systems as a habitat and food resource during migration or during different phases of their life cycles. In addition, the diverse avian fauna which feed upon infauna or dependent fish communities are also affected and their numbers and diversity decline. This overall nutrient driven process is generally termed “eutrophication” and in embayment systems, unlike in shallow lakes and ponds, it is not necessarily a part of the natural evolution of a system.

In most marine and estuarine systems, such as the Barnstable Great Marsh estuary system, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if the level of nitrogen enrichment is controlled, then eutrophication is controlled. As a result, there has been significant effort to develop tools for predicting how modification of watershed nitrogen loads and changes in tidal flushing quantitatively cause changes in the concentrations of water column nitrogen in the receiving estuary. Further development of these approaches generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2002).

These previous tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specifics for any given water body. In contrast, some approaches can be tailored for each individual estuary of interest, but require large amounts of site-specific information and therefore are not generally applied. The present Massachusetts Estuaries Project (MEP) effort uses one such site-specific approach, but includes a tailored and targeted data collection approach that is “parsimonious” in its level of effort (MEP Peer Review, 2011). The assessment focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species within individual estuaries. The linked watershed-embayment model is built using embayment- and watershed-specific measurements, thus enabling calibration of the prediction process for the specific conditions in each of the coastal embayments of southeastern Massachusetts, including the Barnstable Great Marsh estuary system. As the MEP approach requires substantial amounts of site-specific data collection, part of the program is to review previous data collection and modeling efforts. These reviews are both for purposes of “data mining” and to gather additional information on an estuary’s habitat quality and unique features.

Few studies relating to nitrogen loading, hydrodynamics and habitat health have been conducted within the Barnstable Great Marsh estuary system (inclusive of Bass Hole) over the past two decades to help inform the MEP process. Directly supporting the present Massachusetts

Estuaries Project effort to develop a nitrogen threshold for the Barnstable Harbor estuary was the Barnstable Harbor Nutrient Related Water Quality Monitoring Program. Water quality monitoring stations in Barnstable Harbor were sampled through collaborative effort between the Town of Barnstable and scientists from the Coastal Systems Program at UMD-SMAST. Water quality monitoring stations in Bass Hole were sampled by Town of Dennis staff with assays also conducted by the Coastal Systems Program Laboratory. This previous work provided quantitative information on water column parameters over multiple summers (including nitrogen) and was used in the calibration and verification of the MEP water quality model for this estuary. Available previous studies are summarized below.

Barnstable Harbor Nutrient Related Water Quality Monitoring: The MEP analysis requires high quality water quality data in order to complete its assessment and modeling approach. Baseline water quality monitoring was undertaken in the Barnstable Great Marsh estuary system as well as Bass Hole. The Town of Barnstable Water Quality Monitoring Program collected data on nutrient-related water quality throughout the estuarine systems of the Town of Barnstable (specifically the Harbor and Great Marsh) whereas data from Bass Hole was generated through the Town of Dennis Water Quality Monitoring Program. Both programs were developed with technical support from the SMAST Coastal Systems Program and all water quality samples were assayed at the SMAST Coastal Systems Program Laboratory. The Town of Barnstable and Dennis Water Quality Monitoring Programs have collected the principal baseline water quality data necessary for ecological management of each portion of the overall estuary. Both the monitoring programs (Barnstable and Dennis) are citizen-based water quality monitoring programs run by the Towns. In Barnstable the program is run through the Department of Public Works (D. Saad, Town of Barnstable Senior Project Manager). In Dennis, the water quality monitoring program was initiated through the Dennis Water District (D. Larkowski) and then turned over to the Town of Dennis (Water Quality Advisory Committee). Both town programs were provided with technical and analytical assistance from the Coastal Systems Program at SMAST-UMD. During the period the town monitoring programs were actively collecting MEP water samples, the monitoring program approaches had a USEPA and MassDEP approvals (MEP Quality Assurance Project Plan, 2003, Dennis SAP, 2005) and the SMAST Coastal Systems Program Laboratory had USEPA approval for all assay procedures.

During the course of the multi-year sampling program, water samples were collected from each station in each portion of the overall system during 6 sample rounds from June through mid-September starting in 2005 and continuing to present. Sampling was undertaken in this manner to target what is typically the period of poorest nutrient related water quality that is the focus of managing these systems. Marine stations were sampled at approximately two-week intervals during the falling tide (targeting the 2 hours before and after mid-ebb) during the early morning hours (6 to 9 A.M.). In general terms, the Town of Barnstable collected samples from 6 "open" water stations in the Harbor, CSP-SMAST scientific staff collected samples from 5 salt marsh stations and Town of Dennis staff collected samples from 7 stations distributed throughout the Bass Hole salt marsh, which discharges to the Barnstable Great Marsh estuary system.

The common focus of the Town of Barnstable and Dennis Water Quality Monitoring Program efforts has been to gather site-specific data on the current nitrogen-related water quality throughout the Harbor and associated salt marshes to support evaluations of observed water quality and habitat health. The Monitoring Programs generated a data set that elucidated the long-term water quality of the overall system (Figure II-1) and served as the basis for calibration and validation of the MEP water quality model. The monitoring was undertaken as a



Figure II-1. Town of Barnstable and Dennis Water Quality Monitoring Program for Barnstable Harbor (stations "BM" and "GM") and Bass Hole (stations "BSH") respectively. Estuarine water quality monitoring stations sampled by Town of Barnstable and Dennis staff and volunteers and analyzed by SMAST staff during summers 2005, 2006, 2007.

collaborative effort with the Towns coordinating the field effort and chemical assays being completed by the SMAST Coastal Systems Analytical Facility. The Coastal Systems Analytical Facility is located in the School for Marine Science and Technology UMASS-Dartmouth, 706 S. Rodney French Blvd, New Bedford, MA, and the laboratory Points of Contact are Sara Sampieri 508-910-6325 (ssampieri@umassd.edu) or Mike Bartlett (mbartlett@umassd.edu). Use of the SMAST Analytical Facility ensured sufficient sensitivity and accuracy of the analytical protocols and that proper QA/QC procedures were followed to allow incorporation of the data into the MEP analysis. Since the MEP approach relies on site-specific data, the baseline water quality data collected by the towns were a prerequisite to complete the MEP assessment of Barnstable Harbor. Implementation of the MEP's Linked Watershed-Embayment Approach necessarily incorporates the quantitative water column nitrogen data (2005-2015) gathered by the Monitoring Program and watershed and embayment data collected by MEP staff.

Since the results of the long term Water Quality Monitoring Program (2005-2015) and the above studies indicate that portions of the Barnstable Great Marsh estuary system could be threatened by the combination of land-derived nitrogen inputs and intermittent restriction of tidal exchange, the Towns of Barnstable, Dennis, and Yarmouth undertook participation in the Massachusetts Estuaries Project to complete ecological assessment and water quality modeling for the development of nutrient thresholds for protection of the Barnstable Harbor-Great Marshes system.

Initial Study of the Hydrodynamics and Flushing of Barnstable Harbor (ACRE, 1999): This study was completed in 1999 to evaluate the hydrodynamic characteristics of this system for purposes of calculating system flushing rates for the entire system as well as local residence times for selected sub-embayments. The study was performed by Applied Coastal Research and Engineering, Inc. (ACRE) for the Town of Barnstable, Massachusetts under a grant from the Cape Cod Commission. The purpose of the study was to evaluate flushing characteristics for selected areas to guide Town planning efforts within the system's watershed and develop a first order review of sensitivity of the system to watershed nitrogen loading (CCC, 2002).

To develop the flushing characteristics, ACRE (a MEP Technical Team member) developed a calibrated, two-dimensional numerical model of the estuary. This model relied upon data collected by Dutch researchers during an earlier study of the system in 1991-1993 (Van der Molen, 1997), along with tidal elevations collected by ACRE at six locations within the system. This study measured system geometry (marsh elevations, bathymetry) as well as tidal elevations. All collected data were used to generate a computer model that represented key features of the estuary. The model was calibrated against the tidal measurements to assure the essential hydrodynamics were being simulated correctly. Once calibrated, the model was used to calculate the tidal prism (water volume transported into the system during a single flood tide) and system and local residence times of water within various portions of the system.

Seasonal Changes in the Community Structure of the Macrobenthos Inhabiting the Intertidal Sand and Mud Flats of Barnstable Harbor, Massachusetts (R. Whitlatch, 1977): The purpose of this study was to describe the general macrobenthic community structure of a portion of the intertidal sand and mud flats of Barnstable Harbor, Massachusetts, and also to examine in greater detail seasonal changes in patterns of community structure and species composition at one of the sedimentary environments. The study was presented to provide a context for a more detailed examination of methods of resource allocation in deposit-feeding faunal assemblages and micro-dispersion patterns of surface-feeding polychaete annelids. Sixteen preliminary stations were sampled in the western portion of the intertidal sand and mud flats of Barnstable Harbor in June-July 1974. Faunal data collected from these stations were used

to help in delimiting the general characteristics of the various macrofaunal assemblages of this region. One station was chosen from the initial sampling program for more detailed long-term sampling. Samples were collected at low tide with a small hand held core tube 12.5 cm in diameter. The core tube was gently pushed into the substrate to a depth of 17-20 cm and removed with a shovel. The location of sampling sites at each station was determined by random sampling coordinates. Samples were brought to a laboratory and gently washed through a 250 mesh screen. The residues were preserved in 70% alcohol, sorted under a dissecting microscope and the organisms encountered were identified to species. Ultimately, 64 core samples were obtained from the sampling of 16 stations in Barnstable Harbor. Of the 47 species found in the survey, the majority were polychaetes (29 species), crustaceans (9 species) and molluscs (6 species). This serves as a potentially meaningful point of comparison to the MEP infaunal analysis in order to determine how the benthic community has changed from 1974 to present. Among other findings, the study concluded that the majority of macrobenthos at Barnstable Harbor were deposit-feeders which comprised more than 90% of all organisms sampled. The deposit-feeders normally dominate mud and muddy-sand sediments. Suspension-feeders were most abundant in fine sands. The relationship of sedimentary parameters affecting the distribution of both trophic groups proposed by previous researchers (e.g. H. Sanders) is generally supported. While no significant changes were evident in species diversity, evenness, or species number throughout a 19 month sampling period, classification analysis delimited seasonal clustering of both samples and species groupings. These patterns were repeatable over a two year period suggesting that dynamic "equilibrium", no successional change was occurring in Barnstable Harbor at the time of the study.

Regulatory Assessments of Barnstable Harbor Resources - In addition to locally generated studies, the Barnstable Great Marsh estuary system is part of the Commonwealth's environmental surveys to support regulatory needs. The Barnstable Great Marsh estuary system contains a variety of natural resources of value to the citizens of Barnstable, Yarmouth, and Dennis as well as to the Commonwealth. As such, over the years surveys have been conducted to support protection and management of these resources. The MEP gathers the available information on these resources as part of its assessment, and presents some of them here for reference by those providing stewardship for this estuary and some in Section 7 to support the nitrogen thresholds analysis. For the Barnstable Great Marsh estuary system, available agency surveys include:

- Designated Shellfish Growing Area – MassDMF (Figure II-2a,b,c)
- Shellfish Suitability Areas – MassDMF (Figure II-3)
- Area of Critical Environmental Concern - ACEC (Figure II-4)
- Estimated Habitats for Rare Wildlife and State Protected Rare Species – NHESP (Figure II-5)
- Mouth of Coastal Rivers – MassDEP Wetlands Program (Figure II-6a,b,c,d,e,f,g,h)

The MEP effort builds upon earlier watershed delineations (Section III) and land-use analyses and water-use data (Section IV.1), historical eelgrass surveys (Section VII) and water quality surveys discussed above. This information is integrated with MEP higher order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for the Barnstable Harbor Estuary. The MEP has incorporated appropriate and available data from pertinent previous studies and available Town databases to enhance the determination of nitrogen thresholds for the Barnstable Great Marsh estuary system and to reduce costs to the Town of Barnstable and Dennis.

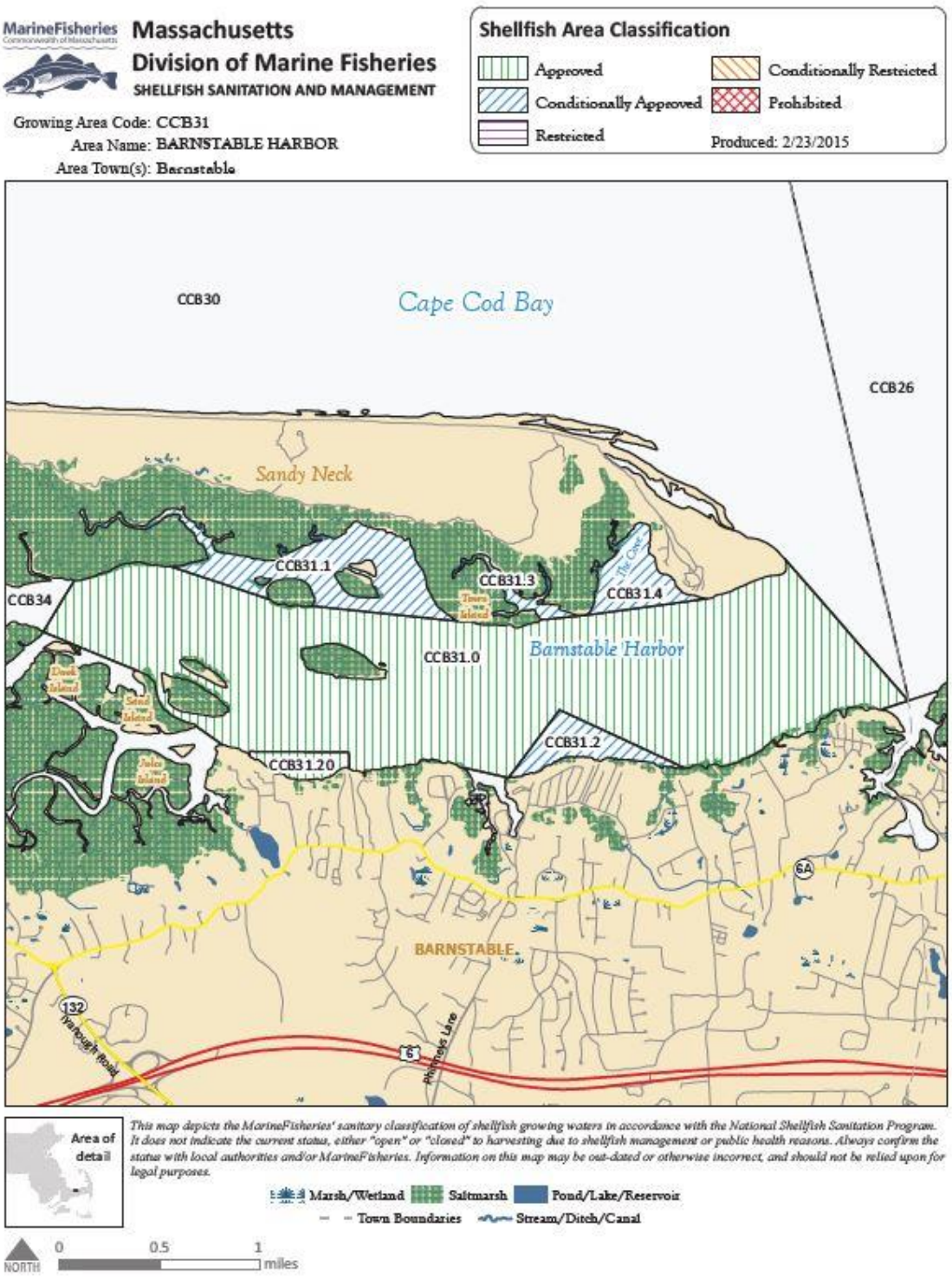


Figure II-2a. Location of shellfish growing areas and their status relative to shellfish harvesting as determined by Mass Division of Marine Fisheries. Closures are generally related to bacterial contamination or "activities", such as the location of marinas. However, areas dominated by wetlands with persistent fecal coliform levels >14 cfu per 100 mL may be prohibited to shellfishing until the cause of the contamination (frequently wildlife and birds) is documented.

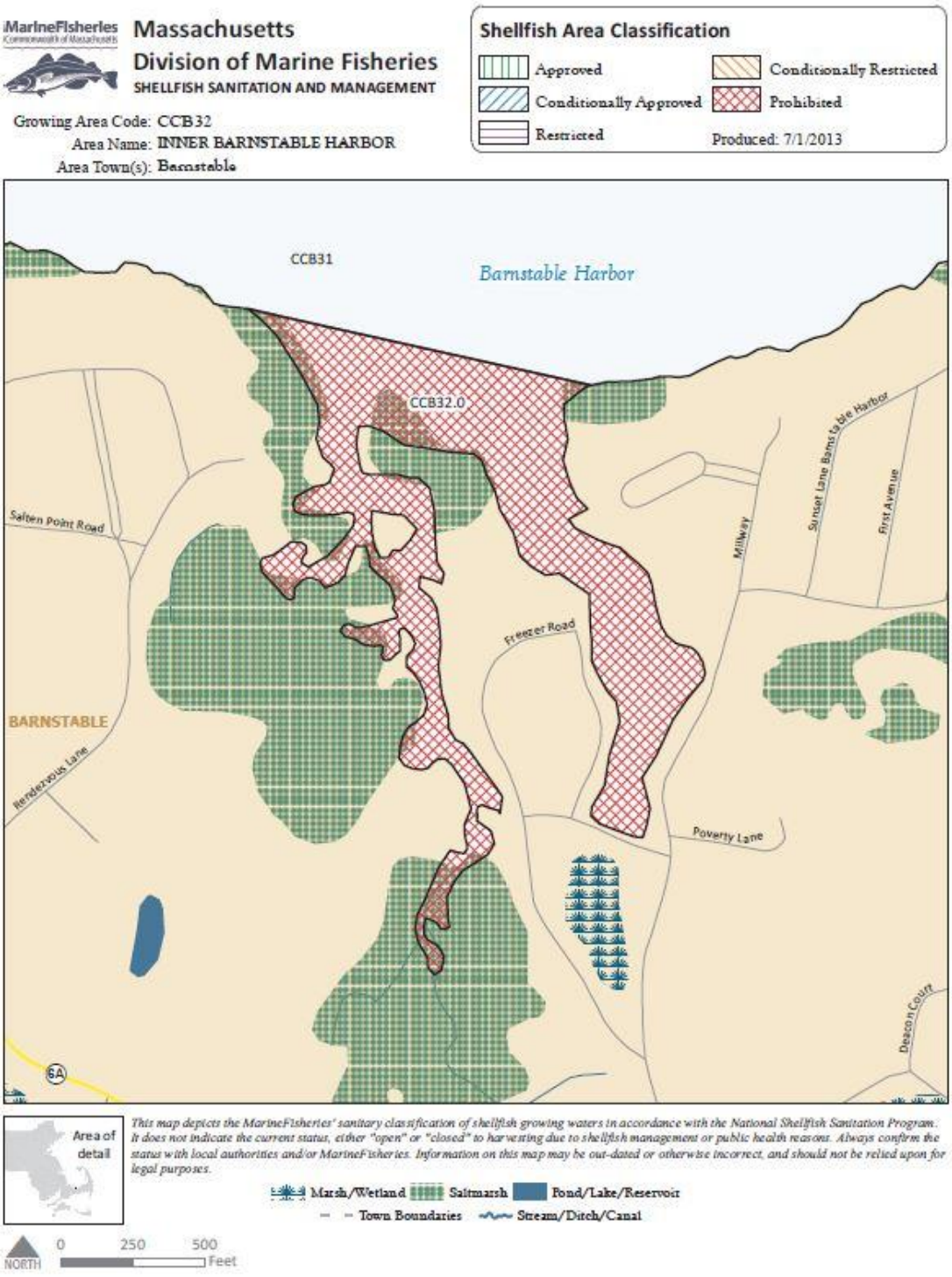


Figure II-2b. Location of shellfish growing areas and their status relative to shellfish harvesting as determined by Mass Division of Marine Fisheries. Closures are generally related to bacterial contamination or "activities", such as the location of marinas. However, areas dominated by wetlands with persistent fecal coliform levels >14 cfu per 100 mL may be prohibited to shellfishing until the cause of the contamination (frequently wildlife and birds) is documented.

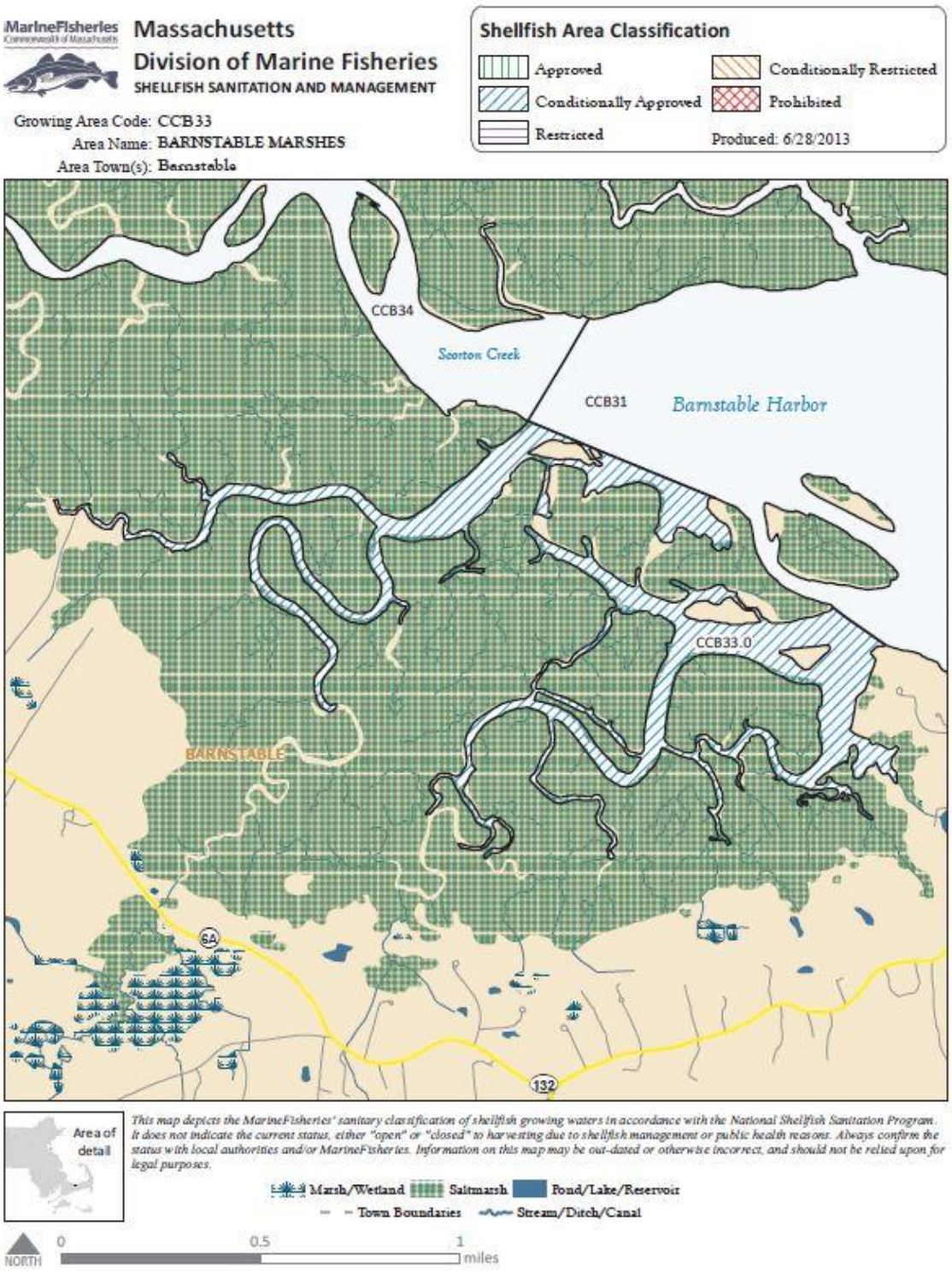


Figure II-2c. Location of shellfish growing areas and their status relative to shellfish harvesting as determined by Mass Division of Marine Fisheries. Closures are generally related to bacterial contamination or "activities", such as the location of marinas. However, areas dominated by wetlands with persistent fecal coliform levels >14 cfu per 100 mL may be prohibited to shellfishing until the cause of the contamination (frequently wildlife and birds) is documented.

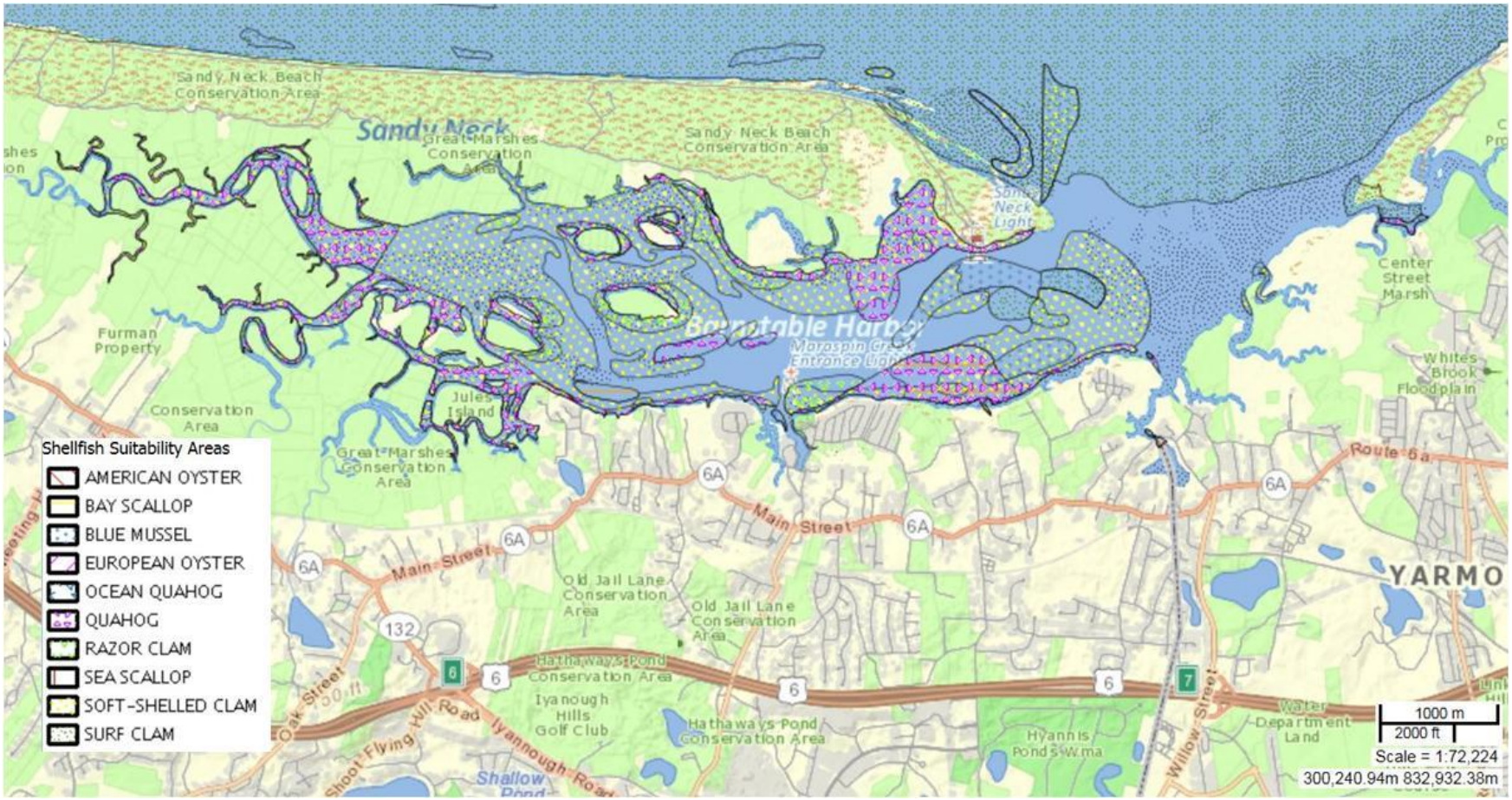


Figure II-3. Location of shellfish suitability areas within the Barnstable Harbor Estuary as determined by Mass Division of Marine Fisheries. Suitability does not necessarily mean "presence". The denoted shellfish areas are generally associated with the lower tidal reaches of the major tidal creeks, which support sediments comprised of medium to fine sands.



Figure II-4. Areas of Critical Environmental Concern (ACEC) within the Barnstable Harbor Estuary extending the Howland Lane / Route 6A interconnection to the Scorton Creek system.



Figure II-5. Estimated Habitats for Rare Wildlife and State Protected Rare Species within the Barnstable Harbor Estuary as determined by - NHESP.

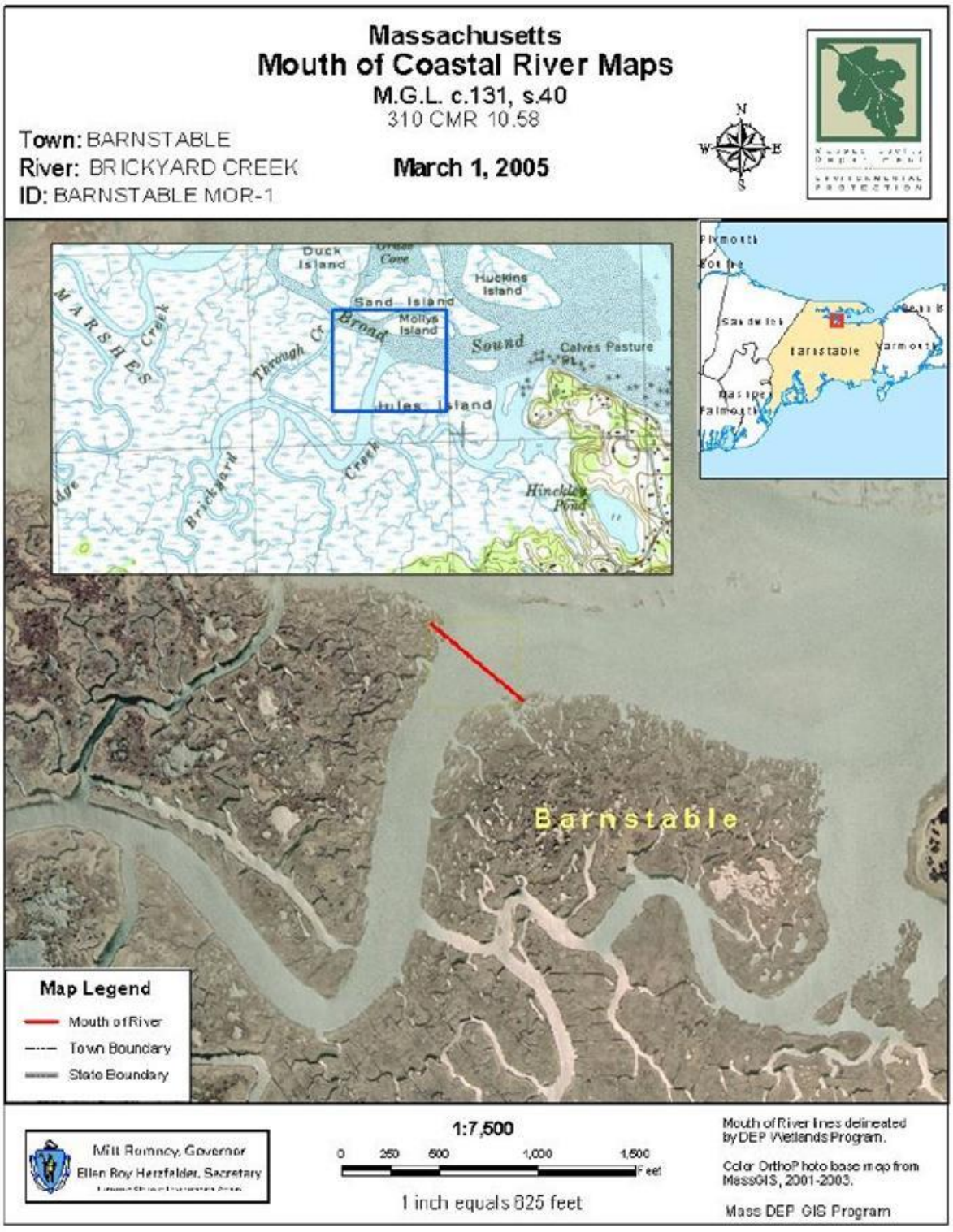


Figure II-6a. Mouth of Coastal Rivers designation for Brickyard Creek as determined by – MassDEP Wetlands Program. Estuaries on the down gradient reach of coastal rivers and major streams are part of the river system, and as such the mouth of the "river" is at the tidal inlet.

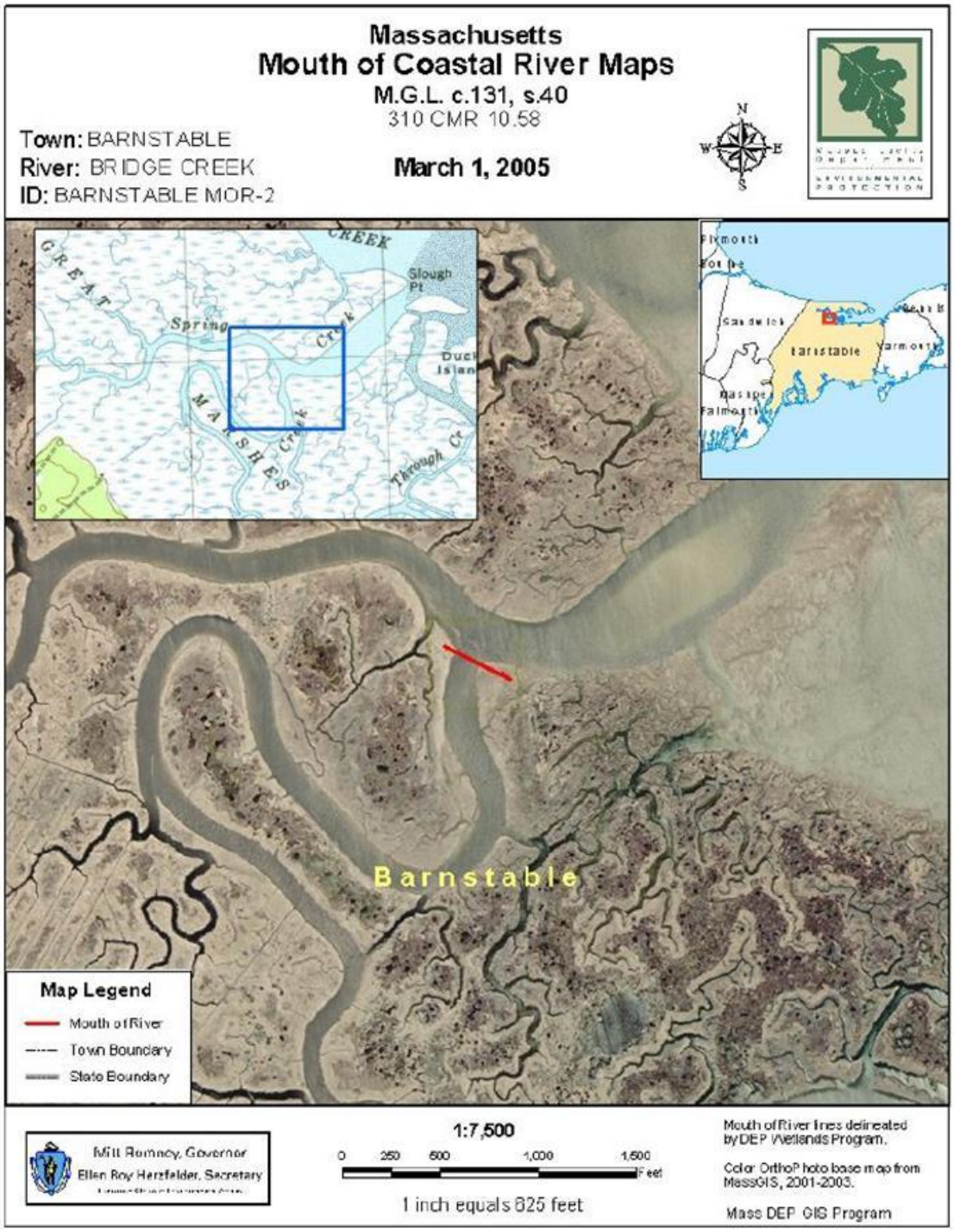


Figure II-6b. Mouth of Coastal Rivers designation for Bridge Creek as determined by – MassDEP Wetlands Program. Estuaries on the down gradient reach of coastal rivers and major streams are part of the river system, and as such the mouth of the "river" is at the tidal inlet.

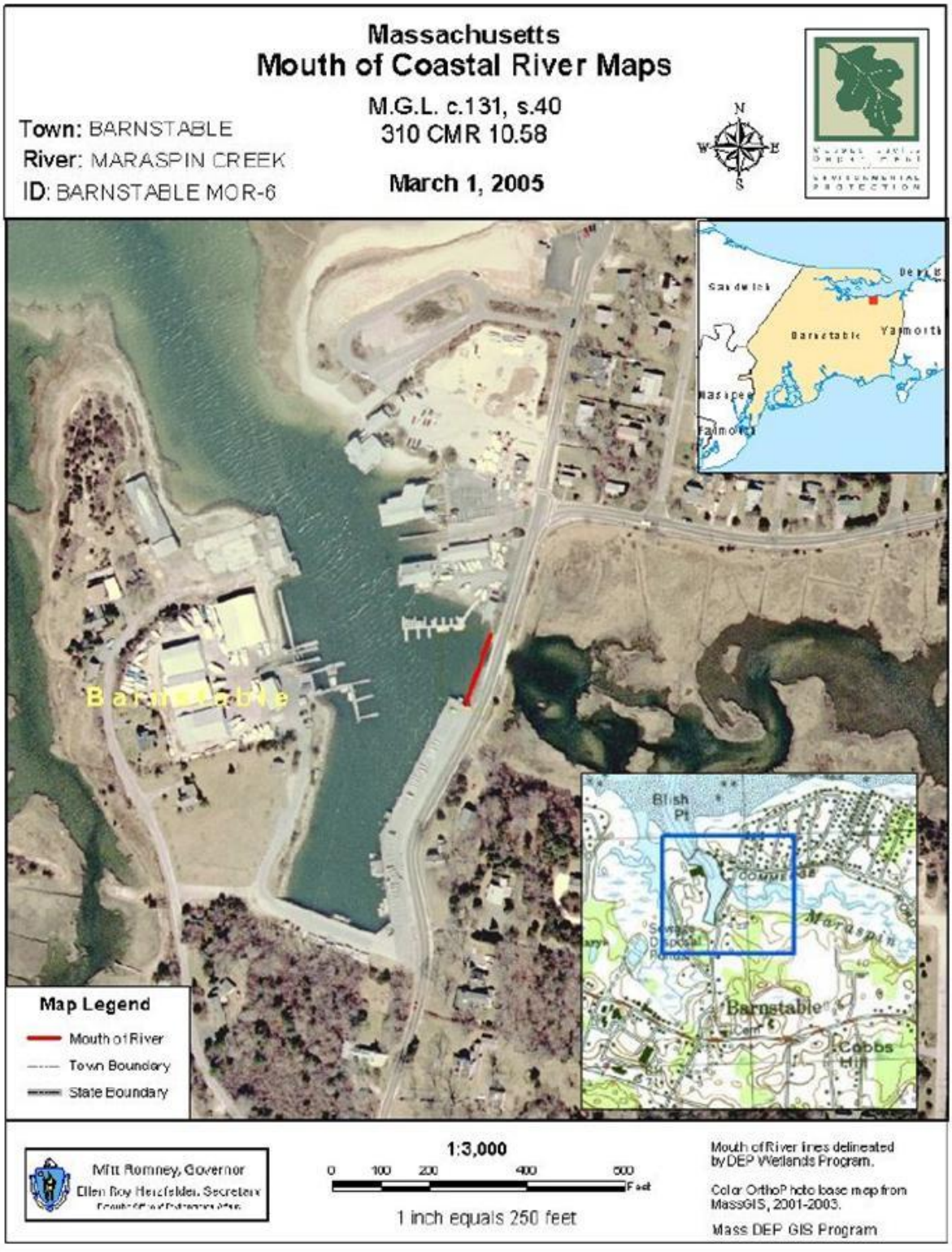


Figure II-6c. Mouth of Coastal Rivers designation for Maraspin Creek discharging to the Millway / Harbor from a south shore salt marsh as determined by – MassDEP Wetlands Program. Estuaries on the down gradient reach of coastal rivers and major streams are part of the river system, and as such the mouth of the "river" is at the tidal inlet.

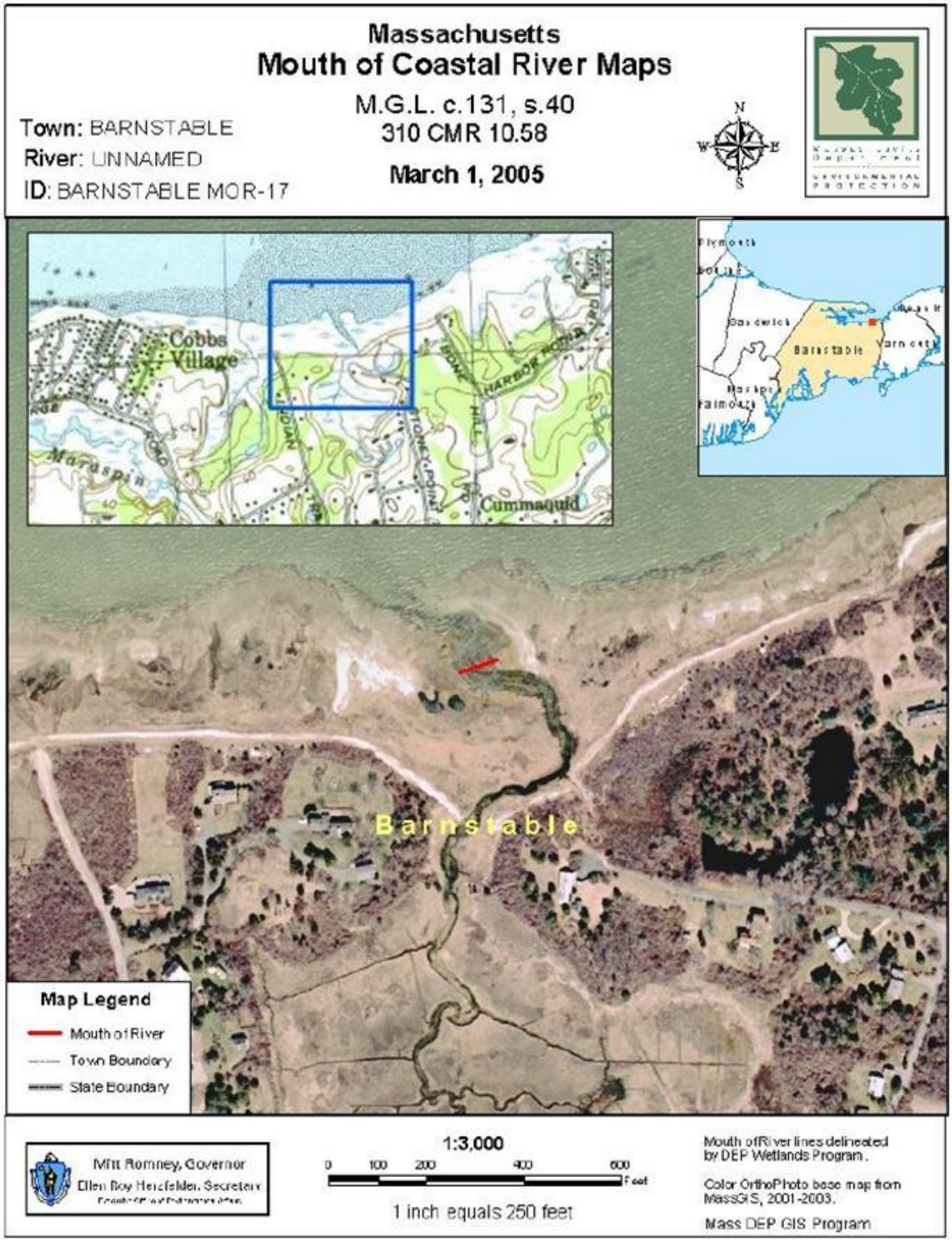


Figure II-6d. Mouth of Coastal Rivers designation for an un-named creek discharging to the harbor from a south shore salt marsh as determined by – MassDEP Wetlands Program. Estuaries on the down gradient reach of coastal rivers and major streams are part of the river system, and as such the mouth of the "river" is at the tidal inlet.

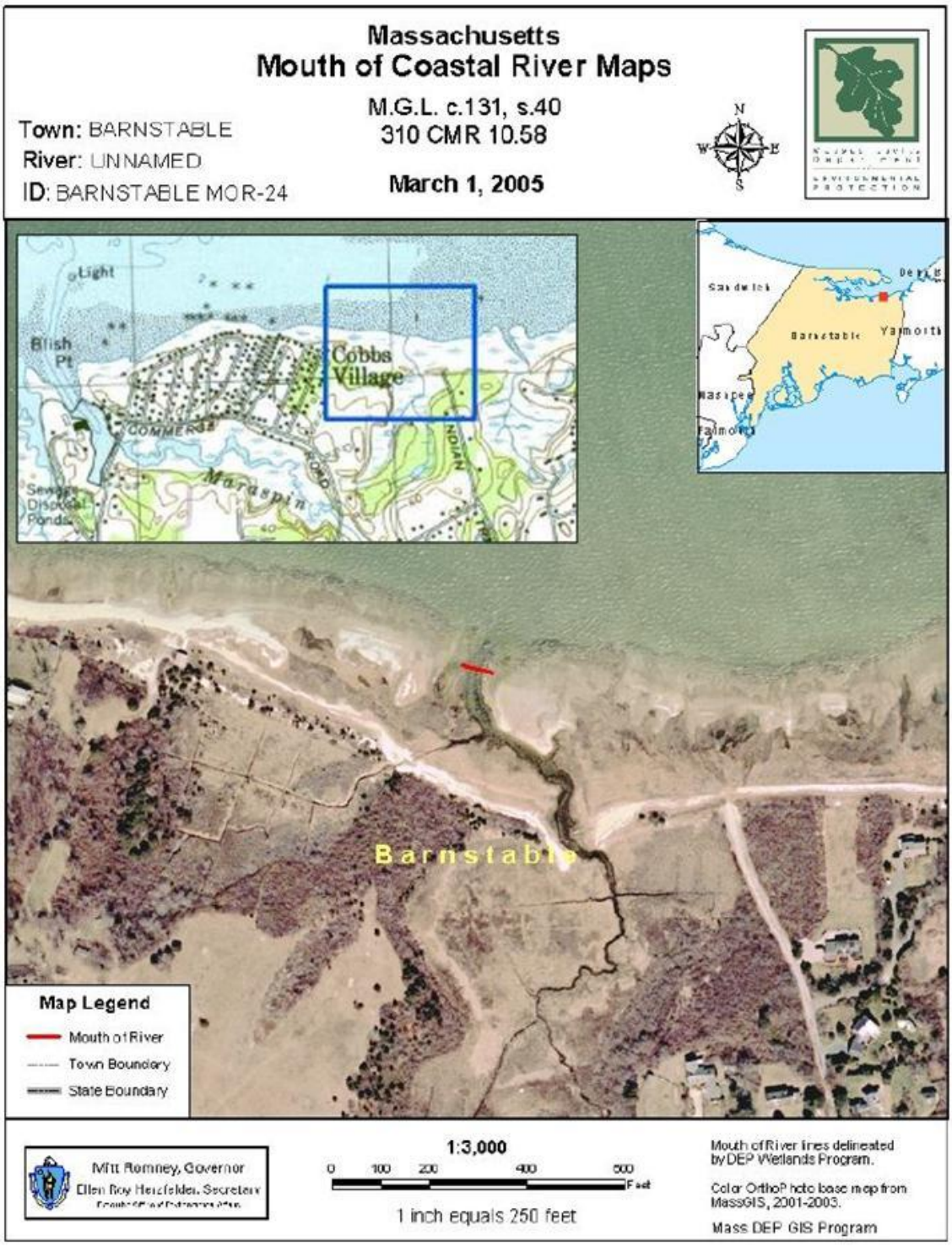


Figure II-6e. Mouth of Coastal Rivers designation for an un-named creek discharging to the harbor from a south shore salt marsh as determined by – MassDEP Wetlands Program. Estuaries on the down gradient reach of coastal rivers and major streams are part of the river system, and as such the mouth of the "river" is at the tidal inlet.

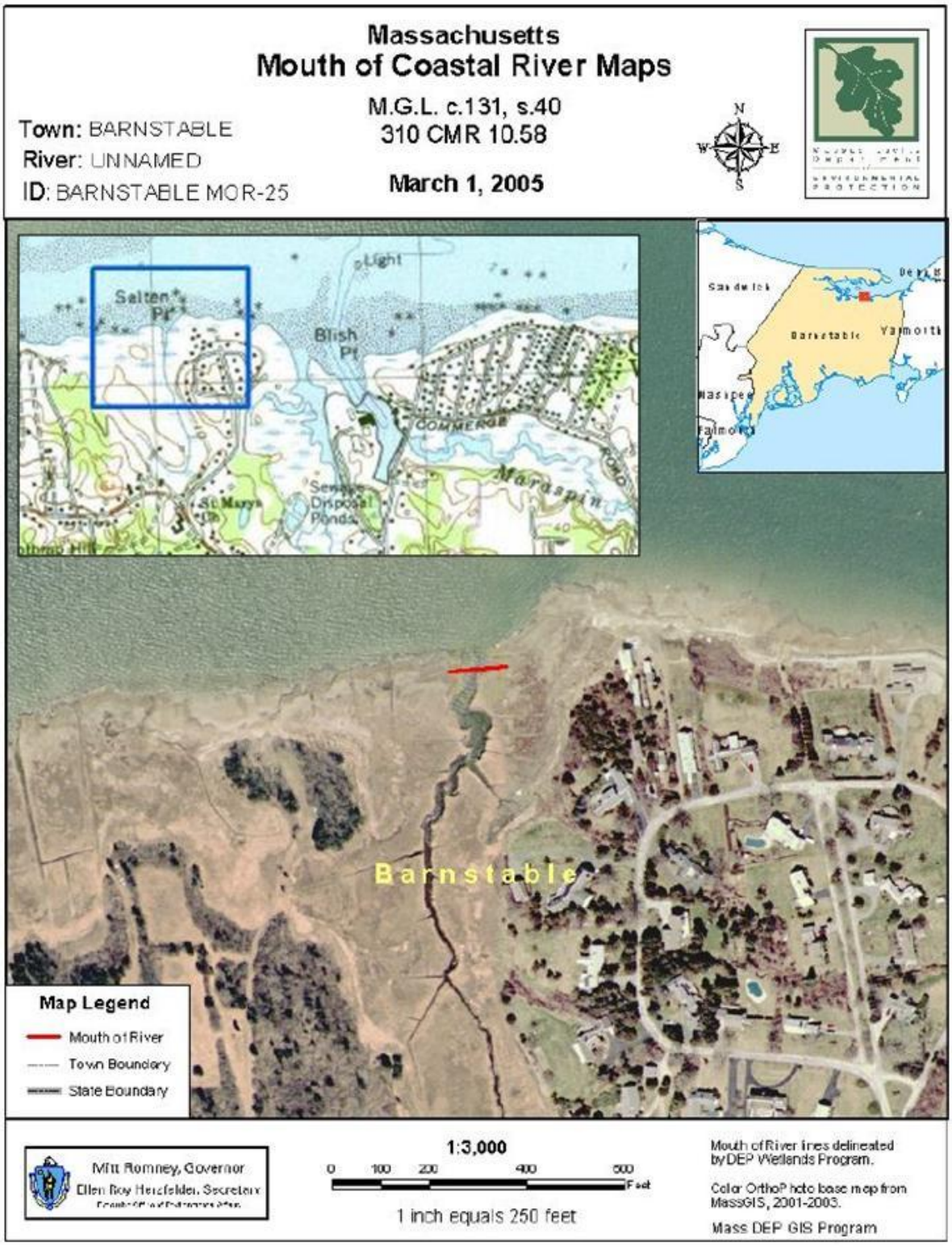


Figure II-6f. Mouth of Coastal Rivers designation for an un-named creek discharging to the harbor from a south shore salt marsh as determined by – MassDEP Wetlands Program. Estuaries on the down gradient reach of coastal rivers and major streams are part of the river system, and as such the mouth of the "river" is at the tidal inlet.

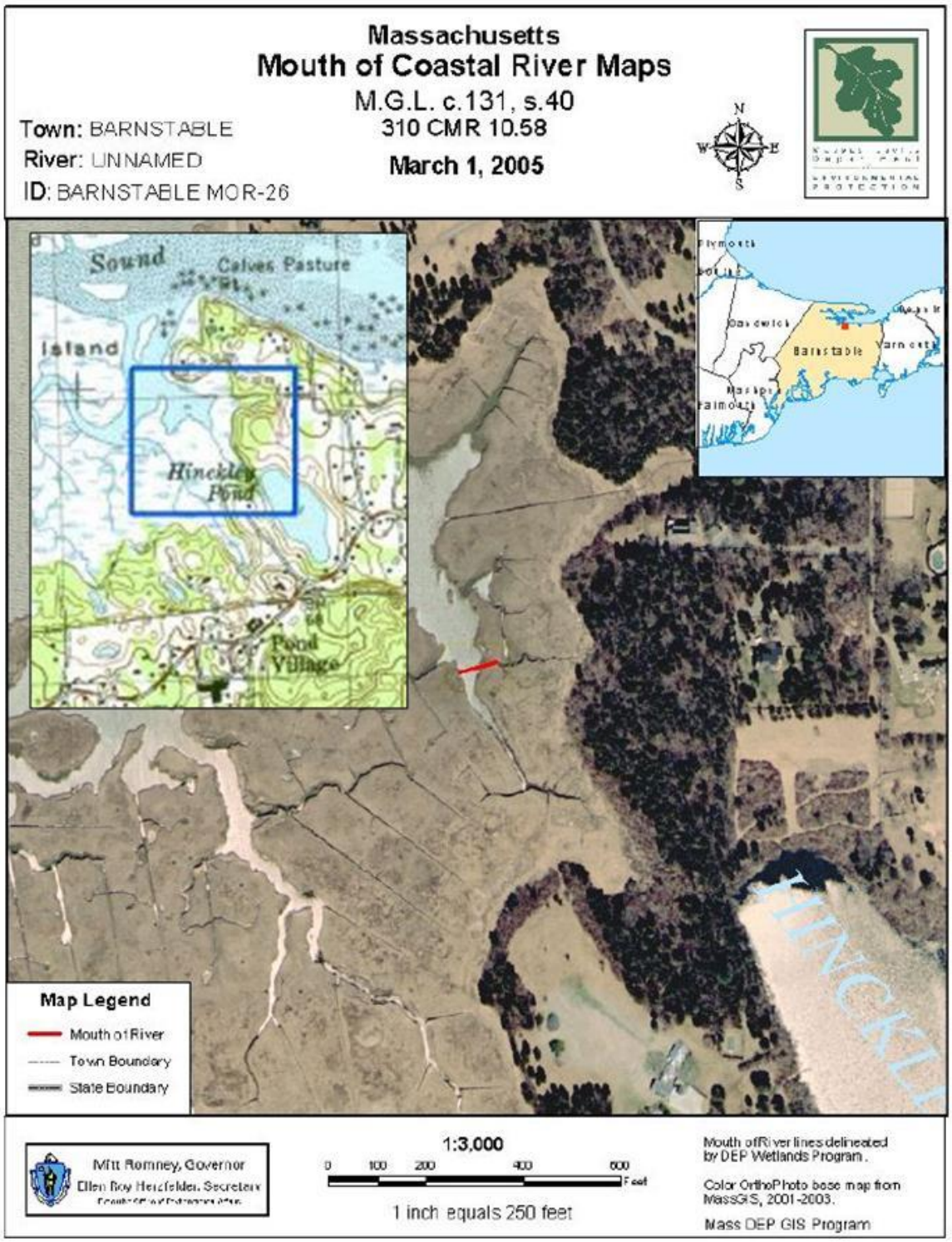


Figure II-6g. Mouth of Coastal Rivers designation for an un-named creek discharging from Hinckley Pond as determined by – MassDEP Wetlands Program. Estuaries on the down gradient reach of coastal rivers and major streams are part of the river system, and as such the mouth of the "river" is at the tidal inlet.

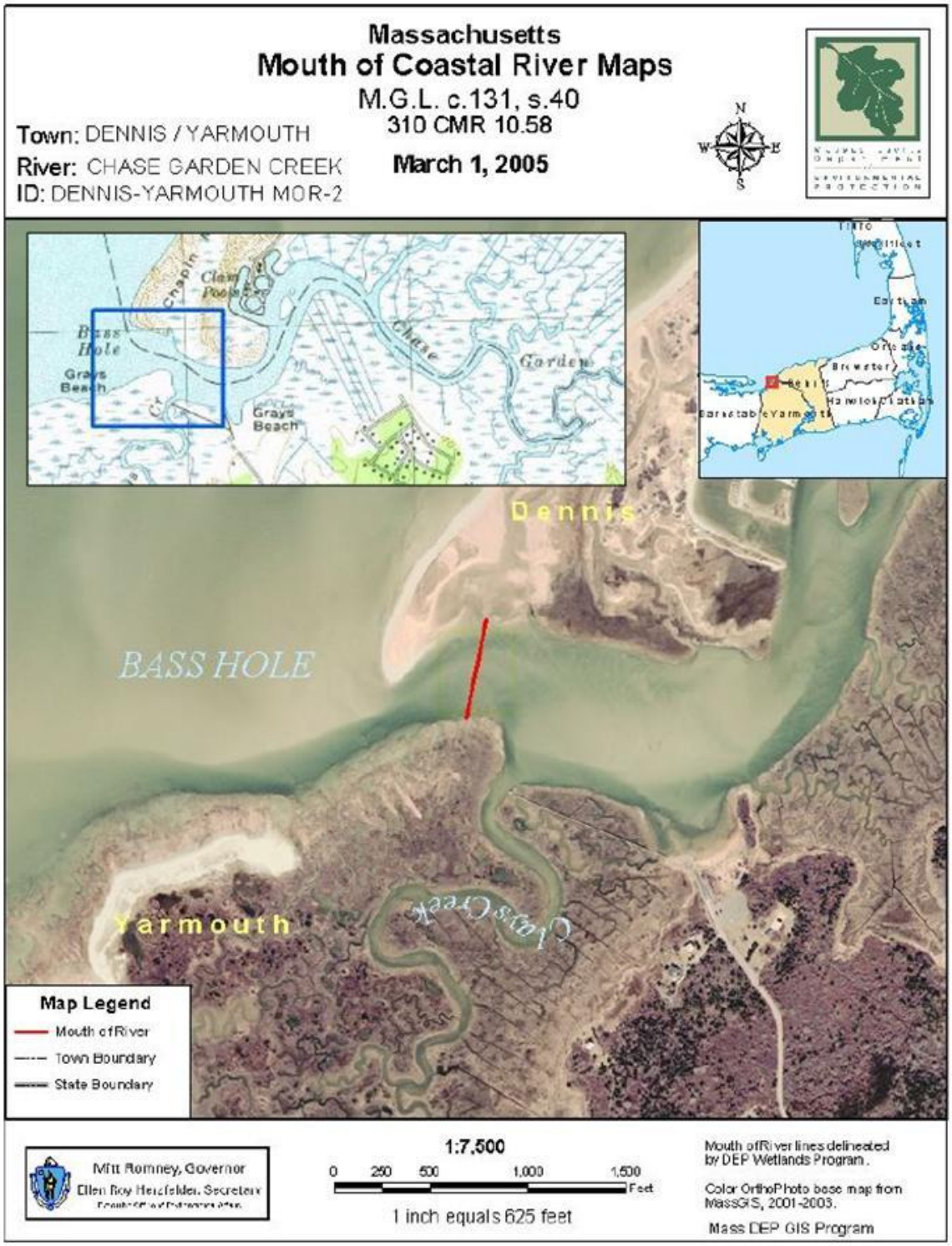


Figure II-6h. Mouth of Coastal Rivers designation for Bass Hole - Chase Garden Creek as determined by – MassDEP Wetlands Program. Estuaries on the down gradient reach of coastal rivers and major streams are part of the river system, and as such the mouth of the "river" is at the tidal inlet.

III. DELINEATION OF WATERSHEDS

III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). The USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. The USGS has a long history of developing regional models for the six-groundwater flow cells on Cape Cod. Through the years, advances in computing, lithologic information from well installations, water level monitoring, stream flow measurements, and reconstruction of glacial history have allowed the USGS to update and refine the groundwater models. The MODFLOW and MODPATH models utilized by the USGS organize and analyze the available data using up-to-date mathematical codes and create better tools to answer the wide variety of questions related to watershed delineation. These questions include surface water/groundwater interactions, groundwater travel times, and drinking water well impacts that have also arisen during the MEP analysis of southeastern Massachusetts estuaries, including the Barnstable Great Marshes. The Barnstable Great Marshes watershed is mostly split between the Towns of Barnstable, Yarmouth, and Dennis, but also includes a small portion of eastern Sandwich.

In the present investigation, the USGS was responsible for the application of its groundwater modeling approach to initially define the watershed or contributing area to the Barnstable Great Marshes under evaluation by the Project Team. The Barnstable Great Marshes estuarine system is a 16.5 square kilometer, shallow estuary with small channel and wide inlet linked to Cape Cod Bay. Numerous small streams flow into the main basin, including Alder Creek, Boat Cove Creek, Bridge Creek, and Chase Garden Creek. A number of smaller subestuaries also ring the main basin, including Bass Hole and the Millway/Barnstable Harbor. Watershed modeling was undertaken to sub-divide the overall watershed to the Barnstable Great Marshes system into functional sub-units based upon: (a) defining inputs from contributing areas to each major portion within the embayment system including those listed, (b) defining contributing areas to major freshwater aquatic systems which attenuate nitrogen passing through them on the way to the estuary (lakes, streams, wetlands), and (c) defining the land areas with groundwater travel times that are greater and less than 10 years time-of-travel to the estuary. These time-of-travel distributions within subwatersheds are used as a procedural check to gauge the potential mass of nitrogen from “new” development, which has not yet reached the receiving estuarine waters at the time of the MEP analysis. The three-dimensional numerical groundwater model employed has also been used to evaluate the contributing areas to public water supply wells in the regional Sagamore and Monomoy flow cells of Cape Cod. The Barnstable Great Marshes watershed is located along the northeastern edge of the Sagamore groundwater lens and the northwestern edge of the Monomoy groundwater lens. USGS model outputs were also compared to surface water discharges measured as part of the MEP stream flow program (2005 to 2006), as well as some selective confirmation of 2009-2011 well pumping rates from the Yarmouth Water Department (personal communication, Dan Mills, YWD Superintendent).

The relatively transmissive sand and gravel deposits that comprise most of Cape Cod create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994a,b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the sources of nitrogen that they carry requires

determination of the portion of the watershed that contributes directly to streams and the portion of the groundwater system that discharges directly into an estuary as groundwater seepage.

III.2 MODEL DESCRIPTION

Initial contributing areas to the Barnstable Great Marsh estuary system and its various subwatersheds, such as Bass Hole, Chase Garden Creek, and Bridge Creek, were delineated using the regional groundwater model of the Sagamore Lens and Monomoy Lens flow cells (Walter and Whealan, 2005). The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh, *et al.*, 2000) was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program MODPATH4 (Pollock, 2000), which uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. This approach was used to determine the contributing areas to the Barnstable Great Marshes system and its subwatersheds and also to determine portions of recharged water that may flow through fresh water ponds and streams prior to discharging into coastal water bodies.

The USGS Sagamore Flow Model grid consists of 246 rows, 365 columns and 20 layers, while the Monomoy Flow Model grid consists of 164 rows, 220 columns, and 20 layers. The horizontal model discretization, or grid spacing, in both portions of the model is 400 by 400 feet. The top 17 layers of the model in both flow cells extend to a depth of 100 feet below NGVD 29 and have a uniform thickness of 10 ft. The top of layer 8 resides at NGVD 29 with layers 1-7 stacked above and layers 8-20 below; the upper three layers of the Monomoy model are dry because the Monomoy has a lower elevation than the overlapping Sagamore groundwater model that was constructed at the same time (Walter and Whealan, 2005). Layer 18 has a thickness of 40 feet and extends to 140 feet below NGVD 29, while layer 19 extends to 240 feet below NGVD 29. The bottom layer, layer 20, extends to the bedrock surface and has a variable thickness depending upon site characteristics (up to 519 feet below NGVD 29 in the Sagamore Lens and up to 525 feet below NGVD 29 in the Monomoy). In the Barnstable Great Marshes watershed area, the groundwater model included bedrock at depths approximately 200 to 300 feet below NGVD 29 (Walter and Whealan, 2005). In the groundwater flow model, these bedrock depths mean that the lowest model layer is inactive throughout most of the watershed area. The rewetting capabilities of MODFLOW-2000, which allows drying and rewetting of model cells, was used to simulate the top of the water table, which also varies in elevation depending on the location within the lens.

Direct rainwater run-off in these Cape Cod aquifer materials is typically rather low. Lithological data used to determine hydraulic conductivities used in the groundwater model were obtained from a variety of sources including well logs from USGS, local Town records and data from previous investigations. Final aquifer parameters in the groundwater models were determined through calibration to observed water levels and available stream flows. Hydrologic data used for model calibration included historic water-level data obtained from USGS records and local Towns and stream flow data collected in 1989-1990 as well as 2003.

The glacial sediments that comprise the aquifer of the both the Sagamore Lens and the Monomoy Lens consist of gravel, sand, silt, and clay that were deposited 15,000 to 16,000 years ago in a variety of depositional environments by continental ice sheets. The Barnstable Great Marshes watershed area generally consists of Lake Deposits bracketed along the southern edge by the Sandwich Moraine (Walter and Whealan, 2005). The Sandwich Moraine was formed when the regional Cape Cod Bay ice lobe re-advanced to the south and excavated and piled up previously deposited materials. The edge of the ice sheet eventually retreated north to a location

within the current Cape Cod Bay and a large lake formed between the ice sheet and the moraine. This Lake Cape Cod Bay trapped fine sediments and clays flowing off the face of the ice sheet along its bottom. These sediments generally underlie the extensive saltwater marshes located along the current northern shoreline of Cape Cod.

Although these are glacial materials vary, modeling and field measurements of contaminant transport at the Massachusetts Military Reservation have shown that groundwater flowpaths are largely unaffected by the transitions between outwash and moraine materials (*e.g*., Masterson, *et al*., 1997). Most of the lake bottom deposit areas along the northern portion are covered by saltwater marshes, but the presence of extensive streams at margin of the marshes suggests that large portions of the upgradient aquifer is discharging along this margin. This is largely supported by the good agreement between stream watershed flows estimated in the groundwater model and MEP streamflows measured at the gauged streams (see Section IV.2). This agreement is also consistent with similar comparisons in other marsh-dominated systems along the northern coast of Cape Cod (*e.g.*, Howes, *et al*., 2007, Howes, *et al.*, 2015).

The regional USGS Sagamore Lens groundwater model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Large withdrawals of groundwater from pumping wells may have a significant influence on water tables and watershed boundaries and therefore the flow and distribution of nitrogen within the aquifer. After accounting for the consumptive loss, water withdrawn from the modeled aquifer by public drinking water supply wells is evenly returned within residential areas designated as using on-site septic systems.

III.3 BARNSTABLE GREAT MARSHES SYSTEM CONTRIBUTORY AREAS

The initial refined watershed and sub-watershed boundaries for the Barnstable Great Marshes embayment system, including the ponds, streams, and water supply wells were modeled by the United States Geological Survey (USGS). Model outputs of the watershed boundaries are usually presented as “saw toothed” lines that reflect the movement of modeled particles between the grid cells that make up the groundwater model and how those cells are organized to reflect natural features, such as pond shorelines, wetlands, river segments, and contributing areas to public water supplies. In order utilize the guidance provided by the model, these modeled lines were “smoothed” to: (a) correct for the model grid spacing, (b) to enhance the accuracy of the characterization pond and coastal shorelines, (c) to include water table data in the lower regions of the watersheds near the coast (as available), (d) to more closely match the sub-estuary segmentation of the tidal hydrodynamic model and (e) to address streamflow measurements collected as part of the MEP. The smoothing refinement process was a collaborative effort developed between the USGS and the rest of the MEP Technical Team. The MEP sub-watershed delineation includes 10-yr time-of-travel boundaries, subwatersheds to public water supply wells, and MEP stream gauges within the overall watershed. The smoothing simplification of watershed delineations/recharge areas lines and other model outputs usually involved visual curve fitting and checking model outputs against aerial maps of ponds, streams, and wetlands. MEP staff also added “subwatersheds” within the marsh shield in order to more accurately characterize the spatial distribution of freshwater inputs to the marsh. These delineations were based on natural segmentation within the marsh and used the natural channels as guides. These are not watersheds in the typical sense because water levels during flood tides cover the whole marsh, but these are a reasonable basis for refining the distribution of freshwater inputs to the marsh.

Overall, 45 sub-watershed areas were delineated within the Barnstable Great Marshes study area (Figure III-1).

Table III-1 provides the daily freshwater discharge volumes for the subwatersheds as calculated from the MEP watersheds; these volumes were used in the salinity calibration of the MEP water quality model and to determine hydrologic turnover in the lakes/ponds, as well as for comparison to the directly measured surface water discharges. The overall estimated freshwater flow into the Barnstable Great Marshes system from the MEP delineated watershed is 171,829 m3/d. This flow includes balanced corrections for flow added to the watershed by the shared, adjacent ponds, such as Lawrence Pond in Sandwich (Howes, *et al*., 2006) and Shallow Pond in Barnstable (Eichner, 2009). Comparison of modeled watershed flow to measured flow at the six MEP gauges, which collected streamflow measurements between September 2006 and August 2007, were within 10% of each other (see Section IV.2). The measured flows are used for calibration of the estuarine water quality model.

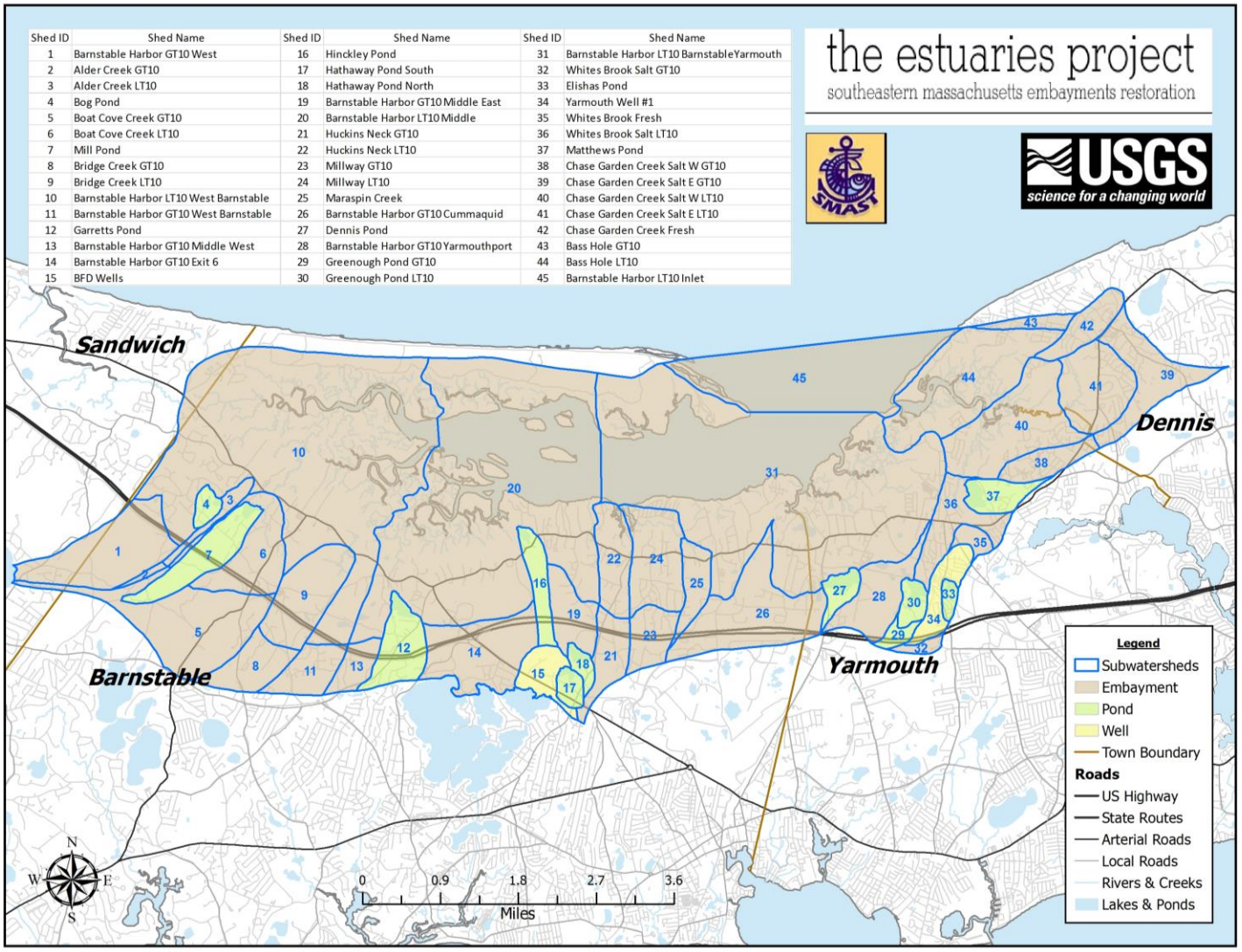
The MEP watershed delineation is the second watershed delineation completed in recent years for Barnstable Great Marshes System. Figure III-2 compares the delineation completed under the current effort with the delineation previously completed by the Cape Cod Commission (Eichner, *et al*., 1998). The CCC delineation was largely based on local and regional water table measurements collected from available groundwater elevation data collected over a number of years, including some of the same data used in the USGS groundwater model, and normalized to average conditions. The Commission's delineation was incorporated into the Commission's regulations through the four versions of the Regional Policy Plan (CCC, 1996, 2001, 2009, and 2012).

The MEP watershed area for the Barnstable Great Marshes System as a whole is 6% larger than 1998 CCC delineation (21,347 acres vs. 20,174 acres, respectively). Comparison of estuary surface shows that the MEP area is 32% larger, mostly due to inclusion of more water within the main inlet. The small watershed area differences are mostly in the land areas included near the main inlet and a slight shift of the regional groundwater divide between Cape Cod Bay and Vineyard Sound further to the south near Dennis and Greenough Pond in Yarmouth. The MEP watershed delineation also includes much more refined interior sub-watersheds to various components of the Barnstable Great Marshes estuarine system, such as selected ponds and streams that were not included in the CCC delineation. The inner subwatershed delineations show the connections between adjacent watersheds and the complexities of flow paths. These refinements are another benefit of the update of the regional groundwater model (Walter and Whealan, 2005).

The MEP watersheds compared favorably with both measured streamflow and pumping rates from public water supply wells. MEP staff gathered streamflow in six streams that flow into various portions of the main system (detailed in Section IV.2). Modeling results were also checked against recent pumping rates from public water supplies within the watershed, as well as where this water was distributed within the overall watershed. The majority of water pumped from Barnstable Fire District wells (watershed #15) is returned to development within the watershed based on the District's service area (personal communication, Thomas Rooney, Superintendent, September 2015). However, a portion of the pumped water (~27% based on average 2006-2008 water use) is removed from the watershed by the limited sewer collection area near Barnstable Village. Similarly, MEP staff reviewed 2009-2011 pumping rates from the Yarmouth wellfield (watershed #34) to address measured MEP flow in Whites Brook (personal communication, Dan Mills, Superintendent, October 2015). This review found that the actual, lower reported pumping rates provided a reasonable balance between the measured and modeled MEP

watershed/stream flows. These types of comparison between measured and modeled information is another step to reinforce the reliability of the watershed delineations.

The evolution of the watershed delineations for the Barnstable Great Marshes system has allowed increasing accuracy as each new version adds new hydrologic data to that previously collected; the model allows all this data to be organized and to be brought into congruence with adjacent watersheds. The evaluation of older data and incorporation of new data during the development of the model is important as it decreases the level of uncertainty in the final calibrated and validated linked watershed-embayment model and the use of this model for the development and evaluation of nitrogen management alternatives. Errors in watershed delineations do not necessarily result in proportional errors in nitrogen loading as errors in loading depend upon the land-uses that are included/excluded within the contributing areas. Small errors in watershed area can result in large errors in loading if a large source is counted in or out. Conversely, large errors in watershed area that involve only natural woodlands have little effect on nitrogen inputs to the down gradient estuary. The MEP watershed delineation was used to develop the watershed nitrogen loads to each of the aquatic systems and ultimately to the estuarine waters of the Barnstable Great Marshes system (Section V.1).



Shed ID	Shed Name	Shed ID	Shed Name	Shed ID	Shed Name
1	Barnstable Harbor GT10 West	16	Hinckley Pond	31	Barnstable Harbor LT10 BarnstableYarmouth
2	Alder Creek GT10	17	Hathaway Pond South	32	Whites Brook Salt GT10
3	Alder Creek LT10	18	Hathaway Pond North	33	Elishas Pond
4	Bog Pond	19	Barnstable Harbor GT10 Middle East	34	Yarmouth Well #1
5	Boat Cove Creek GT10	20	Barnstable Harbor LT10 Middle	35	Whites Brook Fresh
6	Boat Cove Creek LT10	21	Huckins Neck GT10	36	Whites Brook Salt LT10
7	Mill Pond	22	Huckins Neck LT10	37	Matthews Pond
8	Bridge Creek GT10	23	Millway GT10	38	Chase Garden Creek Salt W GT10
9	Bridge Creek LT10	24	Millway LT10	39	Chase Garden Creek Salt E GT10
10	Barnstable Harbor LT10 West Barnstable	25	Maraspin Creek	40	Chase Garden Creek Salt W LT10
11	Barnstable Harbor GT10 West Barnstable	26	Barnstable Harbor GT10 Cummaquid	41	Chase Garden Creek Salt E LT10
12	Garretts Pond	27	Dennis Pond	42	Chase Garden Creek Fresh
13	Barnstable Harbor GT10 Middle West	28	Barnstable Harbor GT10 Yarmouthport	43	Bass Hole GT10
14	Barnstable Harbor GT10 Exit 6	29	Greenough Pond GT10	44	Bass Hole LT10
15	BFD Wells	30	Greenough Pond LT10	45	Barnstable Harbor LT10 Inlet

Figure III-1. Watershed delineation for the Barnstable Great Marshes estuary system. This estuary system exchanges tidal waters with Cape Cod Bay. Subwatershed delineations are based on USGS groundwater model output with modifications to better address pond and estuary shorelines and MEP stream gauge measurements. Ten-year time-of-travel delineations were produced for quality assurance purposes and are designated with a “10” in the watershed names.

Table III-1. Daily groundwater discharge from each of the sub-watersheds in the watershed to the Barnstable Great Marshes system estuary, as determined from the MEP watersheds and corrected return flow from public water supply wells.

Watershed	#	Watershed Area (acres)	% contributing to Estuaries	Discharge	
				m^3/day	ft^3/day
BarnHbr GT10W	1	659	100%	5,056	178,538
Alder Creek GT10	2	22	100%	172	6,074
Alder Creek LT10	3	86	100%	657	23,219
Bog Pond	4	67	100%	514	18,165
Boat Cove Creek GT10	5	848	100%	6,509	229,870
Boat Cove Creek LT10	6	435	100%	3,339	117,910
Mill Pond	7	337	100%	2,587	91,366
Bridge Creek GT10	8	269	100%	2,068	73,028
Bridge Creek LT10	9	469	100%	3,600	127,118
BarnHbr LT10 West Barnstable	10	3,753	100%	28,800	1,017,063
BarnHbr GT10 West Barnstable	11	229	100%	1,760	62,160
Garretts Pond	12	298	100%	2,285	80,685
BarnHbr GT10 MidW	13	153	100%	1,176	41,519
BarnHbr GT10 - Exit 6	14	588	100%	4,514	159,425
BFD Wells	15	176	100%	1,353	47,777
Hinckley Pond	16	180	100%	1,382	48,819
Hathaway Pond S	17	78	100%	600	21,202
Hathaway Pond N	18	65	100%	499	17,628
Barnstable Hbr GT10 MidE	19	255	100%	1,956	69,069
Barnstable Hbr LT10 Mid	20	2,966	100%	22,763	803,852
Huckins Neck GT10	21	230	100%	1,765	62,336
Huckins Neck LT10	22	272	100%	2,087	73,686
Millway GT10	23	216	100%	1,656	58,473
Millway LT10	24	424	100%	3,255	114,944
Maraspin Creek	25	182	100%	1,397	49,327
BarnHbr GT10 Cummaquid	26	736	100%	5,652	199,587
Dennis Pond	27	103	100%	792	27,956
BarnHbr GT10 - Yarmouthport	28	356	100%	2,734	96,550
Greenough Pond GT10	29	59	100%	453	16,011
Greenough Pond LT10	30	95	100%	726	25,646
BarnHbr LT10 - BarnYarm	31	2,736	100%	20,996	741,465
Whites Brook Salt GT10	32	45	100%	346	12,219
Elishas Pond	33	46	100%	349	12,341

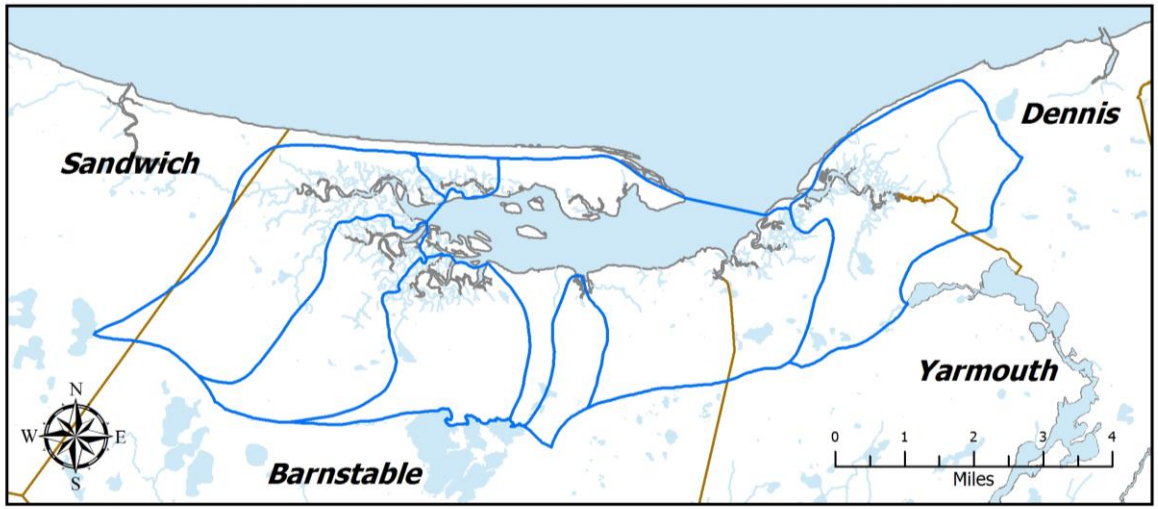
Table III-1 (continued). Daily groundwater discharge from each of the sub-watersheds in the watershed to the Barnstable Great Marshes system estuary, as determined from the MEP watersheds and corrected return flow from public water supply wells.

Yarm_Well1	34	194	100%	1,488	52,534
Whites Brook Fresh	35	71	100%	548	19,348
Whites Brook Salt LT10	36	316	100%	2,427	85,693
Matthews Pond	37	167	100%	1,284	45,361
Chase Garden Crk Salt W GT10	38	188	100%	1,443	50,966
Chase Garden Creek Salt E GT10	39	439	100%	3,369	118,981
Chase Garden Crk Salt W LT10	40	729	100%	5,596	197,606
Chase Garden Crk Salt E LT10	41	454	100%	3,484	123,046
Chase Garden Creek Fresh	42	205	100%	1,574	55,588
Bass Hole GT10	43	86	100%	664	23,435
Bass Hole LT10	44	955	100%	7,327	258,747
Barnstable Hbr LT10 Inlet	45	106	100%	817	28,835
Additions from outside watershed			100%	8,012	282,934
TOTAL BARNSTABLE GREAT MARSHES SYSTEM				171,829	6,068,104

Notes:
1) Discharge volumes are based on 27.25 inches of annual recharge on watershed areas.
2) Watershed flow is added to the system from the watersheds to Lawrence Pond, Lake Wequaquet, and Shallow Pond. These ponds are located along the watershed boundary and add flow to a number of watersheds.
3) listed flows do not include precipitation on the surface of the estuary
4) totals may not match due to rounding.

CCC Regional Policy Plan

Used in 1996, 2001 & 2009 Regional Policy Plans (based on delineation in Eichner, et al., 2002)



MEP, 2015

Delineated based on USGS groundwater modeling

Red lines indicate ten year time-of-travel lines

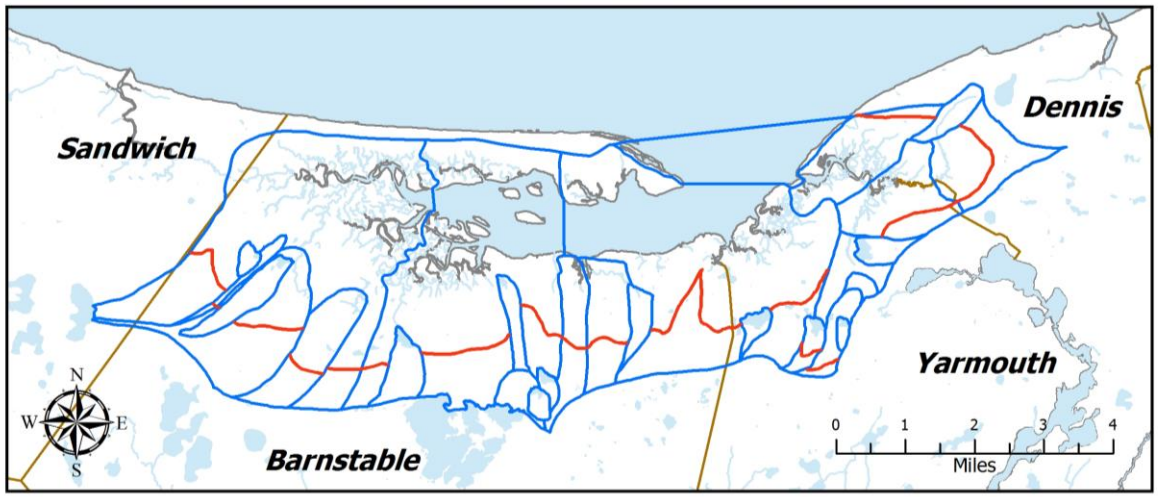


Figure III-2. Comparison of MEP Barnstable Great Marshes watershed and sub-watershed delineations used in the current assessment and the Cape Cod Commission watershed delineation (Eichner and others, 1998), which had been used in three Barnstable County Regional Policy Plans (CCC, 1996, 2001, 2009). The MEP watershed area for the Barnstable Great Marshes system as a whole is 6% larger than CCC delineation. Barnstable Great Marshes exchanges tidal waters with Cape Cod Bay to the north.

IV. WATERSHED NITROGEN LOADING TO EMBAYMENT: LAND USE, STREAM INPUTS, AND SEDIMENT NITROGEN RECYCLING

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS

Management of nutrient related water quality and habitat health in coastal waters requires determination of the amount of nitrogen transported by freshwaters (surface water flow, groundwater flow) from the surrounding watershed to the receiving embayment of interest. In southeastern Massachusetts, the nutrient of management concern for estuarine systems is nitrogen and this is true for the Barnstable Great Marsh estuary system. Determination of watershed nitrogen inputs to these embayment systems requires the (a) identification and quantification of the nutrient sources and their loading rates to the land and aquifer, (b) confirmation that a groundwater transported load has reached the embayment at the time of analysis, and (c) quantification of nitrogen attenuation that can occur during travel through lakes, ponds, streams and marshes prior to reaching the estuary. This latter natural attenuation process results from biological processes that naturally occur within these ecosystems. Failure to account for attenuation of nitrogen during transport results in an over-estimate of nitrogen inputs to an estuary and an underestimate of the sensitivity of a system to new inputs (or removals). In addition to the nitrogen transport from land to sea, the amount of direct atmospheric deposition on each embayment surface must be determined as well as the amount of nitrogen recycling within the embayment, specifically nitrogen regeneration from sediments. Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms, which may be released to the overlying waters or lost to denitrification within the sediments. Permanent burial of nitrogen in the sediments is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters or in some cases a sink for nitrogen reaching the bottom. Failure to include the nitrogen balance of estuarine sediments and the watershed attenuation generally leads to errors in predicting water quality, particularly in determination of summertime nitrogen load to embayment waters.

In order to determine watershed nitrogen loading inputs to the Barnstable Great Marsh estuary system, the MEP Technical Team developed nitrogen-loading rates (Section IV.1) to each component of the estuary and its watersheds (Section III). The Barnstable Great Marsh watershed was sub-divided to define contributing areas or subwatersheds to each of the major inland freshwater systems and to each major component basin of the estuary. Further sub-divisions were made to identify watershed areas where a nitrogen discharge reaches estuary waters in less than 10 years or greater than 10 years. A total of 45 subwatersheds were delineated in the overall Barnstable Great Marsh watershed, including watersheds to six MEP gauged streams, 10 ponds, and 2 public water supply wellfields (see Chapter III). The nitrogen loading effort also involved further refinement of watershed delineations to accurately reflect shoreline areas to freshwater ponds and each portion of the estuary.

The initial task in the MEP land use analysis is to gauge whether or not nitrogen discharges to the watershed have reached the estuary. This review involves a temporal review of land use changes, the time of groundwater travel provided by the USGS watershed model, and review of data at natural collection points, such as streams and ponds. Evaluation and delineation of ten-year time of travel zones are a regular part of the MEP watershed analysis. Ten-year time of travel subwatersheds in the Barnstable Great Marsh watershed have been delineated for ponds, streams and the estuary itself. Review of less than 10 year (LT10) and greater than 10 year travel time (GT10) watersheds indicates that 66% of the unattenuated nitrogen load from the whole watershed is within less than 10 year travel time to the estuary (Table IV-1). When nitrogen loads

from precipitation direct to the estuary surface are added to the LT10 total, the percentage of the overall system load within less than 10 years increases to 73% without adjusting for age of dwellings or public water supply redistribution. The overall review includes refinements for transfer of loads from shared pond subwatersheds: a) Lake Wequaquet, Bearses Pond, and Shallow Pond shared with the Centerville River estuary (Howes, *et al.*, 2006a) and b) Lawrence Pond shared with the Scorton Creek estuary (Howes, *et al*., 2015) and the Three Bays estuary (Howes, *et al.*, 2006b).

This analysis can become complicated by movement of water and nitrogen loads by public drinking water supply and the age of houses/buildings within the GT10 subwatersheds. For example, the Barnstable Fire District (BFD) service area is primarily within subwatersheds less than 10 years of travel time from the estuary, but the wellfield and its contributing area is located within the greater than 10 year delineation. It would be reasonable to add all the nitrogen load from the BFD wellfield watershed (subwatershed #15), including contributions for Hathaway Pond South and Shallow Pond to the LT10 nitrogen load totals. In addition, MEP staff also reviewed the age of single family residences in the greater than 10 year subwatersheds to assess whether nitrogen loads from these subwatersheds are likely to have already reached the estuary. This review of year-built information in the town assessor's database generally indicated that average age of single family residences (the predominant land use) were greater than 20 years. For example, within subwatershed #14 (Barnstable Harbor GT10 Exit 6) the 163 single family residential parcels (unsplit) were constructed an average of 28 years before the MEP stream sampling period (2006-2007).

The overall conclusion from the analysis of the timing of development relative to groundwater travel times (including the GT10 subwatersheds) is that the present watershed nitrogen load appears to accurately reflect the present nitrogen sources to the estuary (after accounting for natural attenuation, see below). Additionally, the distinction between time of travel in the subwatersheds is not important for modeling existing watershed nitrogen loading conditions. Based on the review of all of this information, it was determined that the Barnstable Great Marsh estuary is currently in balance with its watershed load.

In order to determine nitrogen loads from the watersheds, detailed individual lot-by-lot data is used for some portion of the loads, while information developed from other detailed site-specific studies is applied to other portions. The Linked Watershed-Embayment Management Model (Howes, *et al.*, 2001) uses a land-use Nitrogen Loading Sub-Model based upon subwatershed-specific land uses and pre-determined nitrogen loading rates based on regional analyses. For the Barnstable Great Marsh Estuarine System, the model used Town of Barnstable, Town of Yarmouth, Town of Dennis, and Town of Sandwich land-use data that is transformed into nitrogen loads using both regional nitrogen loading factors and local watershed-specific data (such as parcel-by-parcel municipal water use). Determination of the nitrogen loads required obtaining watershed-specific information regarding wastewater, fertilizers, runoff from impervious surfaces and atmospheric deposition. The primary regional factors were derived for southeastern Massachusetts from direct measurements. The resulting nitrogen loads represent the "potential" or unattenuated nitrogen load to each receiving estuarine basin, since attenuation within surface waters (streams, ponds, wetlands) is included at a later stage.

Table IV-1. Percentage of unattenuated nitrogen loads in less than ten year time-of-travel subwatersheds to Barnstable Great Marsh.

WATERSHED		LT10	GT10	TOTAL	%LT10
Name	#	kg/yr	kg/yr	kg/yr	
BarnHbr GT10W	1		1,419	1,419	0%
Alder Creek GT10	2		7	7	0%
Alder Creek LT10	3	384		384	100%
Bog Pond	4	473		473	100%
Boat Cove Creek GT10	5		1,283	1,283	0%
Boat Cove Creek LT10	6	1,171		1,171	100%
Mill Pond	7	1,005		1,005	100%
Bridge Creek GT10	8		1,303	1,303	0%
Bridge Creek LT10	9	1,224		1,224	100%
BarnHbr LT10 West Barnstable	10	6,171		6,171	100%
BarnHbr GT10 West Barnstable	11		1,392	1,392	0%
Garretts Pond	12	1,587		1,587	100%
BarnHbr GT10 MidW	13		668	668	0%
BarnHbr GT10 - Exit 6	14		2,878	2,878	0%
BFD Wells	15		1,023	1,023	0%
Hinckley Pond	16	373		373	100%
Hathaway Pond S	17		338	338	0%
Hathaway Pond N	18		117	117	0%
Barnstable Hbr GT10 MidE	19		327	327	0%
Barnstable Hbr LT10 Mid	20	4,605		4,605	100%
Huckins Neck GT10	21		590	590	0%
Huckins Neck LT10	22	559		559	100%
Millway GT10	23		758	758	0%
Millway LT10	24	2,027		2,027	100%
Maraspin Creek	25	1,360		1,360	100%
BarnHbr GT10 Cummaquid	26		2,538	2,538	0%
Dennis Pond	27		455	455	0%
BarnHbr GT10 - Yarmouthport	28		554	554	0%
Greenough Pond GT10	29		28	28	0%
Greenough Pond LT10	30		164	164	0%
BarnHbr LT10 - BarnYarm	31	9,500		9,500	100%
Whites Brook Salt GT10	32		141	141	0%
Elishas Pond	33	489		489	100%
Yarm_Well1	34	1,769		1,769	100%
Whites Brook Fresh	35	715		715	100%
Whites Brook Salt LT10	36	3,256		3,256	100%
Matthews Pond	37	1,024		1,024	100%
WATERSHED		LT10	GT10	TOTAL	%LT10
Name	#	kg/yr	kg/yr	kg/yr	

Table IV-1. Percentage of unattenuated nitrogen loads in less than ten year time-of-travel subwatersheds to Barnstable Great Marsh.

Chase Garden Crk Salt W GT10	38		1,807	1,807	0%
Chase Garden Creek Salt E GT10	39		4,303	4,303	0%
Chase Garden Crk Salt W LT10	40	3,289		3,289	100%
Chase Garden Crk Salt E LT10	41	4,209		4,209	100%
Chase Garden Creek Fresh	42	1,561		1,561	100%
Bass Hole GT10	43		914	914	0%
Bass Hole LT10	44	1,790		1,790	100%
Barnstable Hbr LT10 Inlet	45	30		30	100%
ponds shared with other watersheds			1,883	1,883	0%
Barnstable Great Marsh Whole System Watershed		48,571	24,890	73,461	66%
Estuary Surface		18,265		18,265	100%
Barnstable Great Marsh Whole System		66,835	24,890	91,726	73%

Notes:

a) Whole system totals may not add due to rounding.

b) Review of public drinking water supply service areas suggest that most of the Barnstable Fire District wells subwatershed nitrogen load (shed #15) should be considered as reaching the estuary in less than 10 years.

c) Review of year-built information for single-family residences within the GT10 subwatersheds (the predominant parcel type in the overall watershed) shows that the average age of residences within the GT10 subwatersheds is generally older than 20 years. This information suggests that average nitrogen loads from the GT10 subwatersheds are also currently reaching the estuary and when combined with the groundwater time-of-travel info confirms that estuarine water quality data is in balance with overall watershed nitrogen loading.

Natural attenuation of nitrogen during transport from land-to-sea within the Barnstable Great Marsh watershed was determined based upon site-specific studies of each major stream discharging to this estuary and assumed attenuation in the upgradient freshwater ponds. Streamflow was characterized at gauge locations from: Alder Creek, Boat Cove Creek, Bridge Creek, Maraspin Creek, White's Brook, and the freshwater portion of Chase Garden Creek. Land-use analysis of the contributing areas to these stream discharge points allowed comparisons between field collected nitrogen load data from the streams and estimates from the nitrogen-loading sub-model. Nitrogen attenuation in individual ponds is generally estimated based on available information. Attenuation through the ponds is conservatively assumed to equal 50% unless available water column monitoring and pond physical data is reliable enough to calculate a pond-specific attenuation factor. Streamflow and associated surface water attenuation is included in the MEP's nitrogen attenuation and freshwater flow investigation, presented in Section IV.2.

Natural attenuation during stream transport or in passage through fresh ponds of sufficient size to effect groundwater flow patterns (area and depth) is a standard part of the data collection effort of the MEP. In the present effort, ten freshwater ponds have delineated subwatersheds within the Barnstable Great Marsh watershed: Bog Pond, Mill Pond, Garretts Pond, Dennis Pond, Hathaway Pond S, Hathaway Pond N, Elishas Pond, Matthews Pond, Hinckley Pond, and Greenough Pond. In addition, delineation was undertaken for four other ponds that are mostly outside of the watershed but are shared with the Barnstable Great Marsh watershed: Lawrence Pond, Lake Wequaquet, Bearses Pond, and Shallow Pond. If smaller aquatic features that have not been included in this MEP analysis were providing additional attenuation of nitrogen, nitrogen

loading to the estuary would only be slightly (~10%) overestimated given the distribution of nitrogen sources within the watershed.

Based upon the evaluation of the watershed systems, the MEP Technical Team used the Nitrogen Loading Sub-Model to estimate nitrogen loading for the subwatersheds that directly discharge groundwater to the estuary without flowing through one of these interim pond and stream measuring points. The direct discharge subwatershed were combined with subwatersheds with surface freshwater attenuation determined from field measurements to select appropriate nitrogen attenuation rates to calculate total watershed loading to the estuary. Internal nitrogen recycling was also determined throughout the tidal reaches of the Barnstable Great Marsh Estuarine System; measurements were made to capture the spatial distribution of sediment nitrogen regeneration from the sediments to the overlying water-column. Nitrogen regeneration focused on summer months, the critical nitrogen management interval and the focal season of the MEP approach and application of the Linked Watershed-Embayment Management Model (Section IV.3).

IV.1.1 Land Use and Water Use Database Preparation

Since the watershed to the Barnstable Great Marsh Estuary is shared among the towns of Barnstable, Yarmouth, Dennis, and Sandwich, Estuaries Project staff obtained digital parcel and tax assessor's data from the town to serve as a base for the watershed nitrogen loading model. Digital parcels and land use/assessors data are from 2011, 2012, 2012, and 2011, respectively. Using GIS techniques, this data was linked to at least three years of individual account water use data from the various water suppliers: Barnstable Fire District, 2006-2008; Hyannis, 2006-2011, Dennis, 2007-2009; Yarmouth, 2005-2011, and Sandwich, 2007-2010. The resulting unified watershed database contains traditional information regarding land use classifications (MassDOR, 2015) plus additional information developed by the towns. The database matching efforts were completed with the assistance from GIS staff from the Cape Cod Commission (CCC).

Figure IV-1 and Figure IV-2 show the land uses within the Barnstable Great Marsh estuary watershed. Land uses in the study area are grouped into 12 land use categories: 1) residential, 2) commercial, 3) industrial, 4) agricultural, 5) mixed use, 6) undeveloped, 7) public service/government, including road rights-of-way, 8) open space, 9) forest, 10) recreational, 11) freshwater, and 12) properties without assessor's land use codes. These land use categories are generally aggregations derived from the major categories in the Massachusetts Assessors land uses classifications (MassDOR, 2015). "Public service" in the MassDOR system is tax-exempt properties, including lands owned by government (*e.g.*, wellfields, schools, open space, roads) and private groups like churches and colleges.

Public service land uses are the dominant land use type in the overall Barnstable Great Marsh watershed and occupy 56% of the watershed area (Figure IV-3). Examples of these land uses are lands owned by town and state government (including golf courses, landfills, conservation lands, and wellhead protection lands), housing authorities, and churches. Residential land uses occupy the second largest area with 29% of the overall watershed area. The majority of the public service lands in the Barnstable Great Marsh watershed are wetlands surrounding the estuary, but these lands also include Sandy Neck Park, which extends along the barrier beach north of the main portion of the estuary. Other large public service lands within the watershed include: the West Barnstable Conservation Area, Marstons Mills Airfield, Olde Barnstable Fairgrounds Golf Course, Town of Barnstable Conservation lands around the Hathaway Ponds, Hyannis Golf Course, Cape Cod Community College, the Boy Scouts' Camp Greenough, the Town of Yarmouth Callery-Darling Conservation Area, and Dennis Highlands Golf Course.

Although the majority of the watershed area is public service land uses, the dominant parcel type within the whole watershed and the various subwatersheds are residential land uses. Residential parcels are 69% of the total parcel count in the overall West Barnstable subwatershed, 65% of parcels in the Mid-basin subwatershed, 73% of the BarnYarm subwatershed, 85% of the Bass Hole/Chase Garden Creek subwatershed, and 75% of all parcels in the overall Barnstable Great Marsh system watershed. Single-family residences (MassDOR land use code 101) are the dominant type of residential parcel; these represent 94% of all residential parcels in overall Barnstable Great Marsh system watershed and 90% of the residential parcel area in the overall watershed. It is notable that land classified by the town assessor as undeveloped is 9% of the overall watershed area.

In order to estimate wastewater flows within the Barnstable Great Marsh study area, MEP staff also obtained parcel-by-parcel water use data from the Sandwich Water District, Barnstable Fire District, Dennis Water Department, and Yarmouth Water Department for respective service areas within the watershed. A minimum of three years of water use was obtained with the following respective time periods: 2007 to 2010, 2006 to 2008, 2007 to 2009, and 2005-2011. The water use data was linked to the town parcel database and assessor's data by CCC GIS staff with QA/QC by MEP staff.

Measured water use is used to estimate wastewater-based nitrogen loading from individual parcels; average water use is used for each parcel with multiple years of data. The final wastewater nitrogen load for each parcel is based upon the measured water-use, wastewater nitrogen concentration, and consumptive loss of water before the remainder is treated in a septic system (see Section IV.1.2). All parcels are assumed to use on-site septic systems unless additional information is available.

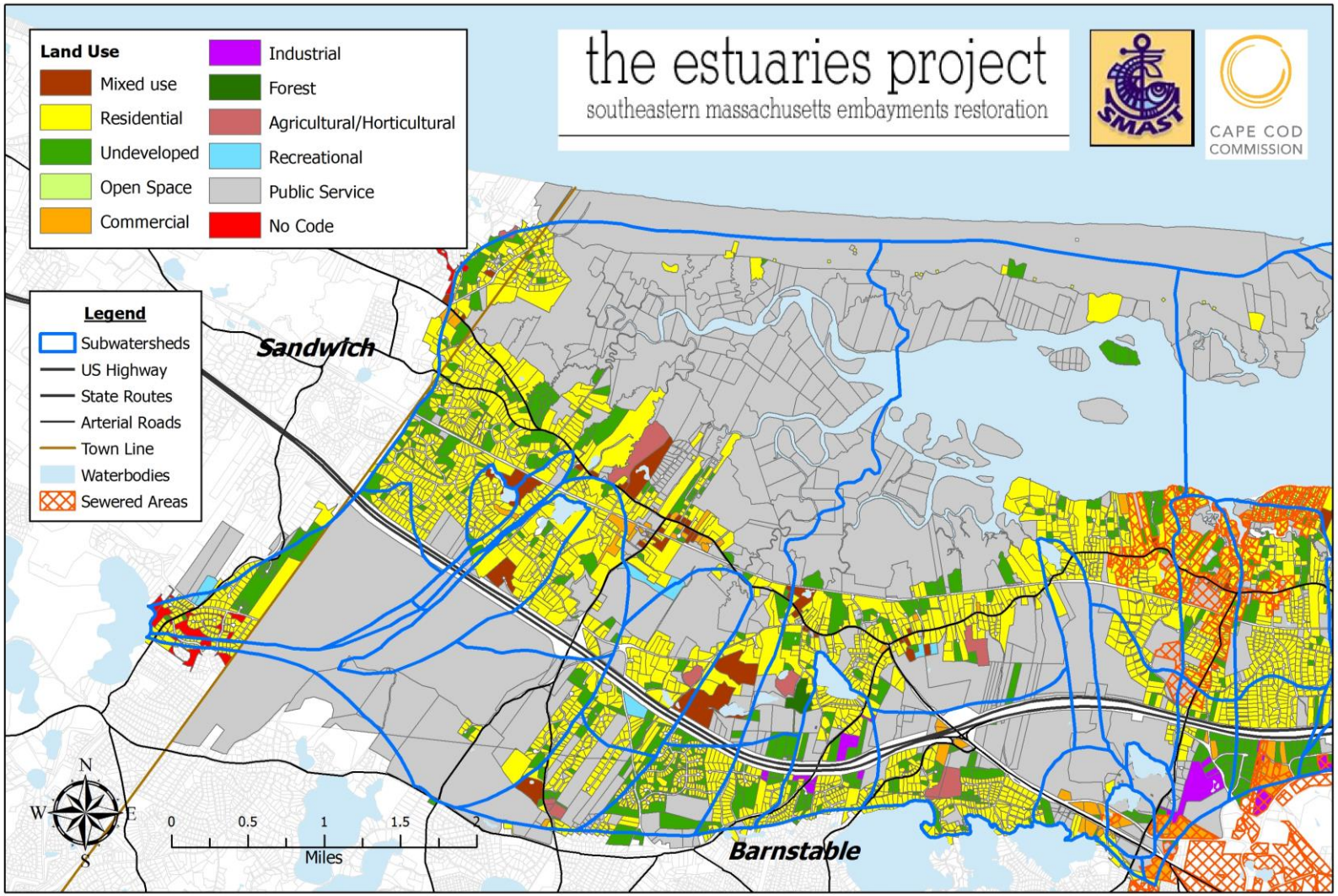


Figure IV-1. Land-use in the western half of the Barnstable Great Marsh system watershed and subwatersheds. Overall watershed includes portions of the towns of Barnstable, Yarmouth, Dennis, and Sandwich. Land use classifications are based on town assessor classifications and MADOR (2015) categories. Parcels along watershed boundaries are assigned to subwatersheds to 1) minimize the splitting of properties for future management purposes and 2) achieve a match of area with the modeled watersheds of 2% or less.

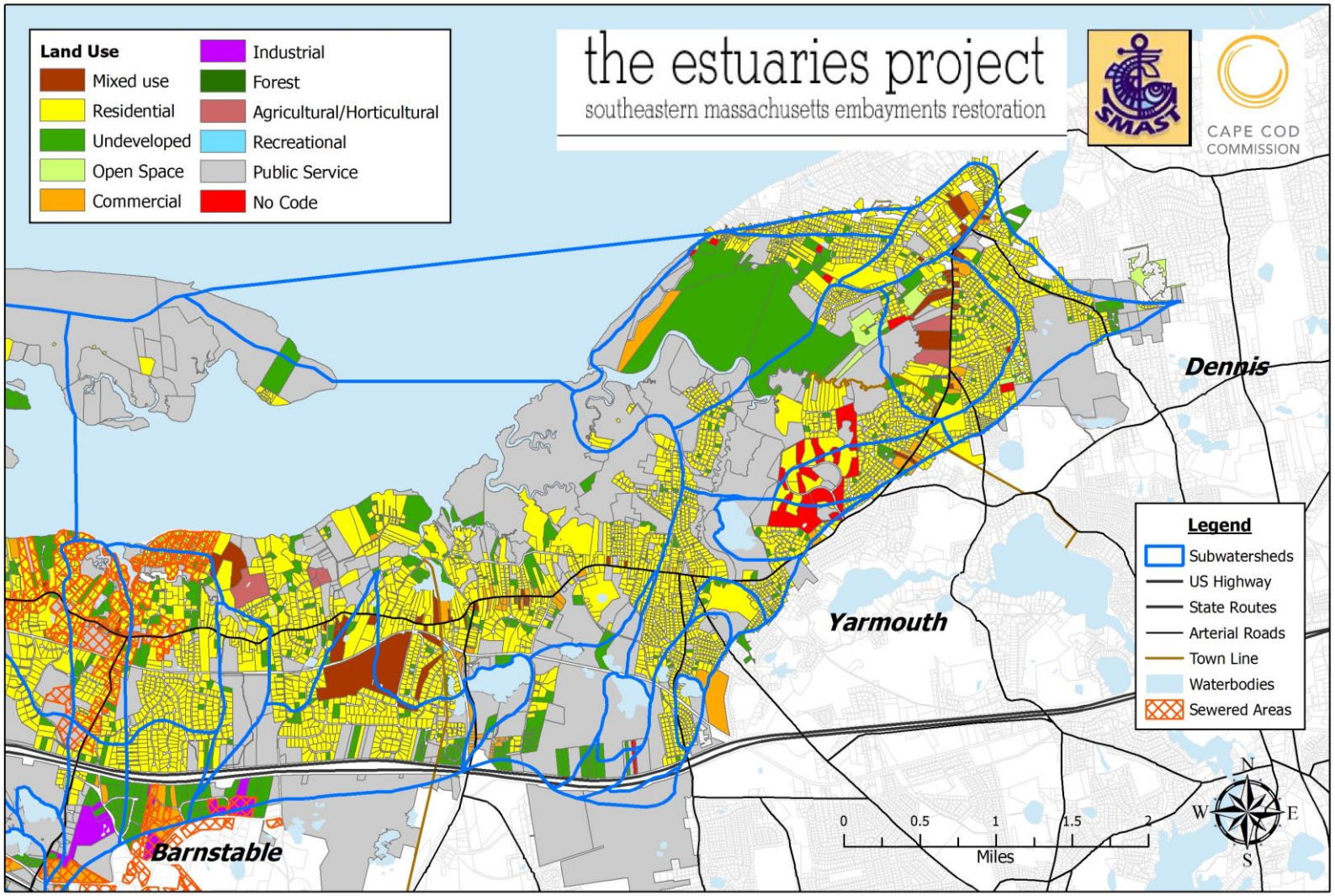


Figure IV-2. Land-use in the eastern portion of the Barnstable Great Marsh watershed and subwatersheds. Overall watershed includes portions of the towns of Barnstable, Yarmouth, Dennis, and Sandwich. Land use classifications are based on town assessor classifications and MADOR (2015) categories. Parcels along watershed boundaries are assigned to subwatersheds to 1) minimize the splitting of properties for future management purposes and 2) achieve a match of area with the modeled watersheds of 2% or less.

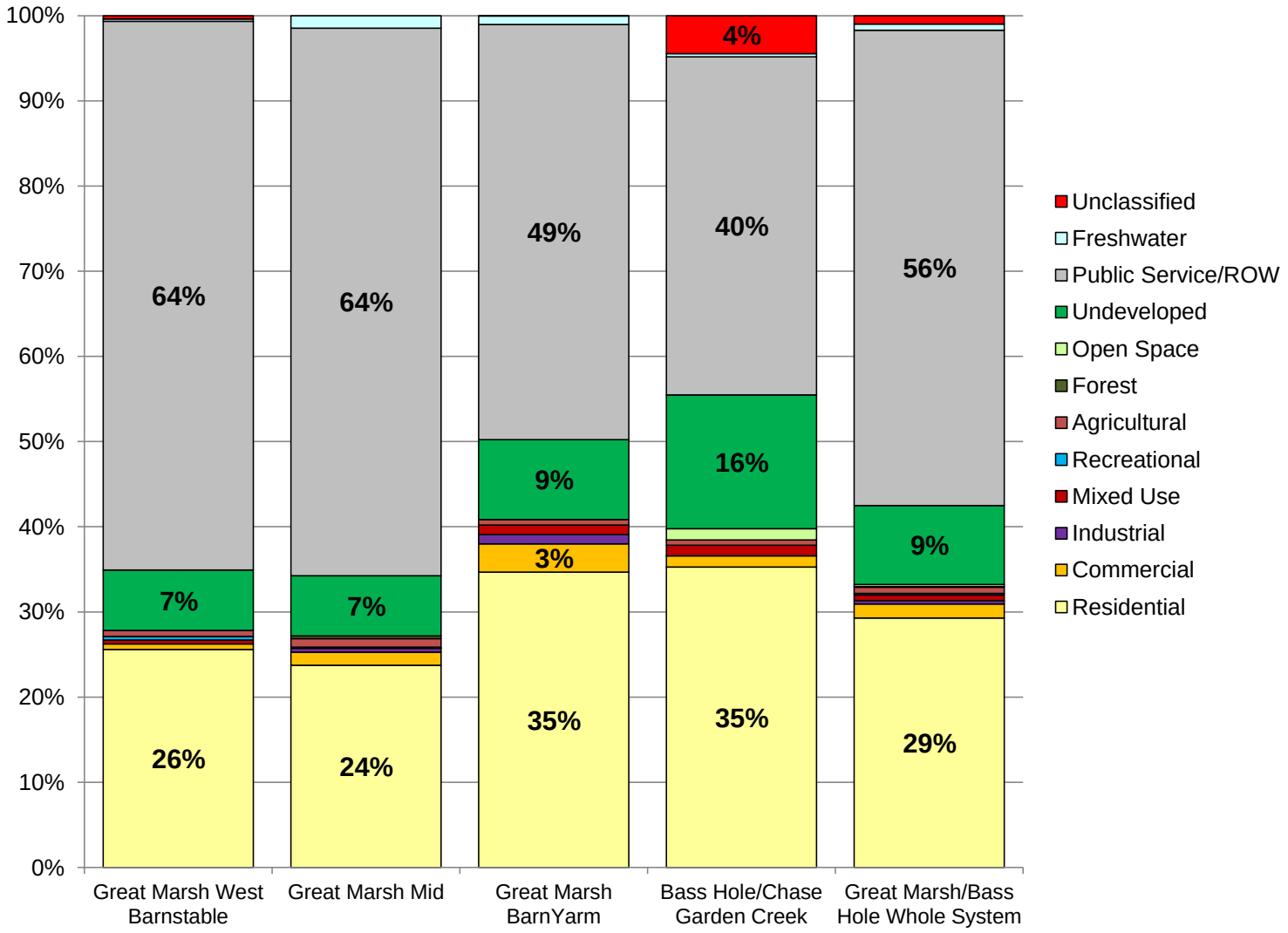


Figure IV-3. Distribution of land-uses by area within the Barnstable Great Marsh system watershed and selected component subwatersheds. Land use categories are generally based on town assessor's land use classification and grouping recommended by MADOR (2015). Unclassified parcels do not have an assigned land use code in the town assessor's databases. Only category percentages greater than or equal to 3% are labelled.

IV.1.2 Nitrogen Loading Input Factors

Wastewater/Water Use

The Massachusetts Estuaries Project septic system nitrogen loading rate is fundamentally based upon a *per capita* nitrogen load to the receiving aquatic system. Specifically, the MEP septic system wastewater nitrogen loading is based upon a number of studies and additional information that directly measured septic system and per capita loads on Cape Cod or in similar geologic settings (Nelson *et al*. 1990, Weiskel & Howes 1991, 1992, Koppelman 1978, Frimpter *et al.* 1990, Brawley *et al.* 2000, Howes, *et al.*, 2001, Costa *et al.* 2001). Variation in *per capita* nitrogen load has been found to be relatively small, with average annual *per capita* nitrogen loads generally between 1.9 to 2.3 kg person-yr^{-1}.

However, given the seasonal shifts in occupancy and rapid population growth throughout southeastern Massachusetts, decennial census data yields accurate estimates of total population only in selected watersheds. To correct for this uncertainty and more accurately assess current nitrogen loads, the MEP employs a water-use approach. The water-use approach is generally applied on a parcel-by-parcel basis within a watershed, where annual water meter data is linked to assessor's parcel information using GIS techniques. The parcel specific water use data is converted to septic system nitrogen discharges (to the receiving aquatic systems) by adjusting for consumptive use (*e.g.,* irrigation) and applying a wastewater nitrogen concentration. The water use approach focuses on the nitrogen load that reaches the aquatic receptors downgradient in the aquifer.

All nitrogen losses within septic systems are incorporated into the MEP analysis. For example, information developed at the Massachusetts Alternative Septic System Test Center at the Massachusetts Military Reservation on Title 5 septic systems have shown nitrogen removals between 21% and 25%. Multi-year monitoring from the Test Center has revealed that nitrogen removal within the septic tank was small (1% to 3%), with most (20 to 22%) of the removal occurring within five feet of the soil adsorption system (Costa *et al.,* 2001). Downgradient studies of septic system plumes in similar soils indicate that further nitrogen loss during aquifer transport is negligible (Robertson *et al*., 1991, DeSimone and Howes 1996).

In its application of the water-use approach to septic system nitrogen loads, MEP staff has ascertained for the Estuaries Project region that while the *per capita* septic load is well constrained by direct studies, the consumptive use and nitrogen concentration data are less certain. As a result, MEP staff has derived a combined term for an effective N Loading Coefficient (consumptive use times N concentration) of 23.63, to convert water (per volume) to nitrogen load (N mass). This coefficient uses a *per capita* nitrogen load of 2.1 kg N person-yr^{-1} and is based upon direct measurements and corrects for changes in concentration that result from *per capita* shifts in water-use (*e.g.*, due to installing low plumbing fixtures or high versus low irrigation usage).

The nitrogen loads developed using this approach have been validated in a number of long and short term field studies where integrated measurements of nitrogen discharge from watersheds could be directly measured. Weiskel and Howes (1991, 1992) conducted a detailed watershed/stream tube study that monitored septic systems, leaching fields and the transport of the nitrogen in groundwater to adjacent Buttermilk Bay. This monitoring resulted in estimated annual *per capita* nitrogen loads of 2.17 kg (as published) to 2.04 kg (if new attenuation information is included). Further, modeled and measured nitrogen loads were determined for a small sub-watershed to Mashapaquit Creek in West Falmouth Harbor (Smith and Howes,

manuscript in review) where measured nitrogen discharge from the aquifer was within 5% of the modeled N load. Another evaluation was conducted by surveying nitrogen discharge to the Mashpee River in reaches with swept sand channels and in winter when nitrogen attenuation is minimal. The modeled and observed loads showed a difference of less than 8%, easily attributable to the low rate of attenuation expected at that time of year in this type of ecological situation (Samimy and Howes, unpublished data).

While census-based population data has limitations in the highly seasonal MEP region, part of the regular MEP analysis is to compare expected water used based on average residential occupancy to measured average water uses. This is performed as a quality assurance check to increase certainty in the final results. This comparison has shown that the larger the watershed the better the match between average water use and occupancy. For example, in the cases of the combined Great Pond, Green Pond and Bournes Pond watershed in the Town of Falmouth and the Popponesset Bay/Eastern Waquoit Bay watershed, both of which cover large areas and have significant year-round populations, the septic nitrogen loading based upon the census data is within 5% of that from the water use approach. This comparison matches some of the variability seen in census data itself. Census blocks, which are generally smaller areas of any given town, have shown up to a 13% difference in average occupancy from town-wide occupancy rates. These analyses provide additional support for the use of the water use approach in the MEP study region.

Overall, the MEP water use approach for determining septic system nitrogen loads has been both calibrated and validated in a variety of watershed settings. The approach: (a) is consistent with a suite of studies on *per capita* nitrogen loads from septic systems in sandy soils and outwash aquifers; (b) has been validated in studies of the MEP Watershed “Module”, where there has been excellent agreement between the nitrogen load predicted and that observed in direct field measurements corrected with other MEP Nitrogen Loading Coefficients (*e.g.*, stormwater, lawn fertilization); (c) the MEP septic nitrogen loading coefficient agrees with specific studies of consumptive water use and nitrogen attenuation between the septic tank and the discharge site; and (d) the watershed module provides estimates of nitrogen attenuation by freshwater systems that are consistent with a variety of ecological studies. It should be noted that while points b-d support the use of the MEP Septic N Coefficient, they were not used in its development. The MEP Technical Team has developed the septic system nitrogen load over many years, and the general agreement among the number of supporting studies has greatly enhanced the certainty of this critical watershed nitrogen loading term.

The independent validation of the water quality model (Section VI) and the reasonableness of the freshwater attenuation (Section IV.2) add additional weight to the nitrogen loading coefficients used in the MEP analyses and a variety of other MEP embayments. While the MEP septic system nitrogen load is the best estimate possible, to the extent that it may underestimate the nitrogen load from this source reaching receiving waters provides a safety factor relative to other higher loads that are generally used for septic systems in regulatory situations. The lower concentration results in slightly higher amounts of nitrogen mitigation (estimated at 1% to 5%)) needed to lower embayment nitrogen levels to a nitrogen target (*e.g.*, nitrogen threshold, cf. Section VIII). The additional nitrogen removal is not proportional to the septic system nitrogen level, but is related to the how the septic system nitrogen mass compares to the nitrogen loads from all other sources that reach the estuary (i.e. attenuated loads).

In order to estimate wastewater flows, MEP staff generally work with municipal or water supplier partners in the study watershed to obtain parcel-by-parcel water use information. In the Barnstable Great Marsh watershed, a minimum of three years of water use was obtained for each

parcel with a municipal water connection from the various water suppliers in each of the towns. Based on this data, average daily water use for single-family residences with municipal water accounts in the Barnstable Great Marsh MEP study area is 216 gpd. If the Barnstable Great Marsh average flow is multiplied by 0.9 to account for consumptive use, the study area wastewater average flow for a single-family residence is 195 gpd. Water use is used as a proxy for wastewater generation from septic systems on all developed properties in the watershed. Wastewater-based nitrogen loading from the individual parcels using on-site septic systems is based upon the average water-use, nitrogen concentration, and consumptive loss of water before the remainder is treated in a septic system (see Section IV.1.2).

The Barnstable Great Marsh watershed is shared among the towns of Barnstable, Yarmouth, Dennis, and Sandwich. In order to provide a check on the measured water use, 2010 US Census average occupancies were reviewed. MEP staff reviewed US Census population values for the Towns of Barnstable, Yarmouth, and Dennis. Sandwich was not included because it occupies only a small portion of the watershed. The state on-site wastewater regulations (*i.e.*, 310 CMR 15, Title 5) assume that two people occupy each bedroom and each bedroom has a wastewater flow of 110 gallons per day (gpd), so for the purposes of Title 5 each person generates 55 gpd of wastewater. Based on data collected during the 2010 US Census, average occupancy within Barnstable, Yarmouth, and Dennis was 2.35, 2.12, and 2.05 people per housing unit. Multiplying these Census occupancies by the state Title 5 estimate of 55 gpd of wastewater *per capita* results in estimated water use per residence of 129, 116, and 113 gpd, respectively.

Given that such a high percentage of housing units on Cape Cod are occupied only on a seasonal basis, estimates of water use based on US Census data need to also include an adjustment for a seasonal population increase. Estimates of summer populations on Cape Cod and the Islands derived from a number of approaches (*e.g.*, traffic counts, garbage generation, and WWTF flows) generally suggest average summer population increases from two to four times the year-round residential populations measured during the US Census. For example, the Town of Barnstable Comprehensive Annual Financial Report estimated that the summer population was 2.9X the year-round population (Town of Barnstable, 2014). If it is assumed that seasonally-classified residential properties in Barnstable, Yarmouth, and Dennis are occupied at three times the 2010 year-round occupancy for three months, the estimated parcel water uses would be 194, 175, and 169 gpd, respectively. If the multiplier is increased to four times the year-round occupancy, the respective estimated water uses are 226, 204, and 197 gpd. If the “summer” period is increased from three months to four months to accommodate the so-called “shoulder seasons” and 3X year-round occupancy is used, the respective town water use estimates are 215 gpd, 194 gpd, and 188 gpd. This analysis of US Census data incorporating reasonable estimates of seasonal population increases suggests that average measured water use within the watershed is an appropriate basis of estimating water uses within the Barnstable Great Marsh watershed and is a suitable estimate for any parcels with private wells or for any future development additions. This analysis further suggests that population and water use information are in reasonable agreement and that the average water use is reasonably reflective of average wastewater estimates.

At the outset of the MEP, project staff decided to utilize the water use approach for determining residential wastewater generation by septic systems because of the inherent difficulty in accurately gauging actual occupancy in areas impacted by seasonal population fluctuations such as most of Cape Cod. The above analysis underscores some of the difficulty in using census information and strongly supports that measured water use, on average, provides the best estimate of wastewater generation within the study area.

Water use information exists for 74% of the 7,242 developed parcels within the Barnstable Great Marsh watershed. Parcels without water use accounts are assumed to utilize private wells for drinking water. These are properties that were classified with land use codes that indicate that they are developed (*e.g.*, 101 or 325) and have been confirmed as having buildings on them through a review of aerial photographs, but do not have a listed account in the water use databases. Of the 1,854 developed parcels without water use accounts, 1,534 (83%) are classified as single-family residences (land use code 101). These parcels are predominantly located within West Barnstable where municipal water supply is not available. All these parcels are assigned the MEP Barnstable Great Marsh watershed average water use of 216 gpd in the watershed nitrogen loading modules.

Wastewater Treatment Facilities and Alternative Septic Systems

When developing watershed nitrogen loading information, MEP project staff typically seeks additional information on enhanced wastewater treatment in the project study area. This information is reviewed and if judged reliable is included in the watershed nitrogen loading model.

MEP staff reviewed MassDEP Groundwater Discharge Permits (GWDPs) database and confirmed with MassDEP staff that the Kings Way wastewater treatment facility (WWTF) in Yarmouth is the only GWDP within the Barnstable Great Marsh watershed (personal communication, Brian Dudley, MassDEP, 9/15). A GWDP is required under MassDEP regulations for wastewater treatment systems with design flows greater than 10,000 gallons per day. The Kings Way WWTF treats wastewater from the Kings Way condominium and golf course complex north of Route 6A. The effluent discharge beds are located under the northern portions of the golf course and within the Chase Garden Creek Salt W LT10 subwatershed (subwatershed #40). MassDEP provided monthly discharge flows and effluent total nitrogen concentrations from 2010 through 2014 (**Figure IV-4**). Based on this information, MEP staff calculated the WWTF had an average effluent discharge of 45,750 gpd and an average annual nitrogen load of 274 kg.

While there is only one wastewater treatment facility discharging within the Barnstable Great Marsh watershed, the watershed also includes an area connected via sewers to the Hyannis Water Pollution Control Facility (HWPCF). This area is predominantly concentrated around Barnstable Village and includes portions of the Millway and Huckins Neck subwatersheds, as well as parcels in the watershed in Independence Park and along Route 132 (see Figures IV-1 and IV-2). Wastewater is collected from these parcels and transported to the HWPCF where it is treated and discharged. Since the wastewater nitrogen loads from these parcels is transported and discharged outside of the watershed, these parcels have no wastewater nitrogen load in the watershed nitrogen loading model.

MEP staff received a list of alternative, denitrifying septic systems in Barnstable, Dennis, and Yarmouth, as well as their total nitrogen effluent monitoring data, from the Barnstable County Department of Health and the Environment (personal communication, Brian Baumgaertel, 9/15). Sandwich is not part of the BCDHE tracking system. From the BCDHE database, project staff identified 23 potential denitrifying septic systems within the Barnstable Great Marsh watershed. After matching these to the parcel database and reviewing the available data, 20 of these had three or more sampling runs and were located on parcels with matching addresses; six are in Barnstable, two are in Yarmouth, and 12 are in Dennis. Four of the systems are on properties with private wells. The average TN concentrations of treated effluent for all these systems are included in the watershed nitrogen loading model.

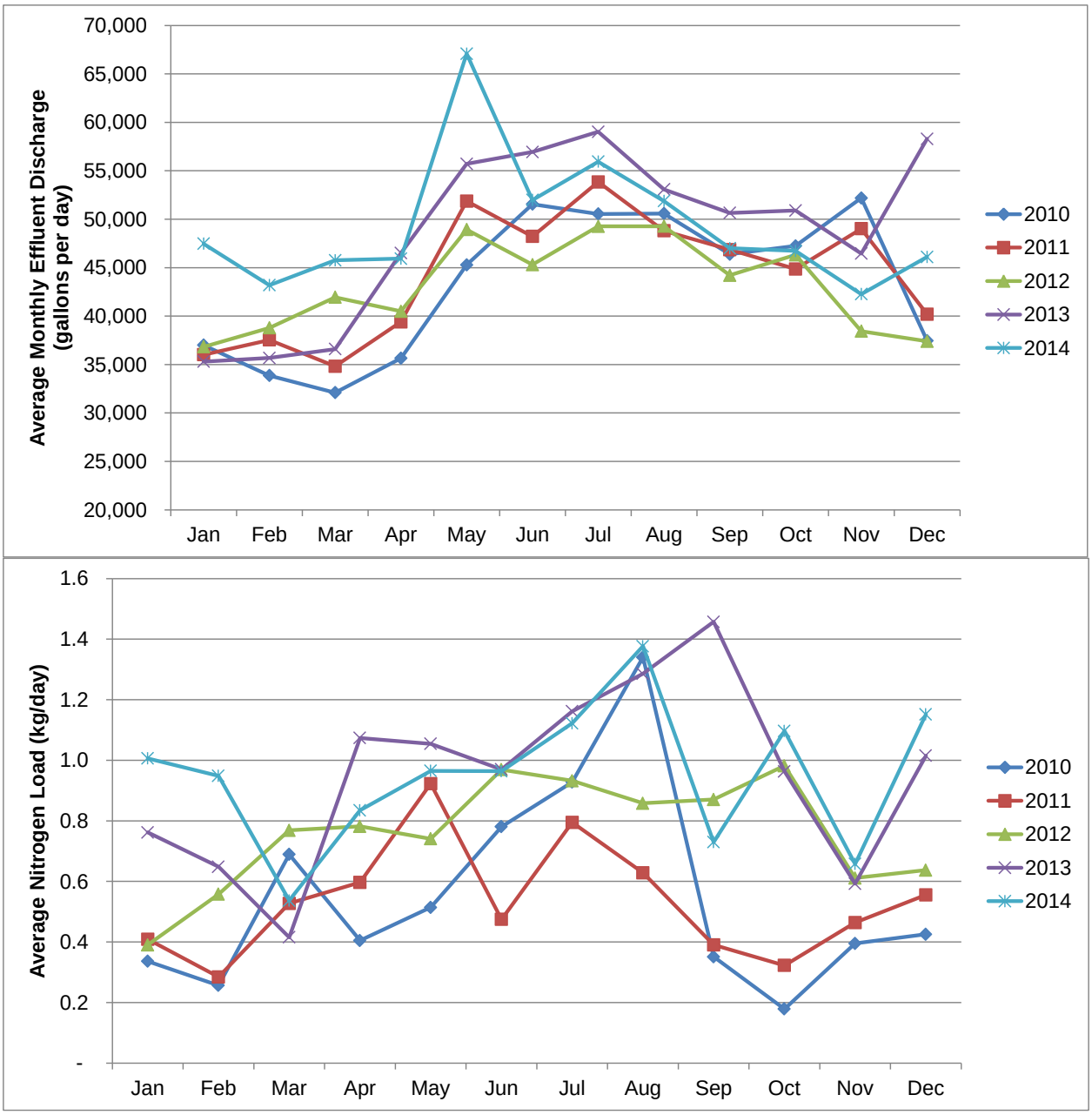


Figure IV-4. Average Monthly Effluent Discharge and Nitrogen Load at the Kings Way WWTF. The Kings Way WWTF is the only large wastewater treatment facility within the Barnstable Great Marshes watershed. The WWTF discharges within the Chase Garden Creek Salt W LT10 subwatershed (subwatershed #40). Based on 2010 to 2014 data supplied by MassDEP, the average effluent flow from the WWTF was 45,750 gpd and an average annual nitrogen load of 274 kg.

Nitrogen Loading Input Factors: Fertilized Areas, Golf Courses, and Agriculture

The second largest source of watershed nitrogen loading to estuaries is usually fertilized areas: lawns, golf courses, and cranberry bogs. Residential lawns are usually the predominant source within this category. In order to add this source to the watershed nitrogen loading model for the Barnstable Great Marsh Estuary, MEP staff reviewed available regional information about residential lawn fertilizing practices and incorporated site-specific information for cranberry bogs and agricultural areas in the watershed. Cranberry bog nitrogen loading was determined based on previous studies conducted in southeastern Massachusetts.

Residential lawn fertilizer use has rarely been directly measured in watershed-based nitrogen loading investigations. Instead, lawn fertilizer nitrogen loads have been estimated based upon a number of assumptions: a) each household applies fertilizer, b) cumulative annual applications are 3 pounds per 1,000 sq. ft., c) each lawn is 5000 sq. ft., and d) only 25% of the nitrogen applied reaches the groundwater (leaching rate). Because many of these assumptions had not been rigorously reviewed prior to the MEP, the MEP Technical Staff undertook an assessment of lawn fertilizer application rates and a review of leaching rates for inclusion in the Watershed Nitrogen Loading Sub-Model.

The initial effort in this assessment was to determine nitrogen fertilization rates for residential lawns in the Towns of Falmouth, Mashpee and Barnstable. This assessment, which was completed prior to the start of the MEP, accounted for proximity to fresh ponds and embayments. Based upon ~300 interviews and over 2,000 site surveys, a number of findings emerged: 1) average residential lawn area is ~5000 sq. ft., 2) half of the residences did not apply lawn fertilizer, and 3) the weighted average application rate was 1.44 applications per year, rather than the 4 applications per year recommended on the fertilizer bags. Integrating the average residential fertilizer application rate with a nitrogen leaching rate of 20% results in a fertilizer contribution of N to groundwater of 1.08 lb N per residential lawn; these factors are used in the MEP nitrogen loading calculations. It is likely that this still represents a conservative estimate of nitrogen load from residential lawns. It should be noted that professionally maintained lawns in the three town survey were found to have the higher rate of fertilizer application and hence higher estimated annual contribution to groundwater of 3 lb/yr. It should be noted that a recent review of fertilizer leaching rates for Cape Cod watersheds indicated that the MEP leaching rate of 20% is fully supported from analysis of all appropriate data, and was a reasonable value for watershed nitrogen modeling in watersheds with soils similar to those on Cape Cod.

In addition to residential fertilizer nitrogen within the watershed, there is also fertilizer nitrogen from portions of six golf courses. A number of the golf courses are shared with other MEP watersheds; in these cases, MEP staff utilized previous course- and turf-specific fertilizer application information obtained from course superintendents. For the “new” courses, MEP staff tried a number of times to contact course superintendents in order to obtain similar information. Staff had previously obtained nitrogen fertilizer information from:

a) Olde Barnstable Fairgrounds Golf Course (personal communication, Bruce McIntryre, Superintendent, 5/06; Centerville River MEP report (Howes, *et al*., 2006a));
b) Bayberry Hills Golf Course (personal communication, Rick Lawlor, Superintendent, 2/09; Bass River MEP report (Howes, *et al*., 2011)); and
c) Dennis Highlands Golf Course (personal communication, Mike Cummings, Superintendent, 6/10; Bass River MEP report (Howes, *et al*., 2011)).

MEP staff also obtained nitrogen fertilizer information from the Cummaquid Golf Club (personal communication, Dana Hancock, Superintendent, 8/15), but did not obtain information from the Golf Club at Yarmouthport or the Hyannis Golf Course. Since course- and turf-specific fertilizer information was not obtained for these two courses, nitrogen application rates and loads were determined based on average application rates developed from 23 courses within the MEP region that have provided this information during previous MEP watershed nitrogen loading assessments. Based on these regional average application rates, average turf application rates for Yarmouthport and Hyannis Golf Courses were estimated to be: greens, 3.5; tees, 3.5; fairways, 3.2, and rough, 2.4 (in lbs/1,000 sq. ft. per year).

In order to develop nitrogen loads for each of the golf courses within the Barnstable Great Marsh watershed, MEP staff reviewed the layout of each golf course from aerial photographs, classified the various turf types (*i.e.*, greens, tees, fairways, and roughs) and determined which subwatershed in which the various turf types were located. The course-specific fertilizer application rates were then combined with a standard MEP 20% turf nitrogen leaching rate and subwatershed-specific nitrogen loads were developed.

Nitrogen loads were also added for site-specific agricultural land uses. Cranberry bog fertilizer application rate and percent nitrogen attenuation are based on an enhanced review of nitrogen export from cranberry bogs in southeastern Massachusetts (DeMoranville and Howes, 2009; Howes and Teal, 1995). This review found that nitrogen export from cranberry bogs differs depending on whether water continuously flows through the bog or is pumped or diverted onto the bog (non-flow through bogs) from an outside source of water. Based on this review, MEP analyses use annual nitrogen exports of 6.95 kg/ha for non-flow through bogs and 23.08 kg/ha for flow through bogs. MEP staff reviewed the configuration of the 11 bogs within the Barnstable Great Marsh watershed and assigned all bogs the flow through bog nitrogen loading rate. In addition, one of the bogs was not assigned a nitrogen loading addition because it discharges into Lake Wequaquet. The areas of the bogs are based on a MassDEP GIS coverage that is maintained by MassDEP for Water Management Act permitting (personal communication, Jim McLaughlin, MassDEP SERO, 1/13).

Nitrogen loads were also added based on agricultural animals within the watershed. MEP staff received a listing of registered horse stables in the Town of Barnstable (personal communication, Sarah Crocker, Barnstable Health Department, 12/15) and reviewed farm activity information available through internet searches and review of aerial photographs in order to develop estimates of farm animal counts. Because of the uncertainties in the development of these estimates, it is assumed that these counts and the resulting agricultural animal loads are somewhat conservative. Species-specific nitrogen loads were developed based on USDA and other species-specific research on nitrogen manure characteristics, including leaching to groundwater. Loads were assigned to individual farm lots based on the animal counts. Details of these loads are included in the MEP Data Disk that accompanies this report.

Nitrogen Loading Input Factors: Other

The nitrogen loading factors for atmospheric deposition, impervious surfaces and natural areas in the Barnstable Great Marsh assessment are from the MEP Embayment Modeling Evaluation and Sensitivity Report (Howes, *et al*., 2001). The factors are similar to those utilized by the CCC's Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and MassDEP's Nitrogen Loading Computer Model Guidance (1999). The recharge rate for natural areas and lawn areas is the same as utilized in the MEP-USGS groundwater modeling effort (Section III).

Factors used in the MEP nitrogen loading analysis for the Barnstable Great Marsh watershed are summarized in Table IV-2.

Road and building areas are based on GIS coverages. The road areas are based on GIS information developed by the Massachusetts Executive Office of Transportation, which provides road, sidewalk, and road shoulder widths for various road segments (April 2012 GIS coverage available through MassGIS). Building footprint areas are based on MassGIS coverage developed based on digitized footprints from 2011 to 2012 aerial orthophotographs supplemented with LiDAR data. MEP staff utilized GIS techniques to sum both of these sets of areas by subwatershed within the Barnstable Great Marshes watershed in order to determine nitrogen loads from these impervious surfaces. Project staff also checked the road information against parcel-based rights-of-way.

Table IV-2. Primary Nitrogen Loading Factors used in the Barnstable Great Marsh MEP analyses. General factors are from MEP modeling evaluation (Howes, *et al*., 2001). Site-specific factors are derived from watershed-specific data.

Nitrogen Concentrations:	**mg/l**
Road Run-off	1.5
Roof Run-off	0.75
Natural Area Recharge	0.072
Direct Precipitation on Embayments and Ponds	1.09
Wastewater Coefficient	23.63
Fertilizers:	
Average Residential Lawn Size (sq ft)[1]	5,000
Residential Watershed Nitrogen Rate (lbs/lawn)[1]	1.08
Leaching rate	20%
Cranberry Bogs nitrogen release – flow through bogs (kg/ha/yr)	23.08
Cranberry Bogs nitrogen release – pump on/pump off bogs (kg/ha/yr)	6.95
Nitrogen Loading Rates for farm animals were based on loads determined in other MEP assessments and USDA guidance, while fertilizer loading rates for golf courses were generally based on course-specific use.	

Recharge Rates:	**in/yr**
Impervious Surfaces	40
Natural and Lawn Areas	27.25
Water Use/Wastewater:	
Existing developed single-family residential parcels wo/water accounts and buildout residential parcels:	216 gpd[2]
Existing developed parcels w/water accounts:	Measured annual water use
Commercial and Industrial Buildings without/WU and buildout additions[3]	
Commercial	
Wastewater flow (gpd/1,000 ft2 of building):	95
Building coverage:	10%
Industrial	
Wastewater flow (gpd/1,000 ft2 of building):	39
Building coverage:	5%
Average Single Family Residence Building Size[3] (sq ft)	2,008

Notes:
1) Data from MEP lawn study in Falmouth, Mashpee & Barnstable of over 2,000 lawns (2001).
2) Based on average measured flow in the MEP Barnstable Great Marsh watershed.
3) Based on characteristics of similarly classified properties with the MEP Barnstable Great Marsh watershed.

IV.1.3 Calculating Nitrogen Loads

Once all the land and water use information is linked to the parcel coverages, parcels are assigned to various watersheds based initially on whether at least 50% or more of the land area of each parcel is located within a respective subwatershed. Following the assigning of boundary parcels, all large parcels are examined individually and are split (as appropriate) in order to obtain less than a 2% difference between the total land area of each subwatershed and the sum of the area of the parcels within each subwatershed. This effort results in "parcelized" watersheds that can be more easily used during the development of management strategies and subsequent regulatory discussions.

The review of individual parcels straddling watershed boundaries includes corresponding reviews and individualized assignment of nitrogen loads associated with lawn areas, septic systems, and impervious surfaces. Building footprints areas, for example, are based on MassGIS review of aerial photographs and this is assigned based on individual parcels and subwatershed lines. Project staff used the average single-family residence building footprint based on available properties in the MEP study area (2,008 sq ft) for any similar residential units without footprint information (*e.g.*, buildings since the MassGIS coverage was developed). Individualized information for parcels with atypical nitrogen loading (condominiums, golf courses, etc.) is also assigned at this stage. It should be noted that small shifts in nitrogen loading due to the above assignment procedure generally have a negligible effect on the total nitrogen loading to the Barnstable Great Marsh estuary. The assignment effort is undertaken to better define sub-estuary loads and enhance the use of the Linked Watershed-Embayment Model for the analysis of management alternatives.

Following the assignment of all parcels, subwatershed modules were generated for each of the 45 subwatersheds in the Barnstable Great Marsh study area. These subwatershed modules summarize, among other things: water use, parcel area, frequency, and private wells by land use categories and road and fresh surface water areas within a given subwatershed. All relevant nitrogen loading data is assigned to each subwatershed. Individual sub-watershed information is then integrated to create the Barnstable Great Marsh Watershed Nitrogen Loading module with summaries for each of the individual 45 subwatersheds. The subwatersheds are generally paired with functional embayment/estuary units for the Linked Watershed-Embayment Model's water quality component.

For management purposes, the aggregated estuary watershed nitrogen loads are partitioned by the major types of nitrogen sources in order to focus development of nitrogen management alternatives. Within the Barnstable Great Marsh overall watershed, the major types of nitrogen loads are: wastewater (*e.g.*, septic systems), fertilizers (including contributions from agriculture and golf courses), impervious surfaces, direct atmospheric deposition to water surfaces, and recharge within natural areas (Table IV-3). The output of the watershed nitrogen-loading model is the annual mass (kilograms) of nitrogen added to the contributing area of each component sub-embayment, by each source category (Figure IV-5). In general, the annual watershed nitrogen input to the watershed of an estuary is then adjusted for natural nitrogen attenuation in streams and ponds during transport to the estuarine system before use in the embayment water quality sub-model.

Table IV-3. Barnstable Great Marsh Watershed Nitrogen Loads. Nitrogen loads are listed by various sources and by subwatershed. Unattenuated nitrogen loads are a sum of all sources without including natural nitrogen attenuation in fresh surface waters. Attenuated nitrogen loads are based on measured and assigned attenuation factors for upgradient streams and freshwater ponds. Stream attenuation factors are based on measured loads (see Section IV.2). All nitrogen loads are kg N yr-1.

		Barnstable Great Marsh/Bass Hole N Loads by Input (kg/y):												*Present N Loads*			*Buildout N Loads*		
Watershed Name	Shed ID#	Wastewater	WWTF	Residential Fertilizers	Golf Course Fertilizers	Cranberry Bog Fertilizers	Crop Fertilizers	Farm Animals	Impervious Surfaces	Water Body Surface Area	"Natural" Surfaces	Buildout	% of Pond Outflow	UnAtten N Load	Atten %	Atten N Load	UnAtten N Load	Atten %	Atten N Load
Whole System		53,984	274	3,549	2,792	373	123	1,525	5,247	1,903	3,842	16,326		73,613		66,221	89,939		81,196
Great Marsh West Barnstable		10,817	-	720	622	373	25	840	1,103	304	1,361	4,191		16,165		14,084	20,356		17,685
BarnHbr GT10W	1	1,095	-	75	-	-	-	-	125	-	125	311		1,419		1,419	1,731		1,731
BarnHbr LT10 West Barnstable	10	4,470	-	286	-	157	-	143	391	-	724	1,862		6,171		6,171	8,033		8,033
BarnHbr GT10 West Barnstable	11	1,208	-	82	-	-	-	-	62	-	40	101		1,392		1,392	1,493		1,493
Lawrence Pond	MEP	99	-	6	-	-	-	-	5	160	16	215	16%	286		102	502		193
Bog Pond	BP	286	-	20	-	5	-	-	24	26	7	79	78%	368		184	447		223
Alder Creek		322	-	21	-	84	-	13	27	8	21	124		496		288	619		361
Boat Cove Creek		1,939	-	137	350	10	10	347	304	110	299	900		3,506		3,214	4,405		4,025
Bridge Creek		1,398	-	93	272	116	15	337	165	-	130	599		2,526		1,314	3,125		1,625
Great Marsh Mid		8,649	-	572	606	-	-	-	965	813	860	2,639		12,465		10,060	15,103		12,398
BarnHbr GT10 MidW	13	560	-	32	-	-	-	-	49	-	28	70		668		668	738		738
BarnHbr GT10 - Exit 6	14	1,911	-	101	492	-	-	-	281	-	93	354		2,878		2,878	3,232		3,232
Barnstable Hbr GT10 MidE	19	219	-	15	-	-	-	-	44	-	49	31		327		327	358		358
Barnstable Hbr LT10 Mid	20	3,471	-	233	-	-	-	-	327	-	573	1,613		4,605		4,605	6,218		6,218
BFD Wells	BFD	233	-	5	43	-	-	-	26	69	10	65	24%	388		282	453		329
Hinckley Pond	HP	256	-	14	71	-	-	-	28	64	34	86	100%	466		233	552		276
Garretts Pond	GP	1,208	-	86	-	-	-	-	120	127	46	301	100%	1,587		793	1,887		944
Hathaway Pond N	HPN	61	-	0	-	-	-	-	24	100	11	63	100%	196		78	259		99
Lake Wequaquet - Main Basin	MEP/SMAST	557	-	68	-	-	-	-	50	283	12	42	15%	989	86%	142	1,031	86%	148
Bearses Pond	MEP/SMAST	143	-	13	-	-	-	-	11	71	3	10	24%	245	84%	39	256	84%	41
Shallow Pond	MEP/SMAST	29	-	3	-	-	-	-	5	99	2	4	28%	89	84%	14	93	84%	15
Great Marsh BarnYarm		14,847	-	1,028	580	-	98	685	1,599	505	976	7,294		20,318		19,379	27,612		26,539
BarnHbr GT10 Cummaquid	26	1,924	-	98	205	-	-	-	180	-	131	1392		2,538		2,538	3,930		3,930
BarnHbr GT10 - Yarmouthport	28	393	-	15	-	-	-	-	52	26	68	428		554		554	982		982
BarnHbr LT10 - BarnYarm	31	7,493	-	538	246	-	29	52	651	-	489	1872		9,500		9,500	11,372		11,372
BFD Wells	BFD	694	-	15	129	-	-	-	78	206	30	194	71%	1,152		839	1,346		977
Yarm_Well1	YW1	627	-	46	-	-	-	-	58	22	11	18	34%	764		681	782		700
Dennis Pond	DP	214	-	-	-	-	-	-	16	215	10	40	100%	455		227	495		248
Greenough Pond	GP	11	-	-	0	-	-	-	6	36	8	46	31%	61		30	107		54
Huckins Neck Total		743	-	96	-	-	-	13	210	-	88	2,500		1,149		1,149	3,650		3,650
Huckins Neck GT10	21	447	-	18	-	-	-	-	83	-	42	2,406		590		590	2,997		2,997
Huckins Neck LT10	22	296	-	77	-	-	-	13	127	-	46	94		559		559	653		653
Millway Total		2,748	-	220	-	-	68	619	350	-	141	802		4,145		3,860	4,948		4,628
Millway GT10	23	590	-	36	-	-	-	-	94	-	38	314		758		758	1,072		1,072
Millway LT10	24	1,595	-	152	-	-	-	-	211	-	70	325		2,027		2,027	2,352		2,352
Maraspin Creek		563	-	32	-	-	68	619	44	-	33	163	100%	1,360		1,074	1,523		1,203

Table IV-3 (continued). Barnstable Great Marsh Watershed Nitrogen Loads. Nitrogen loads are listed by various sources and by subwatershed. Unattenuated nitrogen loads are a sum of all sources without including natural nitrogen attenuation in fresh surface waters. Attenuated nitrogen loads are based on measured and assigned attenuation factors for upgradient streams and freshwater ponds. Stream attenuation factors are based on measured loads (see Section IV.2). All nitrogen loads are kg N yr-1.

		Barnstable Great Marsh/Bass Hole N Loads by Input (kg/y):												*Present N Loads*			*Buildout N Loads*		
Watershed Name	**Shed ID#**	**Wastewater**	**WWTF**	**Residential Fertilizers**	**Golf Course Fertilizers**	**Cranberry Bog Fertilizers**	**Crop Fertilizers**	**Farm Animals**	**Impervious Surfaces**	**Water Body Surface Area**	**"Natural" Surfaces**	**Buildout**	**% of Pond Outflow**	**UnAtten N Load**	**Atten %**	**Atten N Load**	**UnAtten N Load**	**Atten %**	**Atten N Load**
Bass Hole/Chase Garden Creek		19,671	274	1,229	984	-	-	-	1,580	281	646	2,202		24,665		22,698	26,867		24,575
Barnstable Hbr LT10 Inlet	45	6	-	1	-	-	-	-	2	-	21	0		30		30	30		30
Chase Garden Creek Salt W		9,130	274	583	502	-	-	-	818	281	271	999		11,858		10,828	12,857		11,642
Chase Garden Crk Salt W GT10	38	1,389	-	70	162	-	-	-	162	-	24	92		1,807		1,807	1,898		1,898
Chase Garden Crk Salt W LT10	40	2,413	274	151	110	-	-	-	215	-	126	327		3,289		3,289	3,616		3,616
Yarm_Well1	YW1	1,142	-	84	-	-	-	-	105	40	20	34	62%	1,391		1,240	1,424		1,274
Whites Brook Salt		4,185	-	278	230	-	-	-	336	241	101	547		5,372		4,492	5,919		4,854
Whites Brook Salt GT10	32	41	-	-	86	-	-	-	7	-	7	0		141		141	141		141
Whites Brook Salt LT10	36	2,787	-	199	-	-	-	-	225	-	45	93		3,256		3,256	3,349		3,349
Matthews Pond	MP	604	-	41	143	-	-	-	58	159	19	54	100%	1,024		512	1,079		539
Greenough Pond	GP	23	-	-	0	-	-	-	13	79	17	101	69%	132		66	233		117
Whites Brook Fresh		731	-	39	-	-	-	-	33	3	13	298		818		516	1,116		707
Chase Garden Creek Salt E		8,402	-	459	483	-	-	-	561	-	169	1,071		10,073		9,136	11,144		10,067
Chase Garden Creek Salt E GT10	39	3,330	-	190	483	-	-	-	238	-	63	323		4,303		4,303	4,626		4,626
Chase Garden Crk Salt E LT10	41	3,736	-	179	-	-	-	-	220	-	74	515		4,209		4,209	4,724		4,724
Chase Garden Creek Fresh		1,335	-	91	-	-	-	-	102	-	33	233		1,561		624	1,794		718
Bass Hole		2,134	-	185	-	-	-	-	200	-	185	132		2,704		2,704	2,836		2,836
Bass Hole GT10	43	762	-	73	-	-	-	-	66	-	11	47		914		914	960		960
Bass Hole LT10	44	1,371	-	111	-	-	-	-	133	-	174	86		1,790		1,790	1,876		1,876

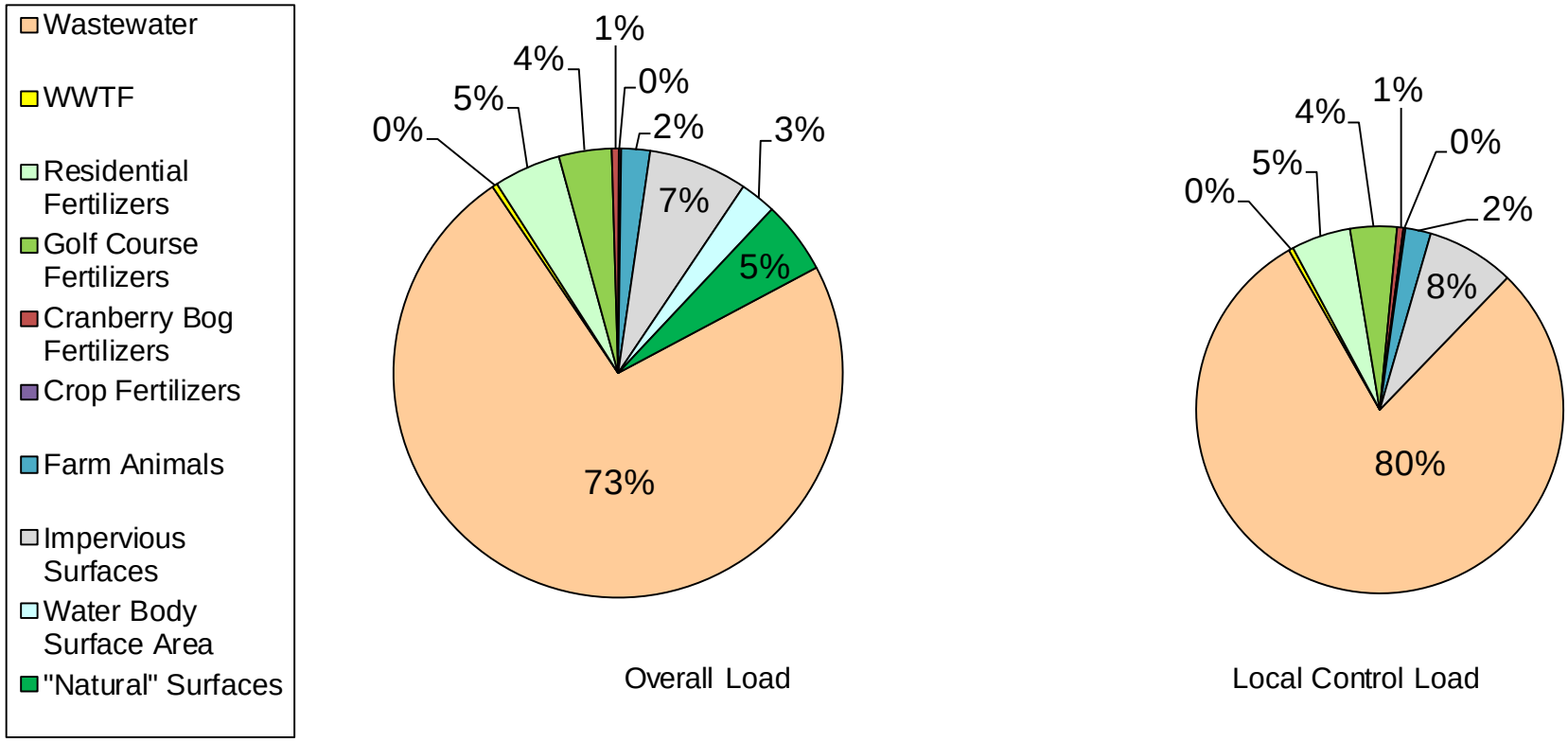
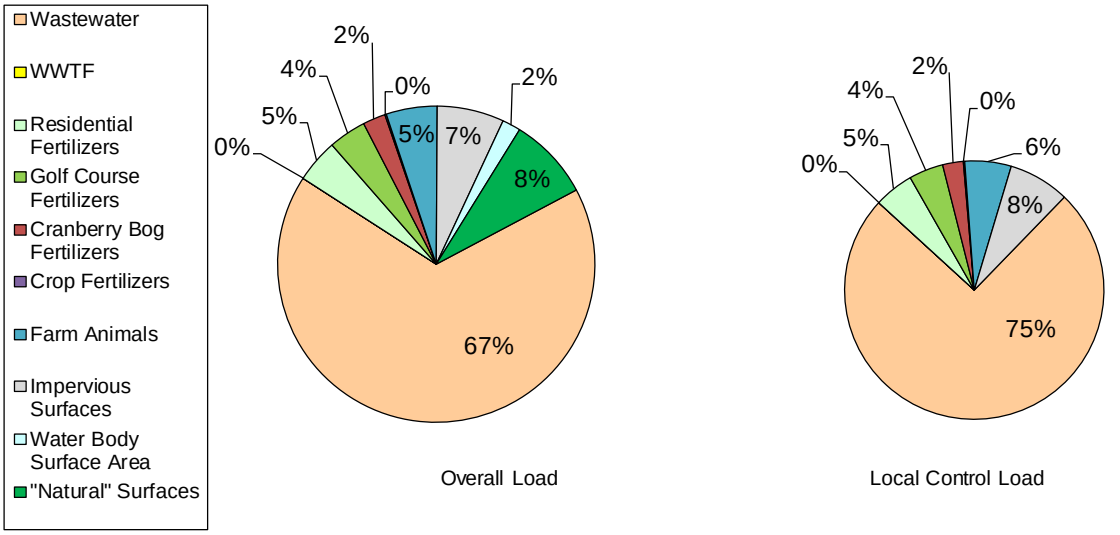
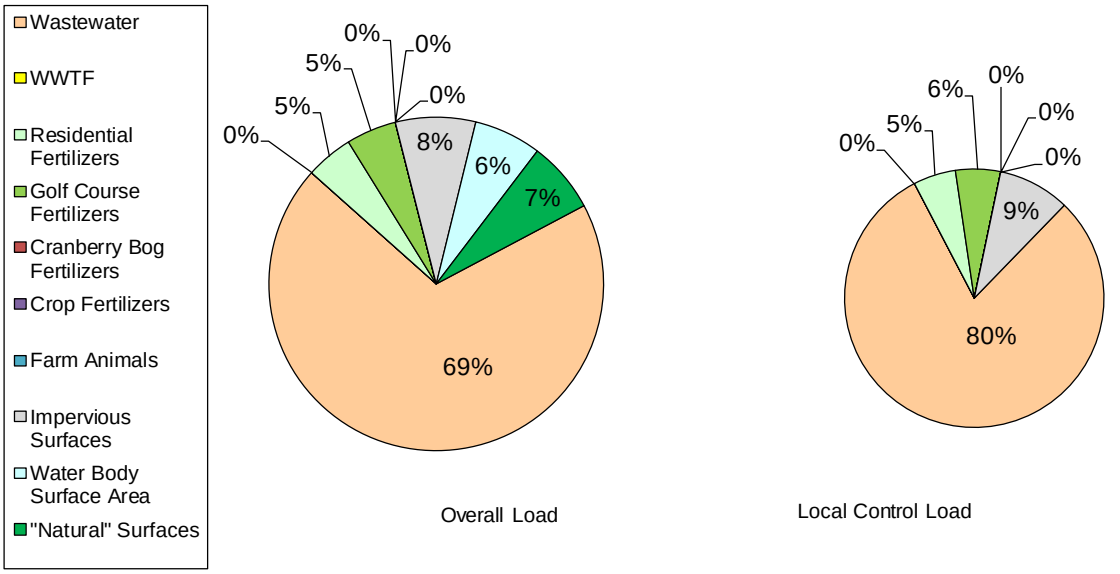


Figure IV-5a. Source-specific unattenuated watershed nitrogen loads (by percent) to the whole Barnstable Great Marsh watershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control. Watershed loads do not include nitrogen load on the surface of the estuary; this load is greater than all other categories of nitrogen load except wastewater.

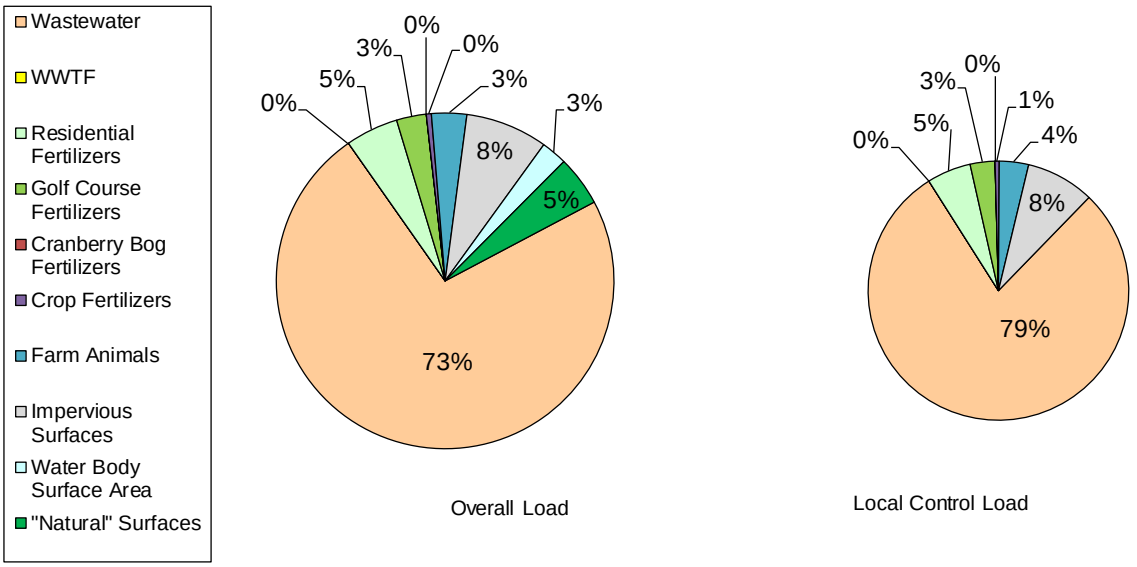


B. Great Marsh West Barnstable

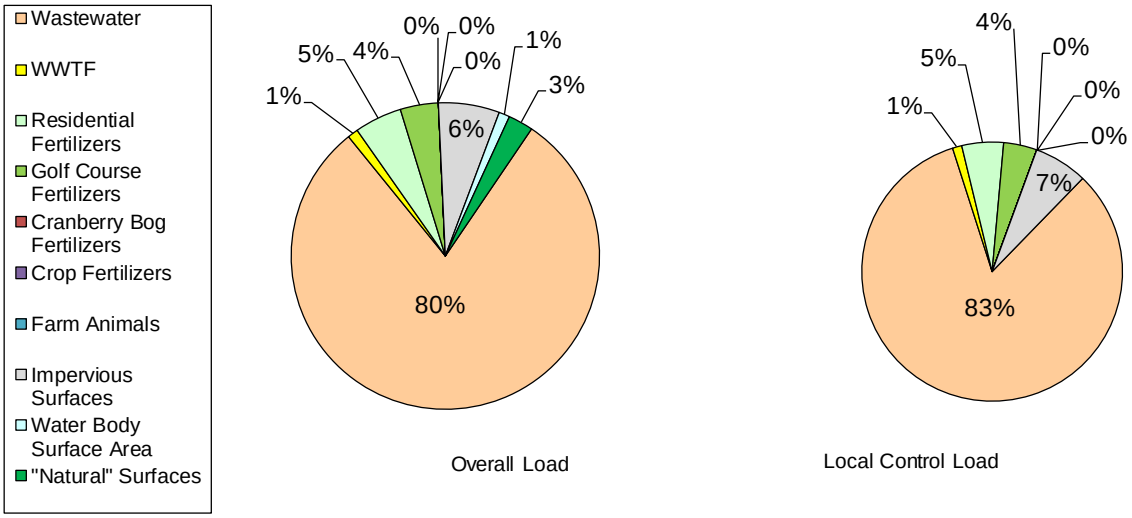


C. Great Marsh Mid

Figure IV-5b,c. Source-specific unattenuated watershed nitrogen loads (by percent) to the B) Great Marsh West Barnstable subwatershed and C) Great Marsh Mid subwatershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control. Watershed loads do not include nitrogen load on the surface of the estuary.



D. Great Marsh BarnYarm



E. Bass Hole/Chase Garden Creek

Figure IV-5d,e. Source-specific unattenuated watershed nitrogen loads (by percent) to the D) Great Marsh BarnYarm subwatershed and D) Bass Hole/Chase Garden Creek subwatershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control. Watershed loads do not include nitrogen load on the surface of the estuary.

Freshwater Pond Nitrogen Loads

Freshwater ponds are one of the primary watershed locations where natural nitrogen attenuation occurs and this attenuation is included in the MEP watershed nitrogen loading model. Freshwater ponds in aquifer systems like those of Cape Cod are generally kettle hole depressions of the land surface that intercept the surrounding groundwater table revealing what some call "windows on the aquifer." Groundwater typically flows into the pond along the upgradient shoreline, then lake water flows back into the groundwater system along the downgradient shoreline. Occasionally, ponds will also have a stream outlet or herring run that also acts as a discharge point which sometimes has flow control to artificially manipulate water level and outflow rate. Ponds may also be connected to each other through streams and rivers, as well as connections that have been developed for cranberry bog operations.

Since watershed nitrogen loads flow into the ponds along with the groundwater, the pond biomass (plants and animals) have the opportunity to incorporate some of the nitrogen, as well as transporting/burying some of it to the pond sediments. As the nitrogen is captured and used in the pond ecosystem, it is also changed amongst its various oxidized and reduced forms. These interactions also allow for some chemical denitrification and release of some of the nitrogen to the atmosphere, as well as permanent burial in the pond sediments of some portion of the load that the pond receives. Through the cumulative effect of these interactions with the pond ecosystem, some of the nitrogen from the pond watershed is removed and is not transferred downgradient or downstream. If this reduced (or attenuated) load does not encounter any streams or other ponds, it will eventually discharge to the downgradient estuary. If it enters another pond or stream prior to discharge, this load can be further attenuated (see Section IV.2 for stream attenuation). In the nitrogen loading summary in Table IV-3, the unattenuated loads are those without any natural nitrogen attenuation included, while the attenuated loads include the attenuation within ponds, streams, and, in some cases, the cumulative effect of attenuation within a number of ponds and streams as the water moves toward discharge into the estuary.

Nitrogen attenuation in freshwater ponds has generally been found to be at least 50% in MEP analyses, so this value is generally used as a standard MEP default attenuation rate when sufficient pond-specific data is not available. Detailed studies of southeastern Massachusetts freshwater systems including Ashumet Pond (AFCEE, 2000) and Agawam/Wankinco River Nitrogen Discharges (CDM, 2001) have supported a 50% attenuation factor as a reasonable, somewhat conservative rate. However, in some cases, if sufficient monitoring information is available, a pond-specific attenuation rate is incorporated into the watershed nitrogen loading model [*e.g.*, 87%, Mystic Lake; 40%, Middle Pond; and 52%, Hamblin Pond in the Three Bays MEP Report (Howes, *et al.*, 2006b) and Mashpee-Wakeby Pond, 86%, and Santuit Pond, 75%, in the Popponesset Bay MEP Report (Howes et al. 2004)]. In order to estimate nitrogen attenuation in the ponds, available physical and water quality data for each pond is reviewed. Available bathymetric information is reviewed relative to measured pond temperature profiles to determine whether an epilimnion (*i.e.*, well mixed, uniform temperature, upper portion of the water column) exists in each pond. This step is completed to assess whether available data is influenced significantly by nitrogen regeneration from the pond sediments. Bathymetric information is necessary to develop a residence or turnover time and complete an estimate of nitrogen attenuation. Collectively, a standard 50% nitrogen attenuation rate is assigned to ponds with delineated watersheds in MEP nitrogen loading models unless sufficient information is available regarding the physical structure of the pond and its water quality conditions to reasonably assign a different pond-specific rate.

In the Barnstable Great Marsh watershed, MEP staff reviewed available data sources for available monitoring and physical characterization data for the 10 ponds with delineated subwatersheds within the overall Great Marsh watershed, as well as the four ponds shared with other MEP watersheds (Table IV-4). Among the 10 ponds within the watershed, review of available bathymetric and available water quality data generally was insufficient to assign a pond-specific nitrogen attenuation rate other than the standard MEP 50% rate. A reasonable bathymetric map is a prerequisite to developing a pond-specific attenuation rate: Bog Pond, Hathaway Pond South, Hinckley Pond, and Mill Pond in Barnstable and Elishas Pond, Greenough Pond, and Matthews Pond in Yarmouth do not have bathymetric maps. Of the remaining three ponds with bathymetric maps, water quality data has been collected during the annual Cape Cod Pond and Lakes Stewardship (PALS) water quality snapshots, but data has not been collected during the rest of the summer to provide proper context for the PALS data and assign a pond-specific nitrogen attenuation rate other than the standard MEP 50% rate.

Hundreds of ponds on Cape Cod have been sampled through the regional Cape Cod Pond and Lake Stewards (PALS) Snapshots and the initiative of local volunteer pond sampling programs. The annual PALS Snapshots are regional volunteer, late-summer pond samplings supported for the last thirteen years by SMAST and the Cape Cod Commission, with pro bono laboratory services provided by the Coastal Systems Program Analytical Facility at SMAST. Sampling protocols developed through the PALS program (Eichner *et al*., 2003) have been used for more extensive pond sampling programs in many communities on Cape Cod. Sampling under these protocols has included field collection of temperature and dissolved oxygen profiles and sampling of standardized depths that include some evaluation of the impact of sediment nutrient regeneration. PALS water samples are analyzed at the SMAST laboratory for total nitrogen, total phosphorus, chlorophyll a, alkalinity, and pH. In some cases, town programs have generated sufficient sampling data collected throughout a number of summers that modified MEP nitrogen attenuation rates can be reliably assigned to freshwater ponds.

PALS sampling was designed to test whether ponds were experiencing impaired conditions during the warmest part of the summer; if a given pond was experiencing impaired conditions during the PALS sampling, then more expansive and targeted sampling was recommended to assess the regular severity of those conditions. If conditions were satisfactory during numerous PALS snapshots, pond sampling and management priorities could be directed toward other ponds. For example, for Lake Wequaquet and Bearses Pond, two of Great Marsh shared ponds, PALS sampling indicated some water quality concerns (*e.g.*, occasional and regular dissolved oxygen concentrations less than MassDEP surface water regulatory minimums, respectively). Based on a request from the Town of Barnstable, CSP/SMAST staff developed a more refined May to November 2007 sampling strategy and water quality assessment that included watershed delineation, watershed land use analysis for nitrogen and phosphorus loading and development of annual water budgets, and included a comprehensive review of 2007 water quality data and all previous years water quality data (Eichner, 2009). The findings from this project led to collection of updated data in 2010 (Eichner and Howes, 2011), continuous water quality recording during the late summers of 2014 (Eichner, *et al*., 2015) and 2015 (in prep), and collection of 2015 sediment cores in Bearses Pond to assess available sediment phosphorus and the dissolved oxygen conditions that partially control the amount of release of sediment phosphorus to the water column (in prep). These more targeted data collections will allow the town to assess water quality management strategies. Collectively, this data also allowed project staff to develop pond-specific nitrogen attenuation rates in this Barnstable Great Marsh MEP assessment for these ponds: Lake Wequaquet, 86% attenuation;

Table IV-4. Freshwater Ponds within the Barnstable Great Marsh MEP Watershed.

Ponds are divided into two groups: a) ponds within the Barnstable Great Marsh MEP watershed and b) ponds on the boundary of the Great Marsh watershed and shared with other MEP watersheds. In order to alter MEP standard 50% natural nitrogen attenuation rate in freshwater ponds, a reliable bathymetric map and sufficient water quality data throughout at least one summer is generally required. Shared pond attenuated nitrogen loads to Barnstable Great Marsh subwatersheds were determined in other previous MEP assessments of Centerville River and Three Bays.

Pond	Town	PALS #	Area	Bathymetry		Max Depth	Sufficient WQ Data	WQ data review
			acres	Y/N	source	m	Y/N	
Ponds with delineated watersheds								
Bog	Barnstable	BA-382	5.6	N		-	N	No data available
Garretts	Barnstable	BA-510	27.9	Y	IEP, 1980	8.6	N	One 1980 sampling + PALS Aug/Sept
Hathaway N	Barnstable	BA-565	20.9	Y	MassDFW	17.4	N	Numerous PALS Aug/Sept
Hathaway S	Barnstable	BA-594	12.6	N		-	N	One 2001 PALS sampling
Hinckley	Barnstable	BA-411	10.3	N		6.5	N	Numerous PALS Aug/Sept
Mill	Barnstable	BA-391	16.7	N		1.4	N	3 in summer 1980; numerous PALS Aug/Sept
Dennis	Yarmouth	YA-472	47.8	Y	MassDFW	6.0	N	Numerous PALS Aug/Sept
Elishas	Yarmouth	YA-493	10.2	N		9.0	N	Numerous PALS Aug/Sept
Greenough	Yarmouth	YA-492	26.4	N		7.5	N	Numerous PALS Aug/Sept
Matthews	Yarmouth	YA-371	35.6	N		1.4	N	Numerous PALS Aug/Sept
Shared Ponds								
Wequaquet	Barnstable	BA-605	596.3	Y	IEP/KV, 1989	10.4	Y	2007 May to Nov bimonthly; WQ Assessment (Eichner, 2009) + 2010, 2014, 2015 continuous monitoring + numerous PALS Aug/Sept
Bearses	Barnstable	BA-617	66.8	Y	IEP/KV, 1989	6.2	Y	
Shallow	Barnstable	BA-626	78.4	Y	KV/IEP, 1993	2.1	N	1986 sufficient sampling + numerous PALS Aug/Sept
Lawrence	Sandwich	SA-431	133.8	Y	MassDFW	9.0	N	Numerous PALS Aug/Sept

Notes:

a) Barnstable Ponds bathymetry sources and sampling frequencies cited from Eichner (2008) with supplemental review of Cape Cod PALS results.
b) Pond areas based on Eichner, *et al*., 2003 or MassGIS wetland coverage (1:12,000)
c) Massachusetts Division of Fisheries & Wildlife (MassDFW) maintains selected pond bathymetric maps on the division website for southeastern Massachusetts: http://www.mass.gov/eea/agencies/dfg/dfw/maps-destinations/pond-maps-southeast-district.html
d) Maximum depths are based on PALS monitoring (if available)
e) Sufficient Water Quality Data assessment is based on whether sufficient data has been gathered to adjust the standard MEP 50% natural nitrogen attenuation rate.

Bearses Pond, 84% and Shallow Pond, 84%. Shallow Pond is mostly within the Bearses Pond and the Gooseberry Pond subwatershed to Lake Wequaquet. Extensive water quality in the two Lake Wequaquet basins and older high-intensity sampling in Shallow Pond allowed CSP/SMAST staff to develop a nitrogen budget for Lake Wequaquet that included Shallow Pond (Eichner, 2009); this assessment is the basis for the Shallow Pond attenuation rate and the nitrogen load from Shallow Pond to the Great Marsh subwatersheds. Lawrence Pond in Sandwich is also a shared pond and its nitrogen load to the Great Marsh subwatersheds was previously determined in the Three Bays MEP assessment (Howes, *et al*., 2006b)

There is one additional pond where the MEP standard attenuation was adjusted, but in the case of Mill Pond, the attenuation rate was adjusted down to 26% based on stream monitoring data collected during the MEP (see Section IV.2). Mill Pond is located in the Boat Cove Creek subwatershed (#7 subwatershed), approximately 350 m upgradient/upstream of the MEP gauge. Since Mill Pond and its watershed are completely within the Creek gauge watershed, measurement of nitrogen loads at the gauge must include the attenuated nitrogen loads from the pond. Comparison of the measured and estimated loads at the gauge showed that with a standard 50% pond attenuation, the estimated watershed load was too low. Review of the available characteristics of Mill Pond showed that it is extremely shallow (maximum depth of 1.4 m). In ponds with similar depths (*e.g.*, Mill Pond in Marstons Mills (Howes, *et al.*, 2006b), Cedar Pond in North Falmouth (Howes, *et al.*, 2013), MEP measurements have shown that nitrogen attenuation rates are often lower than the standard 50%. These lower rates are likely due to shorter residence times; extensive measurements in various types of wetland systems have shown that nitrogen attenuation rates are strongly influence by residence times (*e.g.*, Johnston, 1994; Saunders and Kalff, 2001; Toet, *et al*., 2005). A reasonable estimate of the residence time of Mill Pond would be 20 days or <2% of the Lake Wequaquet residence time (Eichner, 2009). Based on the measured MEP stream data and the characteristics of the pond, the lower nitrogen attenuation rate for Mill Pond is reasonable.

Buildout

Part of the regular MEP watershed nitrogen loading modeling is to prepare a buildout assessment (or scenario) of potential development and accompanying nitrogen loads within the study area watersheds. The MEP buildout is relatively straightforward and is generally completed in four steps: 1) each residential parcel classified by the town assessor as developable is identified and divided by minimum allowable lot size specified in town zoning and the resulting number of new residential units is rounded down, 2) parcels classified as developable commercial and industrial parcels by the town assessor are identified, 3) residential, commercial and industrial parcels with existing development and areas greater than twice zoning's minimum lot size are identified, divided by the minimum lot size and the resulting number of new units is rounded down, and 4) results are discussed with town staff and/or planning board members and the analysis results are modified based on local knowledge.

It should be noted that the initial MEP buildout approach is relatively simple and does not generally include any modifications/refinements for lot line setbacks, wetlands, road construction, frontage requirements, parcel shape requirements, or other more detailed zoning provisions. The MEP buildout approach also does not include potential impacts associated with the higher densities usually associated with 40B affordable housing projects. The fourth step, including the discussions with town planners, and, occasionally, town planning boards and wastewater consultants, usually leads to additional insights on developments that are planned, especially developments planned on government or public service parcels, and updates to assessor classifications, including lands purchased by the town as open space. This final step may lead to

removal and/or additions to the number of parcels initially identified as developable and may include application of more detailed zoning provisions.

As an example of how the MEP approach might apply, assume an 81,000 square foot lot is classified by the town assessor as a developable residential lot (MassDOR land use code 130). This lot is divided by the 40,000 square foot minimum lot size specified in town zoning and the result is rounded down to two. As a result, two additional residential lots would be added to the subwatershed in the MEP buildout scenario. This addition could then be modified during discussion of town staff.

Other provisions of the MEP buildout assessment include town assessor classification of undevelopable lots, standard treatment of commercial and industrial properties, and assumptions for lots less than the minimum areas specified by zoning. Properties classified by the town assessors as "undevelopable" (*e.g.*, MassDOR codes 132, 392, and 442) are not assigned any development at buildout (unless revised by the town review). Commercial and industrial properties classified as developable are not subdivided; the area of each parcel and the watershed-specific factors in Table IV-2 are used to determine an estimated building size and wastewater flow for these properties. Pre-existing lots classified by the town assessor as developable are also treated as developable even if they are less than the minimum lot size specified in zoning; so, for example, a 10,000 square foot lot classified by the town assessor as a developable residential property (MassDOR 130 land use code) and located in a zoning area with a 40,000 square feet minimum lot size will be assigned an additional residential dwelling in the MEP buildout scenario. Most town zoning bylaws have a lower minimum lot size for pre-existing lots (usually 5,000 square feet) that will minimize instances of regulatory takings. Existing developed residential properties that are larger than zoning's minimum lot sizes are also assigned additional development potential only if enough area is available to accommodate at least one additional lot as specified by the zoning minimum. All of these standard approaches may be modified during consultation with town development experts prior to developing associated build-out nitrogen loadings.

Following the completion of the initial buildout assessment for the Barnstable Great Marsh watersheds, MEP staff reviewed the results with town officials. MEP staff reviewed the preliminary watershed buildout results in a series of meetings with the following town staff:

Barnstable: Jo Anne Buntich, Director, Growth Management Department, Elizabeth Jenkins, Regulatory Planner, and Jim Benoit, GIS Director
Yarmouth: Karen Greene, Director of Community Development and Kathy Williams, Town Planner
Dennis: Daniel J. Fortier, Town Planner

Sandwich results were not reviewed given the small number of properties within the watershed.

Town corrections to the initial buildout estimates included removals, additions, and adjustments. All suggested changes from town staff based on the initial review were incorporated into the final MEP buildout for Barnstable Great Marsh.

All the parcels with additional buildout potential within the Barnstable Great Marsh watershed are shown in Figure IV-6. Overall, this buildout includes a projected 1,639 additional residences, 1,821,606 square feet of additional commercial properties and 3,370,249 square feet of additional industrial properties. In the buildout nitrogen loading scenario, each additional residential, commercial, or industrial property added at buildout is assigned nitrogen loads for

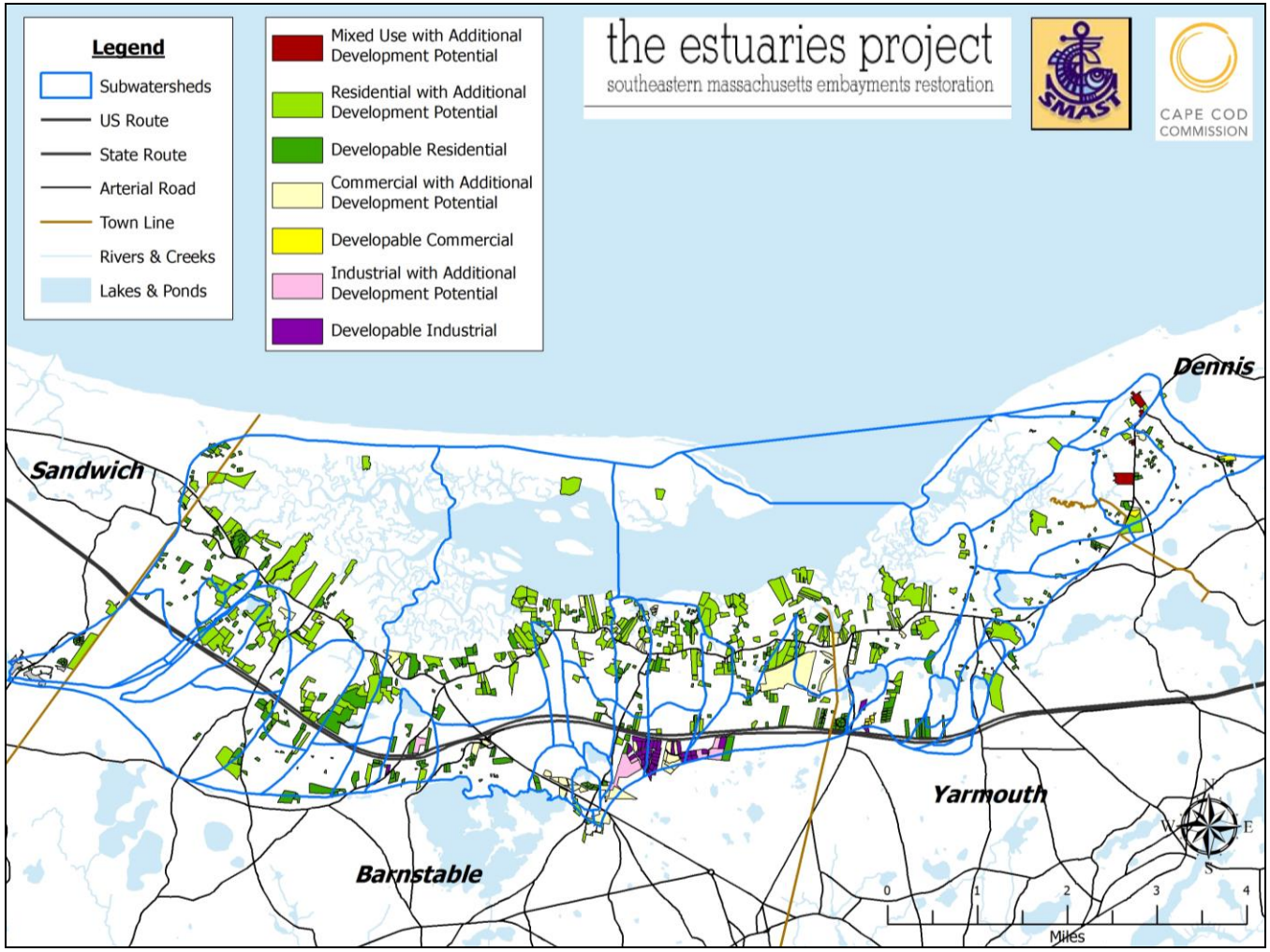


Figure IV-6. Developable Parcels in the Barnstable Great Marsh watershed. Indicated parcels are assigned additional nitrogen loads in the MEP buildout scenario. Buildout is based on existing town zoning and town assessor classifications. Parcels colored light green, red, light yellow, and pink are existing developed parcels (residential, mixed use, commercial and industrial, respectively) with additional development potential based on current zoning, while parcel colored dark green, yellow, and purple are undeveloped parcels classified as developable by the respective town assessors (residential, commercial and industrial, respectively). These buildout results include adjustments indicated by town officials during review of initial MEP buildout estimates.

wastewater and impervious surfaces. Residential additions also include lawn fertilizer nitrogen additions. All wastewater loads are assumed to come from standard on-site septic systems unless the parcel is designated as already having a sewer connection (for additional development on existing lots) or identified within the sewer service area; all properties with the sewer service area are assumed to connect to the Hyannis sewer system and have no assigned wastewater nitrogen loads within the watershed. Cumulative unattenuated buildout loads are indicated in a separate column in Table IV-3. It should be noted that this is one example of a buildout scenario; alternative assumptions about future development could be developed to assess the water quality impacts of other buildout scenarios. Based on the MEP assessment, buildout additions within the Barnstable Great Marsh watersheds will increase the unattenuated watershed nitrogen loading rate by 22%.

IV.2 ATTENUATION OF NITROGEN IN SURFACE WATER TRANSPORT

IV.2.1 Background and Purpose

Modeling and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land or watershed relative to the tidal flushing and nitrogen cycling within the embayment basins. This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out, sewering analysis, enhanced flushing, pond/wetland restoration for natural attenuation, etc.) to changes in water quality and habitat health. Therefore, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems. Rates of nitrogen loading to the sub-watersheds of the Barnstable Great Marsh estuary system being investigated under this nutrient threshold analysis were based upon the delineated watersheds (Section III) and their land-use coverages (Section IV.1).

If all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the estuarine receiving waters. This condition exists in watersheds where nitrogen transport from source to estuarine waters is through groundwater flow in sandy outwash aquifers (such being the case in the developed region of southeastern Massachusetts but more so on Cape Cod). The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. However, in most watersheds in southeastern Massachusetts, nitrogen passes through a surface water ecosystem (pond, wetland, stream) on its path to the adjacent embayment. Surface water systems, unlike sandy aquifers, do support the needed conditions for nitrogen retention and denitrification. The result is that the mass of nitrogen passing through lakes, ponds, streams and marshes (fresh and salt) can be diminished by natural biological processes that represent removal (not just temporary storage). However, this potential natural attenuation of nitrogen load is not uniformly distributed within the watershed, but is associated with ponds, streams and marshes to varying degrees based on habitat and residence time. In the watershed for the Barnstable Great Marsh Estuary, a portion of the freshwater flow and transported nitrogen passes through several surface water systems (e.g. Alder Brook, Boat Cove Creek, Bridge Creek, Maraspin Creek, Whites Brook and Chase Garden Creek) prior to entering the estuary, producing the opportunity for significant nitrogen attenuation under appropriate conditions (Figure IV-7). It should be noted that during the MEP stream gauging assessment, two additional locations were evaluated (heads of Scorton Creek and Brickyard Creek), however, flow in Scorton Creek was too low to measure accurately and Brickyard Creek was dry through 95% of the assessment period. Those locations are depicted in Figure IV-7 but were not included in the MEP assessment.

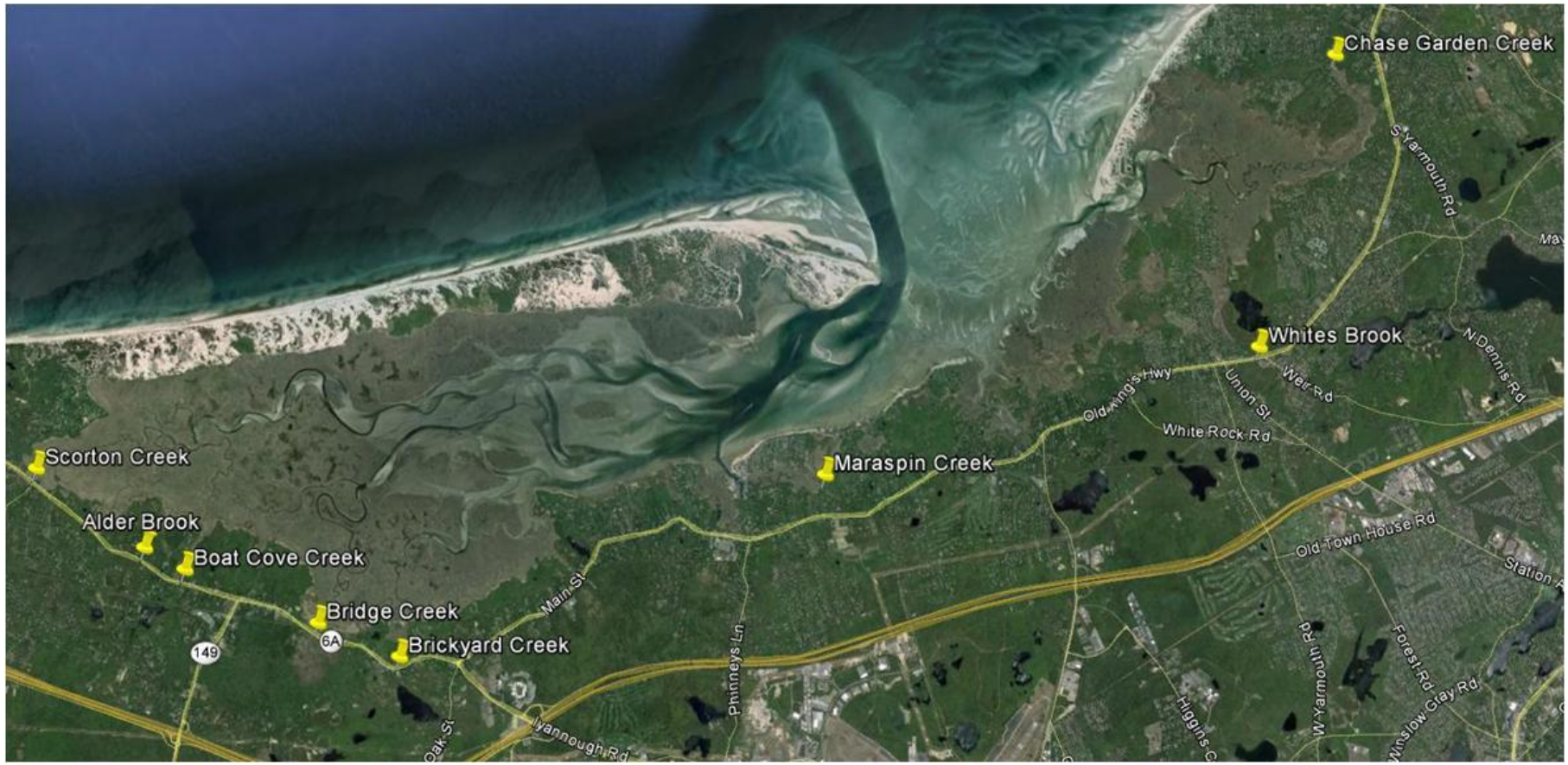


Figure IV-7. Location of Stream gauges (yellow symbols) in the Barnstable Great Marsh estuary system. Two stream gauge locations (Scorton Creek and Brickyard Creek) did not have measureable flow during the gauge deployment period and therefore could not be used for direct measurement of surfacewater load. Rather, loads from those areas of the watershed were considered as being transported to Barnstable Harbor via groundwater.

Failure to determine the attenuation of watershed derived nitrogen overestimates the nitrogen load to receiving estuarine waters. If nitrogen attenuation is significant in one portion of a watershed and insignificant in another the result is that nitrogen management would likely be more effective in achieving water quality improvements if focused on the watershed region having unattenuated nitrogen transport (other factors being equal). In addition to attenuation by freshwater ponds (see Section IV.1.3, above), attenuation in surface water flows is also important. An example of the significance of surface water nitrogen attenuation relating to embayment nitrogen management was seen in the Agawam River, where >50% of nitrogen originating within the upper watershed was attenuated in ponds and streams prior to discharge to the Wareham River Estuary (CDM 2000). Similarly, MEP analysis of the Quashnet River (Town of Falmouth, Cape Cod) indicated that in the upland watershed, which has natural attenuation predominantly associated with riverine processes, the integrated attenuation was 39% (Howes et al. 2004). In addition, a preliminary study of Great, Green and Bournes Ponds in Falmouth, measurements indicated a 30% attenuation of nitrogen during stream transport (Howes and Ramsey 2001). An example where natural attenuation played a significant role in nitrogen management can be seen relative to West Falmouth Harbor (Falmouth, MA), where ~40% of the nitrogen discharge to the Harbor originating from the groundwater effluent plume emanating from the WWTF was attenuated by a small salt marsh prior to reaching Harbor waters. Therefore, proper development and evaluation of nitrogen management options requires determination of the nitrogen loads reaching an embayment, not just loaded to the watershed.

Given the importance of determining accurate nitrogen loads to embayments for developing effective management alternatives and the potentially large errors associated with ignoring natural attenuation, direct integrated measurements of upper watershed attenuation were undertaken as part of the MEP Approach in the Barnstable Great Marshes overall watershed. MEP conducted long-term measurements of natural attenuation relating to the most significant surface water discharges to the estuary in addition to the natural attenuation measures by fresh kettle ponds, addressed above (Section IV.1). These additional site-specific studies were conducted in the 6 major surface water flow systems in the Barnstable Great Marsh estuary system watershed, 1) Alder Brook discharging to the Great Marshes, 2) Boat Cove Brook discharging to the Great Marshes, 3) Bridge Creek discharging to the Great Marshes, 4) Maraspin Creek discharging to the Barnstable Harbor (Millway), 5) Whites Brook discharging to Bass Hole and 6) Chase Garden Creek discharging to Bass Hole. A stream gauge was deployed at the head of Scorton Creek, however flows were too low to measure accurately therefore it was discontinued as a stream gauging site. Similarly, regarding Brickyard Creek, given the small size of the drainage area as well as the intermittent flow (the creek channel was dry 95% of the stream gauge deployment period) by comparison to the other six major surface water discharges measured by the MEP, the technical team agreed to exclude Brickyard Creek from the gauging program.

Quantification of watershed based nitrogen attenuation is contingent upon being able to compare nitrogen load to the embayment system directly measured in freshwater stream flow (or in tidal marshes, net tidal outflow) to nitrogen load as derived from the detailed land use analysis (Section IV.1). Measurement of the flow and nutrient load associated with the freshwater streams discharging to the estuary provides a direct integrated measure of all of the processes presently attenuating nitrogen in the contributing area up-gradient from the various gauging sites. Flow and nitrogen load were measured at the gauges in each freshwater stream site for between 16 and 24 months depending on the stream gauging location (Figures IV-8 to IV-18). During each study period, volumetric discharge measurements were completed on each surface water inflow every month to two months. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities represent the computation of instantaneous stream volumetric flow (Q).

Determination of stream flow at each gauge was calculated and based on the measured values obtained for stream cross sectional area and velocity. Stream discharge was represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity measurement were obtained. Velocity measurements across the entire stream cross section were not averaged and then applied to the total stream cross sectional area.

The formula that was used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma(A * V)$$

where by:

Q = Stream discharge (m^3/s)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection will have a calculated stream discharge value and the summation of all the sub-sectional stream discharge values will be the total calculated discharge for the stream.

Periodic measurement of flows over the entire stream gauge deployment period allowed for the development of a stage-discharge relationship (rating curve) that could be used to obtain flow volumes from the detailed record of stage measured by the continuously recording stream gauges. Water level data obtained every 10-minutes was averaged to obtain hourly stages for a given river/stream/creek/brook. These hourly stages values where then entered into the stage-discharge relation to compute hourly flow. Hourly flows were summed over a period of 24 hours to obtain daily flow and further, daily flows summed to obtain annual flow. In the case of tidal influence on stream stage, the diurnal low tide stage value was extracted on a day-by-day basis in order to resolve the stage value indicative of strictly freshwater flow. The lowest low tide stage values for any given day were utilized in the stage – discharge relation in order to compute daily flow as this stage value is most representative of freshwater flow. A complete annual record of stream flow (365 days) was generated for the surface water discharges flowing into the Barnstable Great Marsh Estuarine System.

The annual flow record for the surface water flow at each gauge was merged with the nutrient data from the weekly water quality sampling performed at each gauge location to determine surfacewater related nitrogen loading rates to the Barnstable Great Marshes Estuary. The nitrogen load discharged from the streams was calculated using the paired daily volumetric discharge and daily nitrogen concentration measurements to determine the mass flux of nitrogen through each specific gauge site. For each of the stream gauge locations, weekly water samples were collected (at low tide for a tidally influenced stage) in order to determine nutrient concentrations from which nutrient load was calculated. In order to pair daily flows with daily nutrient concentrations, interpolation between weekly nutrient data points was necessary. These data are expressed as nitrogen mass per unit time (kg/d) and can be summed in order to obtain weekly, monthly, or annual nutrient loads to the embayment system as appropriate. Comparing these measured nitrogen loads based on stream flow and water quality sampling to predicted loads based on the land use analysis allowed for the determination of the degree to which natural biological processes within the watershed to each gauged stream currently reduces (percent attenuation) nitrogen loading to the overall embayment systems.

IV.2.2 Surface water Discharge and Attenuation of Watershed Nitrogen: Alder Brook Discharge to Barnstable Harbor

Similar to other surface water features in the MEP study region that typically emanate from a specific pond or wetland, Alder Brook, which discharges into the Great Marshes, has a clearly demarcated up-gradient bog/wetland area from which the small brook discharges. Based on numerous previous studies completed by the MEP on other systems in southeastern Massachusetts, the outflow from the bog/wetlands and the wooded areas up-gradient of the Alder Brook gauge very likely contribute to the attenuation of nitrogen during transport, while the stream provides a watershed "drain" that allows for direct measurement of the net nitrogen load, hence nitrogen attenuation. The combined rate of nitrogen attenuation by the biological processes that occur in the various surface water features to each stream site was determined by comparing the present predicted nitrogen loading from land use analysis within the upland contributing area to the bog/wetlands and wooded areas above the gauge site and the measured annual discharge of nitrogen to the downgradient Great Marshes, Figure IV-8.

At the Alder Brook gauge site (established at culvert passing under Route 6A), a continuously recording vented calibrated water level gauge was installed to yield the level of water in the channel that carries the flows and associated nitrogen load to the estuarine system. As the lower reach of Alder Brook is tidally influenced down gradient of Route 6A, the stage record from the gauge was checked to make sure there was no tidal influence in the record at low tide. To confirm that freshwater was being measured, the stage record was analyzed for any semi-diurnal variations indicative of tidal influence and salinity measurements were conducted on the weekly water quality samples collected from the gauge site. Average salinity of the water samples taken from Alder Brook at Route 6A at low tide confirmed that the stream was carrying fresh water at the gauge site ($\leq$0.1 ppt). Therefore, the gauge location was deemed acceptable for making freshwater flow measurements at low tide. Calibration of the gauge was checked monthly. The gauge on Alder Brook was installed on June 12, 2006 and was set to operate continuously for a complete hydrologic year (low flow to low flow, ~12 months). Stage data collection continued until September 18, 2007 for a total deployment of 15 months.

Surface freshwater flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for Alder Brook at the Route 6A gauge site based upon these flow measurements and measured water levels at the gauge site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets allows for the determination of nitrogen mass discharge to the estuary and is reflective of the biological processes occurring in the stream channel and the network of bogs/wetlands and wooded area contributing to nitrogen attenuation (Figure IV-9 and Table IV-5a, b and IV-6a, b). In addition, a water balance was constructed based upon the U.S. Geological Survey/MEP/CCC defined watershed delineations to determine long-term average freshwater discharge expected at each gauge site based on area and average recharge.

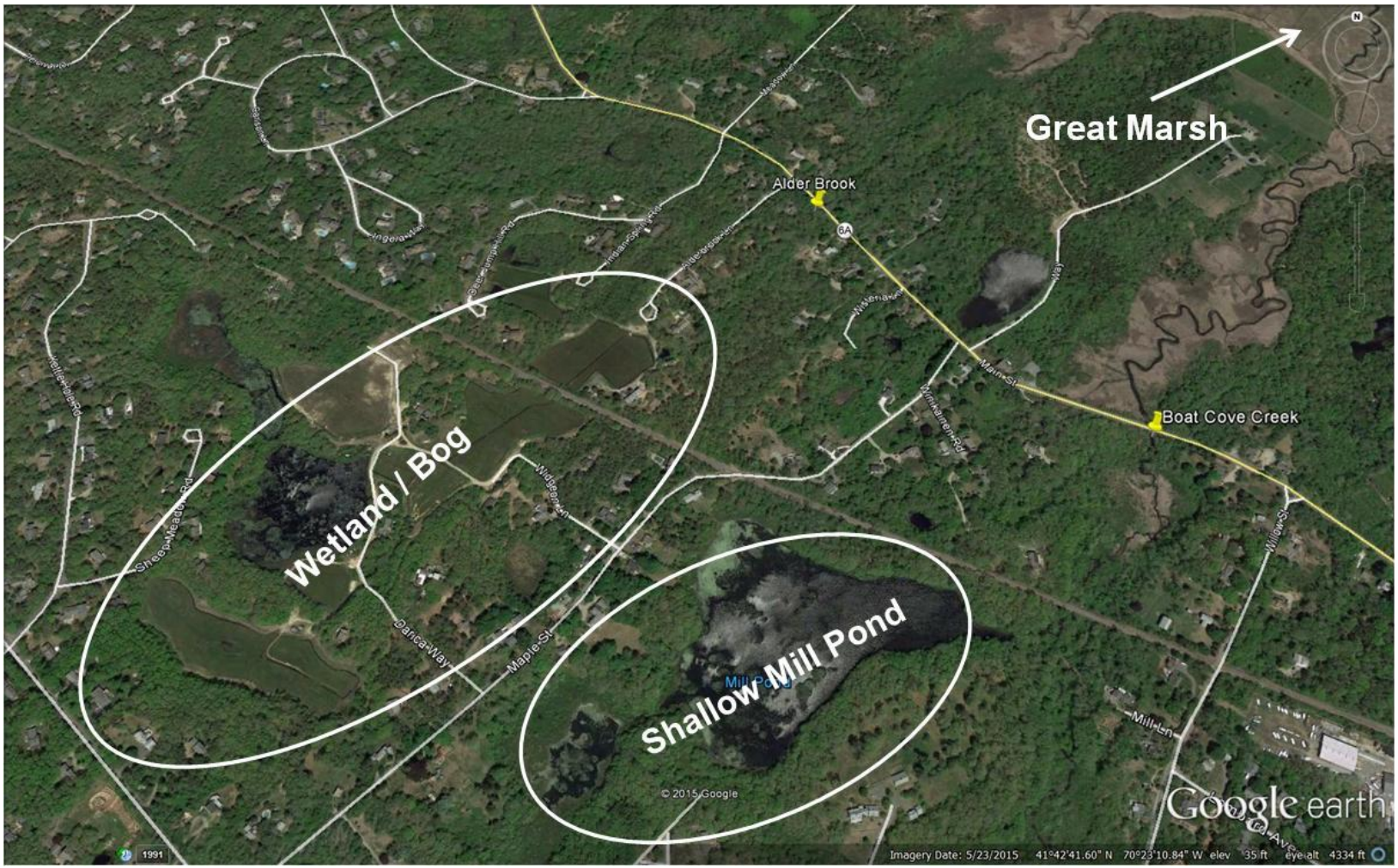


Figure IV-8. Location of MEP stream gauges (yellow symbol) for measuring flow and nitrogen loads transported by Alder Brook and Boat Cove Creek to estuarine waters. Alder Brook receives surfacewater from a upgradient bog/wetland feature whereas Boat Cove Creek discharges from a shallow up-gradient pond.

The annual freshwater flow record for Alder Brook as measured by the MEP was compared to the long-term average flows determined by the USGS/MEP/CCC modeling effort (Table III-1). The measured freshwater discharge from Alder Brook at the Route 6A gauge location was only ~3% below the long-term average modeled flows. The average daily flow based on the MEP measured flow data for the hydrologic year beginning September 2006 and ending in August 2007 (low flow to low flow) was 917 m^3/day compared to the long term average flow of 943 m^3/day determined by the watershed modeling effort. The negligible difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Alder Brook discharging from the sub-watershed indicates that the Brook is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within the Alder Brook outflow were moderate, 0.857 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 0.79 kg/day and a measured total annual TN load of 287 kg/yr. In the Alder Brook flow, nitrate made up a very small fraction (9%) of the total nitrogen pool, indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the bog/wetland areas and stream bed up-gradient of the gauge was being transformed by plants and microbes within the surface water bog/wetlands upgradient of the gauge site. Given the relatively low levels of remaining nitrate in the stream discharge, the possibility for additional uptake by freshwater systems appears to be limited in the Alder Brook sub-watershed.

From the measured nitrogen load discharged by Alder Brook to the Great Marshes and the nitrogen load determined from the stream watershed based land use analysis, it appears that there is moderate nitrogen attenuation of upper watershed derived nitrogen during transport to the down gradient estuary. Based upon the slightly lower total nitrogen load (287 kg yr^{-1}) discharged from Alder Brook at Route 6A compared to that added by the various land-uses to the associated watershed (485 kg yr^{-1}), there was a 41% integrated attenuation of nitrogen in passage through the stream and up-gradient freshwater wetlands prior to discharge to the estuary (i.e. 41% of nitrogen input to watershed does not reach the estuary). This level of attenuation is consistent with other streams evaluated under the MEP with up-gradient wetlands/bogs capable of attenuating nitrogen. The directly measured nitrogen load from Alder Brook was used in the Linked Watershed-Embayment Modeling of water quality (see Section VI, below).

Table IV-5a. Comparison of water flow and nitrogen load discharged by surface waters (freshwater) to the Barnstable Great Marshes. The "Stream" data are from the MEP stream gauging effort. Watershed data are based upon the MEP watershed land use modeling effort (Section IV.1) and the combination of USGS watershed delineations and watershed delineation information provided by the CCC. Delineations were reviewed by MEP Technical Team Members and sub-watershed delineations were developed by the MEP (Section III).

Stream Discharge Parameter	Alder Brook Discharge[(a)] Great Marsh	Boat Cove Creek Discharge[(a)] Great Marsh	Bridge Creek Discharge[(a)] Great marsh	Maraspin Creek Discharge[(a)] Barnstable Hrb.	Data Source
Total Days of Record	365[(b)]	365[(b)]	365[(b)]	365[(b)]	(1)
Flow Characteristics					
Stream Average Discharge (m3/day)	917	12,850	5,472	1,384	(1)
Contributing Area Average Discharge (m3/day)	943	12435	5668	1396	(2)
Discharge Stream 2006-07 vs. Long-term Discharge	-2.84%	3.23%	-3.58%	-0.87%	
Nitrogen Characteristics					
Stream Average Nitrate + Nitrite Concentration (mg N/L)	0.078	0.261	0.171	1.659	(1)
Stream Average Total N Concentration (mg N/L)	0.857	0.685	0.648	2.114	(1)
Nitrate + Nitrite as Percent of Total N (%)	9%	38%	26%	78%	(1)
Total Nitrogen (TN) Average Measured Stream Discharge (kg/day)	0.79	8.797	3.55	2.93	(1)
TN Average Contributing UN-attenuated Load (kg/day)	1.33	8.53	5.97	3.73	(3)
Attenuation of Nitrogen in Pond/Stream (%)	41%	-3%	41%	21%	(4)

(a) Flow and N load to streams discharging to Barnstable Harbor, the Great Marsh and Bass Hole include apportionments of Pond contributing areas as appropriate.
(b) Average September 1, 2006 to August 31, 2007.

(1) MEP gage site data
(2) Calculated from MEP watershed delineations to ponds upgradient of specific gages;
the fractional flow path from each sub-watershed which contribute to the flow in the streams to Barnstable Harbor-Bass Hole;
and the annual recharge rate.
(3) As in footnote (2), with the addition of pond and stream conservative attentuation rates.
(4) Calculated based upon the measured TN discharge from the rivers vs. the unattenuated watershed load.

Table IV-5b. Comparison of water flow and nitrogen load discharged by surface waters (freshwater) to the Bass Hole sub-estuary. The "Stream" data are from the MEP stream gauging effort. Watershed data are based upon the MEP watershed land use modeling effort (Section IV.1) and the combination of USGS watershed delineations and watershed delineation information provided by the CCC. Delineations were reviewed by MEP Technical Team Members and sub-watershed delineations were developed by the MEP (Section III).

Stream Discharge Parameter	Whites Brook Discharge[(a)] Bass Hole	Chase Garden Creek Discharge[(a)] Bass Hole	Data Source
Total Days of Record	365[(b)]	365[(b)]	(1)
Flow Characteristics			
Stream Average Discharge (m3/day)	1,462	1,611	(1)
Contributing Area Average Discharge (m3/day)	1,379	1,574	(2)
Discharge Stream 2006-07 vs. Long-term Discharge	5.68%	2.30%	
Nitrogen Characteristics			
Stream Average Nitrate + Nitrite Concentration (mg N/L)	0.542	0.371	(1)
Stream Average Total N Concentration (mg N/L)	0.959	1.058	(1)
Nitrate + Nitrite as Percent of Total N (%)	57%	35%	(1)
Total Nitrogen (TN) Average Measured Stream Discharge (kg/day)	1.403	1.704	(1)
TN Average Contributing UN-attenuated Load (kg/day)	2.24	4.28	(3)
Attenuation of Nitrogen in Pond/Stream (%)	37%	60%	(4)

(a) Flow and N load to streams discharging to Bass Hole include apportionments of Pond contributing areas as appropriate.
(b) Average September 1, 2006 to August 31, 2007.

(1) MEP gage site data
(2) Calculated from MEP watershed delineations to ponds upgradient of specific gages;
the fractional flow path from each sub-watershed which contribute to the flow in the streams to Barbstable Harbor-Bass Hole;
and the annual recharge rate.
(3) As in footnote (2), with the addition of pond and stream conservative attentuation rates.
(4) Calculated based upon the measured TN discharge from the rivers vs. the unattenuated watershed load.

Table IV-6a. Summary of annual volumetric discharge and nitrogen load from the four major surface water discharges to the Barnstable Great Marsh estuary system (based upon the data presented in Figures IV-9, 10, 12,14 and Table IV-5a.

EMBAYMENT SYSTEM	PERIOD OF RECORD	DISCHARGE (m3/year)	ATTENUATED LOAD (Kg/yr)	
			Nox	TN
Barnstable Harbor - Great Marsh				
Alder Brook MEP measured	**September 1, 2006 to August 31, 2007**	**334,705**	**26**	**287**
Barnstable Harbor - Great Marsh				
Alder Brook	Based on Watershed Area and Recharge	**344,195**	--	--
Barnstable Harbor - Great Marsh				
Boat Cove Creek MEP measured	**September 1, 2006 to August 31, 2007**	**4,690,250**	**1,223**	**3,211**
Barnstable Harbor - Great Marsh				
Boat Cove Creek	Based on Watershed Area and Recharge	**4,538,775**	--	--
Barnstable Harbor - Great Marsh				
Bridge Creek MEP measured	**September 1, 2006 to August 31, 2007**	**1,997,280**	**342**	**1,294**
Barnstable Harbor - Great Marsh				
Bridge Creek	Based on Watershed Area and Recharge	**2,068,820**	--	--
Barnstable Harbor - Millway				
Maraspin Creek MEP measured	**September 1, 2006 to August 31, 2007**	**505,160**	**838**	**1,051**
Barnstable Harbor - Millway				
Maraspin Creek	Based on Watershed Area and Recharge	**509,540**	--	--

Table IV-6b. Summary of annual volumetric discharge and nitrogen load from the four major surface water discharges to the Barnstable Great Marsh estuary system (based upon the data presented in Figures IV-16,18 and Table IV-5b.

EMBAYMENT SYSTEM	PERIOD OF RECORD	DISCHARGE (m3/year)	ATTENUATED LOAD (Kg/yr)	
			Nox	TN
Barnstable Harbor - Bass Hole				
Chase Garden Creek MEP measured	**September 1, 2003 to August 31, 2004**	**588,172**	**218**	**622**
Barnstable - Bass Hole				
Chase Garden Creek	Based on Watershed Area and Recharge	**576,600**	--	--
Barnstable Harbor - Bass Hole				
Whites Brook MEP measured	**September 1, 2003 to August 31, 2004**	**533,627**	**289**	**512**
Barnstable Harbor - Bass Hole				
Whites Brook	Based on Watershed Area and Recharge	**503,335**	--	--

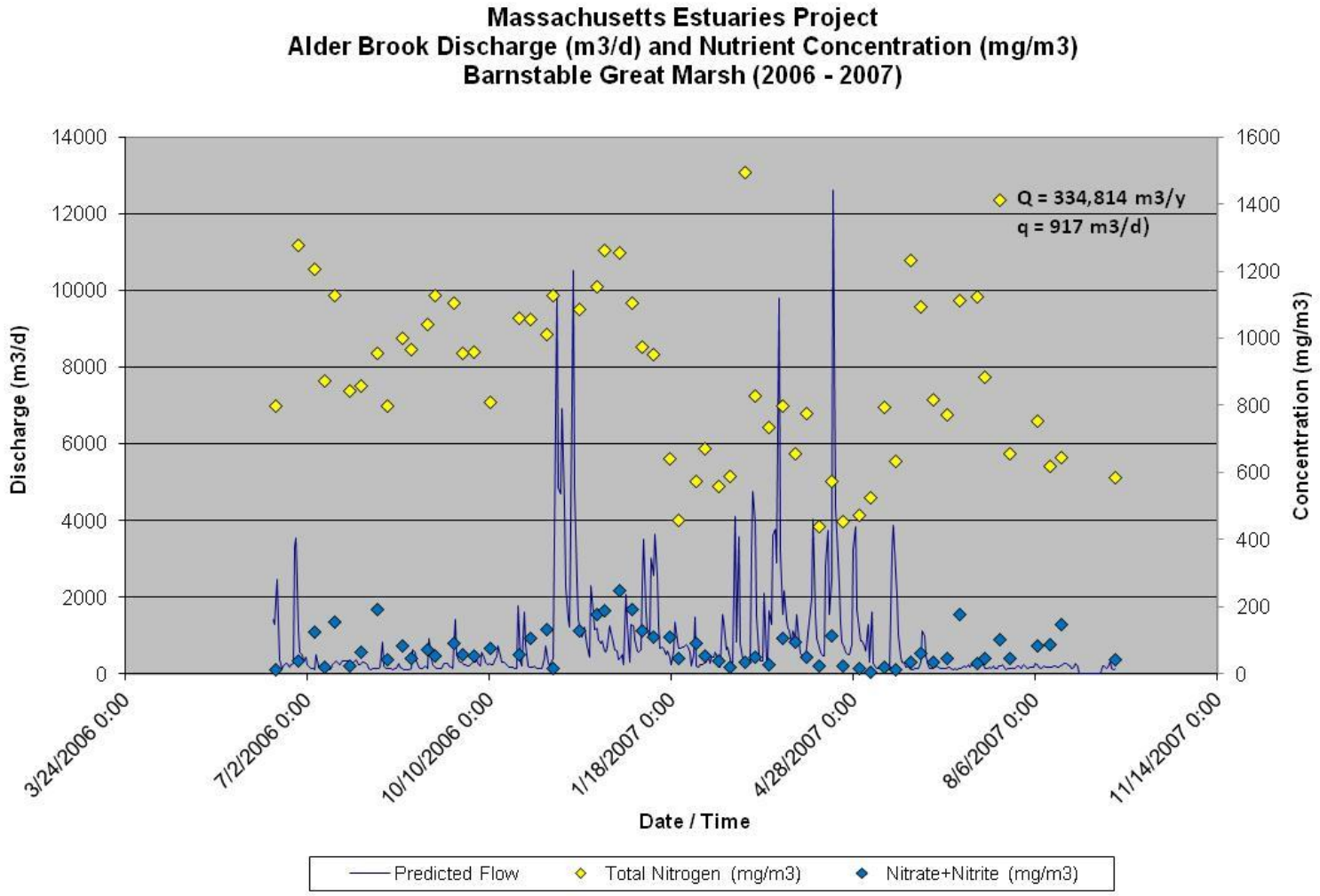


Figure IV-9. Discharge from Alder Brook to Barnstable Great Marshes (solid blue line). Total nitrogen (yellow symbols) and Nitrate + Nitrite (NOx, blue symbols) concentrations are used for determination of attenuated nitrogen load from the sub-watershed (Table IV-3).

IV.2.3 Surface water Discharge and Attenuation of Watershed Nitrogen: Boat Cove Creek Discharge to Barnstable Harbor

Similar to other surface water features in the MEP study region that typically emanate from a specific pond or wetland, Boat Cove Brook, which discharges into the Great Marshes, does have a clearly demarcated up-gradient mill pond from which the small brook originates. Based on numerous previous studies completed by the MEP on other systems in southeastern Massachusetts, the shallow mill pond up-gradient of the Boat Cove Brook gauge likely contributes to the attenuation of nitrogen discharged from the watershed and outflowing to the Creek. The combined rate of nitrogen attenuation by the biological processes that occur in the various surface water features of the subwatershed was determined by comparing the present predicted load from the land use analysis of the sub-watershed region contributing to the mill pond and areas above the gauge site and the measured annual discharge of nitrogen to the Great Marshes, Figure IV-8.

The freshwater flow carried by Boat Cove Brook to the estuarine waters of the Great Marshes was determined using a continuously recording vented calibrated water level gauge deployed where the brook passes through a culvert under Route 6A. As this surface water system was potentially tidally influenced, the creek discharge was checked to confirm the extent of tidal influence and whether freshwater flow could be measured at low tide in the estuary. To confirm that freshwater was being measured, salinity measurements were conducted on weekly water quality samples collected from the gauge site. Average measured sample salinity confirmed that the stream was carrying fresh water at the gauge site ($\leq$0.1 ppt) and was clearly not tidally influenced. As such, a salinity adjustment was not necessary in order to determine daily flows using the MEP developed stage-discharge relation. The Boat Cove Brook gauge location was deemed acceptable for measurements of annual freshwater flow. Calibration of the gauge was checked monthly. The gauge was installed on June 11, 2006 and was set to operate continuously for 16 months such that at least one summer season would be captured in the flow record. Stage data collection continued until December 13, 2007 for a total deployment of 18 months.

Stream flow (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the gauge site based upon these flow measurements and the measured water levels at the gauge site. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume. Integrating the flow and nitrogen concentration datasets allows for the determination of nitrogen mass discharge to the Barnstable Great Marsh estuary system and reflective of the biological processes occurring in the stream channel, wetlands and wooded areas contributing to nitrogen attenuation (Figure IV-10 and Tables IV-5a, b and IV-6a, b). In addition, a water balance was constructed based upon the U.S. Geological Survey/CCC/MEP defined watershed delineations to determine long-term average freshwater discharge expected at the Boat Cove Brook gauge site based on area and average recharge.

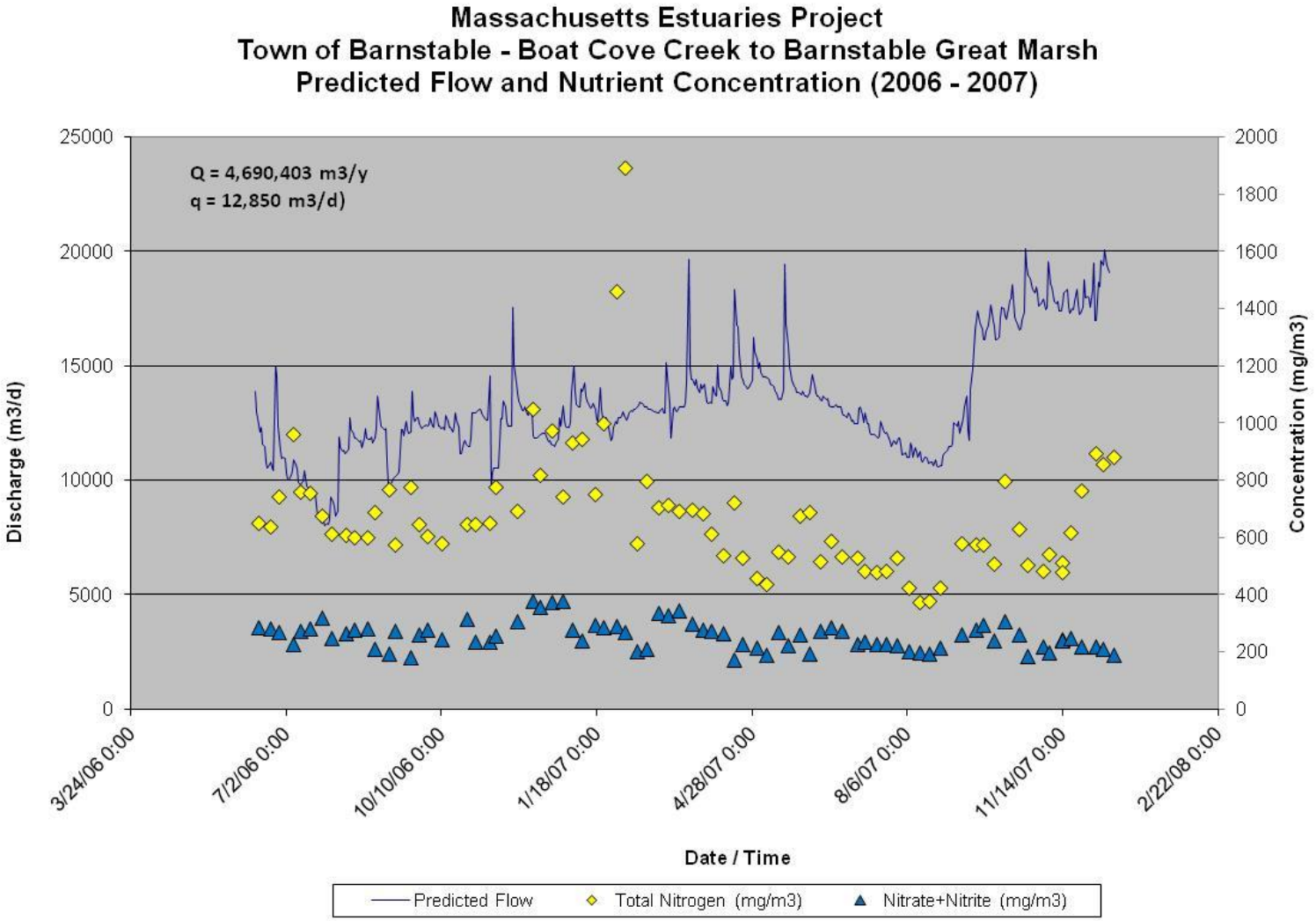


Figure IV-10. Discharge from Boat Cove Brook to the Great Marshes (solid blue line). Total nitrogen (yellow symbols) and Nitrate + Nitrite (NOx, blue symbols) concentrations are used for determination of attenuated nitrogen load from the sub-watershed (Table IV-3).

The annual freshwater flow record for the Boat Cove Brook as measured by the MEP was compared to the long-term average flows determined by the USGS/MEP/CCC modeling effort (Table III-1). The measured freshwater discharge from the Boat Cove Brook at the Route 6A gauge location was only ~3% above the long-term average modeled flows. The average daily flow based on the MEP measured flow data for the hydrologic year beginning September 2006 and ending in August 2007 (low flow to low flow) was 12,850 m^3/day compared to the long term average flows determined by the watershed modeling effort of 12,435 m^3/day. The negligible difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Boat Cove Brook discharging from the sub-watershed indicates that the Brook is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within the Boat Cove Brook outflow were low to moderate, 0.685 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 8.8 kg/day and a measured total annual TN load of 3,211 kg/yr. In Boat Cove Brook, nitrate made less than half of the total nitrogen pool (38%), indicating that a large portion of the groundwater nitrogen (typically dominated by nitrate) discharging to the wetland areas and stream bed up-gradient of the gauge was being taken up by plants and transformed within these different aquatic systems. Given the moderate levels of remaining nitrate in the stream discharge, the possibility for additional uptake by freshwater systems may be possible in the Boat Cove Brook sub-watershed should the Town of Barnstable (through management) want to restore the shallow mill pond that is the primary source water for the brook.

From the measured nitrogen load discharged by Boat Cove Brook to the Great Marshes and the nitrogen load determined from the watershed based land use analysis, it appears that there is insignificant nitrogen attenuation of upper watershed derived nitrogen during transport through the mill pond and Boat Cove Brook discharging to the estuary. Based upon the similar total nitrogen load (3,211 kg yr^{-1}) discharged from Boat Cove Brook at Route 6A compared to that added by the various land-uses within the contributing areas to the associated watershed (3,114 kg yr^{-1}), the integrated attenuation in passage through the stream and up-gradient freshwater wetlands prior to discharge to the estuary is essentially zero (i.e. nitrogen input to watershed reaches the estuary with no attenuation). This lack of attenuation compared to other streams evaluated under the MEP is consistent with the nature of the shallow up-gradient mill pond and wooded areas which lack significant natural mechanisms capable of attenuating nitrogen. Surfacewater and nitrogen load traveling through this small sub-watershed has very little time during transport to interact with biological processes that could attenuate the TN-load. The directly measured nitrogen load from Boat Cove Brook was used in the Linked Watershed-Embayment Modeling of water quality (see Section VI, below).

IV.2.4 Surface water Discharge and Attenuation of Watershed Nitrogen: Bridge Creek Discharge to Barnstable Harbor

Unlike most surface water features in the MEP study region that typically emanate from a specific pond, Bridge Creek, which discharges into the Barnstable Great Marshes, does not have an up-gradient source water pond. Rather, this small creek appears to be groundwater fed and emanates from a wetland/salt marsh area up-gradient of Route 6A. Bridge Creek up-gradient of the gauge located at Route 6A is the terminal end of a tidal creek that flows out of a tributary marsh to the larger Barnstable Great Marshes. The outflow leaving the salt marsh area up-gradient of Route 6A serves as a mechanism for directly measuring potential nitrogen attenuation resulting from natural processes taking place in the salt marsh upgradient and bordering freshwater wetland areas. The combined rate of nitrogen attenuation by the biological processes occurring as the water in Bridge Creek flows to the estuary was determined by comparing the

present predicted nitrogen loading to the sub-watershed region contributing to salt marsh areas and the creek channel above the gauge site and the measured annual discharge of nitrogen to the estuary at the Bridge Creek gauge, Figure IV-11.

The freshwater flow carried by Bridge Creek to the estuarine waters of the Barnstable Great Marshes was determined using a continuously recording vented calibrated water level gauge. As this surface water system was tidally influenced, the creek discharge was checked to confirm the extent of tidal influence and whether freshwater flow could be measured at low tide in the estuary. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gauge site at low tide. Average measured sample salinity was found to be 1.2 ppt, sufficiently fresh to be representative of water and load generated from the up-gradient subwatershed. As such, a salinity adjustment was not necessary in order to determine daily flows using the MEP developed stage-discharge relationship. The Bridge Creek gauge location was deemed acceptable for making flow measurements at low tide and obtaining an estimate of annual freshwater flow from the up-gradient subwatershed. Calibration of the gauge was checked monthly. The gauge was installed on June 17, 2006 and was set to operate continuously for a complete hydrologic year (low flow to low flow, ~12 months). Stage data collection continued until September 12, 2007 for a total deployment of 15 months.

Flow in the creek (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the gauge site based upon these flow measurements and the measured water levels at the gauge site. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume. Integrating the flow and nitrogen concentration datasets allows for the determination of nitrogen mass discharge to the estuarine system and that is reflective of the biological processes occurring in the stream channel, the surrounding salt marsh and the wooded natural areas contributing to nitrogen attenuation (Figure IV-12 and Tables IV-5a, b and IV-6a, b). In addition, a water balance was constructed based upon the U.S. Geological Survey/MEP/CCC defined watershed delineations to determine long-term average freshwater discharge expected at the Bridge Creek gauge site based on area and average recharge.

The annual freshwater flow record for Bridge Creek as measured by the MEP was compared to the long-term average flows determined by the USGS/MEP/CCC modeling effort (Table III-1). The measured freshwater discharge from Bridge Creek at the gauge location (Route 6A) was only ~4% below the long-term average modeled flows. The average daily flow based on the MEP measured flow data for the hydrologic year beginning September 2006 and ending in August 2007 (low flow to low flow) was 5,472 m^3/day compared to the long term average flows of 5,668 m^3/day determined from the watershed modeling effort. The negligible difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Bridge Creek discharging from the sub-watershed indicates that the creek is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within the Bridge Creek outflow were low to moderate, 0.648 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 3.55 kg/day and a measured total annual TN load of 1,294 kg/yr. In the Bridge Creek outflow, nitrate made up less than half of the total nitrogen pool (26%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the wetland areas and stream bed up-gradient of the gauge is being taken up by plants within the salt marsh and the creek bed and being converted to organic forms. Given the low levels of remaining nitrate in the creek discharge, the possibility for additional uptake by

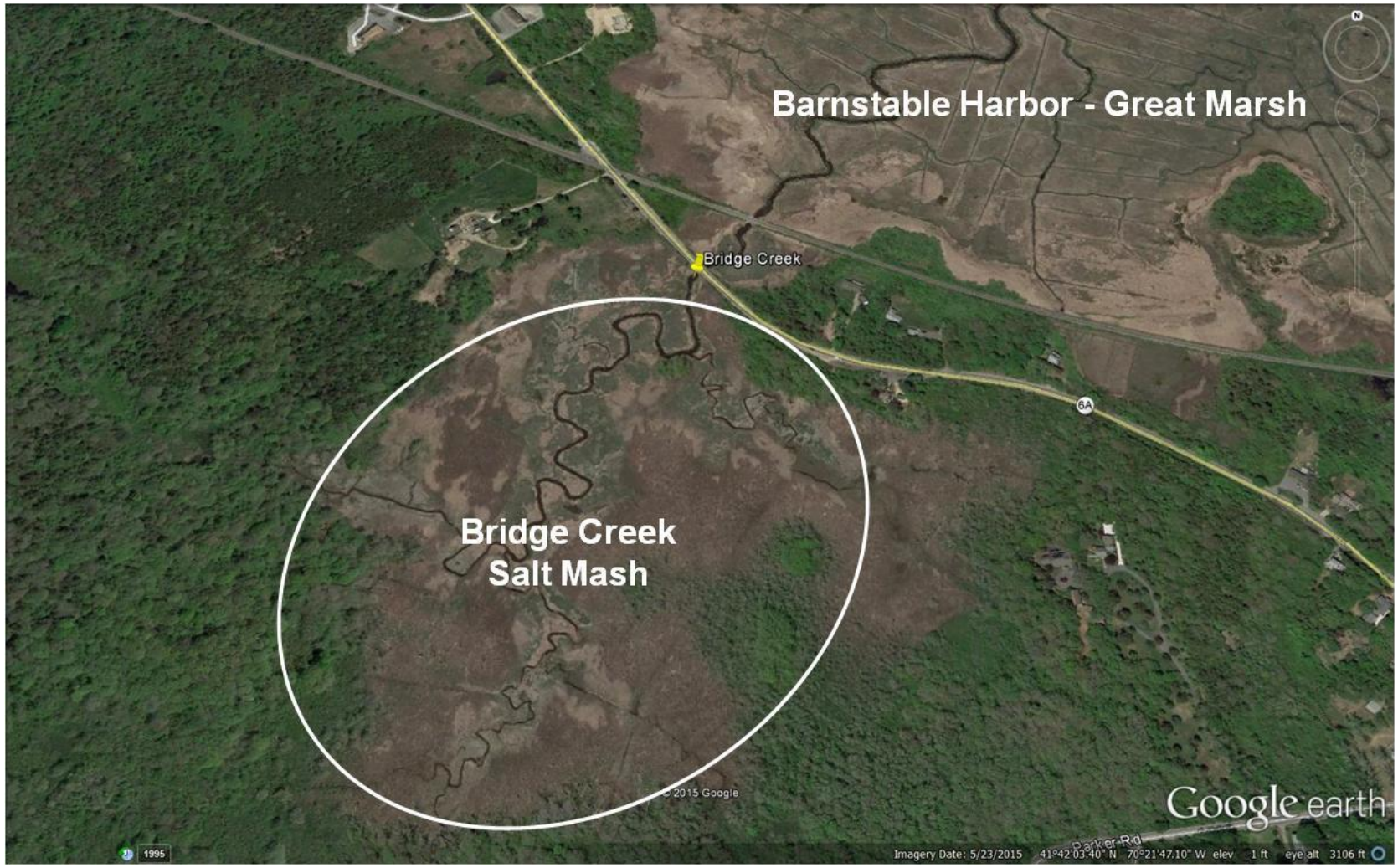


Figure IV-11. Location of MEP stream gauge (yellow symbol) for measuring flow and nitrogen load in Bridge Creek. The Bridge Creek salt marsh receives groundwater flow from surrounding wooded upland and discharges to the down gradient estuarine receiving waters of Barnstable Harbor-Great Marsh.

freshwater systems is limited, even if the Bridge Creek sub-watershed was appropriately structured or had potential aquatic features which could be enhanced or restored to facilitate denitrification.

From the measured nitrogen load discharged by Bridge Creek to the Great Marshes and the nitrogen load determined from the watershed based land use analysis, it appears that there is modest nitrogen attenuation of upper watershed derived nitrogen during transport through Bridge Creek to the estuary. Based upon the lower total nitrogen load (1,294 kg yr^{-1}) discharged from Bridge Creek compared to that added by the various land-uses to the associated watershed (2,180 kg yr^{-1}), a 41% integrated attenuation was calculated in passage through this small tidal creek and the up-gradient salt marsh prior to discharge to the estuary (i.e. 41% of nitrogen input to watershed does not reach the estuary). This level of attenuation is consistent with other streams/creeks evaluated under the MEP with similar aquatic resources (wetland/salt marsh areas). The directly measured nitrogen load from Bridge Creek was used in the Linked Watershed-Embayment Modeling of water quality (see Section VI, below).

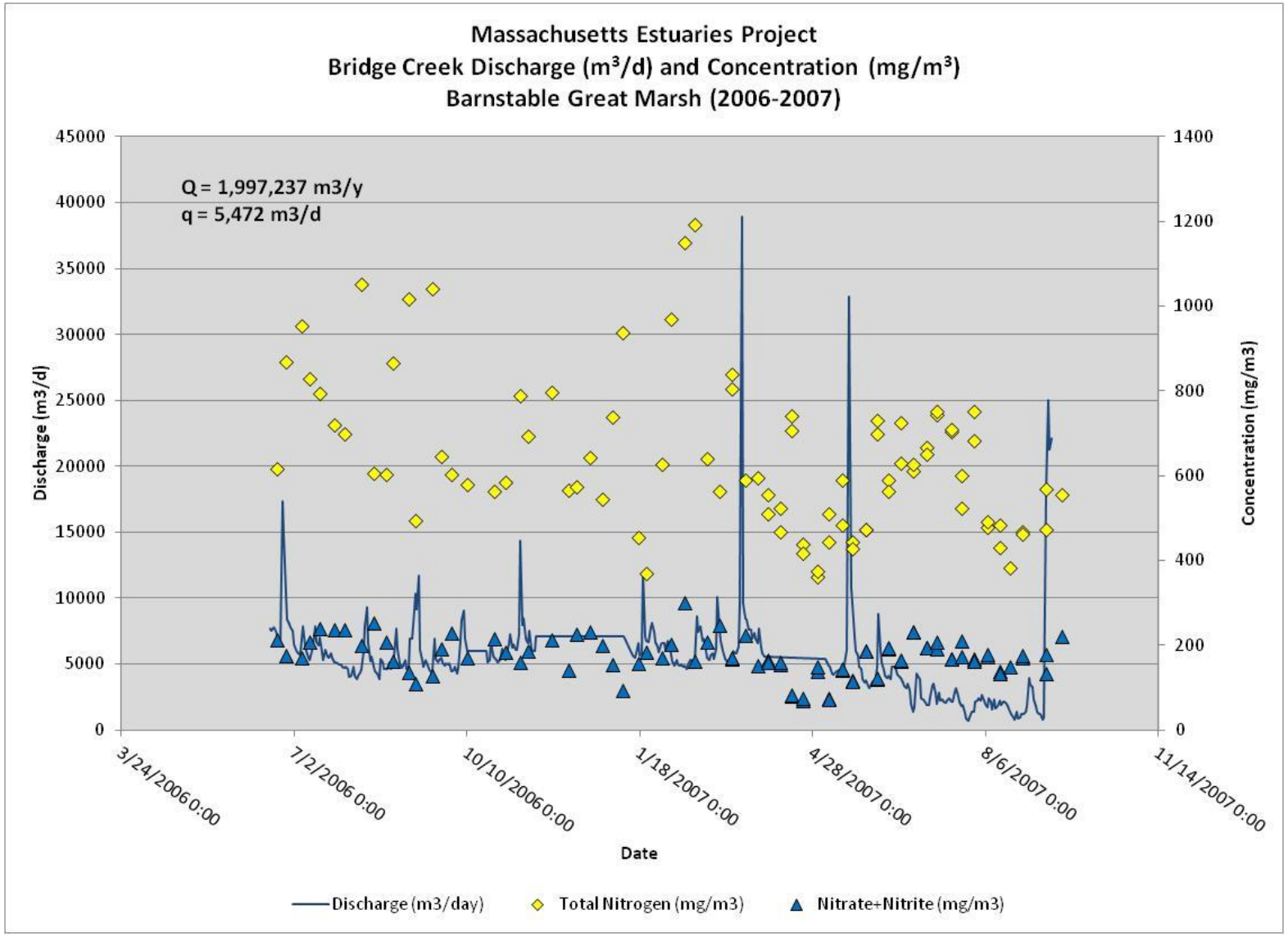


Figure IV-12. Discharge from Bridge Creek to the Barnstable Great Marshes (solid blue line). Total nitrogen (yellow symbols) and Nitrate + Nitrite (NOx, blue symbols) concentrations are used for determination of attenuated nitrogen load from the sub-watershed (Table IV-3)

IV.2.5 Surface water Discharge and Attenuation of Watershed Nitrogen: Maraspin Creek Discharge to Barnstable Harbor-Millway

Unlike most surface water features in the MEP study region that typically emanate from a specific pond, Maraspin Creek, which discharges into Barnstable Harbor, does not have an up-gradient source water pond. Rather, this creek appears to be groundwater fed and emanates from a wetland/salt marsh area bounded by Mill Way and Commercial Road (Figure IV-6c). As the main stem of Maraspin Creek is in a salt marsh with a central tidal channel, the MEP focused its assessment of this surfacewater feature on the upper most reach of the creek up-gradient of Commercial Road. Maraspin Creek up-gradient of the gauge located at Commercial Road is the terminal end of a tidal creek that flows out of a tributary salt marsh into the Millway portion of Barnstable Harbor and is the most likely area to make flow measurements that would be representative of freshwater at low tide. The outflow leaving the small wetland area up-gradient of Commercial Road serves as a mechanism for directly measuring potential nitrogen attenuation resulting from natural processes taking place in the wetland feeding the down gradient salt marsh. The combined rate of nitrogen attenuation by the biological processes occurring as the water in Maraspin Creek flows to the estuarine waters of Barnstable Harbor was determined by comparing the present predicted nitrogen loading to the sub-watershed region contributing to the wetland and creek channel above the gauge site and the measured annual discharge of nitrogen to the estuary at the Maraspin Creek gauge site at Commercial Road (Figure IV-13).

The freshwater flow carried by the uppermost reach of Maraspin Creek and discharging to the estuarine waters of Barnstable Harbor was determined using a continuously recording vented calibrated water level gauge. As this surface water system was potentially tidally influenced at the Commercial Road crossing where the stream gauge was located, the creek discharge was checked to confirm the extent of tidal influence and whether freshwater flow could be measured at low tide in the estuary. To confirm that freshwater was being measured, salinity measurements were conducted on weekly water quality samples collected from the gauge site. Average measured sample salinity at low tide was found to be only 0.3 ppt, indicating a insignificant tidal influence at the gauge location at low tide. As such, salinity adjustment was not necessary to the flows in order to determine daily freshwater flow using the MEP developed stage-discharge relation. The Maraspin Creek gauge location was deemed acceptable for making flow measurements and obtaining an estimate of annual freshwater flow and attenuated nitrogen load. Calibration of the gauge was checked monthly. The gauge was installed on June 14, 2006 and was set to operate continuously for 16 months such that at least one summer season would be captured in the flow record. Stage data collection continued until December 14, 2007 for a total deployment of 18 months.

Flow in Maraspin Creek (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the gauge site based upon these flow measurements and the measured water levels at the gauge site. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume. Integrating the flow and nitrogen concentration datasets allows for the determination of nitrogen mass discharge to Barnstable Harbor - Millway and is reflective of the biological processes occurring in the small wetland up-gradient of the gauge that contributes to nitrogen attenuation (Figure IV-14 and Tables IV-5a, b and IV-6a, b). In addition, a water balance was constructed based upon the U.S. Geological Survey/MEP/CCC defined watershed delineations to determine long-term average freshwater discharge expected at the Maraspin Creek gauge site based on area and average recharge.

The annual freshwater flow record for Maraspin Creek as measured by the MEP was compared to the long-term average flows determined by the USGS/MEP/CCC modeling effort (Table III-1). The measured freshwater discharge from Maraspin Creek at the gauge location (Commercial Rd.) was nearly identical (~1% below) the long-term average modeled flows. The average daily flow based on the MEP measured flow data for the hydrologic year beginning September 2006 and ending in August 2007 (low flow to low flow) was 1,384 m^3/day compared to the long term average flow determined by the watershed modeling effort of 1,396 m^3/day. The negligible difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Maraspin Creek discharging from the sub-watershed indicates that the creek is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within the Maraspin Creek outflow were relatively high, 2.11 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 2.93 kg/day and a measured total annual TN load of 1,051 kg/yr. Nitrate made up well more than half of the total nitrogen pool (80%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the small wetland area up-gradient of the gauge was not being transformed by plants within wetland and up-gradient subwatershed. Given the relatively high levels of remaining nitrate in the stream discharge, the Town of Barnstable should consider looking in more detail at the land uses in the subwatershed for what might be generating inorganic nitrogen load. It is possible that the agricultural activity in the subwatershed up-gradient of the gauge could be contributing through its agricultural practices. Equally important the high nitrate concentrations provide an opportunity for actions to enhance natural attenuation in this system.

From the measured nitrogen load discharged by Maraspin Creek to the upper portion of the Barnstable Harbor - Millway and the nitrogen load determined from the watershed based land use analysis, it appears that there is insignificant nitrogen attenuation of upper watershed derived nitrogen during transport to Maraspin Creek and the estuary. Based upon lower total nitrogen load (1,051 kg yr^{-1}) discharged from Maraspin Creek at the Commercial Road crossing compared to that added by the various land-uses to the associated watershed (1,360 kg yr^{-1}), there was only a 21% removal of transported nitrogen in passage through the stream and up-gradient ponds and freshwater wetlands prior to discharge to the estuary (i.e. 21% of nitrogen input to watershed does not reach the estuary). This level of attenuation compared to other streams evaluated under the MEP is at the low end of the expected range of attenuation in similar watersheds. The directly measured nitrogen load from Maraspin Creek was used in the Linked Watershed-Embayment Modeling of water quality (see Section VI, below).



Figure IV-13. Location of MEP stream gauge (yellow symbol) for measuring flow and nitrogen load in Maraspin Creek. The Maraspin Creek salt marsh receives groundwater flow from surrounding residential upland as well as a small wetland and agricultural area up-gradient of the MEP gauge. The creek discharges to the down gradient estuarine receiving waters of the Barnstable Harbor-Millway.

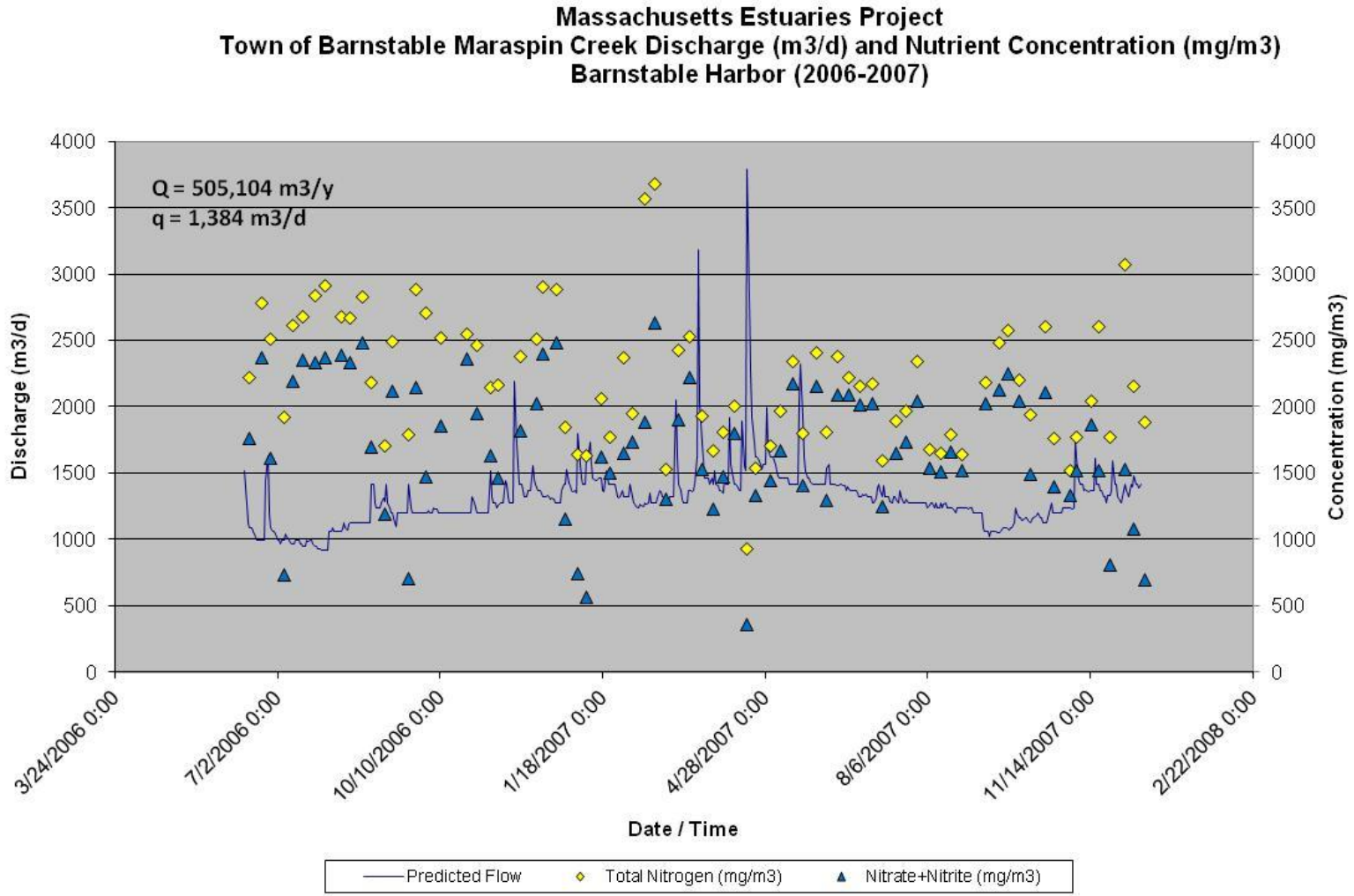


Figure IV-14. Discharge from Maraspin Creek (solid blue line). Total nitrogen (yellow symbols) and Nitrate + Nitrite (NOx, blue symbols) concentrations are used for determination of attenuated nitrogen load from the sub-watershed (Table IV-3).

IV.2.6 Surface water Discharge and Attenuation of Watershed Nitrogen: Whites Brook Discharge to Bass Hole

Unlike most surface water features in the MEP study region, Whites Brook, which discharges into a tributary tidal creek that flows towards the main stem of Chase Garden Creek and Bass Hole, does not have an up-gradient source water pond from which that creek discharges. Rather, this small creek appears to be groundwater fed and emanates from a generally wooded area up-gradient of Route 6A (Figures IV-15a,b). The outflow leaving the wooded area up-gradient of Route 6A travels through a densely developed upland environment just prior to discharging to the head of the tidal creek proximal to Mathews Pond. The Whites Brook flow at the gauge located at the Route 6A crossing can support nitrogen attenuation to the extent that it passes through any wetlands. The combined rate of nitrogen attenuation by the biological processes occurring as the water in Whites Brook flows to the estuary was determined by comparing the present predicted nitrogen loading from the watershed contributing freshwater and associated nitrogen to the wooded areas and brook channel above the gauge site and the measured annual discharge of nitrogen to the tidal creek at the Whites Brook gauge, Figure IV-15a,b.

The freshwater flow carried by Whites Brook to the estuarine waters of Bass Hole was determined using a continuously recording vented calibrated water level gauge. As this surface water system was potentially tidally influenced, the creek discharge was checked to confirm the extent of tidal influence and whether freshwater flow could be measured at low tide in the estuary. To confirm that freshwater was being measured at low tide in the estuary, salinity measurements were conducted on weekly water quality samples collected from the gauge site. Average measured sample salinity was found to be only 0.3 ppt, clearly not tidally influenced. As such, a salinity adjustment was not necessary in order to determine daily flows using the MEP developed stage-discharge relation. The Whites Brook gauge location was deemed acceptable for making flow measurements and obtaining an estimate of annual freshwater flow and nitrogen load. Calibration of the gauge was checked monthly. The gauge was installed on June 14, 2006 and was set to operate continuously for a complete hydrologic year (low flow to low flow, ~12 months). Stage data collection continued until August 2, 2008 for a total deployment of 14 months.

Flow in the brook (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the gauge site based upon these flow measurements and the measured water levels at the gauge site. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume. Integrating the flow and nitrogen concentration datasets allows for the determination of nitrogen mass discharge at the gauge site prior to discharge to the tributary tidal creek flowing into Bass Hole. Nitrogen removal during transport is reflective of the biological processes occurring in the channel bed and any associated wetlands or wooded areas up-gradient of the gauge at Route 6A (Figure IV-16 and Tables IV-5a, b and IV-6a, b). In addition, a water balance was constructed based upon the U.S. Geological Survey/MEP/CCC defined watershed delineations to determine long-term average freshwater discharge expected at the Whites Brook gauge site based on area and average recharge.

The annual freshwater flow record for Whites Brook as measured by the MEP was compared to the long-term average flows determined by the USGS/MEP/CCC modeling effort (Table III-1). The measured freshwater discharge from Whites Brook at the gauge location was 6% above the long-term average modeled flows. The average daily flow based on the MEP measured flow data for the hydrologic year beginning September 2006 and ending in August 2007

(low flow to low flow) was 1,462 m^3/day compared to the long term average flows of 1,379 m^3/day determined from the watershed modeling effort. The insignificant difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Whites Brook discharging from the sub-watershed indicate that the brook is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within Whites Brook outflow were high, 0.959 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 1.40 kg/day and a measured total annual TN load of 512 kg/yr. In the Whites Brook outflow, nitrate made up slightly more than half of the total nitrogen pool (57%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the wetland areas and stream bed up-gradient of the gauge is partially taken up by and transformed to organic forms by plants within the wooded upland and the channel bed of the brook. Given the relatively high levels of remaining nitrate in the Brook waters, the possibility for additional uptake by freshwater systems appear to exist if nitrogen management actions are needed (e.g. pond or bog restoration for enhancing natural attenuation).

From the measured nitrogen load discharged by Whites Brook and the nitrogen load determined from the watershed based land use analysis, it appears that there is modest nitrogen attenuation of upper watershed derived nitrogen during transport through Whites Brook to the estuarine receiving waters. Based upon lower total nitrogen load (512 kg yr^{-1}) discharged from Whites Brook compared to that added by the various land-uses to its associated watershed, 818 kg yr^{-1}, the integrated attenuation in passage through this small brook and associated aquatic components is 37% (i.e. 37% of nitrogen input to watershed does not reach the estuary). This level of attenuation is consistent with other streams/creeks/brooks evaluated under the MEP (including to the Barnstable Great Marshes). The directly measured nitrogen load from Whites Brook was used in the Linked Watershed-Embayment Modeling of water quality (see Section VI, below).



Figure IV-15a. Location of two MEP stream gauges (yellow symbol) on streams discharging to the Bass Hole sub-embayment (southern stream is Whites Brook and northern stream is Chase Garden Creek). Freshwater flow and nitrogen load were measured over a complete year at each gauge site. Bass Hole is a major tributary to the Barnstable Great Marsh estuary system.

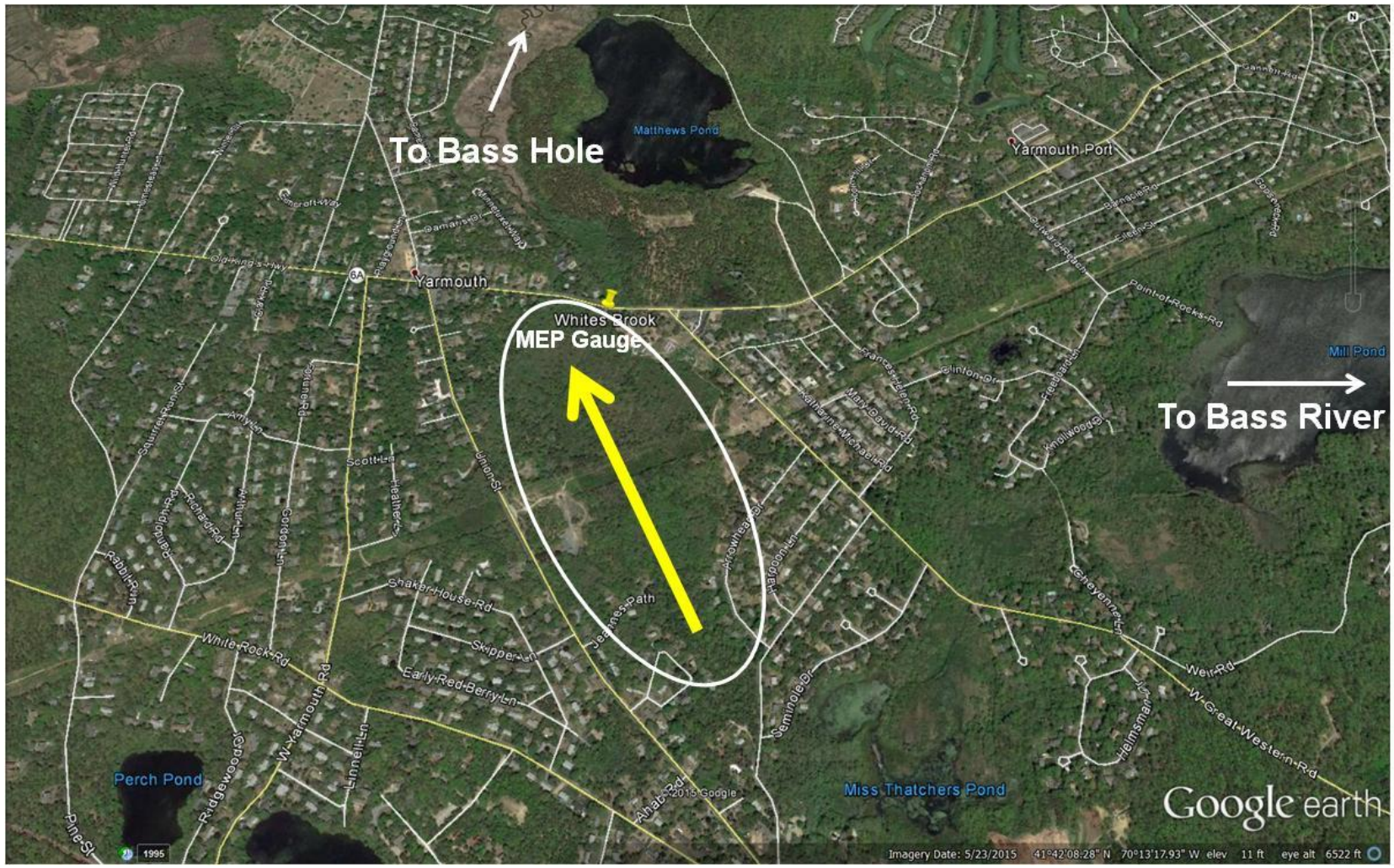


Figure IV-15b. Location of MEP stream gauge (yellow symbol) for measuring flow and nitrogen load in Whites Brook. Yellow arrows show the direction of surfacewater flow draining a small wooded area up-gradient of the Whites Brook gauge.

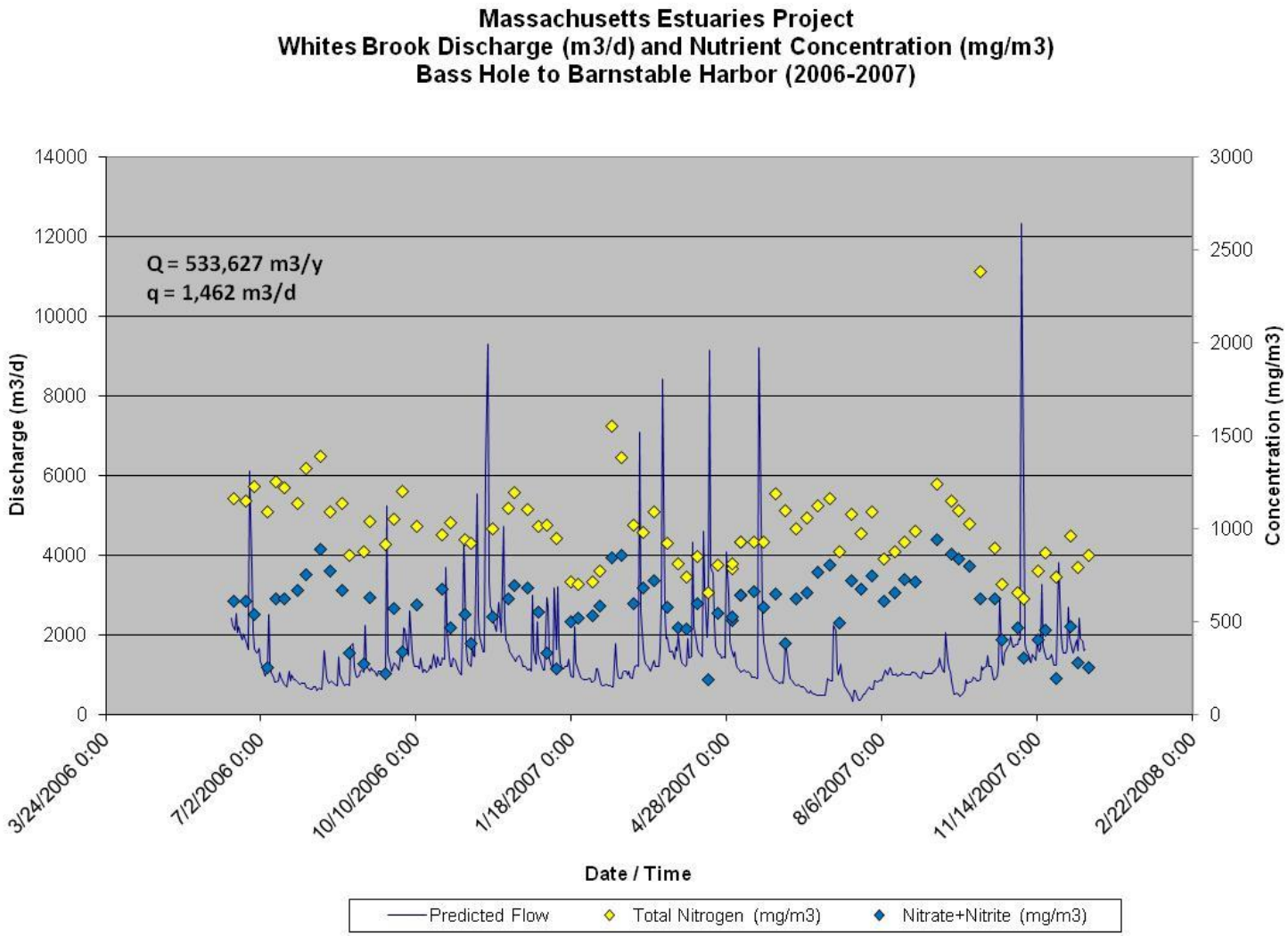


Figure IV-16. Discharge from Whites Brook to Bass Hole (solid blue line). Total nitrogen (yellow symbols) and Nitrate + Nitrite (NOx, blue symbols) concentrations are used for determination of attenuated nitrogen load from the sub-watershed (Table IV-5a, b).

IV.2.7 Surface water Discharge and Attenuation of Watershed Nitrogen: Chase Garden Creek Discharge to Bass Hole

Unlike most surface water features in the MEP study region that typically emanate from a specific pond or wetland, Chase Garden Creek, which discharges directly into Bass Hole, does not have an upgradient sourcewater pond from which that Creek discharges. Rather, the headwaters of the creek emanate from what appear to be bogs situated proximal to the shoreline of Cape Cod Bay, with much of the creek being groundwater fed as it flows through a generally residential area with the area upgradient of the MEP gauge being generally marshy with houses to either side of the creek. This marshy area upgradient of the gauge located at the New Boston Road crossing may be providing some attenuation of nitrogen. The culvert location at New Boston Road provides a good point for a direct measurement of flow and nitrogen load in the creek. The combined rate of nitrogen attenuation by the biological processes occurring as the water in Chase Garden Creek flows toward the estuary was determined by comparing the present predicted nitrogen loading to the sub-watershed region up-gradient of the MEP gauge and the measured annual discharge of nitrogen to Bass Hole at the Chase Garden Creek gauge, Figures IV-15a and 17.

The freshwater flow carried by Chase Garden Creek to the estuarine waters of Bass Hole was determined using a continuously recording vented calibrated water level gauge. As this surface water system was potentially tidally influenced, the creek discharge was checked to confirm the extent of tidal influence and whether freshwater flow could be measured at low tide in the estuary. To confirm that freshwater was being measured, salinity measurements were conducted on the weekly water quality samples collected from the gauge site. Average measured sample salinity was found to be 0.3 ppt, clearly not tidally influenced. As such, a salinity adjustment was not necessary in order to determine daily flows using the MEP developed stage-discharge relation. The Chase Garden Creek gauge location was deemed acceptable for making flow measurements and obtaining an estimate of annual freshwater flow to the estuary. Calibration of the gauge was checked monthly. The gauge was installed on June 14, 2006 and was set to operate continuously for a complete hydrologic year (low flow to low flow, ~12 months). Stage data collection continued until August 2, 2007 for a total deployment of 15 months.

Flow in the creek (volumetric discharge) was measured every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the gauge site based upon these flow measurements and the measured water levels. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume. Integrating the flow and nitrogen concentration datasets allows for the determination of nitrogen mass discharge to the Bass Hole sub-estuary and integrates both watershed nitrogen inputs and nitrogen removals during transport by biological processes occurring in the channel bed and any associated wetlands (Figure IV-18 and Tables IV-5a, b and IV-6a, b). In addition, a water balance was constructed based upon the U.S. Geological Survey/MEP/CCC defined watershed delineations to determine long-term average freshwater discharge expected at the Chase Garden Creek gauge site based on contributing area and average recharge.

The annual freshwater flow record for Chase Garden Creek as measured by the MEP was compared to the long-term average flows determined by the USGS/MEP/CCC modeling effort (Table III-1). The measured freshwater discharge from Chase Garden Creek at the gauge location was only 2% above the long-term average modeled flows. The average daily flow based on the MEP measured flow data for the hydrologic year beginning September 2006 and ending in August 2007 (low flow to low flow) was 1,611 m^3/day compared to the long term average flows

determined by the watershed modeling effort (1,574 m^3/day). The negligible difference between the long-term average flow based on recharge rates over the watershed area and the MEP measured flow in Chase Garden Creek indicates that the creek is capturing the up-gradient recharge (and loads) accurately.

Total nitrogen concentrations within the Chase Garden Creek outflow were high, 1.05 mg N L^{-1}, yielding an average daily total nitrogen discharge to the estuary of 1.70 kg/day and a measured total annual TN load of 622 kg/yr. In the Chase Garden Creek outflow, nitrate made up less than half of the total nitrogen pool (35%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the wetland areas and stream bed up-gradient of the gauge is only partially taken up and transformed by plants to organic forms within the riparian zone and the channel bed of the creek. Given the moderate levels of remaining nitrate in the discharge water from the creek, the possibility for additional uptake by freshwater systems may be limited in the Chase Garden Creek sub-watershed.

From the measured nitrogen load discharged by Chase Garden Creek to Bass Hole and the nitrogen load determined from the watershed based land use analysis, it appears that there is significant nitrogen attenuation of upper watershed derived nitrogen during transport to the Chase Garden Creek gauge location and the estuarine receiving waters. Based upon lower total nitrogen load (622 kg yr^{-1}) discharged from Chase Garden Creek at New Boston Road compared to that added by the various land-uses to the associated watershed (1,561 kg yr^{-1}), the integrated attenuation in passage through this Creek and the marshy riparian areas and bogs is relatively high at 60% (i.e. 60% of nitrogen input to watershed does not reach the estuary). This level of attenuation is consistent with other streams/creeks/brooks evaluated under the MEP with transport through areas with marshy creek banks and wetlands/bogs which are capable of attenuating nitrogen. The directly measured nitrogen load from Chase Garden Creek was used in the Linked Watershed-Embayment Modeling of water quality (see Section VI, below).

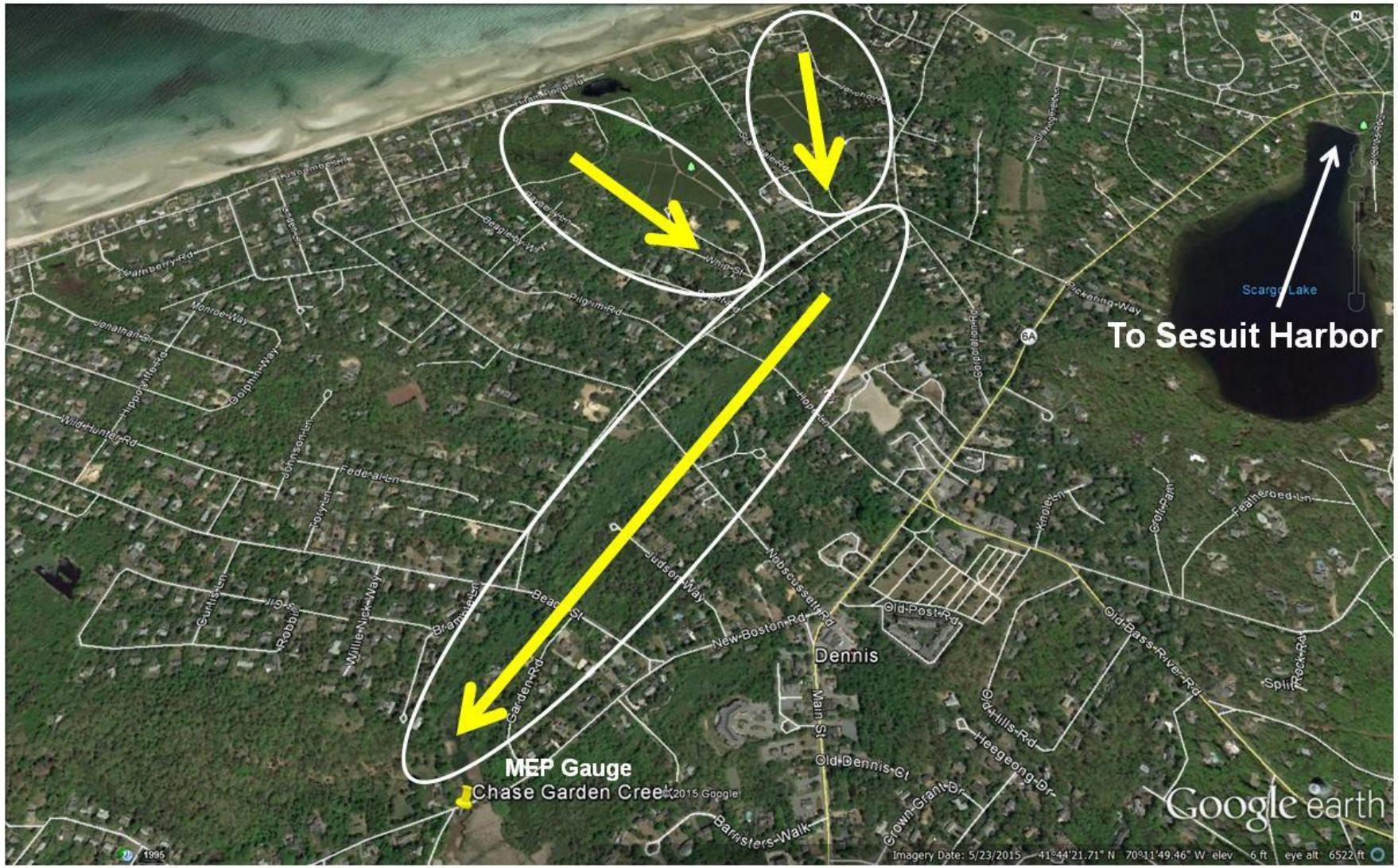


Figure IV-17. Location of MEP stream gauge (yellow symbol) for measuring flow and nitrogen load in Whites Brook. Yellow arrows show the direction of surfacewater flow draining a marshy riparian zone along Chase Garden Creek as well as a network of bogs as the head waters of the Creek.

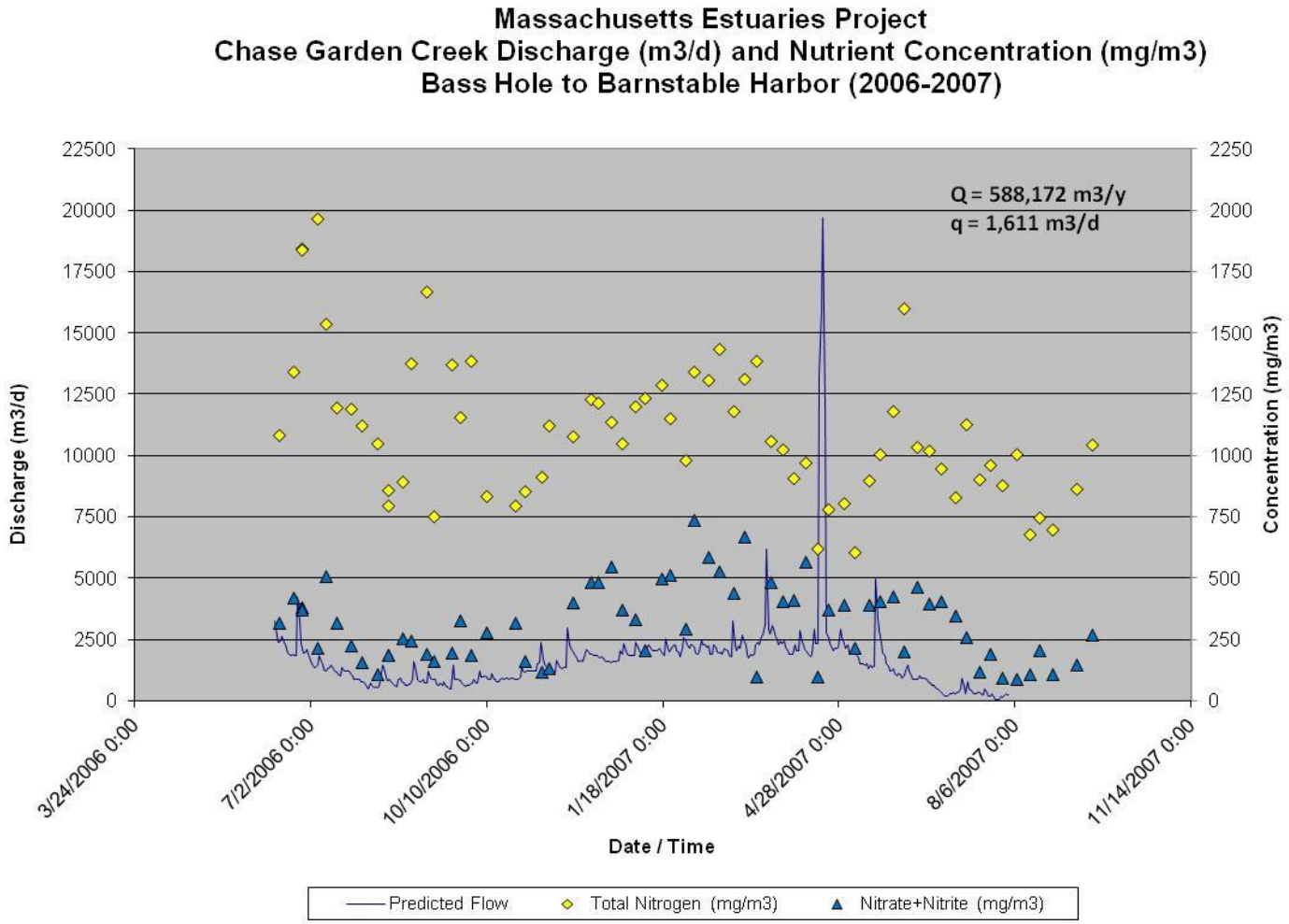


Figure IV-18. Discharge from Chase Garden Creek to Bass Hole (solid blue line). Total nitrogen (yellow symbols) and Nitrate + Nitrite (NOx, blue symbols) concentrations are used for determination of attenuated nitrogen load from the sub-watershed (Table IV-5a, b).

IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS

The overall objective of the benthic nutrient flux survey of the Barnstable Great Marsh estuary system was to quantify the summertime exchange of nitrogen, between the sediments and overlying waters throughout this large system. The mass exchange of nitrogen between water column and sediments is a fundamental factor in controlling nitrogen levels within coastal waters. These fluxes and their associated biogeochemical pools relate directly to carbon, nutrient and oxygen dynamics and the nutrient related ecological health of these shallow marine ecosystems. In addition, these data are required for the proper modeling of nitrogen in shallow aquatic systems, both fresh and salt water.

IV.3.1 Sediment-Water column Exchange of Nitrogen

As stated in the above section, nitrogen loading and resulting levels within coastal embayments are the critical factors controlling the nutrient related ecological health and habitat quality within a system. Nitrogen enters the Barnstable Great Marsh estuary system predominantly in highly bio-available forms from the surrounding upland watersheds and more refractory forms in the inflowing tidal waters. If all of the nitrogen remained within the water column (once it entered) then predicting water column nitrogen levels would be simply a matter of determining the watershed loads, dispersion, and hydrodynamic flushing. However, as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bio-available form nitrate. This nitrate and other bio-available forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved forms into phytoplankton “particles”. Most of these “particles” remain in the water column for sufficient time to be flushed out to a down gradient larger water body (like Cape Cod Bay). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals and deposited on the bottom. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence), a fraction of the phytoplankton with their associated nitrogen “load” become incorporated into the surficial sediments of the embayment.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within enclosed tributary basins, particularly if they are deeper than the adjacent embayment. To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary.

Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic (oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter with its nitrogen content that bio-available nitrogen is returned to the embayment water column for another round of uptake by phytoplankton. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that have been investigated by SMAST and the MEP, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. In contrast in some systems, with deep depositional basins or salt marsh tidal creeks, the sediments can be a net sink for nitrogen even during summer (e.g. Namskaket Salt Marsh (lower reach), Mashapaquit Creek Salt Marsh, West Falmouth Harbor; Centerville River Salt Marsh or Sesachacha Pond on the Island of Nantucket). Embayment basins can also be net

sinks for nitrogen to the extent that they support relatively oxidized surficial sediments, for example in the margins of the main basin to Lewis Bay (Town of Barnstable, Cape Cod). In contrast, most embayments show low rates of nitrogen release throughout much of their basin areas and, in regions of high deposition the anoxic sediments show high release rates during summer months, due to a lessening of coupled nitrification-denitrification. The consequence of high deposition rates is that the basin sediments are unconsolidated, organic rich and sulfidic nature (MEP field observations).

Failure to account for the site-specific nitrogen balance of the sediments and its spatial variation from the tidal creeks and embayment basins will result in significant errors in determination of the threshold nitrogen loading to the Barnstable Great Marsh estuary system. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

IV.3.2 Method for determining sediment-watercolumn nitrogen exchange

For the Barnstable Great Marsh estuary system, in order to determine the contribution of sediment regeneration to nutrient levels during the most sensitive summer interval (July-August), sediment samples were collected and incubated under *in situ* conditions. Sediment samples were collected from a total of 40 cores from 38 sites in the Great Marshes, Barnstable Harbor and Bass Hole portions of the overall system. All the sediment cores for this system were collected in July-August 2006. Measurements of total dissolved nitrogen, nitrate + nitrite (NOx), ammonium were made in time-series on each incubated core sample.

Rates of nitrogen release were determined using undisturbed sediment cores incubated for 24 hours in temperature-controlled baths. Sediment cores (15 cm inside diameter) were collected by SCUBA divers and cores transported by small boat to a shore side lab. Cores were maintained from collection through incubation at *in situ* temperatures. Bottom water was collected and filtered from core sites to replace the headspace water of each core prior to incubation. The number of core samples from each estuarine component (Figure IV-19) are as follows:

Barnstable Harbor Benthic Nutrient Regeneration Cores

- BH-1 1 core (Scorton Creek)
- BH-2 1 core (Scorton Creek)
- BH-3 1 core (Scorton Creek)
- BH-4 1 core (Scorton Water)
- BH-5 1 core (Spring Creek)
- BH-6 1 core (Spring Creek)
- BH-7 1 core (Spring Creek)
- BH-8 1 core (Spring Creek)
- BH-9 1 core (Main Basin Upper)
- BH-10 1 core (Brickyard Creek)
- BH-11 1 core (Brickyard Creek)
- BH-12 1 core (Brickyard Creek)
- BH-13 1 core (Brickyard Creek)
- BH-14 1 core (Brickyard Creek)
- BH-15 1 core (Main Basin Upper)
- BH-16 1 core (Main Basin Upper)

• BH-17	1 core	(Main Basin Upper)
• BH-18	1 core	(Main Basin Upper)
• BH-19	1 core	(Main Basin Upper)
• BH-20 + 21	2 cores	(Main Basin Upper)
• BH-22	1 core	(Main Basin Upper)
• BH-23	1 core	(Millway)
• BH-24 + FD	2 cores	(Millway)
• BH-25	1 core	(Millway)
• BH-26	1 core	(Main Basin Lower)
• BH-27	1 core	(Main Basin Lower)
• BH-28	1 core	(Main Basin Lower)
• BH-29	1 core	(Wharf Creek)
• BH-30	1 core	(Wharf Creek)
• BH-31	1 core	(Lone Tree Creek)
• BH-32	1 core	(Lone Tree Creek)
• BH-33	1 core	(Lone Tree Creek)
• BH-34	1 core	(Lone Tree Creek)

Bass Hole Benthic Nutrient Regeneration Cores

• BASS-1	1 core	(Bass Hole Lower)
• BASS-2	1 core	(Bass Hole Lower)
• BASS-3/4	2 cores	(Bass Hole Lower)
• BASS-5	1 core	(Bass Hole Upper)
• BASS-6	1 core	(Bass Hole Upper)

Sediment-water column exchange follows the methods of Jorgensen (1977), Klump and Martens (1983), and Howes *et al.* (1998) for nutrients and metabolism. Upon return to the field laboratory at the Millway Marina facility on the shore of Barnstable Harbor, the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with filtered water), filtered into acid leached polyethylene bottles and held on ice for nutrient analysis. Ammonium (Scheiner 1976) and ortho-phosphate (Murphy and Reilly 1962) assays were conducted within 24 hours and the remaining samples frozen (-20°C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia *et al.* 1977). Rates were determined from linear regression of analyte concentrations through time.

Chemical analyses were performed by the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST) at the University of Massachusetts in New Bedford, MA. (508-910-6325 or d1white@umassd.edu). The laboratory follows standard methods for saltwater analysis and sediment geochemistry.

IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments

Water column nitrogen levels are the balance of inputs from direct sources (land, rain etc), losses (denitrification, burial), regeneration (water column and benthic), and uptake (e.g.

photosynthesis). As stated above, during the warmer summer months the sediments of shallow estuaries typically act as a net source of nitrogen to the overlying waters and help to stimulate eutrophication in organic rich systems. However, some sediments may be net sinks for nitrogen and some may be in "balance" (organic N particle settling = nitrogen release). Sediments may also take up dissolved nitrate directly from the water column and convert it to dinitrogen gas (termed "denitrification"), hence effectively removing it from the ecosystem. This process is typically a small component of sediment denitrification in embayment sediments, since the water column nitrogen pool is typically dominated by organic forms of nitrogen, with very low nitrate concentrations. However, this process can be very effective in removing nitrogen loads in some systems, particularly in streams, ponds and salt marshes, where overlying waters support high nitrate levels.

In addition to nitrogen cycling, there are ecological consequences to habitat quality of organic matter settling and mineralization within sediments, these relate primarily to sediment and water column oxygen status. However, for the modeling of nitrogen within an embayment it is the relative balance of nitrogen input from water column to sediment versus regeneration which is critical. Similarly, it is the net balance of nitrogen fluxes between water column and sediments during the modeling period that must be quantified. For example, a net input to the sediments represents an effective lowering of the nitrogen loading to down-gradient systems and net output from the sediments represents an additional load.

The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the levels of organic matter within the sediments, whether the sediments are oxic or anoxic and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake throughout the summer months, even though organic nitrogen is being mineralized and released to the overlying water as well. The rate of nitrate uptake, simply dominates the overall sediment nitrogen cycle.

In order to model the nitrogen distribution within an embayment it is important to be able to account for the net nitrogen flux from the sediments within each part of each system. This requires that an estimate of the particulate input and nitrate uptake be obtained for comparison to the rate of nitrogen release. Only sediments with a net release of nitrogen contribute a true additional nitrogen load to the overlying waters, while those with a net input to the sediments serve as an "in embayment" attenuation mechanism for nitrogen, lowering nitrogen levels.

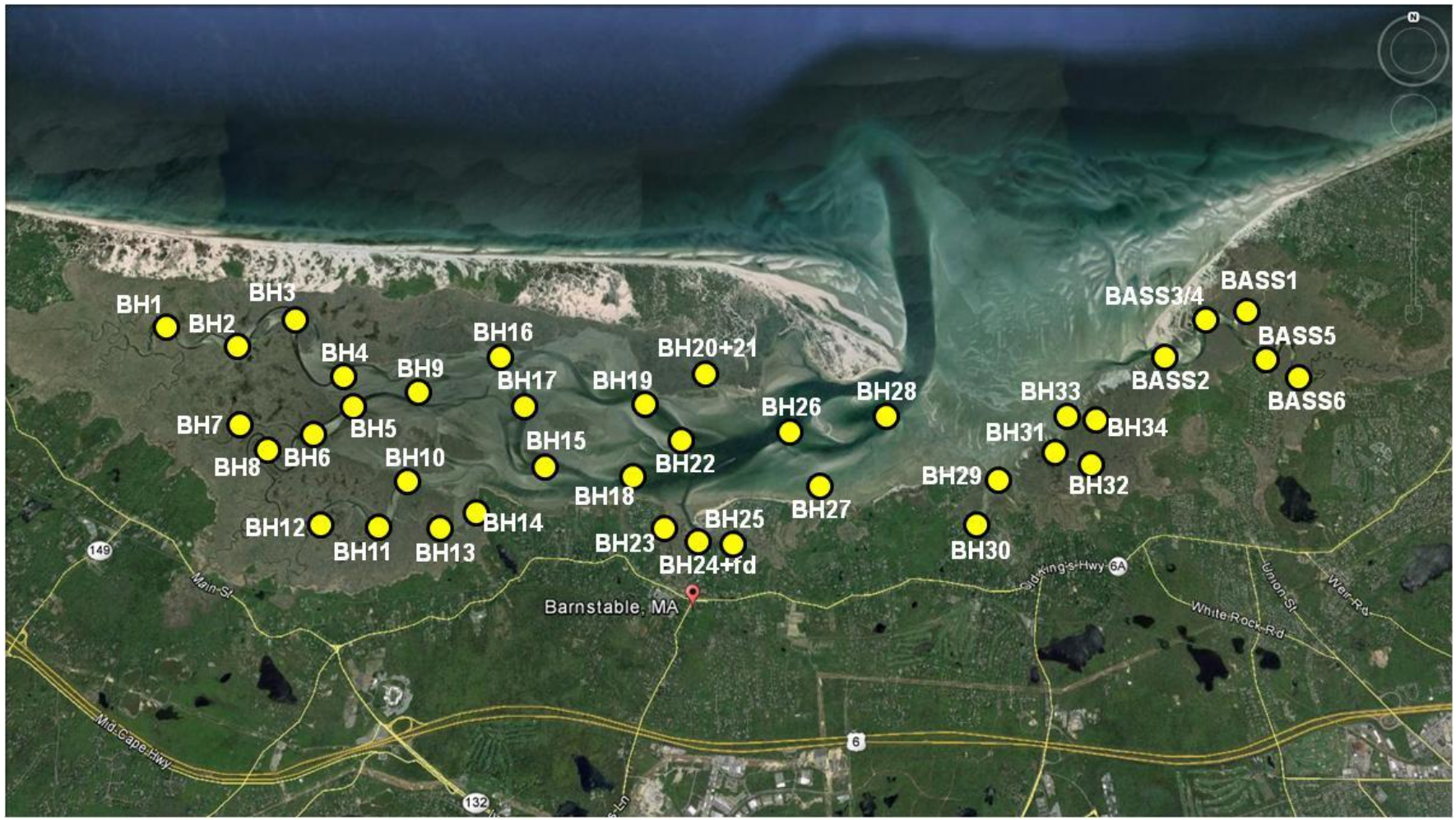


Figure IV-19. Barnstable Great Marsh estuary system sediment sampling sites (yellow symbols) for determination of nitrogen regeneration rates. Numbers are for reference to station identifications listed above.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure IV-20).

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates.

In order to determine the net nitrogen flux between water column and sediments, all of the above factors were taken into account. The net input or release of nitrogen within a specific embayment was determined based upon the measured total dissolved nitrogen uptake or release, and estimate of particulate nitrogen input.

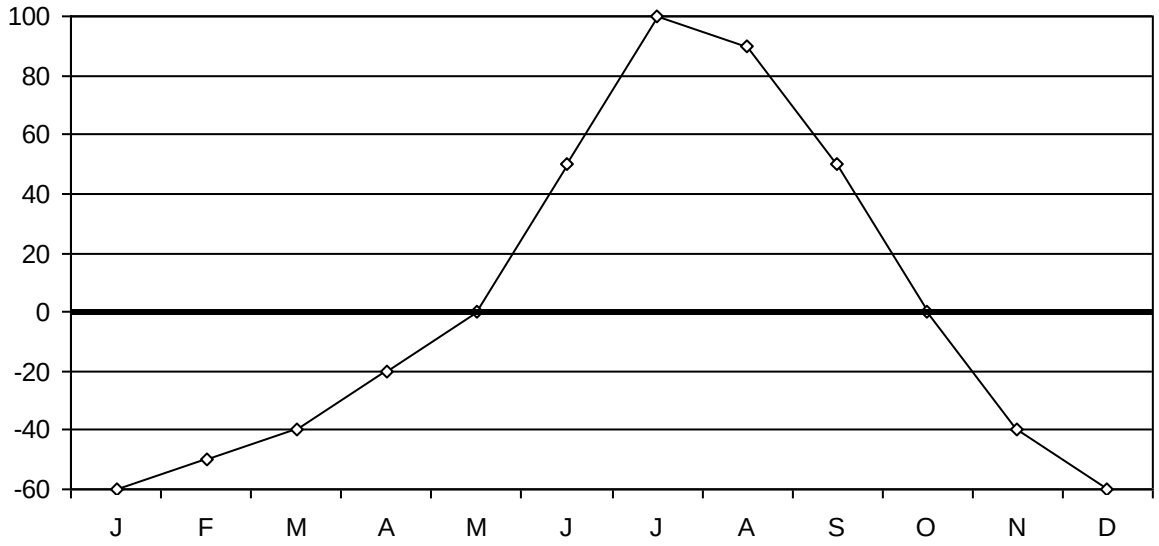


Figure IV-20. Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.

Sediment Nitrogen Release by Standard Core Approach: Sediment sampling was conducted throughout the main tidal channels of the salt marsh portions of the Barnstable Great Marsh estuary system as well as the open water main of the estuary. The distribution of cores was

established to cover gradients in sediment type, flow field and phytoplankton density. For each core the nitrogen flux rates (described in the section above) were evaluated relative to measured sediment organic carbon and nitrogen content, as well as sediment type and an analysis of each site's tidal flow velocities. As expected flow velocities are generally low in the uppermost reaches of the tidal creeks and high in the lower portions of the system situated closer to the inlet to the system. The maximum bottom water flow velocity at each coring site was determined from the hydrodynamic model. These data were then used to determine the nitrogen balance within each sub-embayment.

The magnitude of the settling of particulate organic carbon and nitrogen into the sediments was accomplished by determining the average depth of water within each sediment site, the average summer particulate carbon and nitrogen concentration within the overlying water and the tidal velocities from the hydrodynamic model (Section V). Generally two levels of settling are used. If the sediments were organic rich and fine grained, and the hydrodynamic data showed low tidal velocities, then a water column particle residence time of 8 days was used (based upon phytoplankton and particulate carbon studies of poorly flushed basins). If the sediments indicated coarse-grained sediments and low organic content and high velocities, then half this settling rate was used. However, in the relatively small areas of very high velocity near inlets or main tidal channels or areas of swept sands, a further reduction in deposition is applied. Adjusting the measured sediment releases was essential in order not to over-estimate the sediment nitrogen source and to account for those sediment areas which are net nitrogen sinks for the aquatic system. This approach has been previously validated in outer Cape Cod embayments (Town of Chatham embayments) by examining the relative fraction of the sediment carbon turnover (total sediment metabolism), which would be accounted for by daily particulate carbon settling. This analysis indicated that sediment metabolism in the highly organic rich sediments of the wetlands and depositional basins is driven primarily by stored organic matter (ca. 90%). Also, in the more open lower portions of larger embayments, storage appears to be low and a large proportion of the daily carbon requirement in summer is met by particle settling (approximately 33% to 67%). This range of values and their distribution is consistent with ecological theory and field data from shallow embayments. Additional, validation has been conducted on deep enclosed basins (with little freshwater inflow), where the fluxes can be determined by multiple methods. In this case the rate of sediment regeneration determined from incubations was comparable to that determined from whole system balance.

Net nitrogen release or uptake from the sediments within the Barnstable Great Marsh estuary system were comparable to other salt marsh dominated systems on Cape Cod with similar configurations and flushing rates (e.g. Wellfleet Harbor, Scorton Creek, Sandwich Harbor, Namskaket Marsh, Little Namskaket Marsh). The spatial distribution of nitrogen release/uptake by the sediments within the Barnstable Great Marsh estuary system showed a clear pattern associated with sediment type, water velocity and the associated depositional environments found within the component basins of the estuary. Net nitrogen release was highest (72.9 mg N m^{-2} d^{-1}) in the artificially deepened basins of Barnstable Harbor (millway) which is deepened for navigation which creates ideal conditions for deposition. The organic rich tidal marsh creeks showed low nitrogen release rates, 0.2 – 3.5 mg N m^{-2} d^{-1}, while the high velocity sandy areas in the central main basin of the Great Marshes and the inlet to Bass Hole supported net nitrogen uptake, -3.4 to -6.1 mg N m^{-2} d^{-1}. This pattern of sediment nitrogen release has been frequently observed in other salt marsh dominated systems assessed by the MEP. For example, the adjacent Scorton Creek Estuary showed net nitrogen release in the organic rich upper tidal reaches, 25.5 mg N m^{-2} d^{-1} to net uptake throughout the lower sandy tributary creeks to Long Hill and Scorton Shore, -19.9 and -12.7 mg N m^{-2} d^{-1}, respectively, with the high velocity larger tidal creeks with little organic matter accumulation showing low net uptake, -3.0 mg N m^{-2} d^{-1}. The

same pattern was observed in another Cape Cod Bay salt marsh, Namskaket Creek, where the upper marsh creeks also showed a net release, 45.4 mg N m^{-2} d^{-1}, and the lower creek areas net uptake, -21.2 mg N m^{-2} d^{-1}. Again in Little Namskaket Marsh, the upper marsh creeks showed a net release, 64.5 mg N m^{-2} d^{-1}, and the lower creek areas net uptake, -7.8 mg N m^{-2} d^{-1}.

Within the Barnstable Great Marsh estuary system rates of uptake were also similar to other salt marsh systems on Cape Cod with lower tide ranges than the 10 ft range in marshes tributary to Cape Cod Bay. For example, net nitrogen uptake in the high velocity sandy areas (-3.4 to -6.1 mg N m^{-2} d^{-1}) was similar to that observed for the salt marsh areas in the Centerville River System (-4.5 to -13.2 mg N m^{-1} d^{-1}) and Cockle Cove Salt Marsh, Chatham (MEP Centerville River Final Nutrient Technical Report 2006, MEP Cockle Cove Technical Memorandum-Howes et al. 2006) and the lower basin of the Little River marsh system (-3.1 mg N m^{-1} d^{-1}) on Buzzards Bay. The net release rates from the upper tidal reaches are similar and comparable to other systems. For example, the upper reaches of the Herring River wetland system (9.7-10.5 mg N m^{-1} d^{-1}), Wild Harbor River (1.4 mg N m^{-1} d^{-1}) and salt marsh dominated portions of the Back River (Bourne) and the Slocums and Little River Estuaries (Dartmouth) support similarly small net release rates of 6.5 mg N m^{-2} d^{-1} and 4.6-9.0 mg N m^{-2} d^{-1}, respectively.

Net nitrogen release rates for use in the water quality modeling effort for the component sub-basins of the Barnstable Great Marsh estuary system (Section VI) are presented in Table IV-7 There was a clear spatial pattern of sediment nitrogen flux, with net release from the sediments of the upper reach of the tidal creek and net uptake by the sediments of the lower tidal creek region. The magnitude and pattern of sediment nitrogen release with the Barnstable Great Marsh estuary system is consistent with the distribution of sediment types and deposition rates and is consistent with other similarly structured salt marsh dominated estuaries with low to moderate watershed nitrogen loading. Equally important, sediment processes appear to be in balance with the overlying waters and the nitrogen flux rates consistent with the low nitrogen loading to this system and it relatively high flushing rate.

Table IV-7. Rates of net nitrogen return from sediments to the overlying waters of component basins comprising the Barnstable Great Marsh estuary system. These values are combined with the basin areas to determine total nitrogen mass in the water quality model (Section VI). Measurements represent July -August rates.

Location	Sediment Nitrogen Flux (mg N m^{-2} d^{-1})			Station I.D. *
	Mean	S.E.	# sites	Sta-#
Barnstable Great Marsh estuary system				
Bass Hole Estuary				
Upper	**0.2**	**4.0**	**2**	**Bass 5-6**
Lower	**-6.1**	**1.4**	**4**	**Bass 1-4**
Barnstable Great Marshes				
Central Main Basin Upper	**-5.4**	**2.2**	**4**	**BH 9, 15-17**
Central Main Basin Lower	**-3.4**	**10.3**	**8**	**BH 18-22, 26-28**
Scorton Creek	**0.6**	**13.1**	**4**	**BH 1-4**
Spring Creek	**2.6**	**6.9**	**4**	**BH 5-8**
Brickyard Creek	**2.5**	**13.8**	**5**	**BH 10-14**
Barnstable Harbor	**72.9**	**31.1**	**5**	**BH 23-25**
Wharf Creek	**3.5**	**0.4**	**2**	**BH 29-30**
Lone Tree Creek	**2.8**	**5.1**	**4**	**BH 31-34**

* Station numbers refer to Figure IV-19.

V. HYDRODYNAMIC MODELING

V.1 INTRODUCTION

This hydrodynamic study was performed for Barnstable Harbor, located on the Cape Cod Bay facing shoreline of Barnstable and Yarmouth, Massachusetts to characterize flow and circulation into and out of the system and serves as the basis for nutrient related water quality modeling discussed in Section VI. Barnstable Harbor is the receiving basin of groundwater flow from the historic village of Barnstable, the county seat. A topographic map detail in Figure V-1 shows the general study area. As modeled, the system is comprised of a broad marsh plain called the "Great Marshes" (van der Molen, 1997) at the western end, the main harbor basin in the middle of the system, and another large area of salt marsh at the eastern end, named Chase Garden Creek, which includes the area referred to as Bass Hole. A portion of Chase Garden Creek lies within the Town of Dennis. The Great Marsh and Main Harbor basin are bound to the north by Sandy Neck which extends between the Sandwich town border and the Harbor inlet. The lowest elevations of the system exist in the main natural channel, where maximum depths of approximately -36 feet NAVD occur near the eastern tip of Sandy Neck. The surface coverage of the Barnstable Harbor and Chase Garden Creek together is more than 7,900 total acres, which includes more than 4,400 acres of marsh plain

Tidal exchange with Cape Cod Bay dominates circulation in the Harbor. From measurements made in the course of this study, the average offshore tide range is 10 feet. As the tide propagates through the marsh, its range is attenuated. At interior marsh creek gauge stations deployed for this study, the range was measured to be 6 feet. The reduction in the tide range is mostly due to a truncation of the lower half of the tide, which is caused by the elevation of the marsh creeks in the upper reaches of the marsh plain of the Harbor.

The hydrodynamic study of the Barnstable Harbor and Chase Garden Creek system proceeded as two main efforts that dealt with data collection and development of the hydrodynamic model. In the first portion of the study, bathymetry and tide data were collected in order to accurately characterize the physical system, and to provide data necessary for the modeling portion of the study. The bathymetry survey of Barnstable Harbor and Chase Garden Creek was performed to determine the variation of depths throughout the main sub-embayment areas of the system. This survey addressed the previous lack of adequate bathymetry data for these areas. In addition to the bathymetry survey, tides were recorded at five stations within the Harbor system for 31 days. These tide data were necessary to run and calibrate the hydrodynamic model of the system.

A numerical hydrodynamic model of Barnstable Harbor and its attached sub-embayments was developed in the second portion of this study. Using the bathymetry survey data, a model grid mesh was generated for use with the RMA-2 hydrodynamic code. The tide data from Cape Cod Bay were used to define the open boundary condition that drives the circulation of the model. Data measured within the system were used to calibrate and verify model performance to ensure that it accurately represents the dynamics of the real, physical system.

The calibrated hydrodynamic model of Barnstable Harbor is an integral piece of the water quality model developed in Section 6 this MEP nutrient threshold report. In addition to its use as the hydrodynamic basis for the TN and salinity models, the calibrated hydrodynamic model is a useful tool that can be used to investigate the tidal properties of the system.

V.2 DATA COLLECTION AND ANALYSIS

The field data collection portion of this study was performed to characterize the physical properties of Barnstable Harbor. Bathymetry data were collected throughout the system so that it could be accurately represented as a computer hydrodynamic model and flushing rates could be determined for the system. In addition to the bathymetry, tide data were also collected throughout the Harbor in order to run the circulation model with real tides, and also to calibrate and verify model performance.



Figure V-1. Topographic map detail of Barnstable Harbor and Chase Garden Creek.

V.2.1 Bathymetry Data

Bathymetric data was collected in the Harbor (including the main marsh creeks) during the summer of 2015. The survey employed a boat-mounted fathometer. Positioning data were collected using a differential GPS. Where practical, predetermined survey transects were followed at regular intervals. Collected bathymetry data was tide-corrected to account for the change in water depths as the tide level changed over the survey period. The tide-correction is performed using tide data collected while the survey was run. For the broad areas of tide flats and marsh plain not covered in the boat survey, elevation data were available from a 2013 USGS LiDAR flight of the area. The complied elevation dataset, including all sources of bathymetry and topography, is shown in Figure V-2.

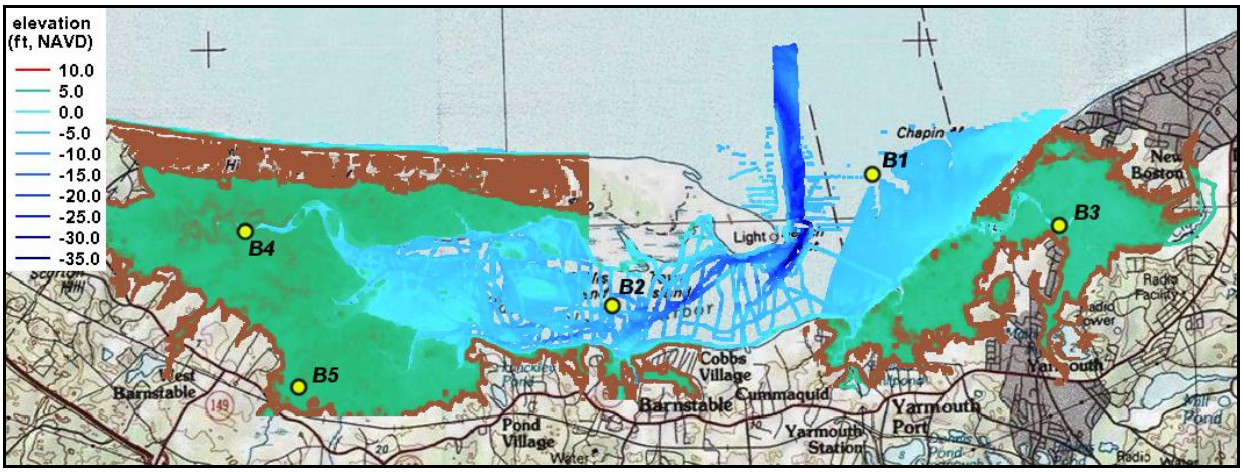


Figure V-2. Bathymetric and topography data used to develop the RMA-2 hydrodynamic model. Points are colored to represent the elevation relative to NAVD. The data sources used to develop the grid mesh are the 2015 bathymetry survey conducted by the MEP Technical Team and USGS 2013 LiDAR topography. Location of tide gauges are also indicated.

V.2.2 Tide Data Collection and Analysis

Tide data records were collected concurrently at five gauging stations shown in Figure V-2, located at the harbor opening to Cape Cod Bay (B1), in the main basin of the harbor (B2), at Chase Garden Creek (B3), in Scorton Creek Cove (B4) and in Bridge Creek (B5). The Temperature Depth Recorders (TDR) used to record the tide data were deployed for a 51-day period between June 16 and August 6, 2015. The elevation of each gauge was surveyed relative to the NAVD vertical datum. The Cape Cod Bay tide record was used as the open boundary condition of the hydrodynamic model. Data from inside the system were used to calibrate the model. In July, the Bridge Creek gauge (B5) was discovered to have been moved at the end of June, 19 days after its initial deployment. The gauge was redeployed on July 22.

Tide records longer than 29 days are necessary for a complete evaluation of tidal dynamics within the estuarine system. Although a one-month record likely does not include extreme high or low tides, it does provide an accurate basis for typical tidal conditions governed by both lunar and solar motion. For numerical modeling of hydrodynamics, the typical tide conditions associated with a one-month record are appropriate for driving tidal flows within the estuarine system.

Plots of the tide data from the five gauges are shown in Figure V-3 for a 48-day period during the gauge deployment. The spring-to-neap variation in tide range is easily recognizable in these plots. The data record begins during a transitional period from spring to neap tides. The first quarter moon occurs June 24, during the first period of diminished neap tides. After this, there is a period of spring tides around July 3, which occurs around the time of the new moon of July 1. The minimum neap tide range in the offshore record is 2.0 feet (July 24), while the maximum spring tide rage (occurring about a week earlier) is 13.4 feet (August 1).

A visual comparison between tide elevations offshore and at the different stations in the system shows that the tide amplitude in the upper reaches is controlled by the bottom elevation of these areas (Figure V-4). There is only a minor reduction of the water elevation at times of high tide (about 5 inches) between the offshore and inshore areas. Low tide elevations are

highest at the Bridge Creek gauge, where the marsh creek channel bottom controls the minimum water levels. At Bridge Creek the low tide elevation during spring tides can be nearly 4 feet higher than offshore in Cape Cod Bay.

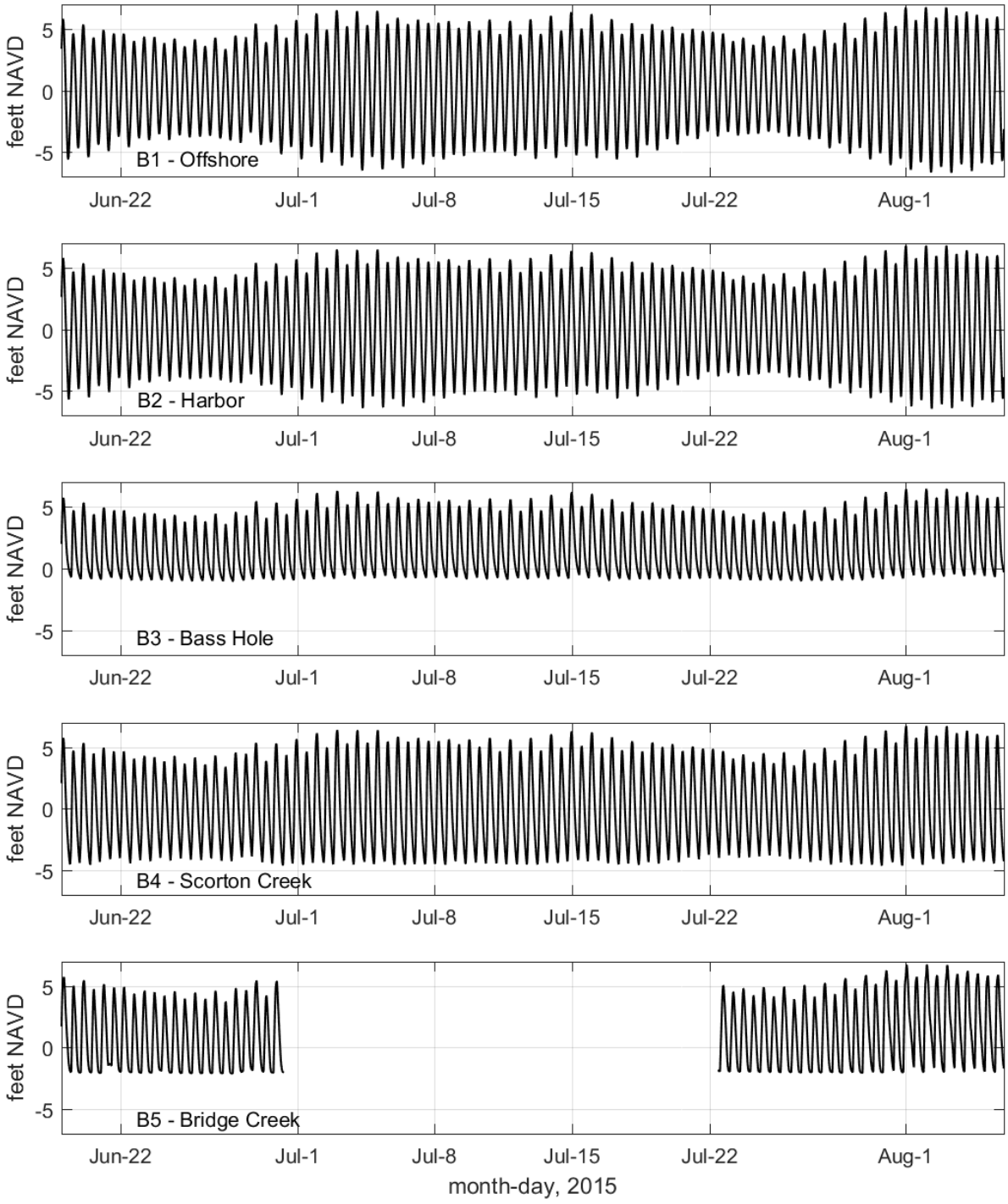


Figure V-3. Plots of observed tides for stations in Barnstable Harbor, for the 48-day period between June 19 and August 6, 2015. All water levels are referenced to the NAVD vertical datum.

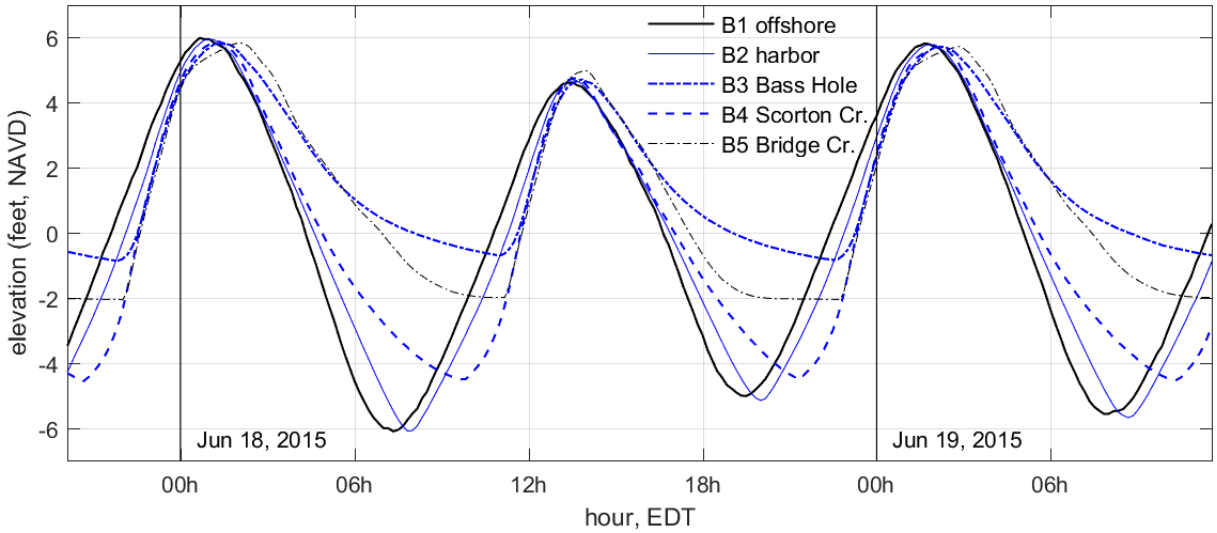


Figure V-4. Four-day tide plot showing tides measured in Cape Cod Bay and at stations in the Barnstable Great Marsh estuary system.

V.2.2.1 Tide Datums

To better quantify the changes to the tide from the inlet to inside the system, the standard tide datums were computed from a 30-day subset of the tide records. These datums are presented in Table V-1. For most NOAA tide stations, these datums are computed using 19 years of tide data, the definition of a tidal epoch. For this study, a significantly shorter time span of data was available; however, these datums still provide a useful comparison of tidal dynamics within the system. The Mean Higher High (MHH) and Mean Lower Low (MLL) levels represent the mean of the daily highest and lowest water levels. The Mean High Water (MHW) and Mean Low Water (MLW) levels represent the mean of all the high and low tides of a record, respectively. The Mean Tide Level (MTL) is simply the mean of MHW and MLW.

Tidal damping in the upper reaches of the Harbor system is seen by the elevated levels of the low water datums, as presented in Table V-1. For example, MLW at the Bridge Creek station is more than four feet higher than it is in the main basin of the Harbor. Though the tide range is truncated in in the marsh channels, the tidal flows are conveyed across the marsh very efficiently, as can be seen by the small amount of different in elevation of high tide at all gauging stations. This is the case even at the Bridge Creek gauging station which is nearly two miles from the open water of the Harbor, where MHW is the same as it is offshore.

V.2.2.2 Tide Harmonic Analysis

A more thorough harmonic analysis of the tidal time series was also performed to produce tidal amplitude and phase of the major tidal constituents, and provide assessments of hydrodynamic ‘efficiency’ of the system in terms of tidal attenuation. This analysis also yielded an assessment of the relative influence of non-tidal, or residual, processes (such as wind forcing) on the hydrodynamic characteristics of each system.

A harmonic analysis was performed on the time series from each gauge location. Harmonic analysis is a mathematical procedure that fits sinusoidal functions of known frequency to the measured signal. The observed astronomical tide is the sum of several individual tidal

constituents, with a particular amplitude and frequency. For demonstration purposes a graphical example of how these constituents add together is shown in Figure V-5. In this case, the amplitudes and phase of 21 known tidal constituents were computed. Table V-2 presents the amplitudes of eight tidal constituents computed for the Barnstable Harbor station records. The M_2, or the familiar twice-a-day lunar semi-diurnal tide, is the strongest contributor to the signal with an offshore amplitude of 4.7 feet. The total range of the M_2 tide is twice the amplitude, or 10.4 feet.

Table V-1. Tide datums computed from 50-day records collected offshore and in the Barnstable Great Marsh estuary system in June, July and August 2015. Datum elevations are given relative to NAVD vertical datum.

Tide Datum	Cape Cod Bay	Harbor	Bass Hole	Scorton Creek	Bridge Cr.
Maximum Tide	6.7	6.8	6.7	6.7	6.5
MHHW	5.5	5.5	5.4	5.4	5.4
MHW	5.1	5.1	5.1	5.1	5.1
MTL	0.1	0.1	1.6	0.4	2.2
MLW	-4.9	-4.9	-1.9	-4.3	-0.7
MLLW	-5.1	-5.2	-2.0	-4.4	-0.9
Minimum Tide	-6.7	-6.4	-2.1	-4.6	-1.0
Mean Range	9.9	10.0	7.0	9.4	5.8

The diurnal constituents (once daily), K_1 and O_1, have amplitudes of approximately 0.5 feet and 0.3 respectively. Other semi-diurnal tides, the S_2 (12.00 hour period), N_2 (12.66-hour period) and L_2 (12.19-hour period) tides, also contribute to the total tide signal, with amplitudes of 0.6 feet, 0.9 feet and 0.2 feet, respectively.

The M_4 and M_6 tides are higher frequency harmonics of the M_2 lunar tide (exactly half the period of the M_2 for the M_4, and one third of the M_2 period for the M_6) and result from frictional attenuation of the M_2 tide in shallow water. While the main diurnal and semi-diurnal constituents tend to decrease in the system, the M_4 is seen to increase by 0.7 feet between Cape Cod Bay and Scorton Creek as energy is transferred from the M_2 to its harmonics. Generally, it can be seen that as the total tide range is attenuated through the system there is a corresponding reduction in the amplitude of the individual tide constituents.

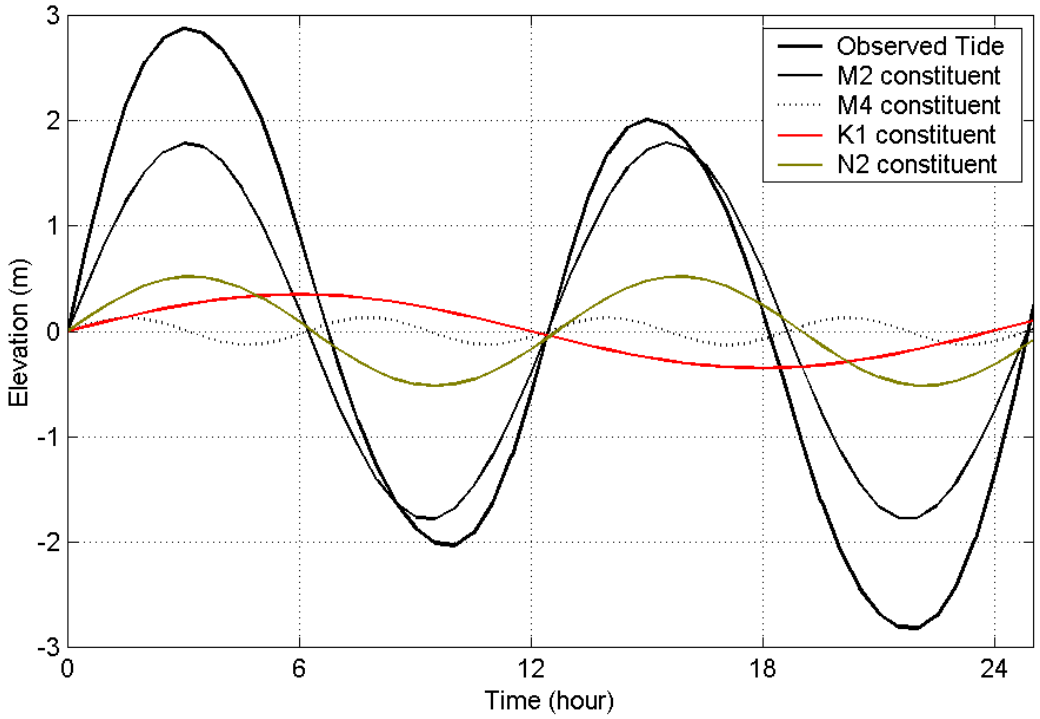


Figure V-5. Example of an observed astronomical tide as the sum of its primary constituents.

Table V-2. Tidal Constituents computed for tide stations in the Barnstable Great Marsh estuary system and offshore in Cape Cod Bay, June, July and August 2015. Constituents for Bridge Creek rely on data from August September 2015, due to the gauge failure in July

	Amplitude (feet)							
Constituent	M_2	M_4	M_6	K_1	N_2	S_2	O_1	L_2
Period (hours)	12.42	6.21	4.14	23.93	12.66	12.00	25.82	12.19
Cape Cod Bay	4.72	0.10	0.18	0.51	0.89	0.55	0.32	0.15
Harbor	4.59	0.29	0.24	0.49	0.83	0.51	0.32	0.16
Bass Hole	2.66	0.84	0.24	0.36	0.39	0.25	0.34	0.17
Scorton Creek	4.31	0.86	0.11	0.44	0.69	0.41	0.34	0.25
Bridge Creek	3.36	0.72	0.21	0.33	0.62	0.36	0.41	0.45

Together with the change in constituent amplitude across Harbor, the phase change of the tide is easily seen from the results of the harmonic analysis. Table V-3 shows the delay of the M_2 at different points in the Barnstable Great Marsh estuary system, relative to the timing of the M_2 constituent in Cape Cod Bay, at the harbor entrance. The largest delay occurs at the Bridge Creek station, where the M_2 phase is offset by one hour.

In addition to the tidal analysis, the data were further evaluated to determine the importance of tidal versus non-tidal processes to changes in water surface elevation. These other processes include wind forcing (set-up or set-down) within the estuary, as well as sub-tidal oscillations of the sea surface. Variations in water surface elevation can also be affected by freshwater discharge into the system, if these volumes are relatively large compared to tidal flow.

The results of an analysis to determine the energy distribution (or variance) of the measured water elevation records for the gauge records in Barnstable Harbor compared to the energy content of the astronomical tidal signal (re-created by summing the contributions from the 21 constituents determined by the harmonic analysis) is presented in Table V-4. Subtracting the tidal signal from the original elevation time series resulted in the non-tidal, or residual, portion of the water elevation changes. The energy of this non-tidal signal is compared to the tidal signal, and yields a quantitative measure of how important these non-tidal physical processes can be to hydrodynamic circulation within the estuary. Figure V-6 shows the comparison of the measured tide from Cape Cod Bay, with the computed astronomical tide resulting from the harmonic analysis, and the resulting non-tidal residual.

Table V-4 shows that the variance of tidal energy was largest in the offshore signal, as should be expected. The analysis also shows that tides are responsible for nearly 100% of the water level changes in Cape Cod Bay and all of Barnstable Harbor for the gauge deployment period. This indicates that the hydrodynamics of the system is influenced predominantly by astronomical tides. The non-tidal residual is largest by percentage in the Bridge Creek, where the non-tidal component is 5% of the total variance of the observed water level changes.

Table V-3. M_2 tidal constituent phase delay (relative to the Cape Cod Bay station) for gauge locations in the Barnstable Great Marsh estuary system, determined from measured tide data.

Station	Delay (minutes)
Harbor	18.0
Bass Hole	47.1
Scorton Creek	45.6
Bridge Creek	58.0

Table V-4. Percentages of Tidal versus Non-Tidal Energy for stations in the Barnstable Great Marsh estuary system and Cape Cod Bay, June, July and August, 2015.

TDR Location	Total Variance (ft^2)	Tidal (%)	Non-tidal (%)
Cape Cod Bay	11.7	100.0	0.0
Harbor	11.1	99.5	0.5
Bass Hole	4.2	96.6	3.4
Scorton Creek	10.1	99.0	1.0
Bridge Creek	6.6	94.7	5.3

V.2.2.3 Tide Flood and Ebb Dominance

An investigation of the flood or ebb dominance of different areas in the Barnstable Great Marsh estuary system was performed using the measured tide data. Estuaries and sub-embayments that are flood dominant are typically areas that collect sediment over time since they have maximum flood tide velocities that are greater than the maximum velocities that occur during the ebb portion of the tide. Salt marshes tend to be flood dominant, as this condition allows them to collect material that is required to maintain healthy marsh resources.

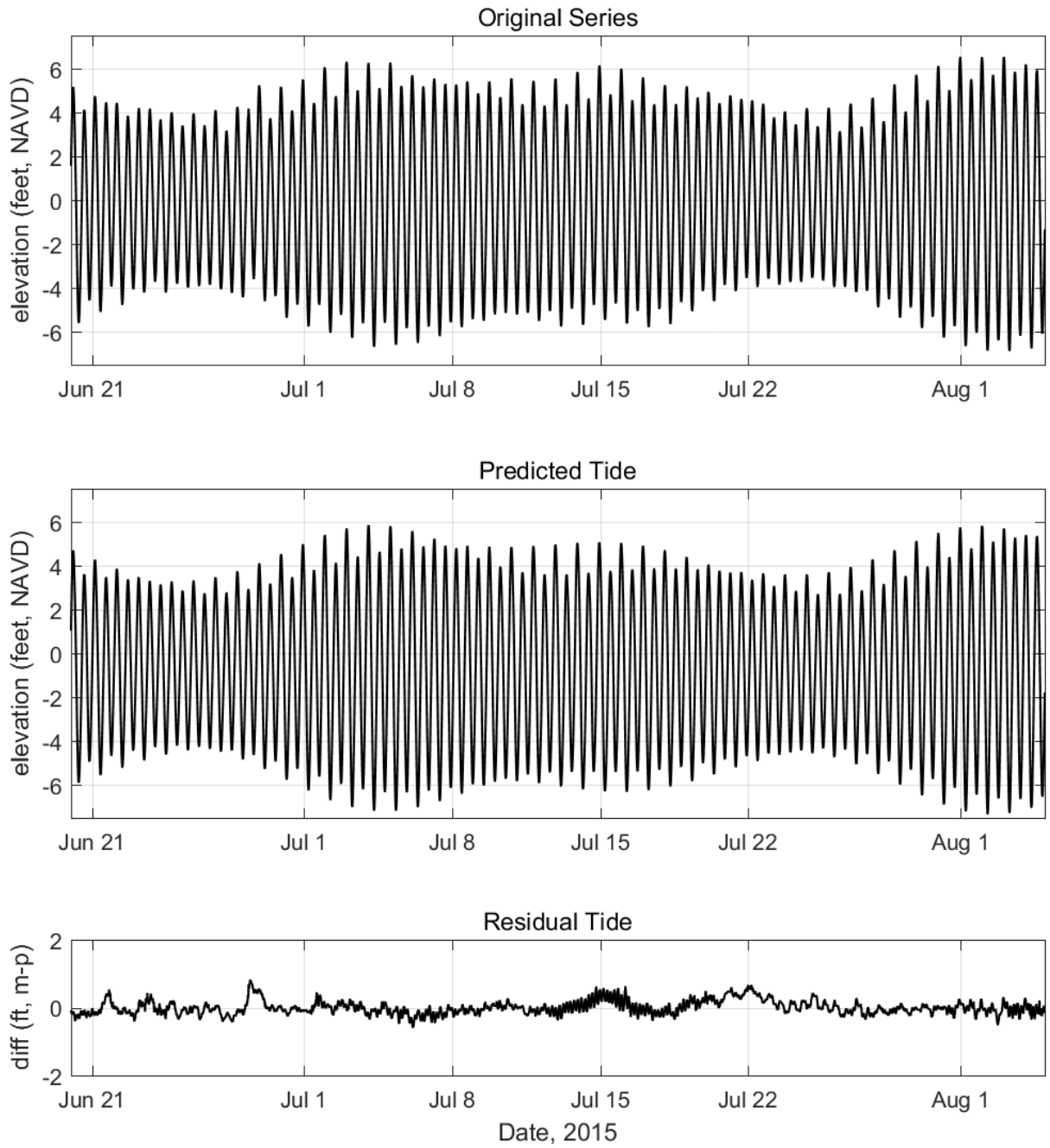


Figure V-6. Plot showing the comparison between the measured tide time series (top plot), and the predicted astronomical tide (middle plot) computed using the 21 individual tide constituents determine in the harmonic analysis of the Cape Cod Bay gauge data, collected offshore Barnstable Harbor. The residual tide shown in the bottom plot is computed as the difference between the measured and predicted time series (r=m-p).

Flood or ebb dominance in channels of a tidal system can be determined by utilizing the results of the harmonic analysis of tidal elevations, or by performing a similar analysis on a time series of tidal currents. A discussion of the method of relative phase determination is presented in Friedrichs and Aubrey (1988). For this method, the same M_2 and M_4 tidal constituents presented in Table V-2 were used as the basis of this analysis.

For constituents based on tidal elevations, the relative phase difference is computed as the difference between two times, the M_2 phase and the phase of the M_4, expressed as $\Phi=2M_2-M_4$. If Φ is between 0 and 180 degrees ($0<\Phi<180$), then the channel is characterized as being flood dominant, and peak flood velocities will be greater than for peak ebb. Alternately, if Φ were between 180 and 360 degrees ($180<\Phi<360$), then the channel would be ebb dominant. If Φ is exactly 0 or 180 degrees, neither flood nor ebb dominance occurs. For Φ equal to exactly 90 or 270 degrees, maximum tidal distortion occurs and the velocity residuals of a channel are greatest. This relative phase relationship is presented graphically in Figure V-7.

Though this method of tidal constituent analysis provides similar results to a visual inspection of a tidal record (e.g., by comparing peak ebb and flood velocities), it allows a more exact characterization of the tidal processes. By this analysis technique, a channel can be characterized as being strongly, moderately, or weakly flood or ebb dominant.

The five gauge stations in the harbor were used for this analysis. These data make it possible to characterize the flood or ebb dominance of different areas of the system from offshore (W-1 in Cape Cod Bay) through to the upper reaches of the main tidal creeks (e.g., W-4, upstream of Uncle Tim's Bridge). The results of this velocity analysis of the Barnstable Harbor measured tide data show that although the offshore gauge is ebb dominant, all interior gauge stations indicate flood dominance. The computed values of $2M_2-M_4$ are presented in Table V-5.

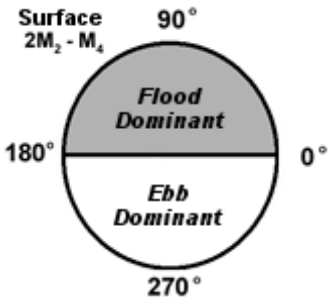


Figure V-7. Relative velocity phase relationship of M2 and M4 tidal elevation constituents and characteristic dominance, indicated on the unit circle. Relative phase is computed as the difference of two times the M2 phase and the M4 phase (2M2-M4). A relative phase of exactly 90 or 270 degrees indicates a symmetric tide, which is neither flood nor ebb dominant.

Table V-5. Barnstable Harbor relative tidal phase differences of M_2 and M_4 tide constituents, determined using tide elevation record records.

location	$2M_2-M_4$ relative phase (deg)	Characteristic dominance
Cape Cod Bay, B1	209.5	moderate ebb
Harbor basin, B2	86.4	strong flood
Bass Hole, B3	49.3	moderate flood
Scorton Creek, B4	69.1	moderate flood
Bridge Creek, B5	52.0	moderate flood

V.3 HYDRODYNAMIC MODELING

For the modeling of the Barnstable Great Marsh estuary system, MEP Technical Team members from Applied Coastal Research and Engineering (ACRE) utilized a hydrodynamic computer model to evaluate tidal circulation and flushing in the Harbor. The particular model

employed was the RMA-2 model developed by Resource Management Associates (King, 1990). It is a two-dimensional, depth-averaged finite element model, capable of simulating transient hydrodynamics. The model is widely accepted and tested for analyses of estuaries or rivers. Applied Coastal staff members have utilized RMA-2 for numerous flushing studies on Cape Cod under the MEP umbrella, including Sandwich Harbor, Wellfleet Harbor, Popponesset Bay, Nantucket Harbor, Falmouth "finger" Ponds (Howes *et al*, 2005), Three Bays (Kelley *et al*, 2003) and Barnstable Harbor (Wood, *et al*, 1999).

V.3.1 Model Theory

In its original form, RMA-2 was developed by William Norton and Ian King under contract with the U.S. Army Corps of Engineers (Norton et al., 1973). Further development included the introduction of one-dimensional elements, state-of-the-art pre- and post-processing data programs, and the use of elements with curved borders. Recently, the graphic pre- and post-processing routines were updated by Brigham Young University through a package called the Surfacewater Modeling System or SMS (BYU, 1998). Graphics generated in support of this report primarily were generated within the SMS modeling package.

RMA-2 is a finite element model designed for simulating one- and two-dimensional depth-averaged hydrodynamic systems. The dependent variables are velocity and water depth, and the equations solved are the depth-averaged Navier Stokes equations. Reynolds assumptions are incorporated as an eddy viscosity effect to represent turbulent energy losses. Other terms in the governing equations permit friction losses (approximated either by a Chezy or Manning formulation) for Coriolis effects and surface wind stresses. All the coefficients associated with these terms may vary from element to element. The model utilizes quadrilaterals and triangles to represent the prototypical system. Element boundaries may either be curved or straight.

The time dependence of the governing equations is incorporated within the solution technique needed to solve the set of simultaneous equations. This technique is implicit; therefore, unconditionally stable. Once the equations are solved, corrections to the initial estimate of velocity and water elevation are employed, and the equations are re-solved until the convergence criteria is met.

V.3.2 Model Setup

There are three main steps required to implement RMA-2:

- Grid generation
- Boundary condition specification
- Calibration

The extent of each finite element grid was generated using 2009 and 2014 digital aerial photographs from the MassGIS online orthophoto database. A time-varying water surface elevation boundary condition (measured tide) was specified at the entrance of the Barnstable Harbor grid based on the tide gauge data collected offshore in Cape Cod Bay. Once the grid and boundary conditions were set, the model was calibrated to ensure accurate predictions of tidal flushing. Various friction and eddy viscosity coefficients were adjusted, through several model calibration simulations for the system, to obtain agreement between measured and modeled tides. The calibrated model provides the requisite information for future detailed water quality modeling.

V.3.2.1 Grid generation

The grid generation process was aided by the use of the SMS package. Digital aerial orthophotos, the summer 2015 bathymetry survey data, and available 2013 LiDAR topography were imported to SMS, and a finite element grid was generated to represent the estuary. The aerial photograph was used to determine the land boundary of the system, as well as determine the surface coverage of salt marsh. The bathymetry and topography data were interpolated to the developed finite element mesh of the system. The completed grid consists of 19,920 nodes, which describe 7,885 total 2-dimensional (depth averaged) quadratic elements. The maximum nodal depth is -36ft (NGVD) in the natural channel of the harbor. The completed grid mesh of the Barnstable Great Marsh estuary system is shown in Figure V-8.

The finite element grid for the system provides the detail necessary to accurately evaluate the variation in hydrodynamic properties of Barnstable Harbor. Areas of marsh were included in the model. The SMS grid generation program was used to develop quadrilateral and triangular two-dimensional elements throughout the estuary. Grid resolution is generally governed by two factors: 1) expected flow patterns, and 2) the bathymetric variability of the system. Relatively fine grid resolution is employed where complex flow patterns are expected, generally near the inlet. Appropriate implementation of wider node spacing and larger elements reduces computer run time with no sacrifice of accuracy.

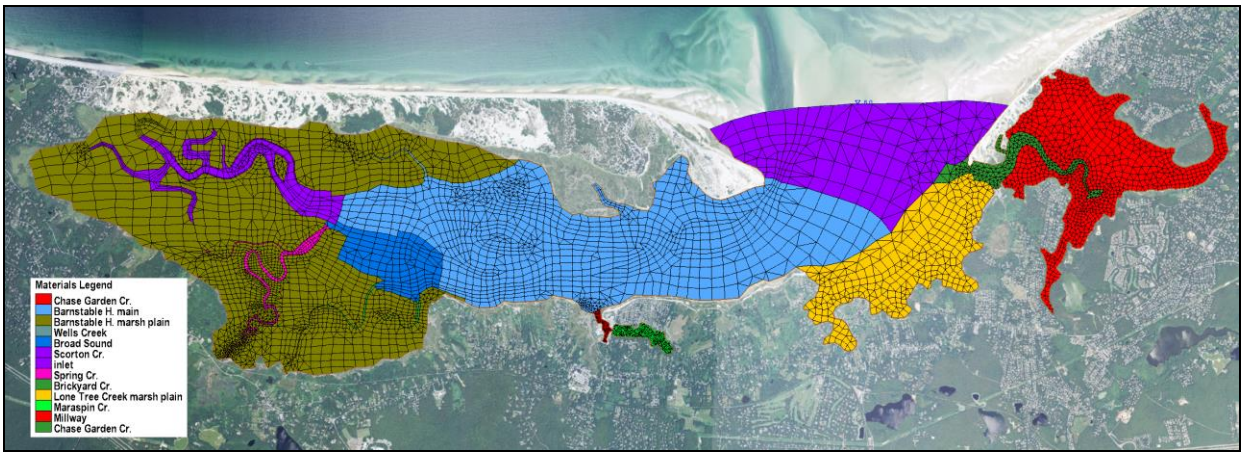


Figure V-8. Plot of hydrodynamic model grid mesh for Barnstable Harbor. Colors are used to designate the different model material types used to vary model calibration parameters and compute flushing rates.

V.3.2.2 Boundary condition specification

Three types of boundary conditions were employed for the RMA-2 model of the Barnstable Great Marsh estuary system: 1) "slip" boundaries, 2) tidal elevation boundaries, and 3) constant flow input boundaries. All of the elements with land borders have "slip" boundary conditions, where the direction of flow was constrained shore-parallel. The model generated all internal boundary conditions from the governing conservation equations. A tidal boundary condition was specified using the data collected at the offshore gauge station. TDR measurements provided the required data. The rise and fall of the tide in the Bay is the primary driving force for estuarine circulation in this system. Dynamic (time-varying) model simulations specified a new water surface elevation at the open boundary of the Barnstable Harbor grid every model time step. The model runs of the Harbor used a 10-minute time step, which the same as the 10-minute

sampling rate of the measured tide data. Details concerning the constant flow input boundary conditions included in the hydro model are discussed in Section VI.

V.3.2.3 Calibration

After developing the finite element grids, and specifying boundary conditions, the model for the Barnstable Great Marsh estuary system was calibrated. The calibration procedure ensures that the model accurately predicts what was observed in nature during the field measurement program. Numerous model simulations are typically required for an estuary model, specifying a range of friction and eddy viscosity coefficients, to calibrate the model.

Calibration of the hydrodynamic model required a close match between the modeled and measured tides from stations inside the system (i.e., from the TDR deployments). Initially, the model was calibrated to obtain visual agreement between modeled and measured tides.

Once visual agreement was achieved, a 14.5-day period (28 tide cycles) was modeled to calibrate the model based on dominant tidal constituents discussed in Section V.2. The half-lunar-month period was extracted from a longer simulation to avoid effects of model spin-up, and to focus on average tidal conditions. Modeled tides for the calibration time period were evaluated for time (phase) lag and height damping of dominant tidal constituents. The calibration was performed for the 14.5-day period beginning July 22, 2015 at 0430 EDT.

After the model was calibrated, an additional model run was made in order corroborate the model performance in a time period outside of the calibration period. The model corroboration run period is 10-days long and begins June 20, 2015 at 0300 EDT.

The completed model was used to analyze existing detailed flow patterns and compute residence times. The flushing analysis used the model calibration period. The ability to model a range of flow conditions is a primary advantage of a numerical tidal flushing model. For instance, average residence times were computed over the entire seven-day simulation. Other methods, such as dye and salinity studies, evaluate tidal flushing over relatively short time periods (less than one day). These short-term measurement techniques may not be representative of average conditions due to the influence of unique, short-lived atmospheric events.

V.3.2.3.a Friction coefficients

Friction inhibits flow along the bottom of estuary channels or other flow regions where velocities are relatively high. Friction is a measure of the channel roughness, and can cause both significant amplitude damping and phase delay of the tidal signal. Friction is approximated in RMA-2 as a Manning coefficient, and is applied to grid areas by user specified material types. Initially, a Manning's friction coefficient value of 0.020 was specified for all element material types. These values correspond to typical Manning's coefficients determined experimentally in smooth earth-lined channels with no weeds (low friction) to winding channels and marsh plains with higher friction (Henderson, 1966).

To improve model accuracy, friction coefficients were varied throughout the model domain. First, the Manning’s coefficients were matched to bottom type. For example, lower friction coefficients were specified for the main marsh creeks, versus the extensive marsh plain areas of the Harbor, which provide greater flow resistance by the presence of marsh vegetation. Final model calibration runs incorporated various specific values for Manning's friction coefficients,

depending upon flow damping characteristics of separate regions within each estuary. Manning's values for different bottom types were initially selected based on ranges provided by the available engineering references (Chow, 1959). Values were incrementally changed as appropriate to obtain a close match between measured and modeled tides. Final calibrated friction coefficients are summarized in the Table V-6.

Table V-6. Manning's Roughness and eddy viscosity coefficients used in simulations of the Barnstable Great Marsh estuary system. These embayment delineations correspond to the material type areas shown in Figure V-9.

System Embayment	bottom friction	eddy viscosity lb-sec/ft^2
Harbor Inlet	0.02	200
Great Marshes creeks	0.03	80
Great Marshes marsh plain	0.05	80
Millway	0.02	80
Chase Garden Creek	0.03	80
Chase Garden Greek marsh plain	0.07	80
Lone Tree marsh creek plain	0.07	100
Maraspin creek marsh plain	0.07	100

V.3.2.3.b Turbulent exchange coefficients

Turbulent exchange coefficients approximate energy losses due to internal friction between fluid particles. The significance of turbulent energy losses increases where flow is swifter, such as inlets and bridge constrictions. According to King (1990), these values are proportional to element dimensions (numerical effects) and flow velocities (physics). In most cases, the modeled systems were relatively insensitive to turbulent exchange coefficients because there were no regions of strong turbulent flow. Typically, model turbulence coefficients were set between 80 and 100 lb-sec/ft^2 (Table V-6). A higher value was used in the inlet region.

V.3.2.3.c Marsh porosity processes

Modeled hydrodynamics were complicated by wetting/drying cycles on the marsh plain included in the model of the Barnstable Harbor/Chase Garden Creek system. Cyclically wet/dry areas of the marsh will tend to store waters as the tide begins to ebb and then slowly release water as the water level drops within the creeks and channels. This store-and-release characteristic of these marsh regions was partially responsible for the distortion of the tidal signal and the elongation of the ebb phase of the tide. On the flood phase, water rises within the channels and creeks initially until water surface elevation reaches the marsh plain, when at this point the water level remains nearly constant as water 'fans' out over the marsh surface. The rapid flooding of the marsh surface corresponds to a flattening out of the tide curve approaching high water. Marsh porosity is a feature of the RMA-2 model that permits the modeling of hydrodynamics in marshes and tide flats. This model feature essentially simulates the store-and-release capability of the marsh plain by allowing grid elements to transition gradually between wet and dry states. This technique allows RMA-2 to change the ability of an element to hold water, similar to a sponge.

V.3.2.3.d Comparison of modeled tides and measured tide data

A best-fit of model output for the measured data was achieved using the aforementioned values for friction and turbulent exchange. Figures V-9 through V-13 illustrate sections of the 8-day simulation periods for the calibration model. Modeled (solid line) and measured (dotted line) tides are illustrated at each model location with a corresponding TDR.

Although visual calibration achieved reasonable modeled tidal hydrodynamics, further tidal constituent calibration was required to quantify the accuracy of the models. Calibration of the M_2 harmonic was the highest priority since M_2 accounted for a majority of the forcing tide energy throughout the system. Four tidal constituents were selected for constituent comparison: the K_1, M_2, M_4 and M_6. After calibrating the model, its performance was further corroborated by running the model for an additional verification time period (August 17 through August 24, 2008).

Measured tidal constituent amplitudes are shown in Table V-7 for the calibration and Table V-9 for the verification simulation. The constituent amplitudes shown in this table differ from those in Table V-2 because constituents were computed for only the separate 7-day sub-sections of the month-long period represented in Table V-2. In Tables V-8 and V-10, error statistics are shown for the calibration and verification.

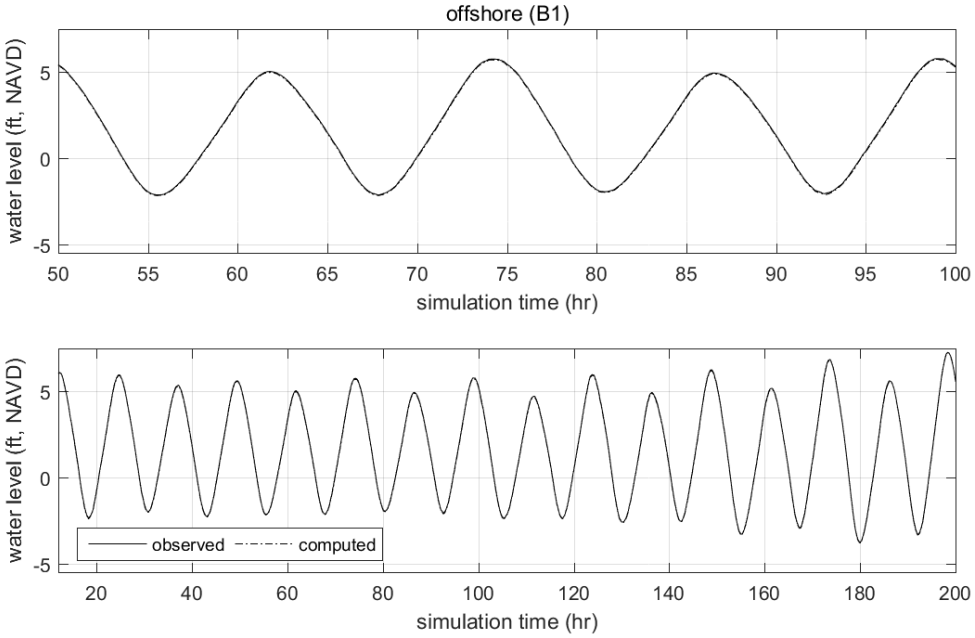


Figure V-9. Comparison of model output and measured tides for the offshore TDR station for the calibration model run (July 21, 2015 at 1600 EDT). The top plot is a 50-hour sub-section of the longer segment of the total modeled time period shown in the bottom plot.

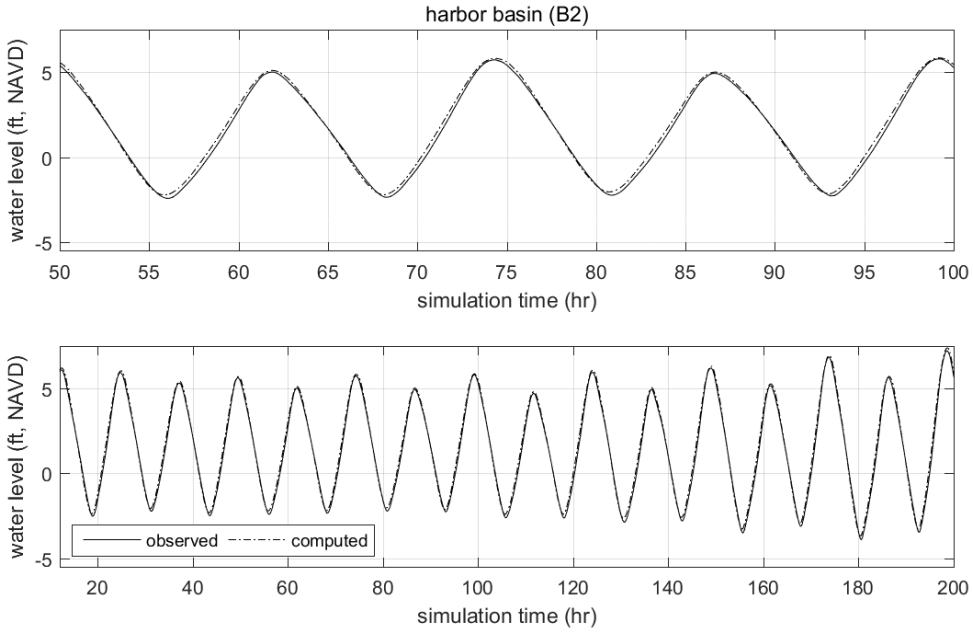


Figure V-10. Comparison of model output and measured tides for the TDR at the main harbor basin station (B2) for the calibration model run (July 21, 2015 at 1600 EDT). The top plot is a 50-hour sub-section of the longer segment of the total modeled time period shown in the bottom plot.

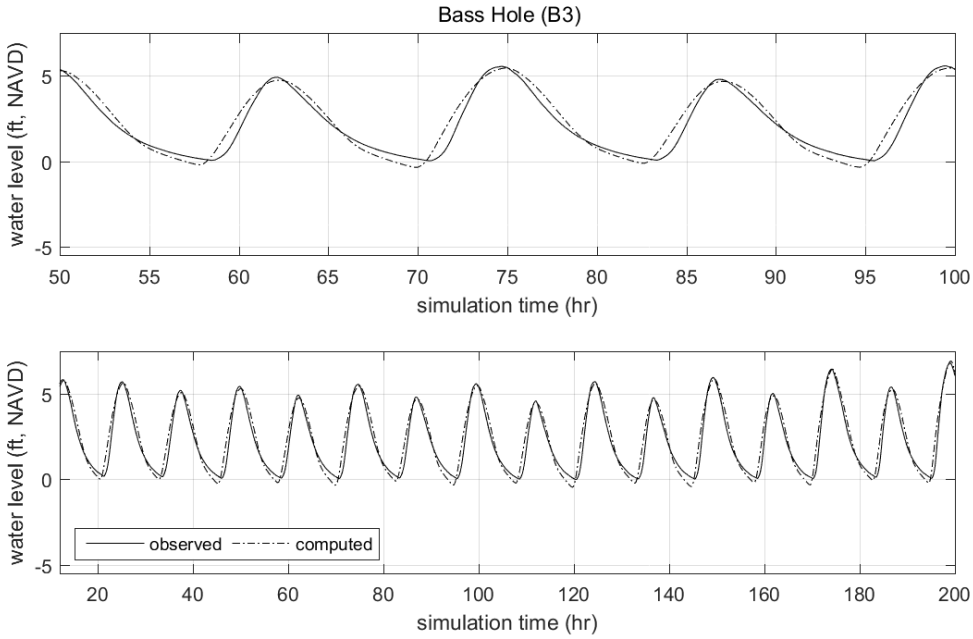


Figure V-11. Comparison of model output and measured tides for the Bass Hole TDR location (B3) for the final calibration model run (July 21, 2015 at 1600 EDT). The top plot is a 50-hour sub-section of the longer segment of the total modeled time period shown in the bottom plot.

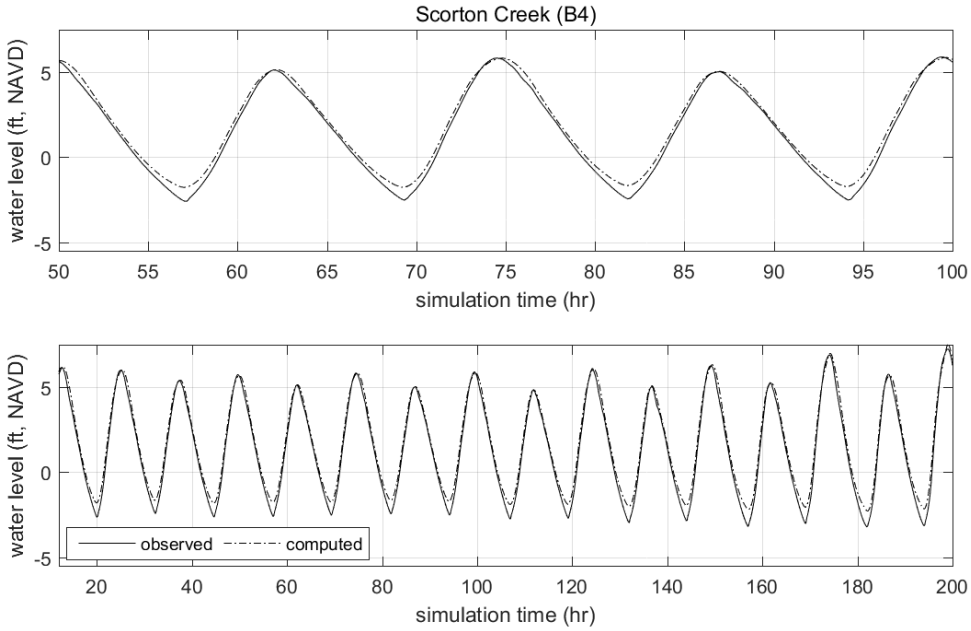


Figure V-12. Comparison of model output and measured tides for the Scorton Creek TDR station (B4) for the final calibration model run (July 21, 2015 at 1600 EDT). The top plot is a 50-hour sub-section of the longer segment of the total modeled time period shown in the bottom plot.

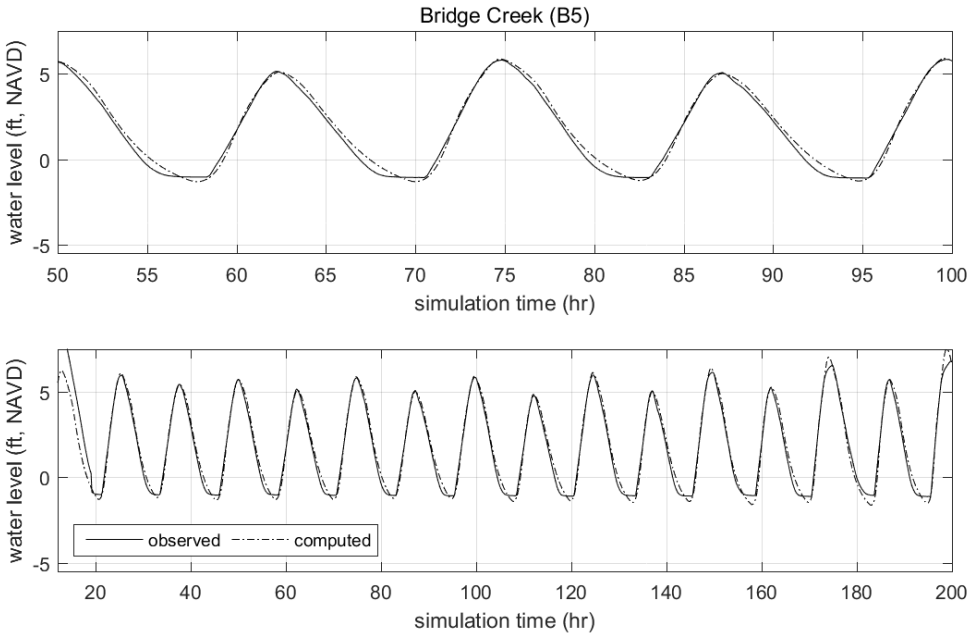


Figure V-13. Comparison of model output and measured tides for the Bridge Creek TDR station (B5) for the final calibration model run (July 21, 2015 at 1600 EDT). The top plot is a 50-hour sub-section of the longer segment of the total modeled time period shown in the bottom plot.

The constituent calibration resulted in excellent agreement between modeled and measured tides. The errors associated with tidal constituent amplitude for both the calibration

and verification simulations were on the order of 0.1 ft, which is of the same order of magnitude accuracy as that of the tide gauges (0.25 ft). Time lag errors for the main estuary reach were generally less than the time increment resolved by the model and tide data (10 minutes), indicating good agreement between the model and data. The skill of the model calibration is also demonstrated by the high degree of correlation (R^2) and low RMS error shown in Table V-9 for all stations.

Table V-7. Tidal constituents for measured water level data and calibrated model output, with model error amplitudes, for Barnstable Harbor, during modeled calibration time period.

Model calibration run						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕK_1
Cape Cod Bay	4.16	0.10	0.18	0.58	19.2	52.4
Harbor	4.13	0.09	0.20	0.57	25.0	57.3
Bass Hole	2.73	0.44	0.13	0.51	42.5	94.2
Scorton Creek	3.79	0.53	0.07	0.54	40.5	72.8
Bridge Creek	3.52	0.70	0.18	0.54	52.1	80.0
Measured tide during calibration period						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕK_1
Cape Cod Bay	4.16	0.09	0.18	0.58	19.8	52.6
Harbor	4.09	0.22	0.23	0.55	28.4	59.0
Bass Hole	2.49	0.81	0.22	0.45	46.7	91.9
Scorton Creek	4.00	0.68	0.02	0.51	41.8	71.8
Bridge Creek	3.36	0.62	0.18	0.50	47.8	103.8
Error						
Location	Error Amplitude (ft)				Phase error (min)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕK_1
Cape Cod Bay	0.00	0.01	0.00	0.00	-1.2	-0.8
Harbor	0.04	-0.13	-0.03	0.02	-7.0	-6.8
Bass Hole	0.24	-0.37	-0.09	0.06	-8.7	9.2
Scorton Creek	-0.21	-0.15	0.05	0.03	-2.7	4.0
Bridge Creek	0.16	0.08	0.00	0.04	8.9	-94.9

Table V-8. Error statistics for the Barnstable Harbor hydrodynamic model, for model calibration.

	R^2	RMS error (feet)
Cape Cod Bay	1.00	0.0
Harbor	0.99	0.2
Bass Hole	0.94	0.5
Scorton Creek	0.98	0.5
Bridge Creek	0.97	0.4

V.3.2.4 Hydrodynamic Model Corroboration

An additional corroboration model run was made to verify the performance of the hydrodynamic model over a span of time that does not overlap the calibration time period. The 10-day period between 0300 June 20 and 0300 June 30, 2015 was selected for the corroboration run since this was an available period when data were recovered from all five tide gauges.

Table V-9. Tidal constituents for measured water level data and calibrated model output, with model error amplitudes, for Barnstable Harbor, during modeled corroboration time period.

Model calibration run						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕK_1
Cape Cod Bay	4.00	0.08	0.18	0.41	-15.9	-65.7
Harbor	4.00	0.08	0.20	0.40	-10.1	-60.1
Bass Hole	2.69	0.43	0.15	0.30	7.7	-39.0
Scorton Creek	3.71	0.52	0.05	0.37	5.7	-46.6
Bridge Creek	3.45	0.67	0.17	0.36	18.0	-39.8
Measured tide during corroboration period						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕK_1
Cape Cod Bay	4.00	0.09	0.18	0.41	-15.2	-65.2
Harbor	3.95	0.19	0.25	0.39	-6.3	-55.8
Bass Hole	2.41	0.82	0.24	0.27	12.5	-40.7
Scorton Creek	3.86	0.68	0.04	0.34	7.6	-41.6
Bridge Creek	3.26	0.60	0.21	0.29	12.0	-31.1
Error						
Location	Error Amplitude (ft)				Phase error (min)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕK_1
Cape Cod Bay	0.00	0.00	0.00	0.00	-1.4	-2.1
Harbor	0.05	-0.11	-0.05	0.01	-7.8	-17.2
Bass Hole	0.28	-0.39	-0.09	0.03	-9.8	6.6
Scorton Creek	-0.15	-0.16	0.02	0.03	-3.9	-19.8
Bridge Creek	0.19	0.07	-0.04	0.07	12.4	-34.7

Table V-10. Error statistics for the Barnstable Harbor hydrodynamic model, for model corroboration.

	R^2	RMS error (feet)
Cape Cod Bay	1.00	0.01
Harbor	0.99	0.20
Bass Hole	0.91	0.55
Scorton Creek	0.96	0.54
Bridge Creek	0.97	0.43

V.3.3 Model Circulation Characteristics

The final calibrated model serves as a useful tool in investigating circulation characteristics of the whole Barnstable Great Marsh estuary system. Inputs of bathymetry and tide data can be leveraged to develop further insight into tidal velocities and flow rates at any point in the model domain. This is a very useful feature of a hydrodynamic model, where a limited amount of collected data can be expanded to determine the physical attributes of the system in areas where no physical data record exists. As an example, Figure V-14 shows color contours and vectors that indicate velocity during a single model time step, during a period of maximum flood currents at the inlet.

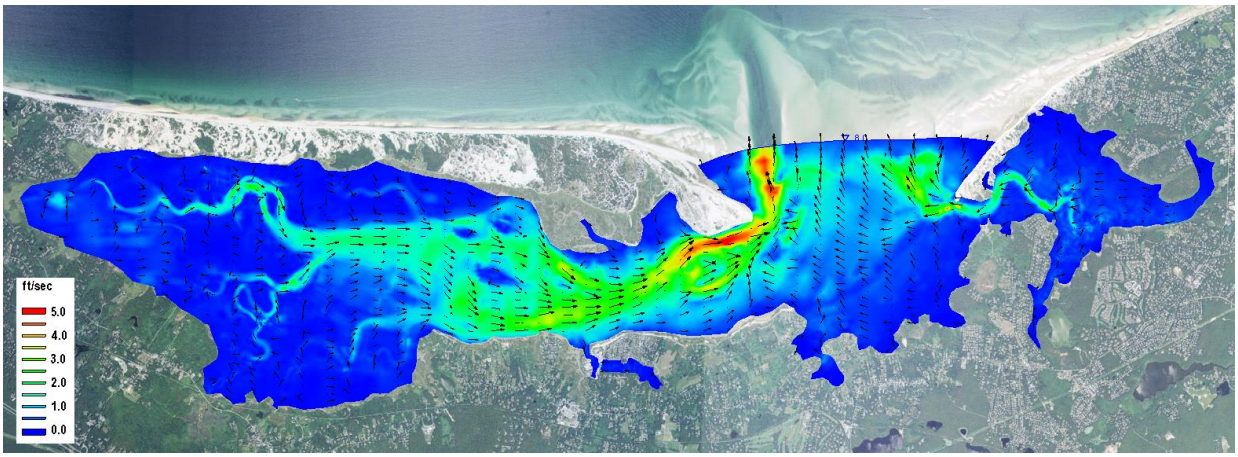


Figure V-14. Example of Barnstable Harbor hydrodynamic model output for a single time step during an ebbing tide. Color contours indicate velocity magnitude, and vectors indicate the direction of flow.

As another example, from the calibration model run of the Barnstable Great Marsh estuary system, the total flow rate of water flowing through the inlet culvert can be computed with the hydrodynamic model. The variation of flow as the tide floods and ebbs is seen in the plot of system flow rates in Figure V-15. During spring tides, the maximum flood flow rates into the harbor reach 191,500 ft^3/sec. Maximum ebb flow rates during spring tides are less than half of the flow rates experienced during spring tides (90,000 ft^3/sec).

V.3.4 Flushing Characteristics

Since the magnitude of freshwater inflow is much smaller in comparison to the tidal exchange through the inlet, the primary mechanism controlling estuarine water quality within the modeled Barnstable Great Marsh estuary system is tidal exchange. A rising tide offshore in Cape Cod Bay creates a slope in water surface from the ocean into the upper-most reaches of the modeled system. Consequently, water flows into (floods) the system. Similarly, the estuary drains into the open waters of Cape Cod Bay on an ebbing tide. This exchange of water between the system and the ocean is defined as tidal flushing. The calibrated hydrodynamic model is a tool to quantitatively evaluate tidal flushing of the harbor system, and was used to compute flushing rates (residence times) and tidal circulation patterns.

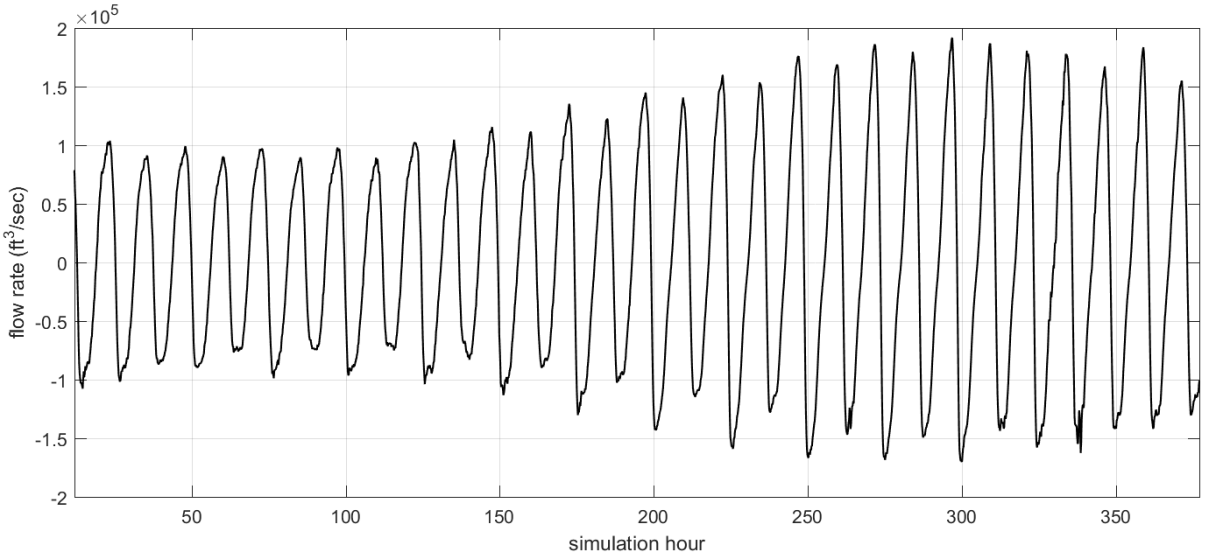


Figure V-15. Time variation of computed flow rates for the whole of the Barnstable Great Marsh estuary system. Model period shown corresponds to spring tide conditions, where the tide range is the largest, and resulting flow rates are correspondingly large compared to neap tide conditions. Positive flow indicated flooding tide flows, while negative flow indicates ebbing tide flows.

Flushing rate, or residence time, is defined as the average time required for a parcel of water to migrate out of an estuary from points within the system. For this study, system residence times were computed as the average time required for a water parcel to migrate from a point within the embayment to the entrance of the system. System residence times are computed as follows:

$$T_{system} = \frac{V_{system}}{P} t_{cycle}$$

where T_{system} denotes the residence time for the system, V_{system} represents volume of the (entire) system at mean tide level, P equals the tidal prism (or volume entering the system through a single tidal cycle), and t_{cycle} the period of the tidal cycle, typically 12.42 hours (or 0.52 days). To compute system residence time for a sub-embayment, the tidal prism of the sub-embayment replaces the total system tidal prism value in the above equation.

In addition to system residence times, a second residence, the local residence time, was defined as the average time required for a water parcel to migrate from a location within a sub-embayment to a point outside the sub-embayment. Using the Millway as an example, the system residence time is the average time required for water to migrate out of the Millway and Maraspin Creek, then across the main basin of Barnstable Harbor, and finally out through the harbor inlet and into Cape Cod Bay. Alternatively, the local residence time is the average time required for water to migrate from the inner harbor and into the main basin of the Harbor (not all the way to the Bay). Local residence times for each sub-embayment are computed as:

$$T_{local} = \frac{V_{local}}{P} t_{cycle}$$

where T_{local} denotes the residence time for the local sub-embayment, V_{local} represents the volume of the sub-embayment at mean tide level, P equals the tidal prism (or volume entering the local sub-embayment through a single tidal cycle), and t_{cycle} the period of the tidal cycle (again, 0.52 days).

Residence times are provided as a first order evaluation of estuarine water quality. Lower residence times generally correspond to higher water quality; however, residence times may be misleading depending upon pollutant/nutrient loading rates and the overall quality of the receiving waters. As a qualitative guide, system residence times are applicable for systems where the water quality within the entire estuary is degraded and higher quality waters provide the only means of reducing the high nutrient levels.

The rate of pollutant/nutrient loading and the quality of water outside the estuary both must be evaluated in conjunction with residence times to obtain a clear picture of water quality. It is impossible to evaluate an estuary's health based solely on flushing rates. Efficient tidal flushing (low residence time) is not an indication of high water quality if pollutants and nutrients are loaded into the estuary faster than the tidal circulation can flush the system. Neither are low residence times an indicator of high water quality if the water flushed into the estuary is of poor quality. Advanced understanding of water quality is obtained from applying the calibrated hydrodynamic model as described in the following section of this report (Section VI) and by extending the model to include pollutant/nutrient dispersion. The water quality model provides an additional valuable tool to evaluate the complex mechanisms governing estuarine water quality in the Harbor system.

Since the calibrated RMA-2 model simulated accurate two-dimensional hydrodynamics in the system, model results were used to compute residence times. Residence times were computed for the entire estuary, as well as two subdivisions of the system. In addition, system and local residence times were computed to indicate the range of conditions possible for the system.

Residence times were calculated as the volume of water (based on the mean volumes computed for the simulation period) in the entire system divided by the average volume of water exchanged over a flood tidal cycle (tidal prism). The mean volumes and tide prisms of the four system divisions used in this analysis are presented in Table V-11.

Table V-11. Barnstable Harbor mean volume and average tidal prism during simulation period.

Embayment	Mean Volume (ft^3)	Tide Prism Volume (ft^3)
Barnstable Harbor/Chase Garden Cr. system	1,315,712,234	1,823,962,385
Barnstable Great Marshes	280,851,338	455,834,605
Chase Garden Creek	113,078,364	183,994,859
Millway/Maraspin Creek	5,783,831	8,278,911

Residence times were averaged for the tidal cycles comprising a representative 14.5 tidal-day period (28 tide cycles), and are listed in Table V-12. The modeled time period used to

compute the flushing rates correspond to the model calibration period, and included a full cycle of neap to spring tide conditions. The RMA-2 model calculated flow crossing specified grid continuity lines (similar to an ADCP transect) for each sub-embayment to compute the tidal prism volume. Since the half-lunar-month period used to compute the flushing rates of the system represent average tidal conditions, the measurements provide the most appropriate method for determining mean flushing rates for the system sub-embayments.

Table V-12. Computed System and Local residence times for the Barnstable Great Marsh estuary system.

Embayment	System Residence Time (days)	Local Residence Time (days)
Barnstable Harbor/Chase Garden Cr. system	0.4	0.4
Barnstable Great Marshes	0.3	1.5
Chase Garden Creek	0.3	3.7
Millway/Maraspin Creek	0.4	82.2

The computed flushing rates for the entire system show that as a whole, the system flushes very well. A flushing time of 0.4 days for the entire estuary shows that on average, water is resident in the system for less than one half day. The low local residence times for the whole of the Barnstable Great Marsh estuary system show that water quality in the system is not impacted negatively by tidal flushing. This is a typical result for estuaries dominated by marsh resources or with extensive tidal flats, where the tide prism volume is of a magnitude comparable to the mean volume of the system.

For the smallest sub-embayments of the Harbor system, computed system residence times are typically two orders of magnitude longer than their corresponding local residence time. System residence times provide a qualitative measure that helps to identify the relative sensitivity of different sub-embayments to nutrient loading.

Based on our knowledge of estuarine processes, we estimate that the combined errors associated with the method applied to compute residence times are within 10% to 15% of “true” residence times, for the Barnstable Great Marsh estuary system. Possible errors in computed residence times can be linked to two sources: the bathymetry information and simplifications employed to calculate residence time. In this study, the most significant errors associated with the bathymetry data result from the process of interpolating the data to the finite element mesh, which was the basis for all the flushing volumes used in the analysis. In addition, limited topographic measurements were available in some of the smaller sub-embayments of the system.

Minor errors may be introduced in residence time calculations by simplifying assumptions. Flushing rate calculations assume that water exiting an estuary or sub-embayment does not return on the following tidal cycle. For regions where a strong littoral drift exists, this assumption is valid. However, water exiting a small sub-embayment on a relatively calm day may not completely mix with estuarine waters. In this case, the “strong littoral drift” assumption would lead to an under-prediction of residence time. Since littoral drift along the shoreline of Cape Cod Bay typically is strong because of the effects of the local winds and tidal induced mixing, the “strong littoral drift” assumption will cause only minor errors in residence time calculations.

VI. WATER QUALITY MODELING

VI.1 DATA SOURCES FOR THE MODEL

Several different data types and calculations are required to support the water quality modeling effort for the Barnstable Great Marsh estuary system. These include the output from the hydrodynamics model, calculations of external nitrogen loads from the watersheds, measurements of internal nitrogen loads from the sediment (benthic flux), and measurements of nitrogen in the water column.

VI.1.1 Hydrodynamics and Tidal Flushing in the Embayments

Extensive field measurements and hydrodynamic modeling of the embayment was an essential preparatory step to the development of the water quality model. The result of this work, among other things, was a calibrated hydrodynamic model representing the transport of water within the Barnstable Great Marsh estuary system. Files of node locations and node connectivity for the RMA-2V model grids were transferred to the RMA-4 water quality model; therefore, the computational grid for the hydrodynamic model was also the computational grid for the water quality model. The period of hydrodynamic model output used for the water quality model calibration was the half-lunar-month (28 tide cycle) period beginning July 22, 2015 0430 EDT. This period overlaps with the time period used for the hydrodynamic model calibration and also the flushing analysis presented in Section V. Each modeled scenario (e.g., present conditions, build-out) required the model be run for a 28-day spin-up period, to allow the model to reach a dynamic “steady state”, and ensure that model spin-up would not affect the final model output.

VI.1.2 Nitrogen Loading to the Embayments

Three primary nitrogen loads to the Barnstable Harbor embayment were utilized in this modeling study: external loads from the watersheds, nitrogen load from direct rainfall on the embayment surface, and internal loads from the sediments. Additionally, there is a fourth load to the Barnstable Great Marsh estuary system, consisting of the background concentrations of total nitrogen in the water entering from Cape Cod Bay. This load is represented as a constant concentration along the seaward boundary of the model grid.

VI.1.3 Measured Nitrogen Concentrations in the Embayment

In order to create a model that realistically simulates the total nitrogen concentrations in a system in response to the existing flushing conditions and loadings, it is necessary to calibrate the model to actual measurements of water column nitrogen concentrations. The refined and approved data for each monitoring station used in the water quality modeling effort are presented in Table VI-1. Station locations are indicated in the area map presented in Figure VI-1. The multi-year averages present the “best” comparison to the water quality model output, since factors of tide, temperature and rainfall may exert short-term influences on the individual sampling dates and even cause inter-annual differences. Three years of baseline field data are the minimum required to provide a baseline for MEP analysis. For stations in Barnstable Great Marsh estuary system, a minimum of seven years and up to 13 years of water quality data were available.

Table VI-1. Measured data and modeled bioactive nitrogen concentrations for the Barnstable Harbor estuarine system used in the model calibration plots of Figures VI-2 and VI-3. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of all measurements. Data represented in this table were collected in the summers of 2002 through 2014. Not all stations have data from all 13 years.

Location	Monitoring station	Data Mean	s.d. all data	N	model min	model max	model average
Scorton Creek	BM-13	0.189	0.056	33	0.063	0.183	0.121
Spring Creek	BM-11	0.190	0.052	33	0.064	0.185	0.127
Barnstable Harbor – upper	BM-12	0.165	0.049	37	0.062	0.167	0.111
Barnstable Harbor – upper	BM-1	0.131	0.039	131	0.062	0.156	0.097
Barnstable Harbor – mid	BM-2	0.111	0.051	137	0.063	0.148	0.085
Barnstable Harbor – lower	BM-3	0.098	0.042	129	0.063	0.118	0.072
Broad Sound	BM-10	0.269	0.097	24	0.070	0.136	0.105
Bass Hole	BSH-1	0.107	0.023	41	0.062	0.187	0.093
Chase Garden Creek - lower	BSH-2	0.108	0.025	41	0.064	0.219	0.111
Chase Garden Creek	BSH-3	0.125	0.033	43	0.064	0.240	0.122
Chase Garden Creek	BSH-4	0.129	0.040	45	0.064	0.277	0.132
Chase Garden Creek	BSH-5	0.275	0.153	41	0.085	0.520	0.271
Chase Garden Creek – upper	BSH-6	0.767	0.206	40	0.383	0.834	0.571
Whites Brook	BSH-7	0.355	0.163	32	0.109	0.587	0.321

VI.2 MODEL DESCRIPTION AND APPLICATION

A two-dimensional finite element water quality model, RMA-4 (King, 1990), was employed to study the effects of nitrogen loading in the Barnstable Harbor estuarine system. The RMA-4 model has the capability for the simulation of advection-diffusion processes in aquatic environments. It is the constituent transport model counterpart of the RMA-2 hydrodynamic model used to simulate the fluid dynamics of Barnstable Harbor. Like the RMA-2 numerical code, RMA-4 is a two-dimensional, depth averaged finite element model capable of simulating time-dependent constituent transport. The RMA-4 model was developed with support from the US Army Corps of Engineers (USACE) Waterways Experiment Station (WES), and is widely accepted and tested. The MEP Technical Team has utilized this model in water quality studies of other embayment systems in southeastern Massachusetts, including Pleasant Bay (Howes *et al*., 2006); New Bedford Harbor (Howes *et al*., 2008); Edgartown Great Pond, MA (Howes *et al*., 2008) and Sandwich Harbor (Howes et al., 2014).

The overall approach involves modeling total nitrogen as a non-conservative constituent, where bottom sediments act as a source or sink of nitrogen, based on local biochemical characteristics. This modeling represents summertime conditions, when algal growth is at its maximum. Total nitrogen modeling is based upon various data collection efforts and analyses presented in previous sections of this report. Nitrogen loading information was derived from the MEP Technical Team watershed loading analysis, as well as the measured bottom sediment nitrogen fluxes. Water column nitrogen measurements were utilized as model boundaries and as calibration data. Hydrodynamic model output (discussed in Section V) provided the remaining information (tides, currents, and bathymetry) needed to parameterize the water quality model of the Barnstable Great Marsh estuary system.



Figure VI-1. Estuarine water quality monitoring station locations in the Barnstable Great Marsh estuary system. Station labels correspond to those provided in Table VI-1.

VI.2.1 Model Formulation

The formulation of the model is for two-dimensional depth-averaged systems in which concentration in the vertical direction is assumed uniform. The depth-averaged assumption is justified since vertical mixing by wind and tidal processes prevent significant stratification in the modeled embayment. The governing equation of the RMA-4 constituent model can be most simply expressed as a form of the transport equation, in two dimensions:

$$\left(\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y}\right) = \left(\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x} + \frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y} + \sigma\right)$$

where c is the water quality constituent concentration; t is time; u and v are the velocities in the x and y directions, respectively; D_x and D_y are the model dispersion coefficients in the x and y directions; and σ is the constituent source/sink term. Since the model utilizes input from the RMA-2 model, a similar implicit solution technique is employed for the RMA-4 model.

The model is therefore used to compute spatially and temporally varying concentrations c of the modeled constituent (i.e., total nitrogen), based on model inputs of: 1) water depth and velocity computed using the RMA-2 hydrodynamic model; 2) mass loading input of the modeled constituent; and 3) user selected values of the model dispersion coefficients. Dispersion coefficients used for each system sub-embayment were developed during the calibration process. During the calibration procedure, the dispersion coefficients were incrementally changed until model concentration outputs matched measured data.

The RMA-4 model can be utilized to predict both spatial and temporal variations in total for a given embayment system. At each time step, the model computes constituent concentrations over the entire finite element grid and utilizes a continuity of mass equation to check these results. Similar to the hydrodynamic model, the water quality model evaluates model parameters at every element at 10-minute time intervals throughout the grid system. For this application, the RMA-4

model was used to predict tidally averaged total nitrogen concentrations throughout the Barnstable Great Marsh estuary system.

VI.2.2 Water Quality Model Setup

Required inputs to the RMA-4 model include a computational mesh, computed water elevations and velocities at all nodes of the mesh, constituent mass loading, and spatially varying values of the dispersion coefficient. Because the RMA-4 model is part of a suite of integrated computer models, the finite-element meshes and the resulting hydrodynamic simulations previously developed for Barnstable Harbor also were used for the water quality constituent modeling portion of this study.

For each model, an initial total N concentration equal to the concentration at the open boundary was applied to the entire model domain. The model was then run for a simulated month-long (28 day) spin-up period. At the end of the spin-up period, the model was run for an additional 14 day (336 hour) period. Model results were recorded only after the initial spin-up period. The time step used for the water quality computations was 10 minutes, which corresponds to the time step of the hydrodynamics input for the Barnstable Harbor hydrodynamic model.

VI.2.3 Boundary Condition Specification

Mass loading of nitrogen into each model included: 1) sources developed from the results of the watershed analysis, 2) estimates of direct atmospheric deposition, and 3) summer benthic regeneration. Nitrogen loads from each separate sub-watershed to the embayment were distributed by watershed. For example, the watershed load for the Millway was input within the model area that represents this small sub-embayment of the Harbor. Benthic loads were distributed between the grid elements within the separate tidal creeks in the Harbor system.

The loadings used to model present conditions in the Barnstable Great Marsh estuary system are given in Table VI-2. Watershed and depositional loads were taken from the results of the analysis of Section IV. Summertime benthic flux loads were computed based on the analysis of sediment cores in Section IV. The area rate ($g/sec/m^2$) of nitrogen flux from that analysis was applied to the surface area coverage computed for each sub-embayment (excluding marsh coverages, when present), resulting in a total flux for each portion of the overall embayment (as listed in Table VI-2). Due to the highly variable nature of bottom sediments and other estuarine characteristics of coastal embayments in general, the measured benthic flux for existing conditions also is variable. Fluxes range between negative (uptake of nitrogen) and positive (source of nitrogen) values in different areas of the system. In the main Harbor basin, the net benthic flux is negative which indicates a net uptake of nitrogen in the bottom sediments. The greatest measured positive fluxes exist in the Millway basin, the dredged boat basin in Barnstable Village.

In addition to mass loading boundary conditions set within the model domain, concentrations along the model open boundary were specified. The model uses concentrations at the open boundary during the flooding tide periods of the model simulations. The bioactive nitrogen concentration of the incoming water was set at the value designated for the open boundary. The boundary concentration in Cape Cod Bay, offshore the harbor inlet, was set at 0.063 mg/L, based on SMAST data collected offshore in the Bay.

Table VI-2. Sub-embayment and surface water loads used for total nitrogen modeling of the Barnstable Great Marsh estuary system, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent **present loading conditions** for the listed sub-embayments.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Barnstable Harbor - west	38.586	2.422	5.304
Barnstable Harbor - mid	27.562	13.800	-11.497
Barnstable Harbor - east	42.600	32.978	-23.366
Millway	10.575	0.211	2.853
Chase Garden Creek - west	29.666	0.140	0.373
Chase Garden Creek - east	25.030	0.003	-
Bass Hole	7.408	0.488	-1.079
System Total	181.427	50.041	-27.412

VI.2.4 Model Calibration

The development of the Barnstable Harbor water quality model began with the parameterization and calibration of the salinity model. Salinity is a conservative water quality constituent and therefore ideally suited for model calibration. Model dispersion coefficients were adjusted so that model output salinity matched measured data from the harbor. Generally, several model runs were required to bring the model into agreement with the water column measurements. Dispersion coefficient (*E*) values were varied through the modeled system by setting different values of *E* for each grid material type, as designated in Section V. Observed values of *E* in coastal estuary areas typically range between order 10 and order 0.001 m^2/sec (USACE, 2001). The final values of *E* used in each sub-embayment of the modeled system are presented in Table VI-3. These values were used to develop the "best-fit" salinity model calibration. For the case of salinity modeling, "best fit" can be defined as minimizing the error between the model and data at all sampling locations, utilizing reasonable ranges of dispersion coefficients within the model domain.

The only required inputs into the RMA-4 salinity model of the system, in addition to the RMA-2 hydrodynamic model output, were salinities at the model open boundary, and freshwater inputs (including inputs from rain, surface streams and groundwater). The open boundary salinity in Cape Cod Bay was set at 31.1 ppt. Surface water and groundwater input salinities were set at 0 ppt. Fresh water inputs into the model are listed in Table VI-4, which includes the sum of groundwater, surface streams, and direct rainfall onto the open water estuary surface of the Harbor, for each model sub-division.

Comparisons between calibrated model output and measured salinity are shown in plots presented in Figures VI-2 and VI-3. In these plots, means of the water column data and a range of two standard deviations of the annual means at each individual station are plotted against the modeled maximum, mean, and minimum concentrations output from the model at locations which corresponds to the MEP monitoring stations.

For model calibration, the target modeled salinities were compared to mean measured salinity data values at all water-quality monitoring stations. The calibration target was set between

the modeled maximum and tidal averaged concentration at each station, in order to represent samples collected at or after the time of mid-ebb tide offshore in Cape Cod Bay.

Table VI-3. Values of longitudinal dispersion coefficient, E, used in calibrated RMA4 model runs of salinity and nitrogen concentration for the Barnstable Great Marsh estuary system.

Embayment Division	E m^2/sec
Chase Garden Creek marsh	10.0
Bass Hole	10.0
Lone Tree Creek marsh plain	1.0
Barnstable Harbor main basin	1.0
Barnstable Harbor inlet	5.0
Barnstable Harbor marsh plain	0.5
Barnstable Harbor marsh creeks	0.5
Millway	1.0
Maraspin Creek	1.0

Table VI-4. Freshwater inputs, including groundwater, surface water (streams), and direct rainfall on estuary surface used as inputs to the model of the Barnstable Great Marsh estuary system.

estuary subdivision/stream input	flow ft^3/sec
Great Marsh West Barnstable	15.68
Alder Creek	0.39
Boat Cove Creek	5.14
Bridge Creek	2.32
Great Marsh Mid	18.04
Great Marsh BarnYarm	17.99
Huckins Neck Total	1.60
Millway Total	2.06
Maraspin Creek	0.57
Chase Garden Creek Salt W	2.97
Whites Brook Salt	2.52
Chase Garden Creek Salt E	3.61
Bass Hole	3.60

Also presented in Figure VI-3 are unity plot comparisons of measured data verses modeled target values for each system. The computed R^2 correlation is 0.92 and the root mean squared (rms) error is 3.2 ppt, both of which demonstrate good agreement between modeled and measured data for this system.

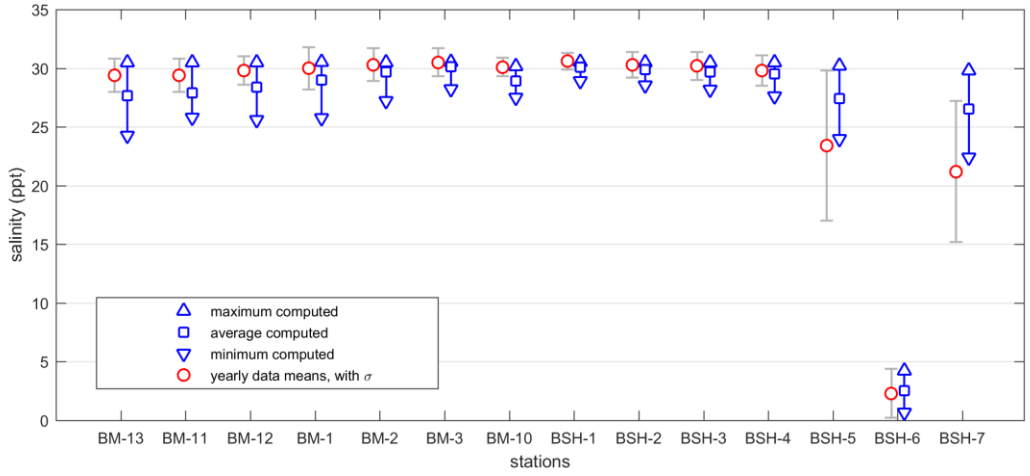


Figure VI-2. Comparison of measured total salinity and calibrated model output at stations in the Barnstable Great Marsh estuary system. Station labels correspond with the MEP IDs provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed concentration for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset

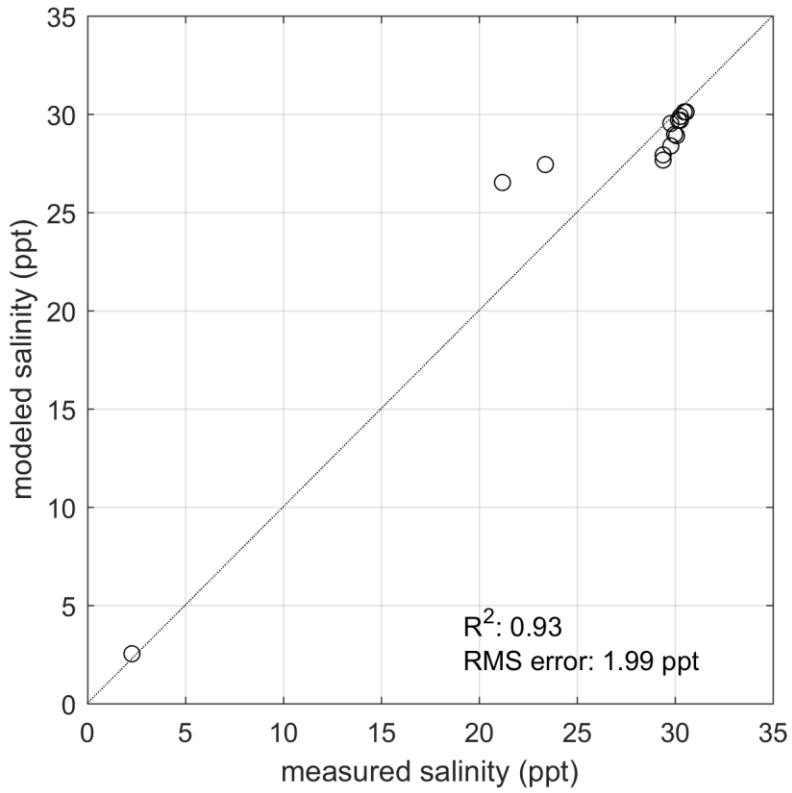


Figure VI-3. Model salinity calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for the model are 0.93 and 1.99 ppt respectively.

A contour plot of calibrated model output is shown in Figure VI-4. In this figure, color contours indicate salinity throughout the model domain. The output in the figure shows average salinity concentrations, computed using the full 14-tidal-day model simulation output period.

VI.2.5 Model Verification

In addition to the model calibration based on salinity, the numerical water quality model performance was verified by modeling bioactive nitrogen (bioactive N). This step was performed for the Barnstable Great Marsh estuary system using N measurements collected at the same stations as the salinity data and N loads from Table VI-2. For the bioactive N verification, none of the model dispersion coefficients were changed from the values used in the salinity calibration. Comparisons of modeled and measured N concentrations are presented in Figures VI-5 and VI-6, with contour plots of model output shown in Figure VI-7. The R^2 correlation of the model and measurements is 0.95 and the rms error of the model is 0.037 mg/L.

VI.2.6 Build-Out and No Anthropogenic Load Scenarios

To assess the influence of nitrogen loading on total nitrogen concentrations within the Barnstable Harbor, the standard “build-out” and “no-load” water quality modeling scenarios were run. These runs included a “build-out” scenario, based on potential development (described in more detail in Section IV), and a “no anthropogenic load” or “no load” scenario assuming only atmospheric deposition on the watershed and sub-embayment, as well as a natural forest within each watershed. Comparisons of the alternate watershed loading analyses are shown in Table VI-5. Loads are presented in kilograms per day (kg/day) in this Section, since it is inappropriate to show benthic flux loads in kilograms per year due to seasonal variability.

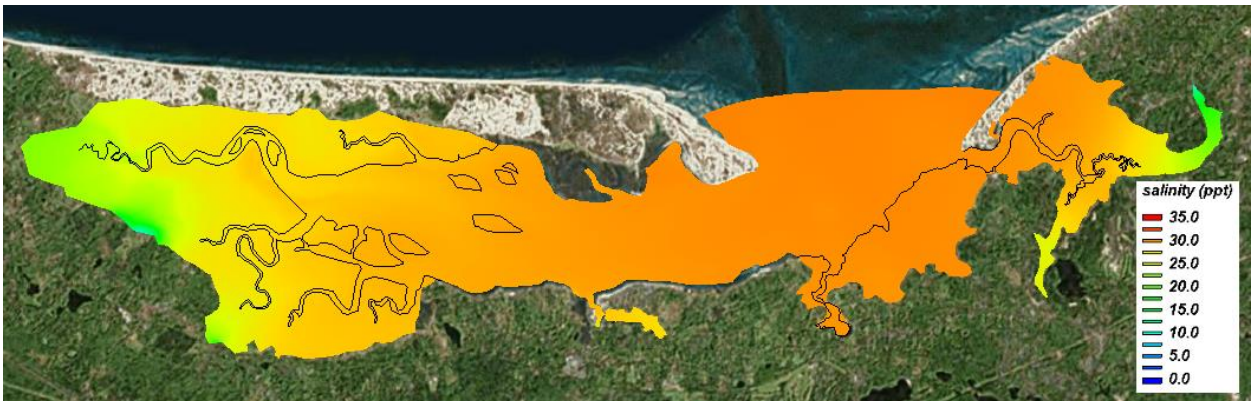


Figure VI-4. Contour Plot of average modeled salinity (ppt) in the Barnstable Great Marsh estuary system.

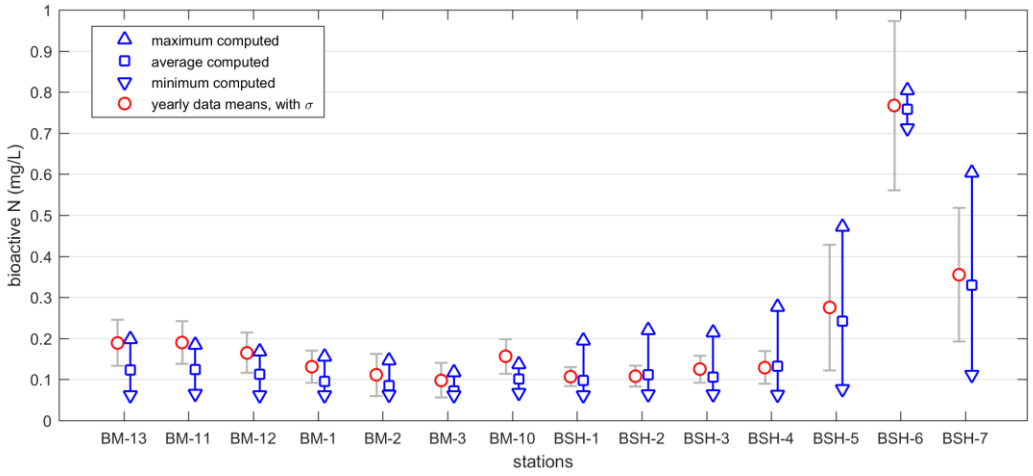


Figure VI-5. Comparison of measured and calibrated TN model output at stations in Barnstable Harbor. Stations labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed TN concentrations for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate ± one standard deviation of the entire dataset.

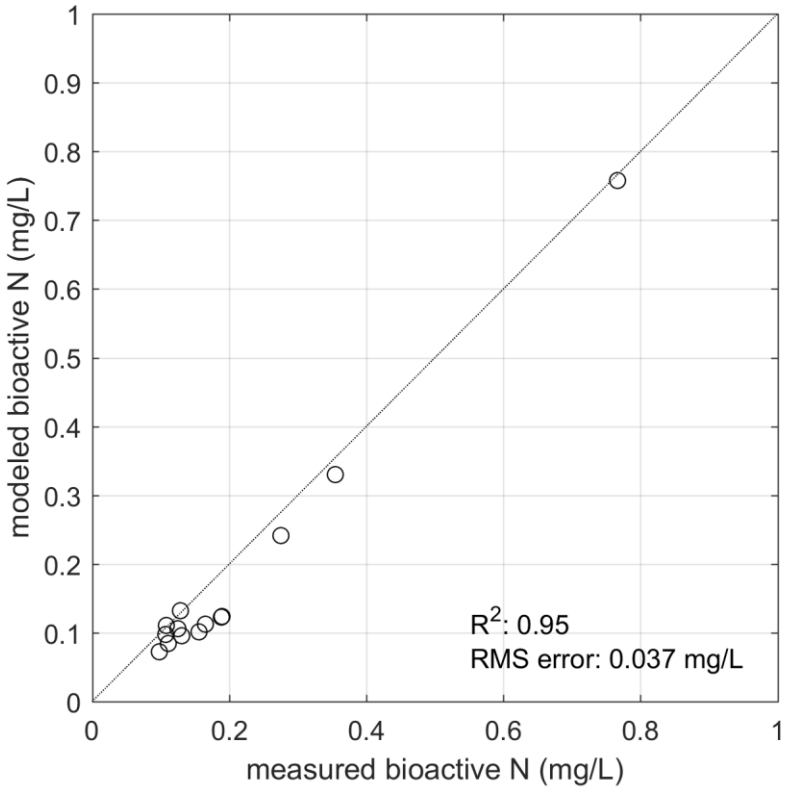


Figure VI-6. Model TN target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) is 0.95 and RMS error for this model verification run is 0.037 mg/L.



Figure VI-7. Contour plot of average total nitrogen concentrations from results of the present conditions loading scenario, for the Barnstable Great Marsh estuary system

Table VI-5. Comparison of sub-embayment watershed loads used for modeling of present, build-out, and no-anthropogenic ("no-load") loading scenarios of the Barnstable Great Marsh estuary system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	Build-out (kg/day)	build-out % change	no load (kg/day)	no load % change
Barnstable Harbor - west	38.586	48.452	+25.6%	5.518	-85.7%
Barnstable Harbor - mid	27.562	33.964	+23.2%	3.159	-88.5%
Barnstable Harbor - east	42.600	60.115	+41.1%	3.458	-91.9%
Millway	10.575	12.679	+19.9%	1.800	-83.0%
Chase Garden Creek - west	29.666	31.896	+7.5%	1.301	-95.6%
Chase Garden Creek - east	25.030	27.581	+10.2%	0.567	-97.7%
Bass Hole	7.408	7.770	+4.9%	0.564	-92.4%
System Total	181.427	222.458	+22.6%	13.934	-92.3%

VI.2.6.1 Build-Out

A breakdown of the total nitrogen load entering each sub-embayment is shown in Table VI-6 for the modeled build-out scenario. The benthic flux for the build-out scenarios is assumed to vary proportional to the watershed load, where an increase in watershed load will result in an increase in benthic flux (i.e., a positive change in the absolute value of the flux), and *vice versa*.

Projected benthic fluxes (for both the build-out and no load scenarios) are based upon projected PON concentrations and watershed loads, determined as:

$$(Projected\ N\ flux) = (Present\ N\ flux) * [PON_{projected}]/[PON_{present}]$$

where the projected PON concentration is calculated by,

$$[PON_{projected}] = R_{load} * \Delta PON + [PON_{(present\ offshore)}],$$

using the watershed load ratio,

$$R_{load} = (Projected\ N\ load) / (Present\ N\ load),$$

and the present PON concentration above background,

$$\Delta PON = [PON_{(present\ flux\ core)}] - [PON_{(present\ offshore)}].$$

Following development of the nitrogen loading estimates for the build-out scenario, the water quality models of the system was run to determine nitrogen concentrations within each sub-embayment (Table VI-7). In this table, the percent change *P* over background presented in this table is calculated as:

$$P = (N_{scenario}-N_{present})/(N_{present}-N_{background})$$

where N is the nitrogen concentration at the indicated monitoring station for present conditions and the loading scenario (i.e., build-out in this case), and also in Cape Cod Bay (background). Bioactive nitrogen concentrations in the receiving waters (i.e., Cape Cod Bay) remained identical to the existing conditions modeling scenarios. For build-out, the percent increase in modeled TN concentrations is greatest at the station near the Harbor mouth (BM-3) and at Broad Sound in the mid-harbor region (BM-10). Concentrations increased 25% above background at these two monitoring stations. The largest bioactive N magnitude change occurs at station BSH-6 in upper Chase Garden Creek, where average bioactive N increases 0.054 mg/L. A contour plot showing average TN concentrations throughout the harbor system is presented in Figure VI-8 for the model of build-out loading.

Table VI-6. **Build-out** scenario sub-embayment and surface water loads used for total nitrogen modeling of the Barnstable Great Marsh estuary system, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Barnstable Harbor - west	48.452	2.422	5.862
Barnstable Harbor - mid	33.964	13.800	-11.903
Barnstable Harbor - east	60.115	32.978	-22.511
Millway	12.679	0.211	3.092
Chase Garden Creek - west	31.896	0.140	0.383
Chase Garden Creek - east	27.581	0.003	-
Bass Hole	7.770	0.488	-1.136
System Total	222.458	50.041	-26.213

Table VI-7. Comparison of model average bioactive N concentrations from present loading and the **build-out scenario**, with percent change over background in Cape Cod Bay (0.063 mg/L), for the Barnstable Great Marsh estuary system.

Sub-Embayment	monitoring station (MEP ID)	present (mg/L)	build-out (mg/L)	% change
Scorton Creek	BM-13	0.121	0.136	+24.7%
Spring Creek	BM-11	0.127	0.141	+23.0%
Barnstable Harbor – upper	BM-12	0.111	0.123	+24.0%
Barnstable Harbor – upper	BM-1	0.097	0.105	+24.2%
Barnstable Harbor – mid	BM-2	0.085	0.090	+23.5%
Barnstable Harbor – lower	BM-3	0.072	0.075	+25.5%
Broad Sound	BM-10	0.105	0.116	+25.0%
Bass Hole	BSH-1	0.093	0.095	+8.8%
Chase Garden Creek - lower	BSH-2	0.111	0.115	+8.6%
Chase Garden Creek	BSH-3	0.122	0.127	+9.0%
Chase Garden Creek	BSH-4	0.132	0.139	+8.9%
Chase Garden Creek	BSH-5	0.271	0.292	+9.9%
Chase Garden Creek – upper	BSH-6	0.571	0.626	+10.6%
Whites Brook	BSH-7	0.321	0.344	+8.6%



Figure VI-8. Contour plot of modeled total nitrogen concentrations (mg/L) in the Barnstable Great Marsh estuary system, for projected build-out scenario loading conditions.

VI.2.6.2 No Anthropogenic Load

A breakdown of the total nitrogen load entering each sub-embayment for the no anthropogenic load ("no load") scenarios is shown in Table VI-8. The benthic flux input to each embayment was reduced (toward zero) based on the reduction in the watershed load (as discussed in Section VI.2.6.1). Compared to the modeled present conditions and build-out scenario, atmospheric deposition directly to each sub-embayment becomes a greater percentage of the total nitrogen load as the watershed load and related benthic flux decrease.

Following development of the nitrogen loading estimates for the no load scenario, the water quality model was run to determine nitrogen concentrations at each monitoring station. Again, total nitrogen concentrations in the receiving waters (i.e., Cape Cod Bay) remained identical to

the existing conditions modeling scenarios. The relative change in total nitrogen concentrations resulting from "no load" was large, with all areas of the system experiencing reductions greater than 100%, compared to the background concentration of 0.063 mg/L in Cape Cod Bay (Table VI-9). Generally, average bioactive N concentrations drop from present conditions. The greatest drop occurs in Chase Garden Creek. One station near the Harbor entrance (BM-3) has an increased concentration, which results from a decrease in the negative benthic flux between the present and "no load" scenarios. This decrease in negative flux causes a reduction of uptake of nitrogen by the Harbor bottom sediments which leads to an increase in N concentrations in this area of the harbor. A contour plot showing TN concentrations throughout the system is presented in Figure VI-9.

Table VI-8. "**No anthropogenic loading**" ("no load") sub-embayment and surface water loads used for total nitrogen modeling of the Barnstable Great Marsh estuary system, with total watershed N loads, atmospheric N loads, and benthic flux

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Barnstable Harbor - west	5.518	2.422	3.210
Barnstable Harbor - mid	3.159	13.800	-10.084
Barnstable Harbor - east	3.458	32.978	-23.655
Millway	1.800	0.211	1.902
Chase Garden Creek - west	1.301	0.140	0.306
Chase Garden Creek - east	0.567	0.003	-
Bass Hole	0.564	0.488	-0.937
System Total	16.367	50.041	-29.258

Table VI-9. Comparison of model average bioactive N concentrations from present loading and the "**No anthropogenic loading**" ("no load"), with percent change over background in Cape Cod Bay (0.063 mg/L), for the Barnstable Great Marsh estuary system.

Station Location	monitoring station (MEP ID)	present (mg/L)	"no load" (mg/L)	% change
Scorton Creek	BM-13	0.121	0.086	-60.0%
Spring Creek	BM-11	0.127	0.091	-56.4%
Barnstable Harbor – upper	BM-12	0.111	0.087	-51.4%
Barnstable Harbor – upper	BM-1	0.097	0.084	-39.2%
Barnstable Harbor – mid	BM-2	0.085	0.083	-10.9%
Barnstable Harbor – lower	BM-3	0.072	0.080	+78.7%
Broad Sound	BM-10	0.105	0.087	-44.3%
Bass Hole	BSH-1	0.093	0.074	-64.2%
Chase Garden Creek - lower	BSH-2	0.111	0.074	-76.8%
Chase Garden Creek	BSH-3	0.122	0.074	-81.6%
Chase Garden Creek	BSH-4	0.132	0.074	-84.3%
Chase Garden Creek	BSH-5	0.271	0.072	-95.6%
Chase Garden Creek – upper	BSH-6	0.571	0.052	-102.2%
Whites Brook	BSH-7	0.321	0.077	-94.7%



Figure VI-9. Contour plot of modeled total nitrogen concentrations (mg/L) in Barnstable Harbor, for no anthropogenic loading conditions.

VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll, and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (fish, shellfish, infauna) which it supports. For the Barnstable Great Marsh estuary system in the Towns of Barnstable and Dennis, MA, the assessment is based upon data from water quality monitoring conducted by the Towns of Barnstable and Dennis with technical support from the Coastal Systems Program (UMASS-SMAST), MassDEP surveys of eelgrass distribution as available (typically 1951, 1995, 2001 and checks by SMAST in 2007), benthic animal communities (fall 2007), sediment characteristics (summer 2007), and dissolved oxygen records (summer 2007). Water quality monitoring in Barnstable Harbor was initiated in 2002 at stations BM1,2,3 and has persisted till present. In 2008 four additional stations were added to the program, BM10,11,12,13 and sampling of these stations continues to present as well. Water quality sampling in the Great Marshes portion of the estuary has also been periodically undertaken at 5 additional stations (GM1,2,3,4,5) in 2005, 2008 and 2012-2014. In Bass Hole, water quality sampling has been continuously conducted by the Town of Dennis at stations BH1-7 from 2005 to 2014. These data form the basis of an assessment of this system's present health, and when coupled with a full water quality synthesis and projections of future conditions based upon the water quality modeling effort, will support nitrogen threshold development for this system (Section VIII). It should be noted that nitrogen enrichment occurs through 2 primary mechanisms, high rates of nitrogen entering from the surrounding watershed and/or low rates of flushing due to restriction of tidal exchange with the low nitrogen waters of Cape Cod Bay. The Barnstable Great Marsh estuary system has increasing nitrogen loading from the associated watersheds from shifting land-uses and may have periodic alterations in circulation and possibly tidal exchange in specific portions of the system due to the dynamics of sand in the main basin and in and around the mouth of Bass Hole. Fundamentally, restrictions of tidal exchange increase the sensitivity of an estuary to nitrogen inputs, however, this is more so the case in a classic embayment setting as opposed to systems like Barnstable Great Marsh estuary system that are dominated by salt marshes with higher assimilative capacities for nitrogen than open water embayments.

VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS

There are a variety of indicators that can be used in concert with water quality monitoring data for evaluating the ecological health of embayment systems. The best biological indicators are those species which are non-mobile and which persist over relatively long periods, if environmental conditions remain constant. The concept is to use species which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

As a basis for a nitrogen thresholds determination, MEP focused on major habitat quality indicators: (1) bottom water dissolved oxygen and chlorophyll-*a* (Section VII.2), (2) eelgrass distribution over time (Section VII.3) and (3) benthic animal communities (Section VII.4). Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate cause being nitrogen loading). However, oxygen conditions can change rapidly and frequently show strong tidal and diurnal patterns. Even severe levels of oxygen depletion may occur only infrequently, yet have important effects on system health. To capture this variation, the MEP Technical Team deployed dissolved oxygen sensors at strategic locations throughout the Barnstable Great Marsh estuary system to record the frequency and

duration of low oxygen conditions during the critical summer period. The MEP habitat analysis uses eelgrass as a sentinel species for indicating nitrogen over-loading to coastal embayments. Eelgrass loss in Cape Cod estuaries associated with nitrogen enrichment is generally through decreased light penetration resulting from increased phytoplankton biomass and resulting suspended organic particles, as well as shading by epiphytes (small plants that colonize eelgrass shoots) and sometimes by drift macroalgae. Each of these factors is a result of nitrogen enrichment and all result in stress to eelgrass beds.

MassDEP mapping of the eelgrass beds was not conducted within the component basins of the Barnstable Great Marsh estuary system, although some surveys were conducted in the near shore waters of Cape Cod Bay just outside the tidal inlet (MassDEP Eelgrass Mapping Program, C. Costello 2010-2013). However, a historical analysis of possible eelgrass distribution was conducted within the estuary which showed only limited area. This is likely because many of the central basin areas have very dynamic sediments, with unstable sands that do not support eelgrass. Surveying completed by the SMAST-MEP Technical Team in the summer of 2007 confirmed the absence of any eelgrass, as would be expected in a tidal salt marsh dominated system that is also composed of a large open water area with a large tidal range, strong tidal currents and large areas of shifting sand flats and sand waves. As a result, temporal changes in eelgrass distribution could not provide a basis for evaluating recent increases (nitrogen loading) in nutrient enrichment of the Barnstable Great Marsh estuary system. The low phytoplankton and macroalgal biomass, oxidized sediments and high light penetration is consistent with a non-nitrogen factor causing the absence of eelgrass, most likely associated with high tidal velocities, unstable sediments and possibly winter storm exposure. As a result, nutrient threshold determination was based strongly on results from the dissolved oxygen and chlorophyll mooring data as well as the benthic infaunal community characterization. Prior to evaluating nitrogen thresholds, analysis of inorganic N/P molar ratios was conducted within the water column throughout the estuary comprised of Barnstable Great Marsh estuary system and their tributary creeks. The results support the contention that nitrogen is the nutrient to be managed in this estuary, as the N/P molar ratio throughout this large estuarine complex averaged 4.6 with a range of 3.1-7.4, clearly below the Redfield Ratio value (16) indicating that nitrogen additions will increase phytoplankton production in this estuary.

In areas that do not support eelgrass beds, benthic animal indicators were used to assess the level of habitat health from “healthy” (low organic matter loading, high D.O.) to “highly stressed” (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment samples were identified and the environments ranked based upon the fraction of healthy, transitional, and stressed indicator species. The analysis is based upon life-history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes *et al.* 1997). These data are coupled with the level of diversity (H’) and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

VII.2 BOTTOM WATER DISSOLVED OXYGEN

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect

communities even if they are relatively rare on an annual basis. For example, USEPA[1] suggests that the chronic protective oxygen level to support growth of estuarine animals is 4.8 mg L^{-1}, with a limit for survival of juvenile and adult organisms of 2.3 mg L^{-1}. However, studies have demonstrated that slightly higher oxygen levels, 3.0 mg/L, can be lethal to larval fish and crustaceans (Poucher and Coiro 1997). Massachusetts State Water Quality Classification indicates that SA (high quality) waters maintain oxygen levels above 6 mg L^{-1}. The tidal waters of the Barnstable Great Marsh estuary system are currently listed under this classification as SA. It should be noted that the classification system represents the water quality that the embayment should support, not the existing level of water quality. It is through the MEP and TMDL processes that management actions are developed and implemented to keep or bring the existing conditions in line with the classification.

Dissolved oxygen levels in temperate estuaries vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates in summer than winter (Figure VII-1). It is not surprising that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute oxygen levels (mg L^{-1}) are found during the summer in southeastern Massachusetts embayments when water column respiration rates are greatest. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen conditions within shallow embayments (Taylor and Howes, 1994). To more accurately capture the degree of bottom water dissolved oxygen depletion during the critical summer period, autonomously recording oxygen sensors were moored 30 cm above the bottom of the main tidal creeks within key regions of the Barnstable Great Marsh estuary system (Figure VII-2). The dissolved oxygen sensors (YSI 6600) were first calibrated in the laboratory and then checked with standard oxygen mixtures at the time of initial instrument mooring deployments. In addition periodic calibration samples were collected at the depth of each sensor and assayed by Winkler titration (potentiometric analysis, Radiometer) during each deployment. Each instrument mooring was serviced and calibration samples collected at least biweekly and sometimes weekly during a minimum deployment of 30 days within the interval from July through mid-September. All of the mooring data from the Barnstable Great Marsh estuary system were collected during the summer of 2007.

Similar to other estuaries in southeastern Massachusetts, the Barnstable Great Marsh estuary system evaluated in this assessment showed high frequency variation related primarily to diurnal influences and to tidal influences. Nitrogen enrichment of estuarine waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site, underscores the need for continuous monitoring within these systems.

[1] USEPA 2000. Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras (133 p.).

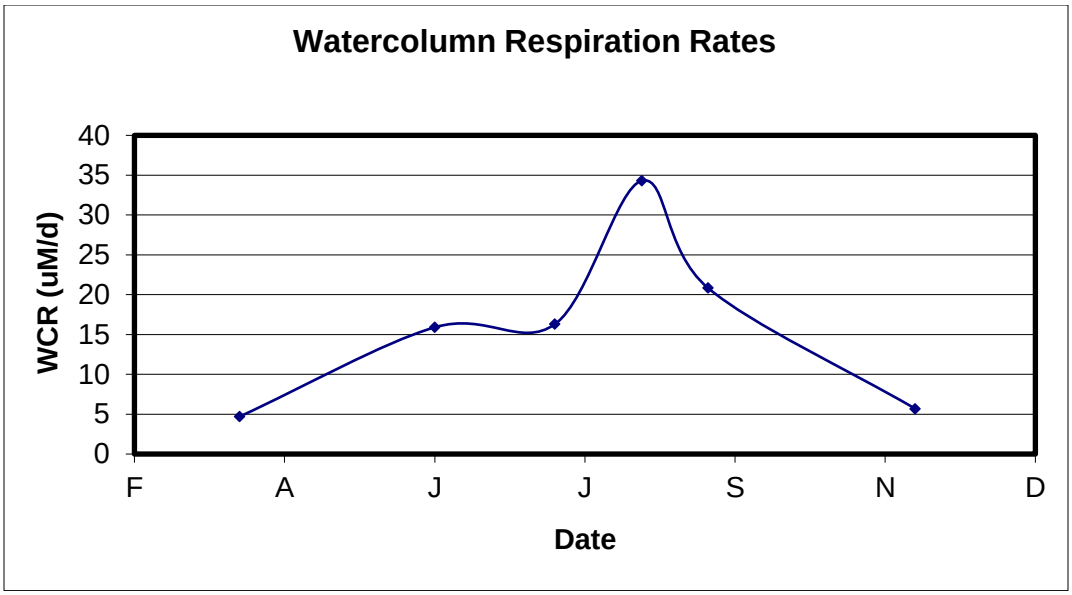


Figure VII-1. Example of typical average water column respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System, Cape Cod (Schlezinger and Howes, unpublished data). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Dissolved oxygen and chlorophyll-*a* records were examined both for temporal trends and to determine the percent of the 28-36 day deployment period that these parameters were below/above various benchmark concentrations (Tables VII-1, VII-2). These data indicate both the temporal pattern of minimum or maximum levels of these critical nutrient related constituents, as well as the intensity of the oxygen depletion events and phytoplankton blooms.

The oxygen data in the tributary creeks is consistent with high organic matter inputs from the surrounding vegetated marsh and creek banks rather than from phytoplankton which show relatively low to moderate enrichment (chlorophyll-a levels generally <10 ug L-1). The high velocity of tidal currents in the main tidal channels (e.g. Great Marshes Main Basin, Scorton Creek, Spring Creek, Bass Hole Upper and Lower) and near complete draining of the creeks at low tide appears to reduce the settling of phytoplankton, hence sediment oxygen uptake. An indication of the areas with low organic matter deposition is the large swept sand areas and sand waves with low organic content and low rates of oxygen uptake. That large portions of the Barnstable Great Marsh estuary system are dominated by salt marsh habitat as well as the large tidal range and vigorous flushing are factors that must be taken into consideration when interpreting the dissolved oxygen data and its relation to nutrient enrichment of the system and any determination of habitat impairment. The observed levels of oxygen depletion in this large estuary and the magnitude of daily oxygen excursion and chlorophyll-*a* levels are consistent with the natural organic rich salt marsh creeks with high tidal flushing that are not being overly enriched by watershed inputs (Figures VII-3 through VII-14).

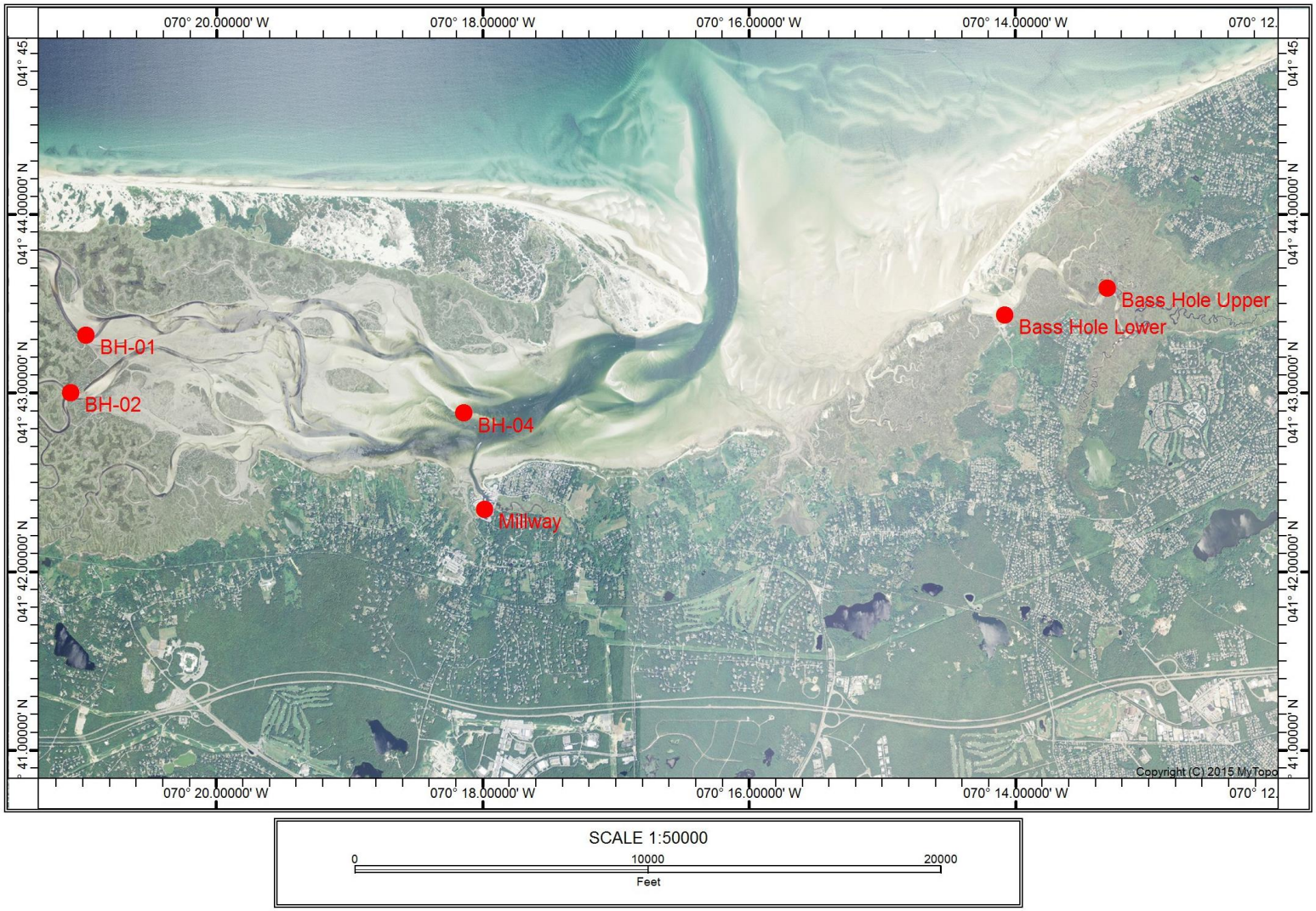


Figure VII-2. Aerial Photograph of the Barnstable Great Marsh estuary system in the Towns of Barnstable and Dennis showing the location of the continuously recording Dissolved Oxygen / Chlorophyll-*a* sensors deployed during the Summer of 2007. BH-01 = Scorton Creek, BH-02 = Springhill Creek, BH-04 = Blish Point (middle of central main basin).

Interpretation of estuarine oxygen records need to consider both the frequency of oxygen depletion and the actual temporal pattern of oxygen levels, specifically as it relates to daily oxygen excursions. The use of only the duration of oxygen below, for example 4 mg L^{-1}, can underestimate the level of habitat impairment in a particular location. Nitrogen enrichment also results in increased phytoplankton (or epibenthic algae) production, as evidenced by oxygen levels that rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). In the Barnstable Great Marsh estuary system, oxygen levels only significantly exceeded atmospheric equilibrium occasionally, although oxygen depletion was commonly observed. The absence of elevated oxygen levels is consistent with the oxygen variations being the response to the naturally organic rich nature of tidal salt marsh creeks rather than eutrophying levels of nitrogen. In these systems the oxygen dynamic is driven by consumption within the tidal creeks, with re-oxygenation through phytoplankton production being limited. As the creeks drain nearly completely at low tide, the rise in oxygen levels is primarily through the entry of oxygen rich coastal waters on the flooding tide.

The dissolved oxygen records indicate that in the nearby Scorton Creek Salt Marsh the upper tidal creeks (away from the tidal inlet) and lower regions of the central main tidal salt marsh creek frequently have oxygen declines to ~4 mg L^{-1}, while the tributary tidal creek along the backside of the barrier beach (Scorton Creek 2 mooring) shows periodic (but not prolonged) oxygen depletion to 2 mg L^{-1} (Table VII-1). Such oxygen depletion is typical of organic and nutrient rich temperate salt marsh creeks. Salt marshes are nutrient and organic matter enriched as part of their ecological design, which makes them such important nursery areas for adjacent offshore waters. However, a natural consequence of their organic rich sediments is periodic oxygen depletion within the tidal creeks, particularly during the summer. The observed level of oxygen depletion in the Scorton Creek salt marsh system is expected, as was the nearly identical pattern recorded by the MEP Technical Team in nearby Namskaket and Little Namskaket Creeks, both located on Cape Cod Bay in the Town of Orleans. Assessment of habitat quality must necessarily consider the natural function and tolerances of the specific estuarine ecosystems being evaluated. The specific results are as follows:

Barnstable Harbor-Bass Hole DO/CHLA Moorings (Figures VII-3 through VII-8):

The Barnstable Great Marsh estuary system is functionally a combination of a large open water main basin with a large tidal range and extensive sand flats and swept sands combined with large tidal salt marsh (the Great Marshes) that has several central tidal creeks and a large tributary salt marsh (Bass Hole, aka Chase Garden Creek) with a central tidal creek.. There are also a number of smaller salt marsh creeks tributary to the main open water basin. The upper reaches of the tidal creeks that penetrate into the salt marshes abutting the main open water basin have nearly vertical creek banks surrounded by extensive emergent marsh vegetated with typical New England high and low salt marsh plants. The lower reaches of the tidal creeks form broader creeks with sediments comprised of marsh deposits and sand transported in by coastal processes. The mid and lower portions of the central creeks have high tidal velocities as they drain water from the extensive upper marsh areas. As a result, the creek bottom sediments of the mid and lower reaches primarily consist of migrating fine and medium sands with some areas of coarse sand and gravel. The sides of the creeks consist of eroding salt marsh peat. In contrast, the upper creek areas support organic rich sediments with some fine sand mixed in. The tide range in adjacent Cape Cod Bay is large, ~10 ft (Chapter V), and the salt marsh areas are regularly flooded at high tide and the salt marsh creeks drain nearly completely with each ebb tide. This is significant when interpreting periodic low DO measurements at some of the mooring sites located in salt marsh dominated areas of this estuarine system.

Moderate to large diurnal shifts in dissolved oxygen were measured at each of the 6 mooring sites, but this is particularly evident in the four (4) moorings deployed in the main tidal creeks discharging to Barnstable Harbor (e.g. Scorton Creek, Spring Creek and Chase Garden Creek which is the main tidal creek that makes up Bass Hole. Interestingly, both the Scorton Creek and the Spring Creek moorings generally maintained oxygen levels >4 mg L^{-1}, which is relatively high for salt marsh creeks. It is likely that the near draining of the creek water at low tide and the large tidal flows with low nutrient and high oxygen Cape Cod Bay water plays a significant role in the oxygen balance, as does the low organic sandy sediments with only moderate levels of oxygen uptake (D. Schlezinger, personal communication). Overall, the oxygen conditions are generally higher than in smaller enclosed temperate salt marshes which are naturally organic and nutrient rich ecosystems. The chlorophyll-*a* levels are generally consistent with this conclusion, however, the average levels over 4 of the deployments were moderate, ranging from 10.2 - 15.2 ug L^{-1} for the two moorings located in the Great Marsh (Scorton Creek and Spring Creek) and 8.5 - 9.0 ug L^{-1} for the two moorings located in Bass Hole (lower and upper respectively. Equally important the Town Water Quality Monitoring Programs have long-term chlorophyll-*a* records from traditional sampling approaches with comparable averages of 3.9 – 6.5 for the main basin, 8.9 – 11.6 in the small tidal creeks of the Great Marshes along the southern shore of the main basin and 8.5 and 9.0 for lower and upper Bass Hole. The high tidal flushing does not generally allow a buildup of phytoplankton during the short residence time (generally < 1 tidal cycle) of phytoplankton within the tidal creeks, however, it is evident in that periodic blooms do occur mainly in the tributary tidal creeks as seen in the continuous records from Scorton Creek and the Spring Creek during the last third of the deployment period. A similar bloom event appears to be developing around the same point in time at the Blish Point mooring located in the mid central open water basin near the inlet to the Millway. Similarly, a bloom event was observed in the tributary marsh of Bass Hole though the upper and lower moorings in that salt marsh indicate that the bloom began earlier than in the Great Marshes, in the first two weeks of the deployment.

In regard to the dissolved oxygen records from the moorings deployed in the salt marsh creeks, the high velocities appear to reduce the sediment oxygen demand and promote sandy oxidized surface sediments over much of the mid and lower tidal reaches. However, it appears that transfers from the emergent marsh and from the upper to lower marsh are sufficient to create the observed periodic low oxygen levels such as those measured in Bass Hole and at times in Spring Creek. It should be noted that there were no prolonged (e.g. several day) hypoxic events in this system, as found in impaired open water basins and the degree of oxygen depletion was significantly less than observed in many healthy New England and Cape Cod salt marshes. Instead, oxygen levels generally cycled from atmospheric equilibration (7 - 8 mg L^{-1}) to ~ 4 to ~2 mg L^{-1} for all sites.

The low to moderate chlorophyll-*a* concentrations at all the mooring locations show modest enhancement over the offshore waters, as the near complete exchange of tidal waters on each tide in the creeks does not allow for chlorophyll levels to build. The absence of prolonged (i.e. multi tidal cycle) oxygen depletion, typically found in nitrogen enriched embayments (due to stimulation of phytoplankton), supports the concept that tidal exchange and natural marsh processes are the primary controls on oxygen dynamics in this estuary. In fact, the daily average dissolved oxygen concentration varied inversely with the tidal amplitude suggesting that longer residence time and greater areal submergence of the marsh was responsible for the lowest oxygen observed oxygen levels. Further evidence for the dominance of marsh processes is the lack of linkage between the observed variations in chlorophyll and the extent of oxygen depletion. In embayments, oxygen minima are typically observed as a bloom declines (senesces), a pattern not seen in the Great Marshes (the opposite is recorded by the Scorton Creek mooring) and only slightly in Bass Hole. Consistent with this latter observation is that the long-term average TN level

at the mooring sites ranged from 0.43-44 mg N L^{-1} in the central main basin to 0.58-0.74 mg N L^{-1} in the tributary tidal creeks and generally <0.50 mg L^{-1} in the mid and lower waters of Bass Hole, The pattern and magnitude of oxygen depletion again does not follow the observed nitrogen gradients, particularly in Bass Hole, as has been found for most embayment systems. It is clear that the organic rich nature of the upper portions of salt marsh creeks and the low organic deposition in the high velocity areas are a predominant control of oxygen levels. It should be noted that the observed levels of TN is typical of salt marsh creeks, and does not indicate impairment in that type of environment. Overall, based upon the measured levels of oxygen and chlorophyll and comparisons to other unimpaired salt marshes tributary to Cape Cod Bay, it does not appear that the Barnstable Great Marsh estuary system is impaired based on these metrics.

Unlike the bulk of the Barnstable Great Marsh estuary system, the Millway is an artificial basin, dredged for navigation and to support marina activities, similar to Rock Harbor, Orleans. The Millway receives ebbing water from Maraspin Creek, a New England pocket salt marsh. Presently, the Millway functions as an open water basin and as such is more sensitive to nitrogen enrichment than the nearby salt marsh areas. Oxygen levels in the Millway were generally high over the record, however there were periods of significant oxygen depletion for an open water basin, <4 mg L^{-1} for 5% of the record. The main issue is that the low oxygen event, with declines to 2 mg L^{-1}, comprised an event rather than sporadic daily depletions over the 36 day record, which suggests stress to benthic animal communities within this basin. It is likely that a deepened basin within a greater salt marsh system and down gradient from Maraspin Creek Marsh, has created an enhanced depositional environment (for phytoplankton and marsh detritus) where sediment processes may be facilitating oxygen demand and supporting the observed oxygen depletion.

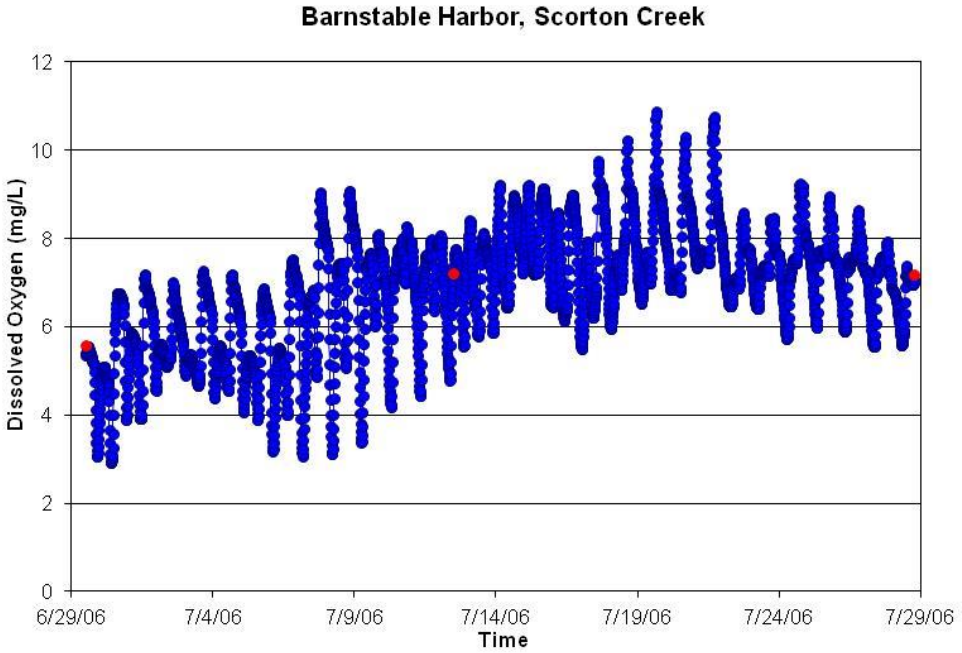


Figure VII-3. Bottom water record of dissolved oxygen at the Barnstable Harbor-Scorton Creek station (BH-01), Summer 2006. Calibration samples represented as red dots.

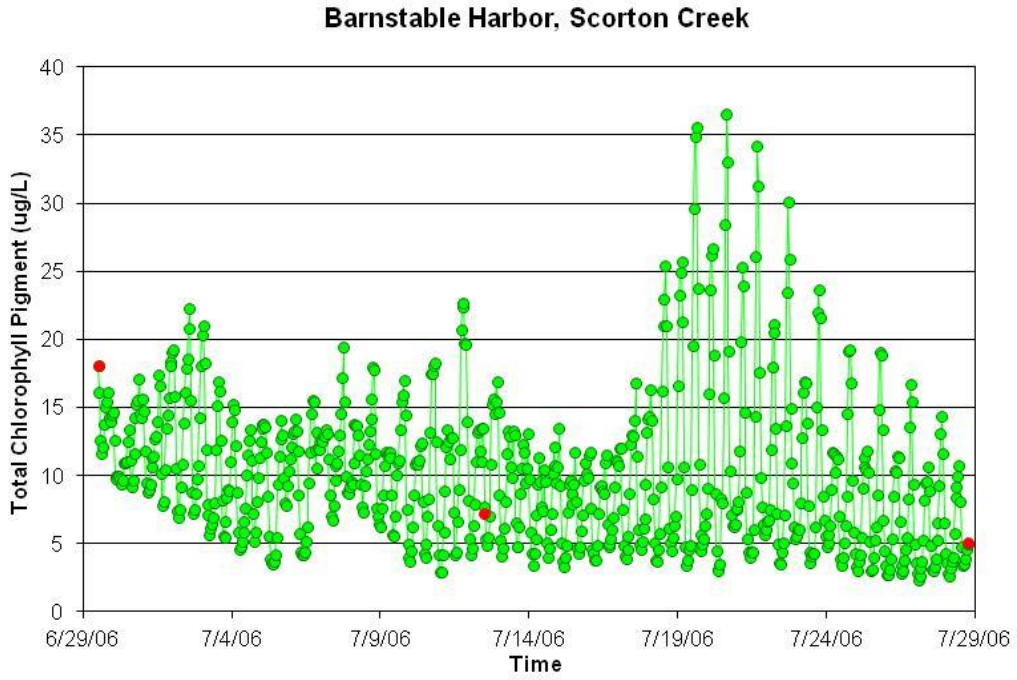


Figure VII-4. Bottom water record of total pigment (Chlorophyll-*a*+pheophytin) in the Barnstable Harbor-Scorton Creek station (BH-01), Summer 2006. Calibration samples represented as red dots.

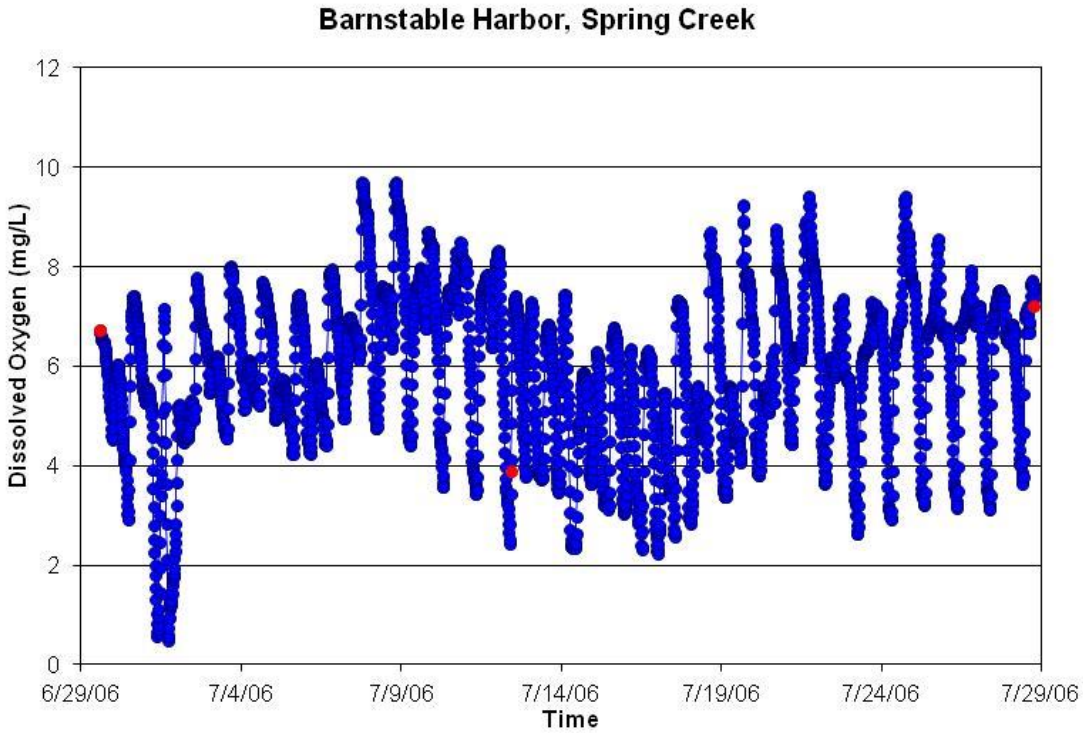


Figure VII-5. Bottom water record of dissolved oxygen at the Barnstable Harbor-Spring Creek station (BH-02), Summer 2006. Calibration samples represented as red dots.

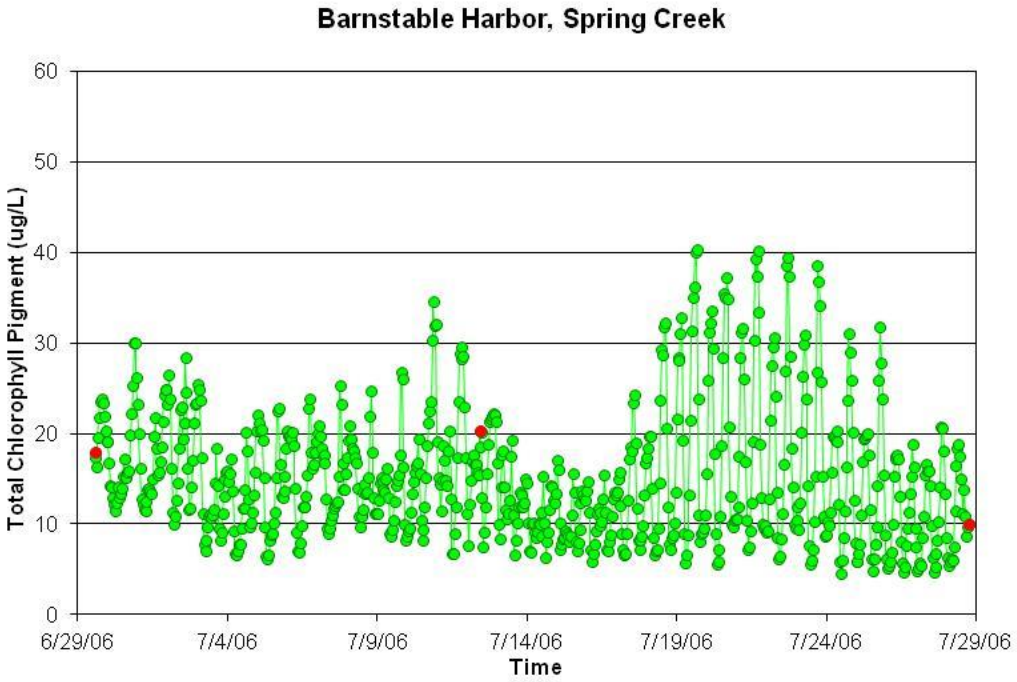


Figure VII-6. Bottom water record of total pigment (Chlorophyll-*a*+pheophytin) in the Barnstable Harbor-Spring Creek station (BH-02), Summer 2006. Calibration samples represented as red dots.

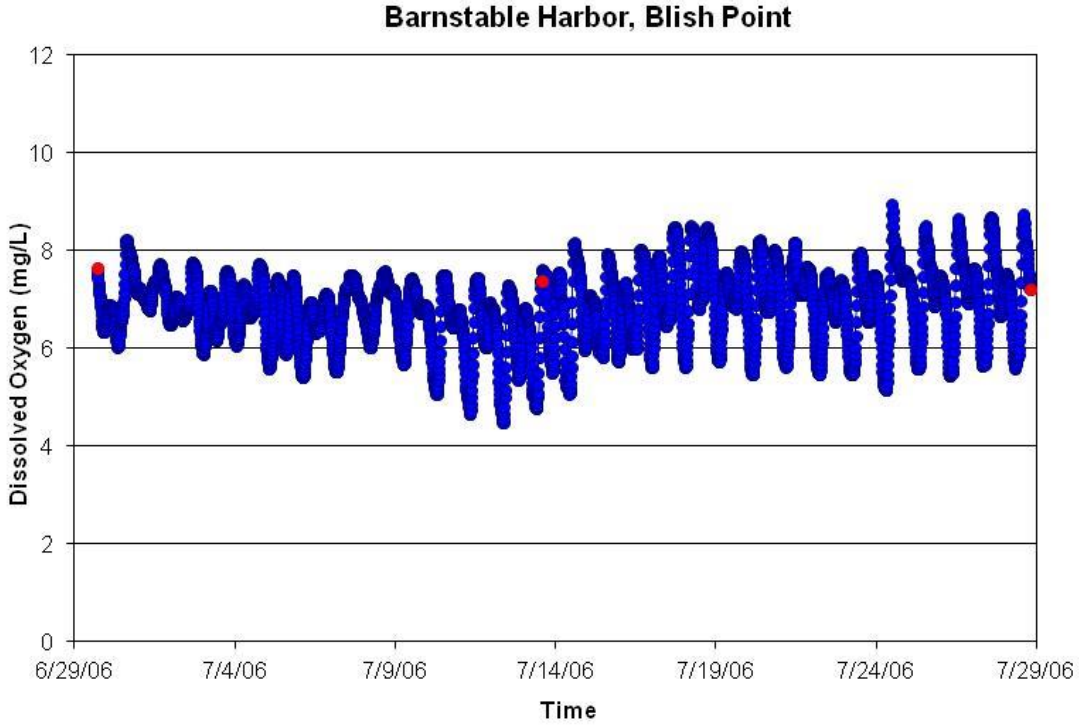


Figure VII-7. Bottom water record of dissolved oxygen at the Barnstable Harbor-Blish Point station (BH-04), Summer 2006. Calibration samples represented as red dots.

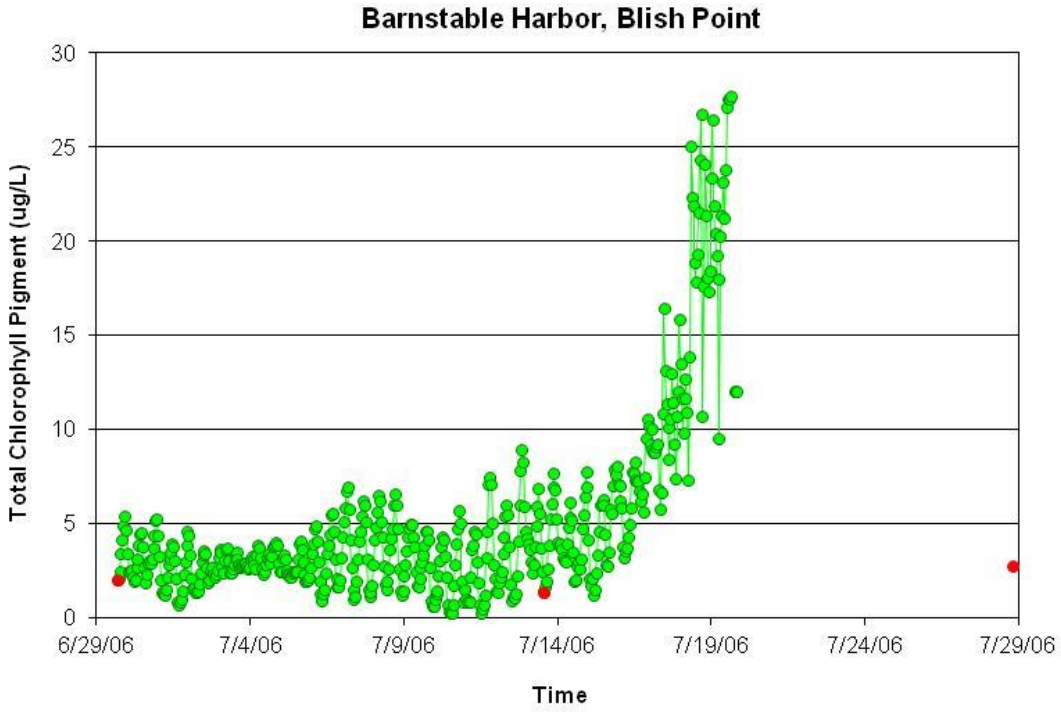


Figure VII-8. Bottom water record of total pigment (Chlorophyll-*a*+pheophytin) in the Barnstable Harbor-Blish Point station (BH-04), Summer 2006. Calibration samples represented as red dots.

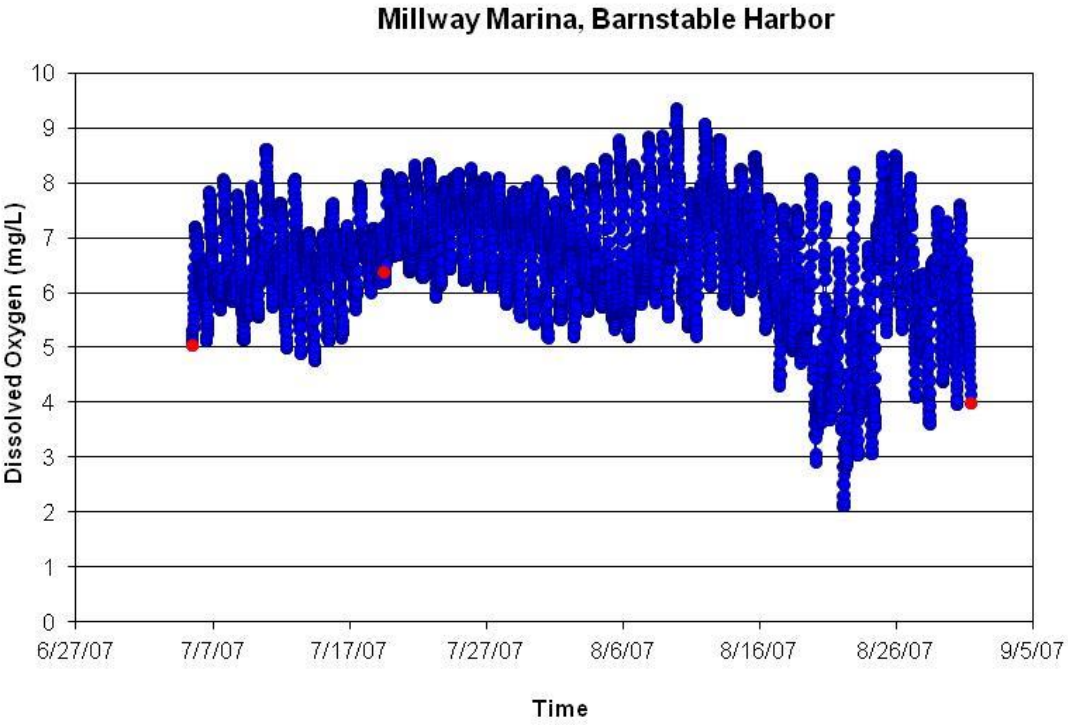


Figure VII-9. Bottom water record of dissolved oxygen at the Barnstable Harbor-Millway Marina station, Summer 2007. Calibration samples represented as red dots.

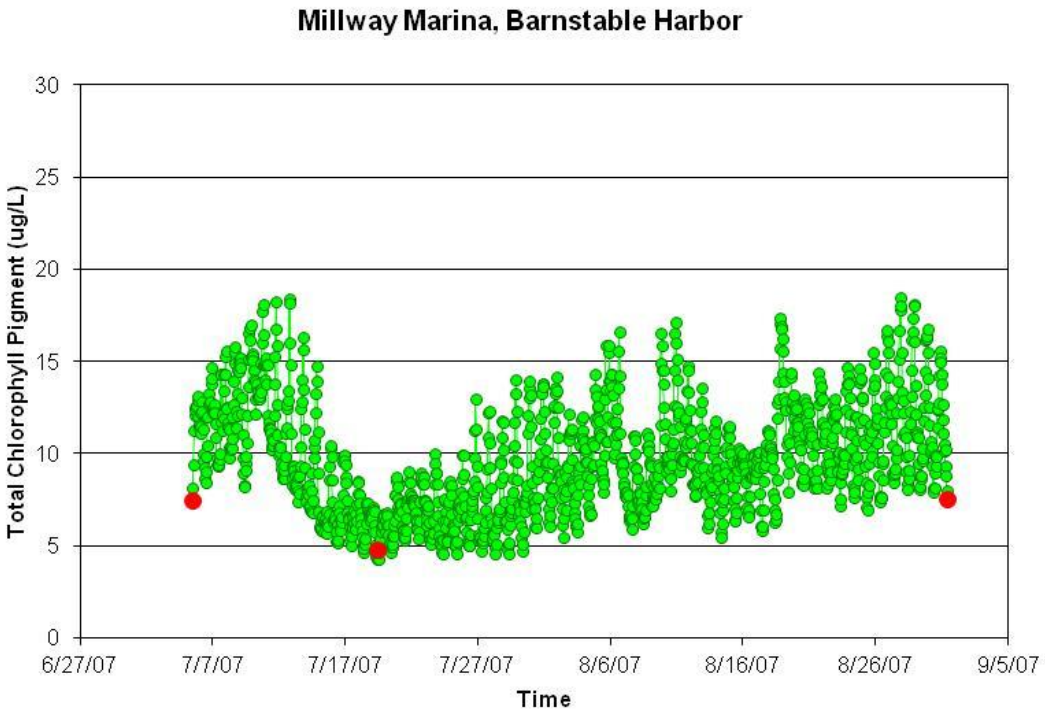


Figure VII-10. Bottom water record of total pigment (Chlorophyll-*a*+pheophytin) in the Barnstable Harbor-Millway Marina station, Summer 2007. Calibration samples represented as red dots.

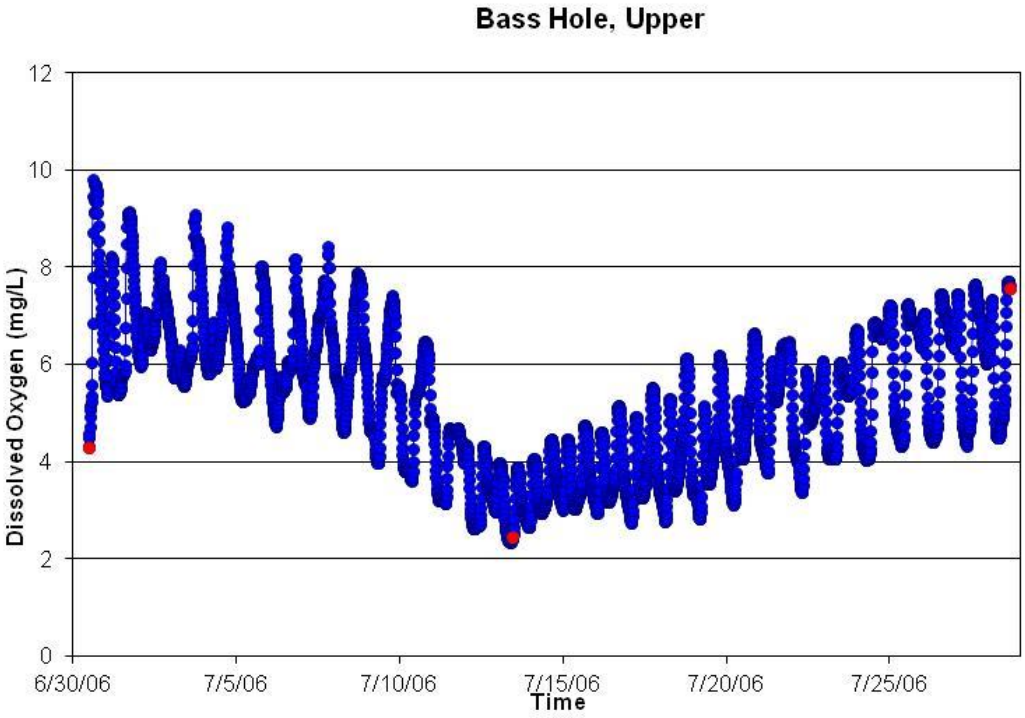


Figure VII-11. Bottom water record of dissolved oxygen at the Bass Hole-Upper station, Summer 2006. Calibration samples represented as red dots.

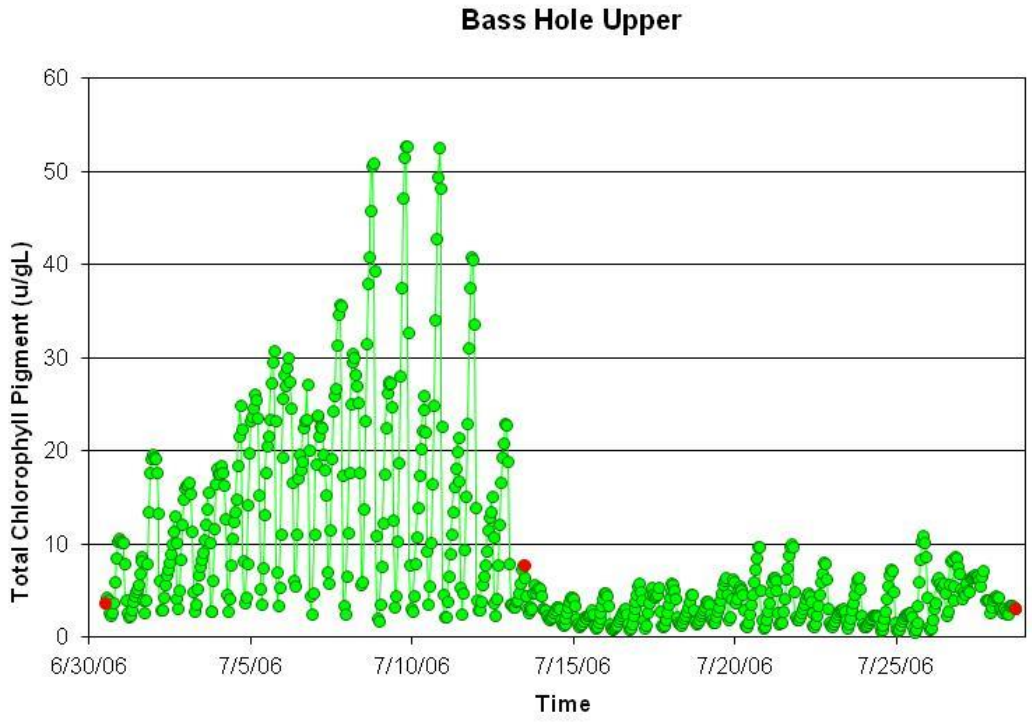


Figure VII-12. Bottom water record of total pigment (Chlorophyll-*a*+pheophytin) at the Bass Hole-Upper station, Summer 2006. Calibration samples represented as red dots.

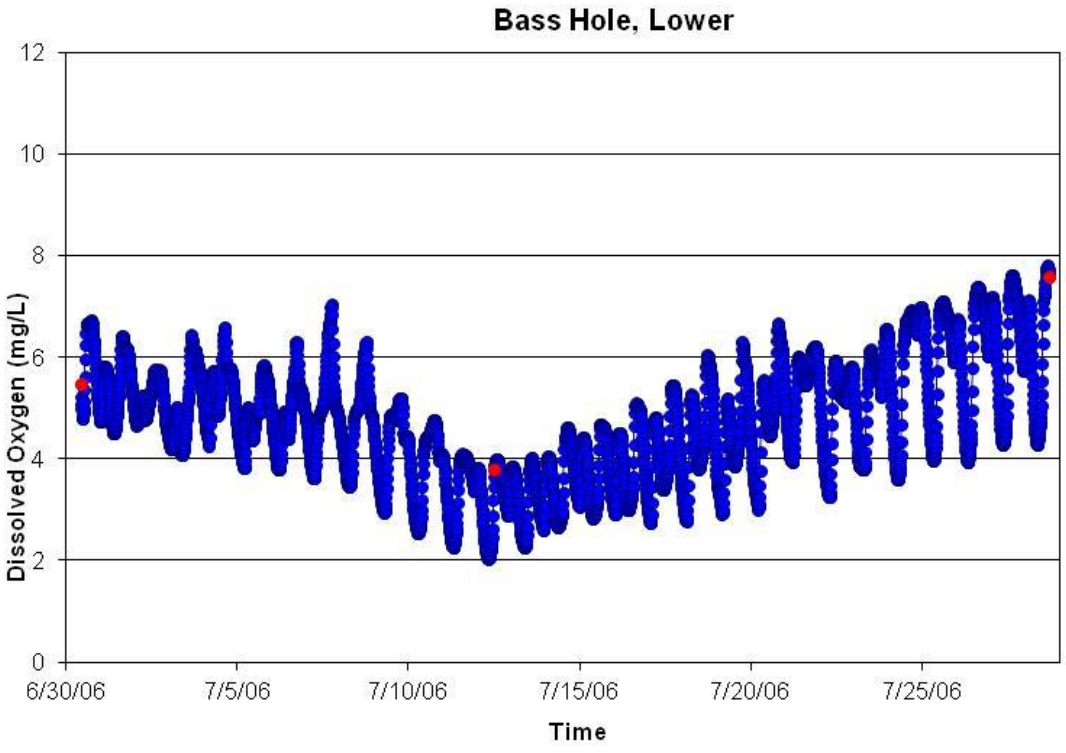


Figure VII-13. Bottom water record of dissolved oxygen at the Bass Hole-Lower station, Summer 2006. Calibration samples represented as red dots.

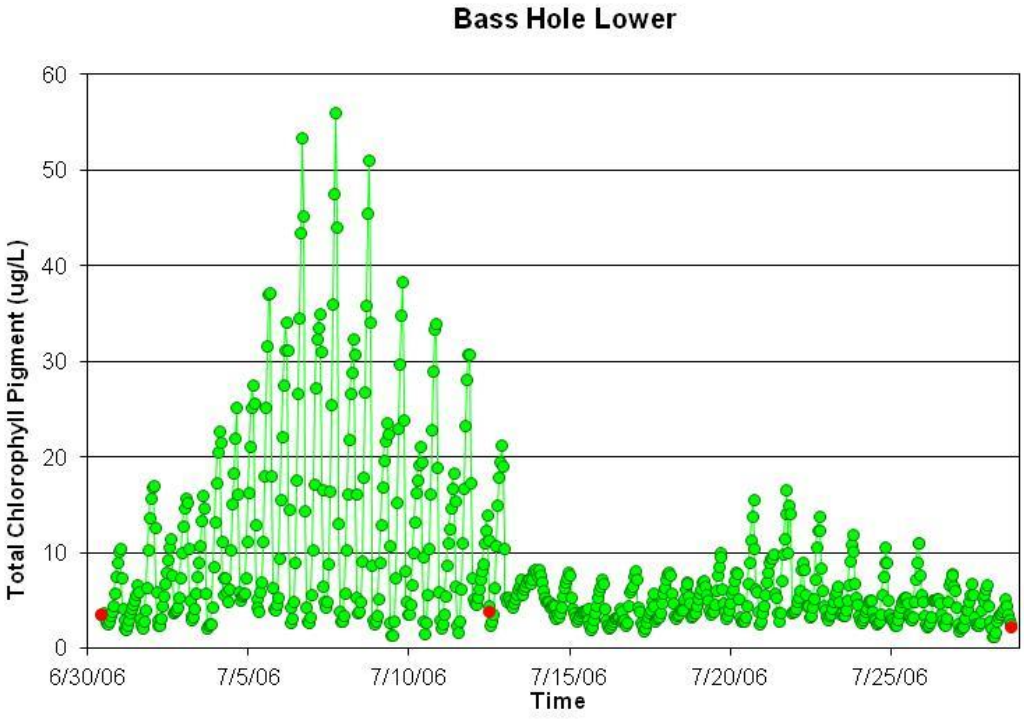


Figure VII-14. Bottom water record of total pigment (Chlorophyll-*a*+pheophytin) in the Bass Hole-Lower station, Summer 2006. Calibration samples represented as red dots.

Table VII-1. Days and percent of time during deployment of in situ sensors that bottom water oxygen was below various benchmark oxygen levels at each of the 6 mooring sites within the Barnstable Great Marsh estuary system. Data collected by the Coastal Systems Program, SMAST.

Mooring Location	Start Date	End Date	Total Deployment (Days)	<6 mg/L Duration (Days)	<5 mg/L Duration (Days)	<4 mg/L Duration (Days)	<3 mg/L Duration (Days)
Bass Hole Lower	**6/30/2006**	**7/28/2006**	**28.3**	**83%**	**60%**	**29%**	**8%**
			Mean	1.12	0.54	0.29	0.15
			Min	0.04	0.06	0.03	0.04
			Max	9.91	6.79	1.88	0.31
			S.D.	2.09	1.18	0.33	0.10
Bass Hole Upper	**6/30/2006**	**7/28/2006**	**28.2**	**66%**	**45%**	**24%**	**5%**
			Mean	0.66	0.56	0.34	0.15
			Min	0.03	0.05	0.01	0.04
			Max	7.86	5.73	1.43	0.32
			S.D.	1.44	1.14	0.28	0.11
Millway Marina	**7/5/2007**	**8/31/2007**	**36.1**	**43%**	**13%**	**5%**	**1%**
			Mean	0.24	0.18	0.09	0.07
			Min	0.01	0.01	0.01	0.01
			Max	0.93	0.77	0.48	0.11
			S.D.	0.22	0.21	0.10	0.04
Scorton Creek	**6/29/2006**	**7/28/2006**	**29.2**	**25%**	**10%**	**3%**	**0%**
			Mean	0.30	0.15	0.09	0.05
			Min	0.03	0.03	0.03	0.05
			Max	1.02	0.31	0.14	0.05
			S.D.	0.29	0.08	0.04	NA
Blish Point	**6/29/2006**	**7/28/2006**	**29.1**	**17%**	**1%**	**0%**	**0%**
			Mean	0.16	0.12	NA	NA
			Min	0.01	0.09	0.00	0.00
			Max	0.28	0.16	0.00	0.00
			S.D.	0.07	0.03	NA	NA
Spring Creek	**6/29/2006**	**7/28/2006**	**29.2**	**49%**	**29%**	**15%**	**4%**
			Mean	0.36	0.20	0.16	0.11
			Min	0.02	0.02	0.01	0.02
			Max	0.94	0.38	0.33	0.30
			S.D.	0.22	0.09	0.08	0.09

Table VII-2. Duration (days and % of deployment time) that chlorophyll-a levels exceed various benchmark levels at each of the 6 mooring sites within the Barnstable Great Marsh estuary system. "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

Mooring Location	Start Date	End Date	Total Deployment (Days)	>5 ug/L Duration (Days)	>10 ug/L Duration (Days)	>15 ug/L Duration (Days)	>20 ug/L Duration (Days)	>25 ug/L Duration (Days)
Bass Hole Lower	**6/30/2006**	**7/28/2006**	**28.3**	**54%**	**23%**	**15%**	**9%**	**7%**
Mean Chl Value = 8.5 ug/L			**Mean**	0.30	0.23	0.19	0.16	0.16
			Min	0.04	0.04	0.04	0.04	0.04
			Max	0.96	0.33	0.29	0.21	0.21
			S.D.	0.17	0.08	0.08	0.06	0.05
Bass Hole Upper	**6/30/2006**	**7/28/2006**	**28.3**	**48%**	**28%**	**21%**	**13%**	**8%**
Mean Chl Value = 9.0 ug/L			**Mean**	0.32	0.33	0.28	0.23	0.18
			Min	0.04	0.13	0.04	0.04	0.04
			Max	0.96	0.42	0.38	0.33	0.29
			S.D.	0.22	0.09	0.10	0.08	0.09
Millway Marina	**7/5/2007**	**8/31/2007**	**57.1**	**98%**	**40%**	**5%**	**0%**	**0%**
Mean Chl Value = 9.3 ug/L			**Mean**	4.30	0.44	0.14	NA	NA
			Min	0.04	0.04	0.04	0.00	0.00
			Max	32.08	2.42	0.38	0.00	0.00
			S.D.	9.02	0.37	0.09	NA	NA
Scorton Creek	**6/29/2006**	**7/28/2006**	**29.3**	**81%**	**46%**	**15%**	**5%**	**2%**
Mean Chl Value = 10.2 ug/L			**Mean**	0.63	0.22	0.13	0.12	0.08
			Min	0.04	0.04	0.04	0.08	0.04
			Max	4.75	0.67	0.25	0.17	0.13
			S.D.	0.86	0.12	0.06	0.03	0.04
Blish Point	**6/29/2006**	**7/28/2006**	**20.2**	**30%**	**11%**	**7%**	**4%**	**1%**
Mean Chl Value = 5.2 ug/L			**Mean**	0.34	0.28	0.27	0.18	0.07
			Min	0.04	0.04	0.04	0.08	0.04
			Max	3.42	0.96	0.50	0.38	0.17
			S.D.	0.77	0.31	0.21	0.12	0.06
Spring Creek	**6/29/2006**	**7/28/2006**	**29.4**	**99%**	**73%**	**44%**	**21%**	**10%**
Mean Chl Value = 15.2 ug/L			**Mean**	4.85	0.42	0.23	0.16	0.14
			Min	0.42	0.04	0.04	0.04	0.04
			Max	25.00	2.67	0.63	0.29	0.21
			S.D.	9.87	0.39	0.15	0.09	0.06

VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS

Eelgrass surveys and analysis of historical data is key part of the MEP Approach. Surveys were conducted in 1995 and 2001 in the vicinity of the mouth of the Barnstable Great Marsh estuary system by the DEP Eelgrass Mapping Program to be integrated into the MEP effort. These surveys were essentially in the near shore waters of Cape Cod Bay and into the mouth of the Barnstable Harbor system but did not extend into the tidal creeks of the Great Marshes portion of the system or Bass Hole. The primary use of the data is to indicate (a) estuarine regions that have historically or presently support eelgrass habitat, and (b) if large-scale system-wide shifts have occurred. To the extent that surveys have been conducted these data sets can provide a view of temporal trends in eelgrass distribution from 1995 to 2001 to 2010-2013 (Figure VII-15); the period in which watershed nitrogen loading significantly increased to its present level. This temporal information can be used to determine the stability of the eelgrass community. However, MassDEP mapping of the eelgrass beds was not conducted within the component basins of the Barnstable Great Marsh estuary system.

A historical analysis of possible eelgrass distribution (1951) was conducted within the estuary using aerial photos, which showed only a limited area supporting eelgrass. The photographic analysis indicated the possible presence of eelgrass in the open water portion of Barnstable Harbor close to the mouth and east of what is commonly referred to as the Millway. This is likely because many of the central basin areas have very dynamic sediments, with unstable sands that do not support eelgrass. The MEP Technical Team confirmed that eelgrass is not currently present in the tidal creeks to the Great Marshes portion of the system or Bass Hole while undertaking field surveys as part of the benthic regeneration and infauna studies and during the deployment and recovery of the instrument moorings (summer and fall 2007).The absence of any eelgrass, was consistent with a salt marsh dominated system that is also composed of a large open water area with a large tidal range, strong tidal currents and large areas of shifting sand flats and sand waves. As a result of the absence of eelgrass or documentation indicating eelgrass loss due to nitrogen enrichment, temporal changes in eelgrass distribution could not provide a basis for evaluating recent increases (nitrogen loading) in nutrient enrichment of Barnstable Harbor and Bass Hole. It should be noted that the historical eelgrass distribution is not confirmed or validated. None-the-less to the extent that it existed, the cause of its disappearance is consistent with a non-nitrogen factor, due to the low phytoplankton and macroalgal biomass, oxidized sediments, fully oxygenated water column (>6 mg/L in 98% of 133 sampling dates by Barnstable Water Quality Monitoring Program) and high light penetration in that region of the estuary. The most likely cause appears to be associated with high tidal velocities, unstable sediments and possibly winter storm exposure. Unstable sediments (shifting sands) have been identified as the mechanism causing eelgrass loss adjacent the 2007 tidal inlet to Pleasant Bay, and similarly the very poor habitat for benthic animals in portions of Chatham Harbor. Aerial photos of the Great Marshes document the extensive swept sands (Figure VII-2, VII-15,16) in the eastern region of the Great Marshes open water basin and tidal inlet. In addition, the absence of eelgrass from the tidal creeks like those tributary to the Great Marsh is typical of Cape Cod salt marshes which do not generally support eelgrass habitat, particularly when the creeks nearly completely drain during each ebb tide The absence of eelgrass, for at least the past 60 years, has been documented for Namskaket and Little Namskaket Marshes, to the north also on Cape Cod Bay as well as Sandwich Harbor and Scorton Creek to the west of Barnstable Harbor, all salt marsh dominated systems with large tidal ranges on Cape Cod Bay.

In contrast to the estuarine basins, an area of eelgrass is present offshore slightly to the east of the inlet to Barnstable Harbor, based on the 1995, 2001 and 2010-2013 eelgrass survey conducted by the DEP Eelgrass Mapping Program. However, there was no evidence of the eelgrass bed in the same area during the 2006 survey of this small offshore bed. It is not possible at this time to determine if this represents an anthropogenically driven decline or natural variation at this site, however, given the dynamic nature of this area, it is possible that the lack of eelgrass during the 2006 survey could be the result of storm activity and vigorous littoral transport. Additional spatial and temporal sampling undertaken by the MassDEP Eelgrass Mapping Program in the future might be a way to better understand shifts in eelgrass beds in that area.

Based on the salt marsh dominated function of large portions of the Barnstable Great Marsh estuary system, historical absence of eelgrass in all of the other salt marsh systems on Cape Cod that exchange waters with Cape Cod Bay and the similarity of these tidal creeks to Sandwich Harbor, Scorton Creek, Namskaket Creek and Little Namskaket Creek that have also not historically supported eelgrass habitat, the MEP Technical Team concludes that the Barnstable Great Marsh estuary system has not supported eelgrass for many decades, if not longer. Based upon all available information, it appears that the Barnstable Great Marsh estuary system is not structured to support eelgrass habitat. Therefore, threshold development for protection/restoration of this system will focus on infaunal animal habitat quality. This is typical for New England salt marsh dominated estuaries, which are naturally organic and nutrient rich and generally contain little water in the creeks at low tide as well as having open water areas with strong tidal currents and actively shifting sand bottoms near their tidal inlets. This conclusion has been confirmed in a wide range of salt marsh dominated basins throughout southeastern Massachusetts by the MEP Technical Team.

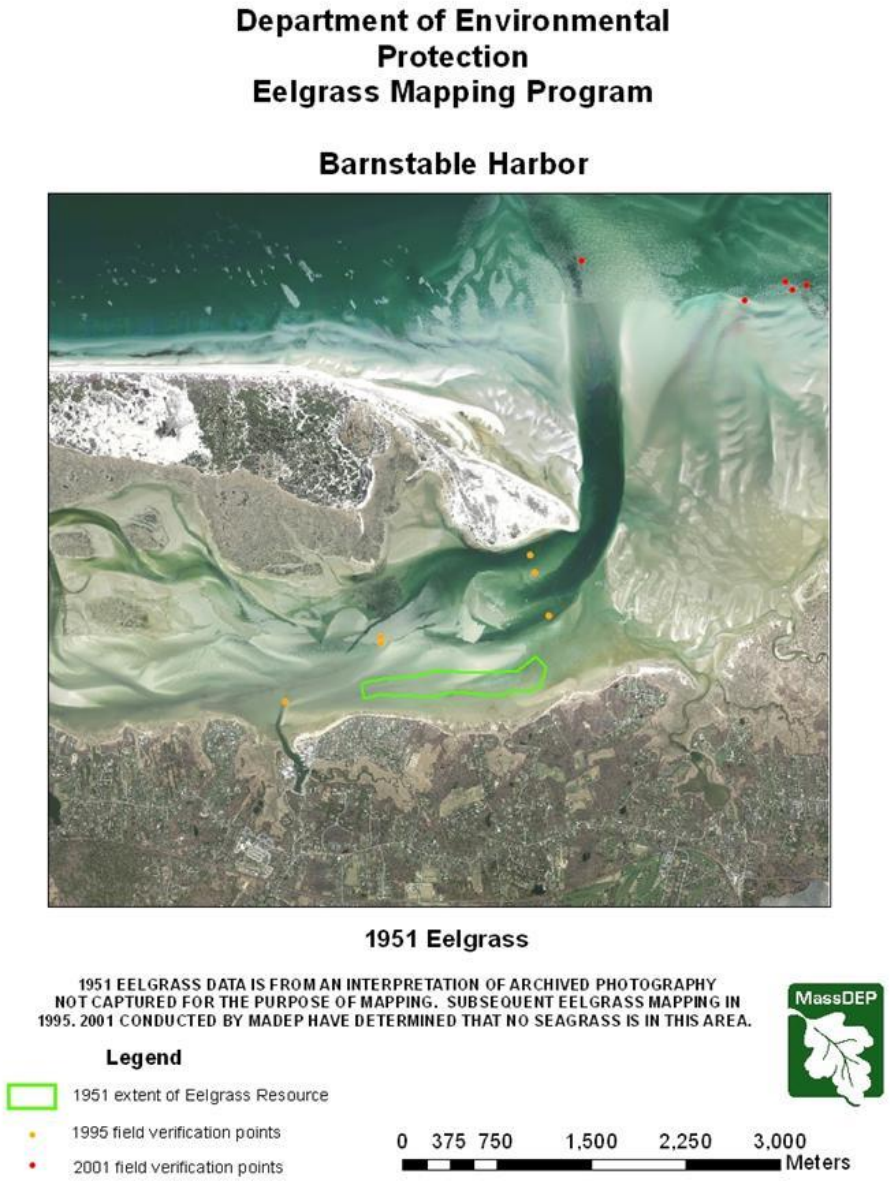


Figure VII-15. Estimated eelgrass bed distribution in Barnstable Harbor based on photo-interpretation of 1951 aerial. Beds were not identified in 1995 and 2001 (map from the MassDEP Eelgrass Mapping Program). MassDEP surveying did not extend into the salt marsh tidal creeks, however, no eelgrass was observed in the Barnstable Great Marsh estuary system during SMAST-MEP surveying in 2007.



Figure VII-16. Eelgrass bed distribution offshore of the Barnstable Great Marsh estuary system (2010-2013). Beds were not identified in 1995 and 2001 (map from the MassDEP Eelgrass Mapping Program). MassDEP surveying did not extend into the salt marsh tidal creeks, however, no eelgrass was observed in any of the component basins during SMAST-MEP surveying in 2007.

VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling was conducted at 23 locations within the major tidal creeks and open water areas throughout the Barnstable Great Marsh estuary system (Figure VII-17), with replicate assays at each site. In all areas and particularly those that do not support eelgrass beds, benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity (H') and Evenness (E) of the community. It should be noted that, although there are no eelgrass beds in the entirety of the system, this is almost certainly due to the system functioning as a large intertidal salt marsh as well as the fact that the open water area is dynamic and dominated by shifting sand flats. The Great Marshes and Bass Hole portions of the system, like all the other large salt marshes tributary to Cape Cod Bay, do not appear to have historically supported eelgrass habitat and therefore the absence of eelgrass is "natural" and does not indicate impairment. As such, to the extent that the overall embayment system can support healthy infaunal communities given specific nutrient conditions in the water column, the benthic infauna analysis is important for determining the level of impairment (moderately impaired→significantly impaired→severely degraded). This assessment is also important for the establishment of site-specific nitrogen thresholds (Section VIII).

Barnstable Harbor Infaunal Characteristics:

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information (Table VII-3). The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas, as shown by the oxygen and chlorophyll records and eelgrass coverage, have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5. The infauna study of the salt marsh dominated portions of the estuary and the open water lower main basin indicated that the tidal creeks are presently supporting a salt marsh infaunal habitat typical of large unimpaired salt marsh systems on Cape Cod with open basins in their lower reaches. Infauna communities within the tidal creeks were indicative of the fine grained organic rich environment typical of salt marshes or of high velocity areas with sandy sediments and were consistent with the observed levels of oxygen depletion and water column TN. The communities within the upper reach had high numbers of individuals with moderate numbers of species and diversity and Evenness as also was found in the tributary creeks in the lower estuary, while the lower open basin supported highly productive communities with moderate to high diversity and Evenness. Only the small artificial marina basin of the Millway showed any impairment of benthic habitat. All of the areas surveyed supported almost no stress indicator organisms (Tubificids, Capitellids) and were generally dominated by polychaetes (Spionids) with some crustaceans and mollusks. Most species were deposit feeders, similar to other New England salt marshes. Areas of high tidal water velocities in some portions of the main channel have winnowed the fines from the sediments and created a medium to coarse sand with shifting sediments. The result is similar to tidal inlets or Chatham Harbor's shifting sands which do not

support extensive benthic habitat, being naturally disturbed. The observed communities in the tributary creeks and upper main basin were typical of New England salt marsh creek bottom environments in summer. The soft-bottomed areas supported communities with organic enrichment tolerant species and were dominated by *Streblospio* and polychaetes, the major invertebrate family comprising the benthos. Also present were significant numbers of crustaceans and mollusks. Sediments throughout the estuary (exception of Millway) were oxidized and consolidated with no observed anoxia, but periodic oxygen depletion typical of salt marshes, high water quality and low to moderate chlorophyll-*a.* In addition, the bioactive nitrogen levels (dissolved inorganic N = particulate organic N, i.e. DIN + PON) were generally low (long term averages, <0.16 mg N L^{-1}) except in upper creeks at low tide where creek water is highly modified by groundwater inflows. Bioactive N was selected as the critical nitrogen form for analysis of the Barnstable Great Marsh estuary system due to the very high background dissolved organic nitrogen (DON) associated with the extensive salt marsh areas. Bioactive nitrogen was also the critical management element in the Pleasant Bay Estuary MEP analysis for the same reasons (see Howes et al. 2006 and Chapter VIII-2). This approach is supported by very low reactivity of dissolved organic matter in coastal waters, with measurements age of over 1,000 years. Moreover, while the DIN in bioactive N is readily available for plant uptake on the order of minutes to hours and PON can settle to the sediments and be degraded, the refractory nature of DON gives is a negligible role in this estuary's potential eutrophication. Given the high rate of water turnover within the Barnstable Great Marsh estuary system would mean that the nitrogen in DON would need to be biologically available within 24-48 hours, the flushing time of most of the main basin and tidal creeks comprising this system or it is removed to Cape Cod Bay without having an effect on the estuary.

Overall, the infauna survey indicated that all areas within the Barnstable Great Marsh estuary system are supporting healthy infauna habitat typical of open salt marsh dominated basins or organic rich New England salt marsh tidal creeks, hence high quality relative to each specific estuarine ecosystem type. The mid-lower main channel is partially structured by its areas of high water velocity and physical disturbance to the sediment. The lack of nitrogen related impairment is supported by the general absence of surface algal mats and macroalgae, with only a few patches of very sparse *Ulva* or *Gracillaria* being observed. The near absence of macroalgal accumulations is consistent with the relatively low bioactive nitrogen levels within the saline waters of this system, <0.13 mg N L^{-1} (long-term average). By comparison, high quality benthic habitat in sub-basins of the system was found at 0.21 mg L^{-1}. Similarly in the adjacent Scorton Creek Salt Marsh, high quality habitat was found in areas with bioactive N <0.18 mg/L and nearby Sandwich Harbor Estuary with extensive marshes had similarly high quality habitat with similar bioactive N levels $\leq$0.16 mg/L., All of these salt marsh dominated systems had similar environmental conditions, with macroalgal accumulations nearly absent. Based upon all lines of evidence it appears that the Great Marshes and Bass Hole basins are presently supporting high quality infaunal habitat and have not exceeded their threshold nitrogen levels for assimilating additional nitrogen without impairment. The exception is the Millway which functions as a depositional basin functioning as an embayment tributary to the Great Marshes. It appears that the deep basin to support marina and navigation activities is a focal point for deposition of phytoplankton and marsh detritus. The result is benthic habitat consisting of soft unconsolidated (fluid) organic rich sediments without an oxidized surface layer that are sulfidic. The result is a depauperate benthic animal community with <10 organisms per grab, more than an order of magnitude less than even impaired habitats. At present the Millway supports a severely degraded benthic habitat, with very low productivity.

Table VII-3. Benthic infaunal community data for the Barnstable Great Marsh estuary system, which is a major tidal salt marsh system tributary to Harbor. Measured number of species and individuals, with estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations. Samples represent surface area of 0.0625 m^2. Stations refer to map in Figure VII-10.

Sub-Embayment	Station ID	Total Actual Species	Total Actual Individuals	Species Calculated @75 Indiv.	Weiner Diversity (H')	Evenness (E)
Barnstable Great Marshes						
Central Main Basin – lower	BH20,22,26,27	16	680	12	2.53	0.64
Central Main Basin – upper	BH 9,15,17	12	137	7	2.32	0.67
Scorton Creek	BH 1,3,4	8	254	7	1.50	0.51
Spring Creek	BH 6,7	5	193	5	1.40	0.69
Brickyard Creek	BH10,11,12,14	9	819	7	1.77	0.62
Millway/Barnstable Hbr	BH 24	1	9	na	0.32	0.32
Wharf Creek	BH 30	17	300	13	2.74	0.68
Bass Hole						
Bass Hole – lower	Bass 1-3	19	147	14	2.47	0.58
Bass Hole – upper	Bass 5-6	21	412	13	2.90	0.66



Figure VII-17. Aerial photograph of the Barnstable Great Marsh estuary system showing location of benthic infaunal sampling stations (green symbols).

Other Resource Characteristics:

In addition to benthic infaunal community characterization undertaken as part of the MEP field data collection, other biological resources assessments were integrated into the habitat assessment portion of the MEP nutrient threshold development process as developed by the Commonwealth and available. The Massachusetts Division of Marine Fisheries has an extensive library of shellfish resources maps which indicate the current status of shellfish areas closed to harvest (Figure VII-18a,b,c) as well as the suitability of a system for the propagation of shellfish (Figure VII-19). As is the case with few systems on Cape Cod, the majority of Barnstable Great Marsh estuary system is classified as approved for the taking of shellfish at any time during the year. In a few nearshore areas the system is conditionally approved, generally the tidal creeks leaving salt marshes or the areas in the vicinity of discharging tidal creeks. The conditional approval classification for these areas during specific times of the year is most likely due to bacterial inputs from wildlife and birds associated with the wetland areas of the system. One area commonly referred to as the Millway is classified as prohibited to shellfishing as an active marina and possibly due to inputs from storm water, septic systems, and commercial activity. In conjunction with existing shellfish area classifications, the Barnstable Great Marsh estuary system is also classified as supportive of specific shellfish communities (Figure VII-12). The major shellfish species with potential habitat within the Barnstable Great Marsh estuary system are soft shell clams (*Mya*) in the more open water areas that are dominated by sandy bottom and quahogs (*Mercenaria*) that appear to dominate the upper and lower portions of the tidal channel network. Interspersed among the areas suitable for soft shell clams and quahogs are small areas suitable for surf clams.

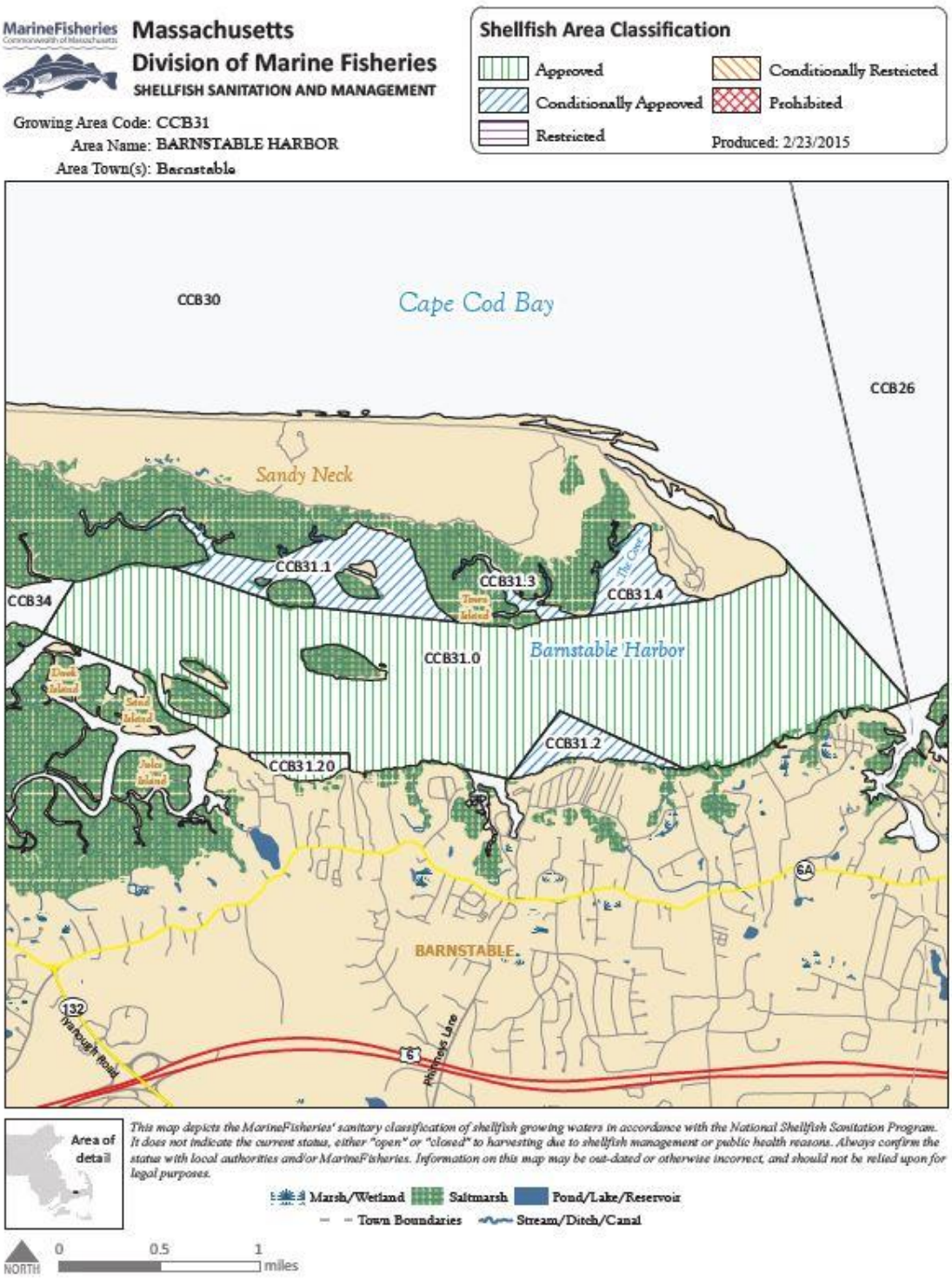


Figure VII-18a. Location of shellfish growing areas in the Barnstable Harbor embayment system and the status relative to shellfish harvesting as determined by Massachusetts Division of Marine Fisheries. Closures are generally related to bacterial contamination from wildlife or human "activities", such as the location of marinas, septic tanks or stormwater discharges.

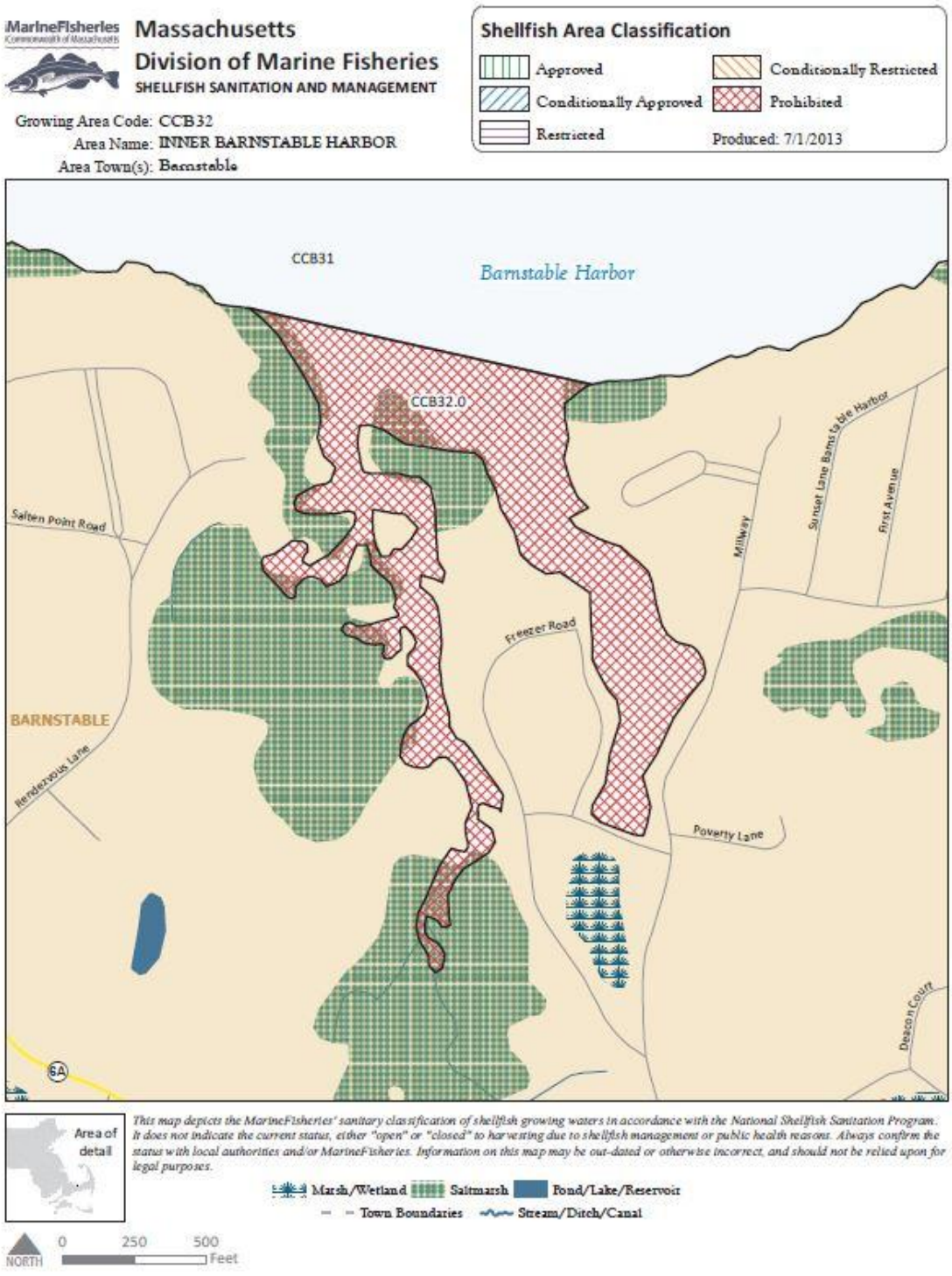


Figure VII-18b. Location of shellfish growing areas in the Millway portion of the Barnstable Harbor embayment system and the status relative to shellfish harvesting as determined by Massachusetts Division of Marine Fisheries. Closures are generally related to bacterial contamination from wildlife or human "activities", such as the location of marinas, septic tanks or stormwater discharges.

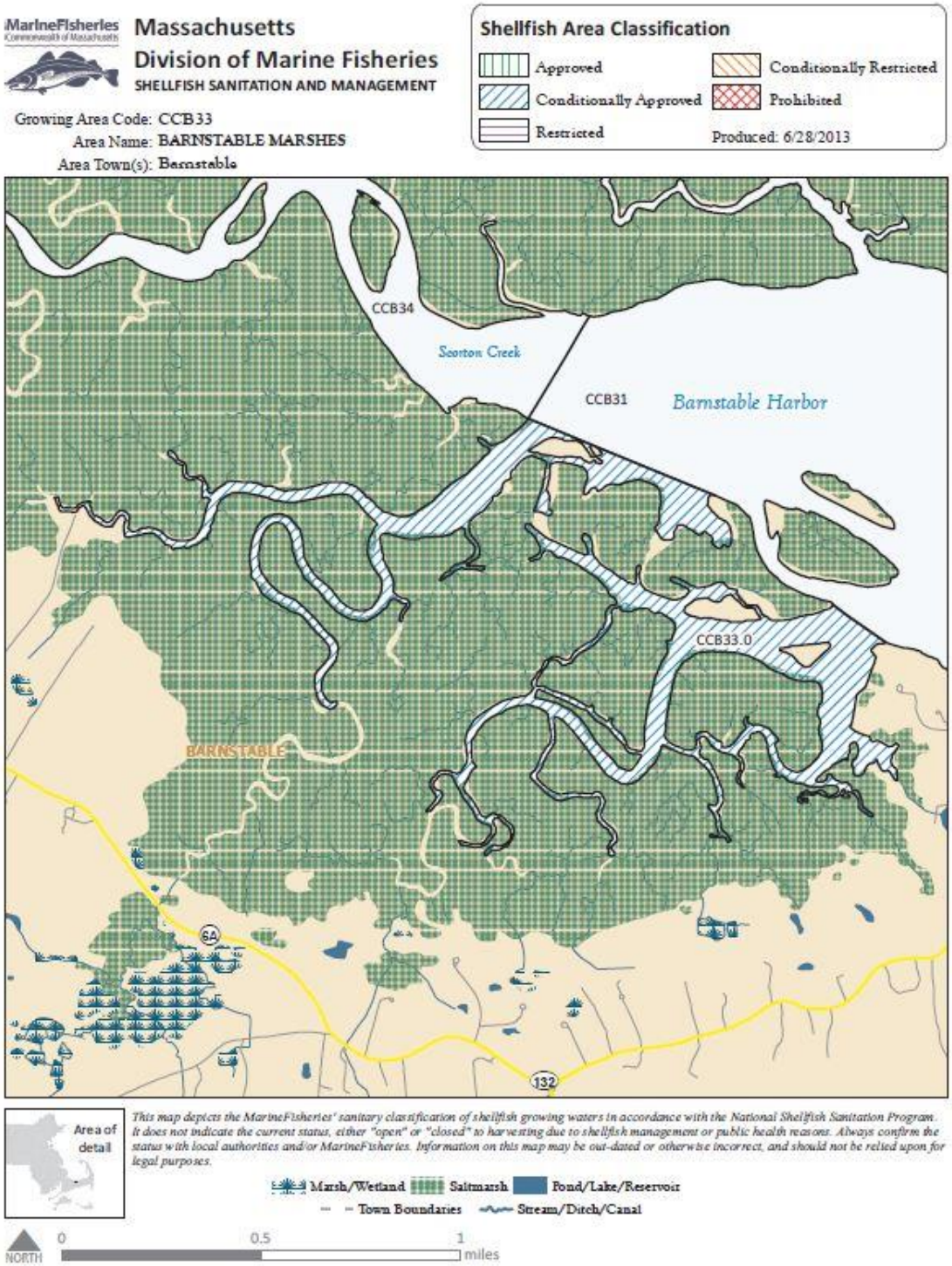


Figure VII-18c. Location of shellfish growing areas in the Great Marshes portion of the Barnstable Harbor embayment system and the status relative to shellfish harvesting as determined by Massachusetts Division of Marine Fisheries. Closures are generally related to bacterial contamination from wildlife or human "activities", such as the location of marinas, septic tanks or stormwater discharges.

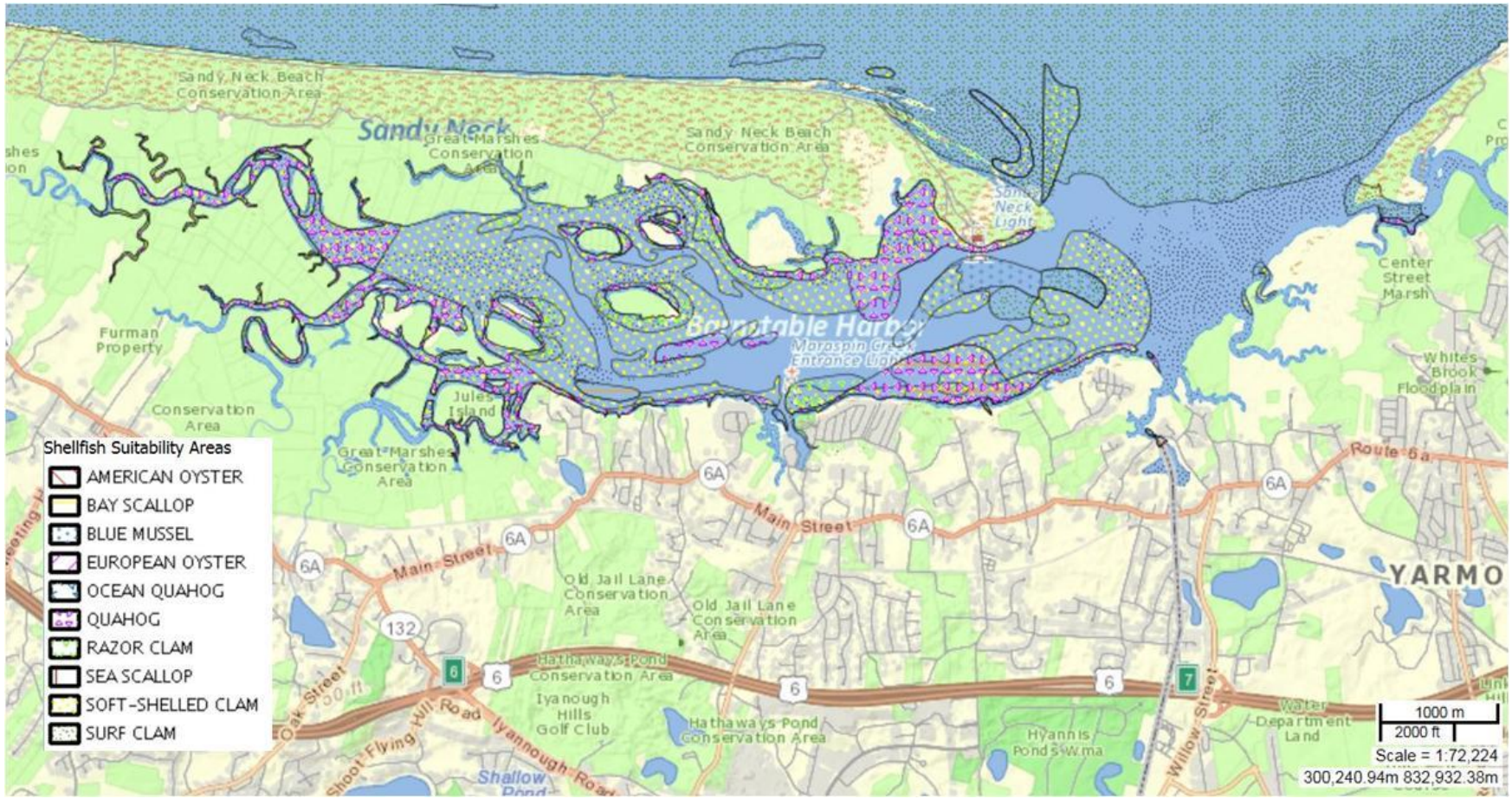


Figure VII-19. Location of shellfish suitability areas within the Barnstable Harbor estuary as determined by Massachusetts Division of Marine Fisheries. Suitability does not necessarily mean "presence". The delineated areas generally coincide with creek bottoms dominated by fine and medium sand.

VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS

VIII.1. ASSESSMENT OF NITROGEN-RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires the integration of key habitat parameters (infauna and eelgrass), sediment characteristic data, and nutrient related water quality information (particularly dissolved oxygen and chlorophyll a). Additional information on temporal changes within each sub-embayment and its watershed further strengthen the analysis. These data were all collected to support threshold development within the component sub-embayments comprising the Barnstable Great Marsh estuary system by the MEP Team and were discussed in Section VII. Nitrogen threshold development builds on these data and links habitat quality to summer water column nitrogen levels from long-term baseline water quality monitoring (Towns of Barnstable and Dennis Water Quality Monitoring Programs, and MEP Technical Team).

The Barnstable Great Marsh estuary system is a complex estuary composed of 3 types of basins: 1) tidal embayments (open water basins with little associated salt marsh), the Millway; 2) open water lower basin with tributary salt marsh creeks (salt marsh dominated open basins), main basin of the Great Marshes; and 3) salt marsh tidal creeks some with organic rich sediments within extensive salt marsh which contain little water at low tide and some with high velocities and areas of shifting sands. Each of these 3 basins has a different natural sensitivity to nitrogen enrichment and organic matter loading and each has its own benthic community indicative of an unimpaired or impaired habitat. Evaluation of habitat quality considered the natural structure of each system and the types of infaunal communities that they support under low and high levels of nitrogen enrichment. Infaunal habitat is the focus of protection/restoration in this complex estuary as eelgrass has not been documented and presumptive eelgrass loss to the extent that it is real, does not appear to be associated with nutrient enrichment At present, the Barnstable Great Marsh estuary system is showing differences in nitrogen enrichment and habitat quality among its various component basins (Table VIII-1).

In field surveys since the 1990's, the Barnstable Great Marsh estuary system have not supported eelgrass habitat. Based on the salt marsh dominated function of large portions of the Barnstable Great Marsh estuary system, historical absence of eelgrass in all of the other salt marsh systems on Cape Cod that exchange waters with Cape Cod Bay and the similarity of these tidal creeks to Sandwich Harbor, Scorton Creek, Namskaket Creek and Little Namskaket Creek, that have also not historically supported eelgrass habitat, the MEP Technical Team concludes that the Barnstable Great Marsh estuary system has not supported eelgrass for many decades, if not longer. Based upon all available information, it appears that the Barnstable Great Marsh estuary system is not structured to support eelgrass habitat. Therefore, threshold development for protection/restoration of this system will focus on infaunal animal habitat quality. This is typical for New England salt marsh dominated estuaries, which are naturally organic and nutrient rich and generally contain little water in the creeks at low tide as well as having open water areas with strong tidal currents and actively shifting sand bottoms near their tidal inlets. This conclusion has been confirmed in a wide range of salt marsh dominated basins throughout southeastern Massachusetts by the MEP Technical Team.

Portions of the estuary and the open water lower main basin indicate that the tidal creeks are supporting a salt marsh infaunal habitat typical of large unimpaired salt marsh systems on

Cape Cod with open basins in their lower reaches. Infauna communities within the tidal creeks were indicative of the fine grained organic rich environment typical of salt marshes or in some cases of high velocity channel areas with sandy sediments. Communities were consistent with the observed levels of oxygen depletion, phytoplankton biomass, the lack of macroalgal accumulations and water column nitrogen The communities within the upper reaches of the creeks had high numbers of individuals with moderate numbers of species and diversity and Evenness as was also found in the tributary creeks in the lower estuary. The lower open basin supported highly productive communities with moderate to high diversity and evenness. Only the small artificial marina basin of the Millway showed any impairment of benthic habitat. All of the areas surveyed supported almost no stress indicator organisms (Tubificids, Capitellids) and were generally dominated by polychaetes (Spionids) with some crustaceans and mollusks. Most species were deposit feeders, similar to other New England salt marshes.

The observed communities in the tributary creeks and upper main basin were typical of New England salt marsh creek bottom environments in summer. The soft-bottomed areas supported communities with organic enrichment tolerant species and were dominated by *Streblospio* and polychaetes were the major invertebrate family comprising the benthos, but with also significant numbers of crustaceans and mollusks. Sediments throughout the estuary were oxidized and consolidated with no observed anoxia, but showed periodic oxygen depletion typical of salt marshes, high water quality and low to moderate chlorophyll-*a*.

Given the strong salt marsh influences on these basins, which tend to reduce species numbers and diversity even in "pristine" systems, it appears that the salt marsh dominated sub-basins are not showing indications of excessive nutrient enrichment and are currently supporting high quality habitat. It should be noted that salt marshes are naturally nutrient and organic matter enriched and the benthic animal communities found within these basins are consistent with salt marsh influenced systems throughout the region. Similarly, the main creeks (tidal channels) do not appear to be impaired by nitrogen enrichment, although they have fewer species and numbers than open water bays. The creeks do generally support only few stress indicator species The larger tidal channels (usually near the mouth) appear to have shifting sediments due to the very high tidal velocities. Sand waves are common as are shifting sand bars. The MEP has encountered similar conditions in other high velocity channels, with the similar finding of a reduced benthic community, composed of non-organic stress indicators. In these regions the community appears to be structured primarily by the unstable sediments, rather than effects associated with water column conditions (nitrogen, oxygen, chlorophyll).

The exception to the high quality benthic habitat is the Millway which is a depositional basin functioning as an embayment tributary to the Great Marshes. It appears that the deep basin to support marina and navigation activities is a focal point for deposition of phytoplankton and marsh detritus. The result is benthic habitat consisting of soft unconsolidated (fluid) organic rich sediments that are sulfidic and without an oxidized surface layer. The result is a depauperate benthic animal community with <10 organisms per grab sample, more than an order of magnitude less than even impaired habitats. At present the Millway supports a severely degraded benthic habitat, with very low productivity which will persist as long as it remains a depositional site or until the organic matter available for settling is reduced (i.e. phytoplankton).

The results of the evaluations of the key habitat indicators (infaunal animals, eelgrass. dissolved oxygen/chlorophyll-*a*) coupled with macroalgal survey data were used to assess the overall habitat quality of each component sub-embayment to the Barnstable Great Marsh estuary system (Table VIII-1). The results of the habitat assessment show consistent assessments

Table VIII-1. Summary of Nutrient Related Habitat Health within the Barnstable Great Marsh estuary system, a salt marsh dominated estuary on Cape Cod, MA., based upon assessment data presented in Chapter VII. D.O. (dissolved oxygen) and Chl a (chlorophyll a) from the mooring data (VII.2). WQMP=Town Water Quality Monitoring Program results.

Sub-Embayment	Nutrient related Health Indicator					
	D.O.	Chl a	Macro-algae	Eelgrass	Infaunal Animals	Overall
Barnstable Great Marshes						
Central Main Basin -- lower	H[2]	H[8]	--[13]	--[14,15]	H[16]	**H[19]**
Central Main Basin – upper	H[2]	H[8]	--[13]	--[14]	H[17]	**H[20]**
Scorton Creek	H[1,3]	H[9]	--[13]	--[14]	H[17]	**H[20]**
Spring Creek	H[1.3]	H[9]	--[13]	--[14]	H[17]	**H[20]**
Brickyard Creek	H[1,4]	H[10]	--[13]	--[14]	H[17]	**H[20]**
Millway/Barnstable Hbr	MI/SI[5]	MI[12]	--[13]	--[14]	SD[18]	**SD[18, 21]**
Wharf Creek	--.[6]	--.[6]	--[13]	--[14]	H[16]	**H[20]**
Bass Hole (Chase Garden Creek)						
Bass Hole – lower	H[1,7]	H[11]	--[13]	--[14]	H[16]	**H[20]**
Bass Hole – upper	H[1,7]	H[11]	--[13]	--[14]	H[16]	**H[20]**

1) natural oxygen depletions, typical of salt marsh creeks, which can go anoxic at night due to natural high organic sediments and high oxygen uptake..
2) generally >6 mg/L infrequent oxygen depletions to 5-6 mg/L, 3%-5% of WQMP samples, mid basin mooring (Blish Pt) >6 mg/L 82% of record, rarely 5mg/L, 1% of record. .
3) tidal creeks almost always >4 mg/L infrequent oxygen depletions to 4-5 mg/L, 3%of WQMP; >4 mg/L at Scorton and Spring Creeks, 97% & 85% of record, rarely 3 mg/L.
4) highly organic marsh creek: lower reach DO to 3 mg/L 4% of WQMP, uppermost reaches frequently 2-3 mg/L, 30%-46% of samples, never <2mg/L as in many salt marshes
5) oxygen depletion, >5 mg/L 87% of mooring record, but periodic events to <4mg/L 5% of record, unconsolidated sediments highly reducing (sulfidic) and organic enriched.
6) no data, but sediments highly oxidized
7) oxygen depletion typical of saltmarsh creeks, frequently to 3 mg/L, ~5% of mooring record; WQMP >4mg/l 98% of dates lower basin, frequently 3 mg/L in upper small creeks,
8) low summer chlorophyll levels averaging 2.8-4.5 ug/L on 133 WQMP dates, 5.2 ug/L at mid basin mooring with bloom to 20 ug/L.
9) low-moderate chlorophyll levels 7.3-7.4 ug/L on 35 WQMP dates, bloom to 20 ug/L with means of 10-15 ug/L over mooring record in these main tidal creeks.
10) low-moderate = 7-8 ug/L (lower) and 10-14 ug/L (smaller upper creeks), WQMP 26 dates
11) low-moderate chlorophyll levels <4 ug/L (lower) and ~12 ug/L (upper) creek on 45 WQMP dates, mooring record similar to WQMP, but for late bloom to 20 ug/L with means of ~9 ug/L upper & lower
12) moderate chlorophyll for embayment mooring average 9.3 ug/L, bloom to >15 ug/L
13) drift algae sparse or absent
14) no evidence this basin is supportive of eelgrass.
15) no evidence presumptive eelgrass loss due to nitrogen enrichment
16) high # species (16) & individuals (>250) or moderate individuals (~150), high-moderate diversity (.2.5) & evenness (0~0.65),dominated by polychaetes with mollusks and crustaceans with few stress indicator species.
17) for saltmarshes: typical # species & individuals, moderate diversity & evenness, dominated by polychaetes (Spionids) with variable crustaceans with few stress indicator species.
18) severely depleted benthic community, <10 individuals per grab, consistent with the observed soft “fluid” sulfidic sediments
19) marsh open basin: high DO, low Chla,, macroalgae absent with productive benthic community
20) typical high quality saltmarsh, naturally organic/nutrient enriched with moderate DO and Chla levels, supporting typical benthic communities, with few stress indicator species.
21) as embayment: moderate DO depletion and Chla levels, but degraded benthic habitat

H = healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment; SD = Severe Degradation; -- = not applicable to this estuarine reach

between indicators and follow the long-term levels of water column nitrogen (see Section VIII.3, below). All of these data were integrated in the development of the nitrogen thresholds for the protection of infaunal habitats throughout the Barnstable Great Marsh estuary system and restoration of these habitats within the Millway (Section VIII.2).

VIII.2. THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout and embayment system, is to first identify a sentinel location within the embayment and second to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality (threshold nitrogen level). The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level are determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved. For the Barnstable Great Marsh estuary system, the protection/restoration target should reflect both recent pre-degradation habitat quality and be reasonably achievable.

The threshold nitrogen level for an embayment represents the tidally averaged watercolumn concentration of nitrogen that will support the habitat quality being sought. The watercolumn nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The watercolumn nitrogen concentration is modified by the extent of sediment regeneration.

The threshold nitrogen level for the Barnstable Great Marsh estuary system was developed to restore or maintain high habitat quality. High habitat quality in this case is defined as supportive of healthy and productive infaunal communities. Dissolved oxygen and chlorophyll-*a* were considered in the assessment as was macroalgae occurrence and distribution. Due to the complexity of the Barnstable Great Marsh estuary system and distances between sub-basins and complex circulation, three “sentinel” stations were developed targeting the Great Marshes, the Millway and Bass Hole, as these 3 component basins are functioning somewhat independently. The Great Marshes sentinel station is based upon the average of adjacent upper marsh stations BH-11 and BH-12, long-term water quality monitoring stations, while the Bass Hole station BSH-4 is at the upper boundary of the main tidal creek. The Millway station was developed (as for the Three Bays Estuary) using the modeled observed concentrations. The thresholds use tidally average nitrogen levels from the water quality model of the long-term measurements. The MEP uses tidally averaged nitrogen concentrations as it increases the accuracy, by reflecting what the environment experienced over complete tidal cycles rather than at a single point in the cycle.

The approach developed by the MEP has been to select sentinel stations based upon location within a system, generally in the upper tidal reaches as this is typically where water quality is lowest. Therefore, restoration or protection of the sentinel sub-embayment will necessarily create high quality habitat throughout the estuary. Second, the sentinel station should be in a sufficiently large basin to prevent steep horizontal water quality gradients, such as would be found in the region of entry of a stream or river or in the upper most region of a narrow, shallow estuary. This second criteria relates to the ability to accurately determine the baseline nitrogen level and to conduct the predictive modeling runs. Finally, the site of the sentinel station should be able to obtain the minimum level of habitat quality acceptable for the greater system (unless a multiple classification is to be used).

After the sentinel sub-system (or systems) is selected, the nitrogen level associated with high and stable habitat quality typically derived from a lower reach of the same system or an adjacent estuary or estuaries is used to develop the nitrogen concentration target. Finally, the watershed nitrogen loading rate is manipulated in the calibrated water quality model to determine the watershed nitrogen load which will produce the tidally averaged target nitrogen level at the sentinel location (Section VIII-3 below). Differences between the required modeled nitrogen load to achieve the target nitrogen level and the present watershed nitrogen load represent nitrogen management goals for restoration or protection of the embayment system as a whole.

Based upon the absence of eelgrass throughout the Barnstable Great Marsh estuary system (Chapter VII), infaunal animal habitat was selected as the target for the development of the site-specific nitrogen threshold.

The MEP's analysis of the Barnstable Great Marsh estuary system found very high levels of dissolved organic nitrogen within the embayment's waters (based upon data from the Barnstable and Dennis Water Quality Monitoring Programs). While some small portion of the dissolved organic nitrogen is actively cycling, the vast majority is refractory (non-biologically active) within the timeframe of the flushing of the overall system. The result is that the dissolved organic nitrogen presents a large non-active pool generally separate from the nitrogen fractions active in eutrophication and impacts to habitat quality (i.e. ammonium and nitrate+nitrite, particulate organic nitrogen). The biologically active nitrogen pools are represented by the species directly available to phytoplankton and algae (plant available nitrogen), ammonium and nitrate+nitrite, and the particulate organic nitrogen comprised primarily of phytoplankton (live and dead). Together this nitrogen group is termed bioactive nitrogen. Given the large dissolved organic nitrogen pool within Barnstable Great Marsh estuary system, the MEP Technical Team adopted the same approach used previously for the TMDL analysis of Pleasant Bay. In this previous analysis, the threshold was developed based upon the bioactive nitrogen pool, which appears to be relatively consistent between embayments both within and outside of Pleasant Bay as it is for the Barnstable Great Marsh estuary system. Equally important the dissolved organic nitrogen component in TN, but not part of bioactive nitrogen, is relatively uniform (unchanging) throughout the Barnstable Great Marsh estuary system averaging 0.228 mg L^{-1} across all stations (2.03 x BactN + 0.228 = TN mg/L, R^2=0.8), indicating its low reactivity.

In meeting the threshold value and achieving restoration, the bioactive nitrogen threshold has less uncertainty than the total nitrogen threshold given the biogeochemistry of these systems. Therefore, while both values form the basis for guiding nitrogen reductions to achieve ecological restoration, the total nitrogen value should only be evaluated in light of the bioactive nitrogen threshold. Critical nitrogen threshold levels were developed to support healthy infaunal animal habitat, see below.

The level of bioactive nitrogen supportive of high quality infaunal community habitat appears to be relatively constant among salt marsh dominated basins. Therefore, the MEP Technical Team set a single threshold of 0.16 mg L^{-1} for these basins, and 0.21 mg L^{-1} for the sub-embayment of the Millway, 0.21 mg L^{-1} has been used in Bassing Harbor and Pleasant Bay to restore high quality infaunal communities in the associated salt ponds and coves not supportive of eelgrass. Given the similar structure and function of the Millway, this was deemed to be justified and a reasonable approach. The lower levels for the salt marsh dominated sites reflects that they are currently well below the 0.16 threshold and are not showing impairment.

The infaunal habitat threshold was derived in a similar manner to the site-specific eelgrass threshold relying depends heavily upon the present distribution of infaunal communities relative

to water column nitrogen levels and measured oxygen depletions. For embayment basins, like the Millway, data from moderately impaired infaunal communities in Ryders Cove with tidally averaged bioactive nitrogen levels of 0.244 mgN L^{-1}; moderately impaired infaunal communities, in The River adjacent the inlet to Lonnies Pond (0.217 mgN L^{-1}), the Namequoit River (0.216-0.239 mgN L^{-1}). While healthy infaunal habitat in the lower Pochet Basin is found at bioactive N levels of 0.18 mgN L^{-1}. For these basins, it appears that the infaunal threshold lies between 0.18 and 0.22 mgN L^{-1} tidally averaged bioactive nitrogen. Based upon the summary above, animal community and nitrogen analysis in enclosed embayment basins tributary to larger estuaries indicates that restoration/protection of a healthy habitat would target a bioactive nitrogen threshold of 0.21 mgN L^{-1},

In the tributary salt marsh creeks and salt marsh dominated basins, the tidally averaged bioactive nitrogen levels were generally low (~0.11 mg L^{-1}) except in the upper-most reaches of the creeks at low tide where creek water is highly modified by groundwater inflows. Bioactive N was selected as the critical nitrogen form for analysis of the Barnstable Great Marsh estuary system infauna habitat threshold, due to the very high background dissolved organic nitrogen (DON) associated with the extensive salt marsh areas.

At present, the infaunal animal habitat in all areas within the Barnstable Great Marsh estuary system are supporting high quality infauna communities, typical of open salt marsh dominated basins or organic rich New England salt marsh tidal creeks, hence high quality relative to each specific estuarine ecosystem type. The mid-lower main channel is partially structured by its areas of high water velocity and physical disturbance to the sediment. The lack of nitrogen related impairment is supported by the general absence of surface algal mats and macroalgae, with only a few patches of very sparse *Ulva* or *Gracillaria* being observed. The near absence of macroalgal accumulations is consistent with the relatively low bioactive nitrogen levels within the saline waters of this system, <0.13 mg N L^{-1} (long-term average) By comparison, high quality benthic habitat in Pleasant Bay sub-basins was found at 0.21 mg L^{-1}. Similarly in adjacent Scorton Creek Salt Marsh high quality habitat was found in areas with bioactive N <0.18 mg/L and nearby Sandwich Harbor Estuary with extensive marshes had similarly high quality habitat with similar bioactive N levels $\leq$0.16 mg/L., All of these salt marsh dominated systems had similar environmental conditions, with macroalgal accumulations nearly absent. Based upon all lines of evidence it appears that the Great Marshes and Bass Hole basins are presently supporting high quality infaunal habitat and have not exceeded their threshold nitrogen levels for assimilating additional nitrogen without impairment. It also appears that the tidally averaged threshold bioactive nitrogen level for these systems that can be supported from the comparative assessments is 0.16 mg L^{-1}. The nitrogen loads associated with the threshold concentration at the sentinel locations are discussed in Section VIII.3, below.

VIII.3 DEVELOPMENT OF TARGET NITROGEN LOADS

The tidally averaged total nitrogen thresholds derived in Section VIII-2 were used to adjust the calibrated constituent transport model developed in Section VI. The nitrogen thresholds were used to determine the amount of total nitrogen mass loading reduction required for restoration of or to prevent impairments to infaunal habitats in the Barnstable Great Marsh estuary system. Contrary to most estuarine systems evaluated as part MEP, the threshold concentration was set higher than present conditions, meaning that the system would be allowed to have a higher load than present and still be able to meet the threshold. Other MEP studies that resulted in an allowable increased threshold loading have all had extensive salt marsh resources (like Sandwich Harbor and Namskaket Marsh), which is the case for both Barnstable Great Marshes and Bass Hole.

Therefore, for Barnstable Great Marshes, watershed nitrogen loads were sequentially raised in the model until the nitrogen levels reached the tidally averaged bioactive N concentration at the selected sentinel stations (BM-11, BM-13 and BSH-4) selected for the threshold (0.16 mg/L). One new site was added in the Barnstable Harbor/Millway, which did not have a long-term monitoring station. For the Millway, loads where required to be lowered in order to achieve the 0.21 mg/L threshold concentration set for this small basin. The Millway is a dredged basin with upgradient salt marsh that is depositional and supports degraded sediment infaunal communities. A similar basin and ecological response was detailed for the Rock Harbor Estuary (Orleans), which is dredged and depositional and also supports impaired benthic animal communities, although the up-gradient salt marsh creek is unimpaired.

It is important to note that load changes to achieve the nitrogen management threshold could be produced by changing of any or all sources of nitrogen to the system. The load changes presented below represent only one of a suite of potential approaches that could to be evaluated by the Town. The threshold scenario presented here is used to establish the general degree and spatial pattern of loading that will be allowable for this system. A comparison between present septic and total watershed loading and the loadings for the modeled threshold scenario is provided in Tables VIII-1 and VIII-2, respectively.

As shown in Table VIII-2, the threshold set for this system would allow up to a 39.6% increase the total watershed loading. In this particular scenario run, the watershed increase in achieved solely by increasing the total septic load to the system by 53.1% (increasing the total septic load by about one-half). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Table VIII-3 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-3, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent ‘worst-case’ summertime conditions. The benthic flux for this modeling effort is modified from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Cape Cod Bay, as discussed in Section VI.

The comparison between model results of existing loading conditions and the selected loading scenario to achieve the target TN concentrations is shown in Table VIII-4. To achieve the allowable ensemble threshold nitrogen concentration, increases in average TN concentrations of typically greater than 30% occur in Bass Hole (Chase Garden Creek) and more than 45% in the western end of the Great Marshes (Table VIII-5).

Although the above modeling results provide one manner of achieving the selected threshold level for the system, the specific example does not represent the only method for achieving this goal. However, this example provides a general sense of what could be possible when considering future N loading increases to the Harbor.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Barnstable Great Marsh estuary system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Barnstable Great Marshes – west	26.364	50.737	+92.4%
Barnstable Great Marshes – mid	19.488	48.719	+150.0%
Barnstable Great Marshes - east	32.397	32.397	0.0%
Millway	7.205	2.522	-65.0%
Bass Hole – west	23.107	30.385	+31.5%
Bass Hole – east	20.822	36.438	+75.0%
Bass Hole	5.847	5.847	0.0%
System Total	135.230	207.045	+53.1%

Table VIII-3. "Comparison of sub-embayment ***total watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios for the Barnstable Great Marsh estuary system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loads. Note that the Great Marshes are also called "Barnstable Harbor" and Bass Hole, "Chase Garden Creek by residents.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Barnstable Great Marshes - west	38.586	62.959	+63.2%
Barnstable Great Marshes - mid	27.562	56.793	+106.1%
Barnstable Great Marshes - east	42.600	42.600	+0.0%
Millway	10.575	5.892	-44.3%
Bass Hole – west	29.666	36.944	+24.5%
Bass Hole – east	25.030	40.647	+62.4%
Bass Hole	7.408	7.408	0.0%
System Total	181.427	253.242	+39.6%

Table VIII-4. Threshold sub-embayment loads used for total nitrogen modeling of the Barnstable Harbor system, with total watershed N loads, atmospheric N loads, and benthic flux. Note that the Great Marshes are also called "Barnstable Harbor" and Bass Hole, "Chase Garden Creek by residents.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Barnstable Great Marshes - west	62.959	2.422	6.758
Barnstable Great Marshes - mid	56.793	13.800	-12.351
Barnstable Great Marshes - east	42.600	32.978	-22.405
Millway	5.892	0.211	2.350
Bass Hole – west	36.944	0.140	0.408
Bass Hole – east	40.647	0.003	-
Bass Hole	7.408	0.488	-1.190
System Total	253.242	50.041	-26.430

Table VIII-5. Comparison of model average bioactive N concentrations from present loading and the threshold scenario, with percent change over background in Cape Cod Bay (0.063 mg/L), for the Barnstable Harbor system.

Station Location	monitoring station (MEP ID)	present (mg/L)	threshold (mg/L)	% change
Scorton Creek	BM-13	0.121	0.156	+60.0%
Spring Creek	BM-11	0.127	0.161	+55.0%
Great Marshes – upper	BM-12	0.111	0.139	+57.4%
Great Marshes – upper	BM-1	0.097	0.116	+56.9%
Great Marshes – mid	BM-2	0.085	0.096	+48.0%
Great Marshes – lower	BM-3	0.072	0.077	+51.1%
Broad Sound	BM-10	0.105	0.126	+47.4%
Bass Hole – Inlet	BSH-1	0.093	0.104	+36.8%
Bass Hole – lower	BSH-2	0.111	0.128	+35.8%
Bass Hole – mid	BSH-3	0.122	0.144	+37.2%
Bass Hole – mid	BSH-4	0.132	0.158	+37.2%
Bass Hole – upper	BSH-5	0.271	0.366	+45.5%
Bass Hole – upper	BSH-6	0.571	0.695	+24.4%
Whites Brook	BSH-7	0.321	0.361	+15.3%



Figure VIII-1. Contour plot of tidally averaged modeled total nitrogen concentrations (mg/L) in the Barnstable Great Marsh estuary system at the nitrogen threshold loading. Yellow markers indicate sentinel stations used to determine the threshold (average of BM-11, BM-13, BSH-4 and the Millway station).

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Appendix DD

Groundwater Protection Overlay Districts (Barnstable Town Code 240-35)

§ 240-35. Groundwater Protection Overlay Districts. [Added 11-7-1987 by Art. 2; amended 11-4-1989 by Art. 5; 8-19-1993 by Order No. 93-105]

A. Purpose. The purpose of this section is to protect the public health, safety, and welfare by encouraging nonhazardous, compatible land uses within groundwater recharge areas.

B. Districts established. In order to carry out the purpose of this section, the following overlay districts are hereby established, and shall be considered as superimposed over any other district established by this chapter:

AP	Aquifer Protection Overlay District
GP	Groundwater Protection Overlay District
WP	Well Protection Overlay District

(1) The GP Groundwater Protection Overlay District is based on Zone 11 delineations to existing, proven future, and proposed future public supply wells, as determined by Geraghty and Miller, Inc., and as shown on Figure 44, in their report entitled "Groundwater Conditions, Town of Barnstable, Massachusetts, Volumes I of III; together with Appendices A-D and E-H in Volumes II of III and III of III," dated November 1993 and "Corrections, Zone II Delineations for Public Water Supply Wells, Town of Barnstable, Massachusetts," dated December 1993; except that the GP Groundwater Protection Overlay District (Zone II), to Barnstable Fire District wells 3 and 4, is delineated by Whitman and Howard, Inc. in a report entitled "Report on Prolonged Pumping Test and Zone II Delineation at Test Well Site 8-90, Barnstable Fire District, Barnstable, Massachusetts," dated October 1991. The Zone II delineations to existing and proven future wells have been approved by the Department of Environmental Protection, Executive Office of Environmental Affairs, Commonwealth of Massachusetts, in a letter to the Town of Barnstable dated March 13, 1996.

(2) The WP Well Protection Overlay District is based on a five-year time of travel zone to existing, proven future and potential future public supply wells, delineated by Geraghty and Miller Inc., in reports referenced above, except that the WP Zone to Barnstable Fire District Well No. 2 is delineated by Earth Tech, consultant to Barnstable Fire District, summarized in a letter and a map to the district dated May 13, 1997. The WP Well Protection Overlay District to

Barnstable Fire District 2 is that portion of the five-year time of travel zone located within the GP Groundwater Protection Overlay District (Zone 11).

(3) The AP Aquifer Protection Overlay District consists of all areas of the Town, except those areas within the GP Groundwater and WP Well Protection Overlay Districts. The reports, letters and maps are on file with the Town Clerk. **[Amended 9-17-1998 by Order No. 99-012]**

C. Overlay Districts Map. The overlay districts established by this section (the GP Groundwater Protection District; the WP Well Protection Overlay District; and the AP Aquifer Protection Overlay District) are shown on the Official Zoning Map, § 240-6A, Identification of Zoning Map. **[Amended 9-17-1998 by Order No. 99-012]**

D. District boundaries. Where the overlay district boundaries divide a lot, each portion of that lot shall be subject to all the regulations applicable to the district in which it is located. **[Amended 9-17-1998 by Order No. 99-012]**

E. AP Aquifer Protection Overlay District regulations.

(1) Permitted uses. The following uses are permitted in the AP Aquifer Protection Overlay District:

(a) Any use permitted in the underlying zoning districts, except for those uses specifically prohibited by Subsection E(2) herein.

(2) Prohibited uses. The following uses are prohibited in the AP Aquifer Protection Overlay District:

(a) Any use prohibited in the underlying zoning districts.

F. GP Groundwater Protection Overlay District regulations.

(1) Permitted uses. The following uses are permitted in the GP Groundwater Protection Overlay District:

(a) Any use allowed in the underlying zoning districts, except those uses specifically prohibited in Subsection F(2) herein:

(2) Prohibited uses. The following uses are prohibited in the GP Groundwater Protection Overlay District:

(a) Any use prohibited in the underlying zoning districts.

(b) Landfills and open dumps as defined in 310 CMR 19.006.

(c) Junkyards, salvage yards and automobile graveyards, as defined in MGL Ch. 140B, § 1.[1]

(d) Mining of land, removal of sand and gravel, and quarrying of other raw materials.

(e) The removal of soil, loam, sand, gravel and other mineral substances to within four feet of the historic high-water mark unless the substances removed are redeposited within 45 days and the final grade exceeds four feet above the historic high-water mark, and except for excavations for the foundations of buildings and structures and the installation of utilities.

(f) Underground fuel storage tanks.[2]

(g) Storage for resale of heating fuels, including but not limited to, oil, coal, gas and kerosene.

(h) Sewage treatment plant, disposal works, or small package treatment facility subject to 314 CMR 5.00, except for the following:

[1] The replacement or repair of an existing facility that will not result in a design capacity greater than the design capacity of the existing system(s);

[2] Treatment works approved by the Department of Environmental Protection designed for the treatment of contaminated ground or surface waters; and

[3] Sewage treatment works including package treatment facilities, which are owned and operated by the Town of Barnstable, and located in areas with existing water quality problems attributable to current septic systems where there will be a net improvement in water quality with the installation of the treatment facility.

(i) Commercial feeding of livestock.

(j) Storage of road salt or other deicing materials.

(k) Metal plating, finishing and polishing.

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1. **Editor's Note: See Ch. 502, Junk Dealers.**
2. **Editor's Note: See Ch. 326, Fuel and Chemical Storage Systems.**

(l) Chemical and bacteriological laboratories.

(m) Boat, motor vehicle and aircraft cleaning, service and repair.

(n) Dry-cleaning processing establishments.

(o) Furniture stripping, painting and refinishing.

(p) Any other use which generates, treats, stores or disposes of hazardous waste that are subject to MGL Ch. 21C and 310 MCR 30.00, except for the following uses:

[1] Very small quantity generators as defined by 310 CMR 30.00;

[2] Waste oil retention facilities for retailers of motor oil required and operated in compliance with MGL Ch. 21, § 52A.

[3] Treatment works approved by the Department of Environmental Protection designed in accordance with 314 CMR 5.00, for the treatment of contaminated ground or surface waters.

[4] Household hazardous waste collection centers or events operated according to 310 CMR 30.390.

(q) Landfilling of sludge and septic as defined in 310 CMR 32.05.

(r) Storage of sludge and septage, as defined in 310 CMR 32.05, unless in compliance with 310 CMR 32.30 and 310 CMR 32.41

(s) Storage of animal manures unless protected from the elements and contained in a structure which prevents leachate from contaminating groundwater, in accordance with all the requirements of the United States Soil Conservation Service.

(t) Stockpiling and disposal of snow and ice removed from highways and streets located outside of the GP and WP Districts which contains sodium chloride, calcium chloride, chemically treated abrasives or other chemicals used for ice and snow removal.

(u) Storage of liquid petroleum products of any kind, except those incidental to:

[1] Normal household use and outdoor maintenance or the heating of a structure;

[2] Waste oil retention facilities required by MGL Ch. 21, § 52A;

[3] Emergency generators required by statute, rule or regulation;

[4] Treatment works approved by the Department designed in accordance with 314 CMR 5.00 for the treatment of contaminated ground or surface waters;

and provided that such storage is either in a freestanding container within a building or in a freestanding container above ground level with protection adequate to contain a spill the size of the container's total storage capacity; however, replacement of existing tanks or systems for the keeping, dispensing or storing of gasoline is allowed consistent with state and local requirements; and

[5] Any other use which involves as a principal activity or use the generation, storage, use, treatment, transportation or disposal of hazardous materials.

(v) Storage of commercial fertilizers, as defined in MGL c 128, § 64, unless such storage is within a structure designed and engineered to prevent escape or transport of commercial fertilizers to the groundwater under any circumstances. **[Added 1-17-2013 by Order No. 2013-001]**

(3) Lot coverage. Unless the applicant demonstrates that all runoff is recharged on site, no more than 15% or 2,500 square feet, whichever is greater, of the total area of any lot shall be rendered impervious by the installation of buildings, structures and paved surfaces. If all recharge is disposed of on site, no more than 50% of the total upland area of any lot shall be made impervious by the installation of buildings, structures, and paved surfaces. For the purposes of this section, a temporary (i.e., not more than 182 days) air-supported or removable bubble/dome over a sports and recreation facility’s outdoor use (e.g., outdoor field, track, court, and swimming pool) shall not be considered a building or structure. **[Amended 8-17-2017 by Order No. 2017-165]**

(4) Site clearing. A minimum of 30% of the total upland area of any lot shall be retained in its natural state. This shall not prevent the removal of dead, diseased or damaged trees. For sports and recreation facilities, the site clearing/natural state requirements shall not apply where the proposed stormwater management system will be designed and constructed to provide a minimum water quality volume treatment equal to one inch times the total impervious area of the post-development site; and to provide treatment to remove at least 44% total suspended solids prior to discharge to the infiltration system. **[Amended 8-17-2017 by Order No. 2017-165]**

(a) Additionally, a long-term operations and maintenance plan shall be developed and implemented to ensure that stormwater management systems function as designed. At a minimum, the plan shall include:

[1] Stormwater management system(s) owners;

[2] The party or parties responsible for operation and maintenance, including how future property owners will be notified of the presence of the stormwater management system and the requirement for proper operation and maintenance;

[3] The routine and nonroutine maintenance tasks to be undertaken after construction is complete and a schedule for implementing those tasks;

[4] A plan that is drawn to scale and shows the location of all stormwater BMPs in each treatment train along with the discharge point;

[5] A description and delineation of public safety features; and

[6] An estimated operations and maintenance budget.

(b) The plan shall be subject to review and approval by the Director of Public Works as a condition of site plan review approval. stormwater operation and maintenance reports documenting compliance with the plan shall be submitted annually to the Director of Public Works and Director of Planning and Development.

G. WP Well Protection Overlay District regulations. **[Amended 8-19-1993 by Order No. 93-105]**

(1) Permitted uses. The following uses are permitted in the WP Well Protection Overlay District:

(a) Any use allowed in the underlying zoning districts, except those specifically prohibited in Subsection G(2) herein:

(2) Prohibited uses. The following uses are prohibited in the WP Well Protection Overlay District:

(a) Any use prohibited in the underlying zoning districts.

(b) All uses prohibited in Subsection F(2) herein.

(c) Parking and/or storage of transport vehicles for fuel, including but not limited to oil, coal and gas.

(d) Parking and/or storage of transport vehicles for toxic and/or hazardous substances.

(e) Any use which uses, generates or stores, including racking for resale, toxic or hazardous substances, totaling at any one time more than 50 gallons liquid volume or 25 pounds dry weight.

(3) Lot coverage. Unless the applicant demonstrates that all runoff is recharged on site, no more than 15% or 2,500 square feet, whichever is greater, of the total area of any lot shall be rendered impervious by the installation of buildings, structures and paved surfaces. If all recharge is disposed on on site, no more than 50% of the total upland area of any lot shall be made impervious by the installation of buildings, structures, and paved surfaces. For the purposes of this section, a temporary (i.e., not more than 182 days) air-supported or removable bubble/dome over a sports and recreation facility’s outdoor use (e.g., outdoor field, track, court, and swimming pool) shall not be considered a building or structure. **[Amended 8-17-2017 by Order No. 2017-165]**

(4) Site clearing. A minimum of 30% of the total upland area of any lot shall be retained in its natural state. This shall not prevent the removal of dead, diseased or damaged trees. For sports and recreation facilities, the site clearing/natural state requirements shall not apply where the proposed stormwater management system will be designed and constructed to provide a minimum water quality volume treatment equal to one inch times the total impervious area of the post-development site; and to provide treatment to remove at

least 44% total suspended solids prior to discharge to the infiltration system. **[Amended 8-17-2017 by Order No. 2017-165]**

(a) Additionally, a long-term operations and maintenance plan shall be developed and implemented to ensure that stormwater management systems function as designed. At a minimum, the plan shall include:

[1] Stormwater management system(s) owners;

[2] The party or parties responsible for operation and maintenance, including how future property owners will be notified of the presence of the stormwater management system and the requirement for proper operation and maintenance;

[3] The routine and nonroutine maintenance tasks to be undertaken after construction is complete and a schedule for implementing those tasks;

[4] A plan that is drawn to scale and shows the location of all stormwater BMPs in each treatment train along with the discharge point;

[5] A description and delineation of public safety features; and

[6] An estimated operations and maintenance budget.

(b) The plan shall be subject to review and approval by the Director of Public Works as a condition of site plan review approval. stormwater operation and maintenance reports documenting compliance with the plan shall be submitted annually to the Director of Public Works and Director of Planning and Development.

Appendix EE

Interim Saltwater Estuary Regulation (Barnstable Town Code 360-45)

ARTICLE XV
Protection of Saltwater Estuaries
[Adopted 6-30-2008]

§ 360-45. Interim regulations. [Amended 2-10-2009]

A. Purpose.
   (1) The findings of a state-wide estuary investigation indicate that a substantial portion of the Town's saltwater estuaries are in jeopardy from the long-term buildup of nitrate-nitrogen, primarily from the subsurface discharge of sewage effluent. These findings have caused the Massachusetts Department of Environmental Protection to establish total maximum daily loads (TMDL) for nitrogen for the watershed areas of these estuaries. "Watershed" is defined as the area of land from which water flows downhill into a particular body of water. In these nitrogen-impaired estuaries the TMDL will require an actual reduction in the amount of nitrate-nitrogen discharged into these embayments. Since most of the nitrate-nitrogen in these watersheds is from subsurface discharge of sewerage effluent into the groundwater that flows to these embayments, and since it is likely that a plan for corrective action will take years to formulate and implement, the Board is adopting the following interim regulations to mitigate the adverse impact to these estuaries from such discharges. The Town has long recognized the need to protect its water resources and has imposed discharge limits on subsurface disposal of sewage in other nitrogen-sensitive areas. The restrictions proposed herein are similar to those imposed by Town ordinance and/or Board of Health regulation in other nitrogen sensitive areas in the Town. These regulations are temporary and will be in effect only until the Town adopts and implements a Comprehensive Plan to address the nitrogen reduction required in these estuary systems by the proposed TMDL.
   (2) To date, final reports have been produced for Popponesset Bay, Three Bays and the Centerville River watersheds. All three of these estuary systems will require a reduction in total nitrogen discharge in order to meet the state-mandated TMDL. Further reports are expected on Lewis Bay and Barnstable Harbor.

B. Restrictions. No permit for the construction of an individual sewage disposal system on any building lot shall be granted within the watersheds for the estuaries that have been identified as requiring a reduction in the current TMDL of nitrate-nitrogen as identified by the map entitled "Massachusetts Estuary Project,

Zones of Contribution to Saltwater Estuaries, Town of Barnstable, March 10, 2008," unless the following standards are met:

(1) The maximum allowable discharge of sanitary sewage, based on the sewage design flow criteria listed in 310 CMR 15.203, Title 5, of the State Environmental Code, shall not exceed 440 gallons per 40,000 square feet of lot area, with the following exceptions:
   (a) For approved building lots on which no building currently exists and that are less than 30,000 square feet in area, the maximum allowable sewage discharge shall be 330 gallons.
   (b) For parcels with existing buildings, the maximum allowable flow shall be either 440 gallons per 40,000 square feet, except as described in Subsection B(1)(a) above or whatever is currently permitted, whichever is greater.
(2) Nothing in this regulation shall prohibit the approval by the Board of Health of any application involving the maintenance, repair or alteration of an existing individual sewage disposal system, provided that said application does not involve an increase in design flow as defined by existing Board of Health regulations. Where an increase in design flow is involved, the applicant must demonstrate compliance with this regulation.

C. Variances. A variance from this regulation may be granted by the Board of Health only if the applicant can demonstrate that:
(1) Connection to Town sewer is not available; and
(2) That enforcement thereof would do manifest injustice; and
(3) The alternative proposal will provide the same degree of environmental protection as a design in full conformance with this regulation. This standard shall be met by a site/septic design which results in equilibrium concentrations of nitrate/nitrogen at the down-gradient property line not exceeding five ppm, utilizing the Cape Cod Commission formulas found in its Technical Bulletin 91-001 (final). In undertaking this calculation, the applicant may utilize off-site lands located elsewhere in the Estuaries Contribution Area as defined by the map entitled "Massachusetts Estuary Project, Zones of Contribution to Saltwater Estuaries, Town of Barnstable, March 10, 2008," provided that:
   (a) The existing nitrogen loading for the off-site property is included in the calculations; and
   (b) A deed restriction limiting the off-site property to the current nitrogen loading as stated in the calculations and running to the Barnstable Board of Health or other entity suitable to that Board is recorded at the Barnstable

Registry of Deeds in the titles to both the subject property and the off-site property. The restriction shall be in a form suitable to the Barnstable Town Attorney. Proof of recording shall be provided to the Board of Health, the Town Assessing Department and the Town Building Department prior to the issuance of a DWIP for the subject property.

D. Craigville Beach District implementing regulation. Notwithstanding anything to the contrary contained in Subsections A through C above, this interim regulation shall apply to all properties within the Craigville Beach Zoning District as a Craigville Beach District implementing regulation unless and until a property is connected by a building sewer to the public sewer system. In all other respects, the provisions of Subsections A through C above shall apply to all properties within the Craigville Beach District. **[Adopted 1-19-2011 by Ord. No. 11-01 of the Barnstable County Assembly of Delegates pursuant to Ch. 716 of the Acts of 1989 (Cape Cod Commission Act)]**

Appendix FF

2016 Final Barnstable SewerCAD Tech Memo

Memorandum

April 6, 2016

To	Dale Saad – Town of Barnstable		
Copy to	GHD Project Team		
From	J. Jefferson Gregg, P.E., BCEE Sandy Tripp, P.E., BCEE	Tel	(774) 470-1640
Subject	Town of Barnstable Nutrient Management Project SewerCAD Modeling	Job no.	8616263

1 PURPOSE OF MEMO

The purpose of this technical memorandum is to summarize the findings of the Barnstable Town-Wide SewerCAD modeling project. The memorandum includes discussion of the project scope and previous modeling; a summary of the Town of Barnstable collection system; an overview of the SewerCAD modeling software and Town of Barnstable model; discussion of the Barnstable SewerCAD model results and recommendations; and discussion of the flow tie-in areas and their impact to the Barnstable collection system.

2 PROJECT BACKGROUND

2.1 Project Scope

As part of Town of Barnstable's Nutrient Management Planning efforts started in 2009 (also referred to as the Comprehensive Wastewater Management Planning (CWMP) Project), it was recommended that the Town of Barnstable (Town) expand their existing downtown SewerCAD model to include their entire wastewater collection system. The Town retained GHD Inc. to incorporate collection system data existing as of July 2013 into its existing 2005 SewerCAD model of downtown Hyannis.

The updated model is loaded with current and future wastewater flow data and exercised to determine collection system capacity and potential bottlenecks. The project team held meetings with the Town to review initial results and calibrate the model to better reflect the collection system. The finalized model is then to be exercised with four future wastewater flow tie-ins, representing possible areas the Town may wish to connect to the collection system. Results from modeling are summarized in this Memorandum. This model does not discuss or model the vacuum sewer system or any sections of low pressure sewer. Flows from low pressure sewer connections to gravity are added to the nearest manhole. The vacuum sewer system is an independent system that pumps directly to the WPCF and does not impact other gravity collection system sections. Schooner Village, which connects to the vacuum sewer system by gravity, is not included in the model.

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2.2 2005 SewerCAD Model Background

In November of 2005 GHD (formerly Stearns & Wheler, LLC) produced a Technical Memorandum for the Town of Barnstable entitled *"Downtown Hyannis SewerCAD Modeling."* The 2005 SewerCAD Model was developed to evaluate collection system capacity limitations for the downtown portions of Hyannis and for the Growth Incentive Zone (GIZ). A summary of the findings from the 2005 Memorandum is presented below:

- The gravity sewer along South Street from Sea Street to Barnstable Road/Ocean Street is over capacity during maximum quarter and peak hour conditions.
- The Pleasant Street gravity sewer is over capacity during peak hour conditions.
- The reserve capacity of the Main Street gravity sewer during both maximum quarter and peak hour flow conditions is adequate.

Prior to 2013 and following the 2005 modelling efforts, modifications made to the existing collection system as part of three different projects were performed to address some of the historic bottlenecks, specifically those along South Street. Improvements made to the 720 Main Street pumping station with new force mains connected directly to the Hyannis Water Pollution Control Facility (WPCF) allowed flow from the western end of South Street to be sent directly to the WPCF and pick up flow from the new Area H-1 service area pumping station. In addition, the construction of the Lincoln Road pumping station with direct connection to the Hyannis WPCF picked up flow from the western end of West Main Street and the High School. This pumping station provides a means to collect wastewater from this area, remove stress on the 720 Main Street pumping station, and provide capacity to support future collection system extensions in this area.

While these improvements eased some of the existing issues, they do not address all of the future flow conditions in the service area. Under future conditions (discussed later in the document), Downtown Hyannis flow projections to the South Street sewer and Old Colony pumping station still project that the system will be over capacity and in need of an upgrade.

3 TOWN OF BARNSTABLE COLLECTION SYSTEM

The collection system in Barnstable dates back to as early at 1937. Most of the downtown is served by 8- and 10-inch vitrified clay sewers. A trunk line, ranging from 8- to 21-inch diameter, runs the length of South Street and feeds the Old Colony pumping station.

Sewers along Ocean Street and the Bay Shore Road area date from 1968. These sewers are mostly asbestos cement and range in diameter from 8- to 16-inch. Wastewater from these areas flows to three pumping stations which pump directly to the WPCF.

The asbestos cement sewers along West Main Street range from 8- to 18-inch and were constructed in 1972. Previously, wastewater from this area flowed to the 720 Main Street pumping station; however in order to alleviate demand on that station, flows to the west of Tevyaw Road now flow directly to the Lincoln Road pumping station which pumps directly to the WPCF through 9,800 linear feet of dual ductile iron 8- and 12-inch force mains.

The sewers serving the areas surrounding Gosnold Street, Old Colony Road, and Oak Neck Road are 8-inch and 10-inch PVC lines which were installed in 1989. Wastewater is pumped through a combination of five

pumping stations to the intersection of South Street and Ocean Street where it flows to the Old Colony pumping station which then pumps directly to the WPCF.

The Village of Barnstable system was constructed in 1980, and serves Route 6A, Hyannis Road, Millway Road, Commerce Road, and the residential streets off Commerce Road. All of the residential streets are served by 8-inch sewers, and two small pumping/ejector pot stations which all flow to 14- to 18-inch trunk lines that end at the Freezer Road pumping station. All of these sewers are asbestos cement. The flow from Freezer Road Pumping Station is pumped directly to the WPCF.

The commercial area along Independence Drive consists of 8-inch PVC sewers that feed into the Independence Drive pumping station and are later pumped up to the WPCF from the Bearses Way station. Remaining sewers feeding the Bearses Way station consist of 8- to 21-inch PVC.

The Stewarts Creek (H-1 East and West) areas were constructed in 2010 and consist of 8-inch PVC gravity sewer pipe and various small diameter PVC pressure sewer (not modeled). The H-1 West area flows by gravity to the Marston Ave pumping station which then pumps into the gravity sewer at the west end rotary which flows by gravity to the 720 Main Street pumping station; and that station pumps directly to the WPCF. The H-1 East area flows to the Sea Street pumping station which pumps into a force main running north that pumps into the gravity sewer along Sea Street which flows into the Old Colony Road pumping station.

A vacuum sewer system along Bearses Way and Route 28 (between Bearses Way and the Airport Rotary) picks up properties (primarily commercial and hotel types) and sends wastewater directly to the WPCF. As stated previously, this was not modeled through SewerCAD due to its unique operating parameters and system dynamics.

Figure 3-1 provides a schematic of the pumping station and force main layout. A summary of the Town's pumping station information can be found in Section 5, Table 5-2.

4 SEWERCAD MODEL

4.1 Background on SewerCAD

SewerCAD is a sanitary sewer modeling software that is commonly used for the design/analysis of new gravity sewer systems as well as the evaluation of existing gravity sewer systems and pumping stations. The software models flow and headloss conditions through a system of pipes and pumping stations. This allows the modeler to design for size, length, material, invert depths, etc. for pipe networks as well as size pumping stations and pumps to handle predicted flows. It also allows the modeler to determine the capacity of an existing sewer system, predict the impact of adding new sewer areas to an existing system, and identify bottlenecks and potential surcharging or overflow conditions. The program is designed for modelling gravity sewer and associated pumping stations and was not used to model vacuum sewer systems or grinder/pressure sewer systems.

4.2 Physical Creation of the Model

The Town-wide SewerCAD model (Model) was developed from the original SewerCAD model of Downtown Hyannis developed in 2005, as discussed previously. Both the 2005 and the current SewerCAD models are Steady State models since flow versus time data (diurnal curves) is not available. Pumping stations with two

pumps were assumed to run with one pump on and one pump off as an emergency backup. Pumping stations with three pumps were modeled with two pumps running (if needed) and one pump off as a backup. Record drawings provided by the Hyannis WPCF staff were used to update the 2005 model to include the remaining collection system. Pumping stations and force mains were also included in the model although they were not previously included in the 2005 model.

For some areas the record documents were either unavailable or illegible. The following areas fall into that category:

- Sea Meadow area
- Settler's Lane area
- Sudbury Lane area
- Bryant Lane area

These areas were handled by either assigning the area flows as a point load to the nearest manhole or by interpolating the invert elevations and/or pipe lengths based on available information. Record document data was also unavailable for some of the Town's pumping stations and in those cases the elevations and wet well dimensions were assumed for the model in order to estimate pumping station outputs.

GHD reviewed data gaps with the Town; Section 5.1.5 identifies areas where the Town should consider field verification of inverts and updating their record drawings for those areas.

4.3 Loading of the Model

The Town of Barnstable GIS department provided GHD with existing and future water use data from years 2006, 2007, 2008, and 2009 based on the Town's 2010 parcel data. Sewer account data was current as of January 2015. A factor of 3.95 was used to convert the average annual water consumption to a peak summer month wastewater flow based on the following:

- An assumption that 90% of water consumption becomes wastewater. This factor was used in the Massachusetts Estuaries Project (MEP) and is widely used in many publications.
- Based on the Needs Assessment Report Table 4-1 (Barnstable Needs Assessment Volume 1-CWMP, 2011), the Hyannis WPCF experiences a maximum month average wastewater flow of 1.94 MGD. Using the 2011 TR-16 Standards Figure 2-1, a peaking factor of 3.3 was obtained to convert the maximum month flow to the "Peak on Max Day" flow.
- A factor of 1.33 was used to convert the average annual flow to a maximum month (summer) wastewater flow. This was based on the ratio of the maximum month wastewater flow to average annual wastewater flow seen at the WPCF (1.94 MGD/1.46 MGD). This extra peaking factor was used so that the peak flows represent the average over the course of the summer months and not solely the average annual flow.

Multiplying these factors together (0.9 x 3.3 x 1.33) equates to a peaking factor of 3.95 which was used for existing and future wastewater flows as discussed in Section 4.4.

An infiltration and inflow (I/I) of 500 gallons per day/inch diameter/mile (gpd/in.dia/mile) based on the 2011 TR-16 standards was used for all gravity sewer pipe lengths. This value allows the model to remain conservative and account for peak rainy day flows. Previously, an I/I of 210 gpd/in.dia/mile was estimated as part of the 2011 Needs Assessment Report based on an estimated average annual infiltration rate of 0.08 MGD. For modeling purposes, the more conservative 500 gpd/in.dia/mile was used to reflect peak wet weather conditions and high groundwater impacts on the system that may not be reflected in the average 210 gpd/in.dia/mile value.

Data sources used in the model include the following:

- Water use data (2006 – 2009)
- Parcel data (2010)
- Peaking factor
- Sewered parcels (Jan 2015)
- Infiltration and inflow

The Town of Barnstable GIS department provided data in March of 2014 and updated the sewer user and flow data in March of 2015. The GIS data set provided to GHD included the following (including descriptions as provided by the Barnstable GIS department):

- **MAPPAR** = 6 or 9 digit map/parcel number
- **PARCEL_ID** = 6, 9, or 12 digit map/parcel number w/ "CND" appended to the end for condos
- **GIS_FIRE_DISTRICT** = fire district in which the parcel falls
- **GIS_VILLAGE** = village in which the parcel falls
- **TOTAL_ACRES** = acreage of the parcel from the Assessor's database
- **owner** = parcel owner (note this is older data from FY 2007)
- **existing_res_DU** = existing residential dwelling units from the previously done buildout analysis
- **existing_comm_SF** = existing non-residential building square footage from the previously done buildout analysis
- **total_res_DU_at_buildout** = total residential dwelling units at buildout
- **total_commSF_at_buildout** = total non-residential building square footage at buildout
- **WATERSHED** = generalized watershed in which the parcel falls
- **PUBLIC_WATER** = indicates a value of "Y" for parcels on public water
- **LO_NUM** = parcel location street number
- **SITE_STREET** = parcel location street name
- **WATER_AVG_GAL_DAY** = existing / current water consumption based on the data available at the time (roughly 2006-2009)

- **PUBLIC_SEWER_JAN2011** = indicates a value of "Y" for parcels with sewer accounts as of January 2011
- **future_projected_water_consumption** = calculated gallons per day based on the average water consumption per DU and/or per 1000 sq.ft. non-commercial building area from Tables 5-11 & 5-12 (from the 2011 Barnstable Needs Assessment Report) for the appropriate village multiplied by total_resDU_at_buildout and/or total_commSF_at_buildout
- **"PUBLIC_SEWER_JAN2015"** = new sewer account data based on FY2015 and water consumption data based on 2009 or 2010 parcels. Town GIS combined or adjusted data as necessary to account for changes between the parcel years.

4.4 Model Scenarios/Alternatives

Multiple scenarios were created to simulate the various flows that could be experienced by the Town's collection system. The following wastewater flow scenarios were created:

- **Existing average wastewater flow-peaked:** Average wastewater flows from sewered parcels connected to the collection system as of January 2015. Wastewater flows were based on 2006-2009 water use data and multiplied by peaking factor of 3.95 (as discussed above).
- **Future projected wastewater flow:** Future wastewater flows for all properties planned to connect to the collection system as of January 2015. Wastewater flows were based on the 2011 Need Assessment Report, Tables 5-11 and 5-12, which developed, per village, "average water consumption per dwelling unit" and "average water consumption per 1,000 square-feet of non-residential use" and multiplied by a peaking factor of 3.95. For parcels where the existing average wastewater flow was higher than the future projected wastewater flow, the greater of the two flows was used.

SewerCAD parameters were adjusted to run the model for the following alternative:

- **All pumping stations "on" alternative:** The pumping station flow rates were used to load the model and were all set to "on." This alternative was used to model downstream pipe networks since the pipe network will experience the flows pumped and not the wastewater flows estimated from the water use of the service area.

This alternative was run with the two discussed wastewater flow scenarios resulting in a total of two SewerCAD models under existing and future conditions. It should be noted that the "all pumping stations on" is a conservative approach that assumes all pumping stations are running at the same time under peak conditions. This does not account for attenuation within the system, as not all stations are the same distance from each point in the system that they pump into. This approach provided a conservative means to examine stress on the collection system piping, however it creates a potential overestimate at the downstream pumping station especially under the future conditions (for stations that receive flow from more than one upstream station) and presumes that no improvement at that station is made. The model under these conditions can create artificial upstream surcharging if the model conditions indicate that the downstream pumping station is over capacity. Therefore, to avoid creating this condition, those stations that appeared over capacity were identified as stations that may require future upgrade, however they were modelled as an



"outfall" which would prevent creating this artificial surcharge condition. By identifying these areas, the model highlights pipes and stations that will need to be monitored as future expansion and growth occurs to avoid creating these conditions.

5 Results

5.1 Model Results

Results from the SewerCAD model and the GIS database are summarized on the following figures:

5.1.1. Figure 5-1 Sewersheds and Pipe Diameters

Figure 5-1 summarizes the sewersheds and pipe sizes. This figure shows the existing collection system and service areas (sewersheds) to each existing pumping station. Each area is called out in a different color as are the various gravity pipe sizes. Currently the system is made up of gravity sewer pipe from 6- to 21-inches in diameter based on the information imported from the record drawings as discussed previously. The figure does not show sizes for the force mains, vacuum sewer, or pressure sewers.

5.1.2. Figure 5-2 Existing Gravity Sewer Pipe Material

Figure 5-2 displays the gravity sewer pipe material type for each sewer section. Pipe materials were identified in the past facilities planning documents. Currently the Town's gravity collection system is constructed of the following pipe materials: vitrified clay (VC); asbestos cement (AC); polyvinyl chloride (PVC); and ductile iron (DI). The figure does not show force main material (typically DI and AC), vacuum sewer material (PVC) and pressure sewer (which is mainly PVC).

5.1.3. Figure 5-3 Pipe Capacity Existing Conditions

Figure 5-3 summarizes the collection system estimated modelled capacity using **existing** peaked wastewater flows. Flow information, as discussed previously, was compiled for the existing collection system area and input into the model. The model was then run and the results of this model run indicate areas where, under conservative flow conditions (all pumping stations pumping at the same time and I/I included), possible surcharged collection system piping or manholes could exist.

Figure 5-3 indicates that under existing modeled conditions (all pumping stations on) the following areas display potential impacts of over-capacity or surcharging. These areas should be reviewed with the WPCF staff during summer peak flow conditions to verify if these areas are showing signs of surcharging:

- Marks Path Area (sections on Route 28 and also Whitehall Way)—Impacts potentially a result of sections of gravity sewer with an "adverse slope" (less than TR-16 minimum) and/or the impact of the pumping station that shows that peak flows exceed its current capacity under both existing and future conditions. Because pipe slope will influence results, that can be verified through survey of the up and down stream manholes to calculate the actual slope of the pipe. Station capacity can be verified through additional evaluation of the station (for example a drawdown test).
- Sea Street—Impact likely a result of pipe slopes less than TR-16 minimums. The pipe segments of the 1949 sewer pipe located on Sea Street just south of the South Street intersection, have very

shallow slopes. This area may also be influenced by the limited downstream pipe capacity to Old Colony along South Street.

- South Street to Old Colony Pumping Station—This section, as has been identified in the past, is approaching its capacity and the modelling indicates that the last section of gravity sewer before entering the station could be over capacity under peak conditions. The relocation of western sections of sewers has alleviated some of the projected capacity issues, but did not resolve them.
- Harbor Bluff Road from Gosnold Pumping Station—This section of sewer appears influenced in the model by the minimum pipe slope and the potential that the Gosnold Station pumps are only seeing minimal force main headloss and therefore are pumping at a rate closer to the capacity of the pipe (around 330+ gpm). The Town should consider inspecting this area to see if it is showing signs of surcharging and consider performing a drawdown test at the station to confirm its pumping rate. When modeling this based on available design information (220 gpm at 25 TDH) the pipe capacity is between 70 and 75 percent.

5.1.4. Figure 5-4 Pipe Capacity Future Conditions

Figure 5-4 summarizes the collection system estimated modelled capacity using **future** peaked wastewater flows. Under these conditions (again modeling all pumping stations on), the following potential bottleneck areas are identified:

- Marks Path issues remain the same, however the pumping station itself is also anticipated to be over capacity under peak future flow conditions.
- South Street/Old Colony—As identified in several previous studies this area is limited by the 10- and 12-inch gravity sewers running down South Street. In addition, the capacity of the Old Colony Station with common force main is limited. Future flow projections from the Town's GIS system indicate that the Old Colony Station will significantly exceed its current pumping capacity under future conditions. Future growth and possible pipe slope issues extend up from South Street onto Pleasant Street, Center Street and Winter Street. Significant flow increase is projected based on the future flow data provide by the Town that would be processed by Old Colony pumping station and its associated collection system, and therefore this area should be periodically monitored as growth and redevelopment occurs. Old Colony's limited capacity will result in its need to be upgraded if flows in this service area continue to increase towards the future condition. Further station evaluation is recommended since this is such a critical piece to the Town's infrastructure in addition to more detailed observations during peak flow conditions to determine how the station is operating and what its current peak capacity is.
- Winter Street, Center Street, and Pleasant Street sections to Old Colony pumping station show impacts based on projected future peak flows for that service area.
- Harbor Bluff Road sewer to Bay Shore Pumping Station, does not change from the existing conditions identified previously.
- Several other stations under this scenario may approach or exceed their capacity, as discussed in Section 5.2.

5.1.5. Figure 5-5 Adverse Pipe Slopes

Figure 5-5 shows existing collection system and piping with adverse slopes. Adverse slopes are those that are either identified as negative (indicating the downstream invert is higher than the upstream invert), or pipes that have slopes that are less than the minimum recommended TR-16 slope. Pipe slope is important in that it impacts the way capacity is calculated. This figure is used to show several areas, based on the record drawing information available, where the existing collection system have pipe slopes that are less than the minimum slope requirements as called out in the 2011 Edition of TR-16 and are directly correlated to areas where pipes are considered over capacity under existing and future conditions as shown on Figures 5-3 and 5-4.

There are a number of additional pipe sections in the system that have slopes less than the recommended TR-16 minimums; however, based on the model these do not appear to be in sections where capacity is projected to be exceeded and therefore are not shown on the figure. Figure 5-5 was created based on selecting sections of pipe that meet certain criteria to allow the Town to focus on certain locations. As shown on this Figure, about 16 pipe segments meet the following conditions:

- A slope that is less than TR-16 minimum by more than 15 percent (in some cases there are segments that are slightly less than TR-16 minimums, however that can be a function of how the slope was calculated, therefore GHD looked for what could be considered more significant differences in slope).
- Pipe capacity is greater than 90 percent of capacity under either existing or future conditions.

These pipe segments are listed in Table 5-1.

The following Table summarizes those pipes with slopes less than minimum:

Table 5-1 Adverse Pipe Slope Locations

Street/Location and Pipe ID	Pipe Diameter and Material	Record Drawing Slope (ft/ft)	Minimum TR-16 [(1)] Slope (ft/ft)
Whitehall Way (5 five pipe segments)	8-inch AC	0.003 and 0.0032	0.004
Route 28 (west of Marks Path PS) (two pipe segments)	10-inch PVC	0.0021	0.0028
Sea Street (between Summerside and South Street) (three pipe segments)	8-inch VC	0.0022 to 0.0034	0.004
Intersection of Main and Sea Street Ext.	8-inch VC	0.0013	0.004
At Ocean Street Pumping Station	8-inch AC	0.0015	0.004
Center Street	10-inch PVC	0.0019	0.0028
Barnstable Road between North and Main Street	8-inch VC	0.003	0.004
At Bay Shore Pumping Station	10-inch AC	0.0024	0.0028

Notes:
1. TR-16 Guides for the Design of Wastewater Treatment Works 2011 Edition

There were also a few cases where initial indications showed negative pipe slopes or shallow slopes. Following discussions with the Town, several areas were corrected from the Draft Technical Memorandum; however there are some outstanding areas where GHD recommends the Town verify the invert information. These areas are discussed below.

There are two areas, one at the Freezer Road Pumping Station and one at the Oak Neck Road Pumping station where the invert information shown on the available record drawings indicate inverts at the station which are higher than the preceding upstream manhole. Since the inverts in question are shown on different drawing sheets, it is possible that these were not corrected following construction. At this time the Town has stated that the same invert be used (flat slope) for modeling purposes. GHD recommends that the Town verify these inverts in the future to update their records and the model.

In addition to these two locations, GHD also recommends the Town resurvey inverts located in the sections of gravity sewer from the syphon on Millway south to its first intersection with Freezer Road and then from that intersection to the Freezer Road Pumping Station (as shown on record drawings reference numbers: H38, H39, H-41). Invert elevations in this area are either not listed or varied between different sheets in the record drawing set. Therefore, inverts and slopes were estimated based on the available slope and invert information provided on these record drawings.

It is also recommended that the Town resurvey the inverts starting at Route 28 and heading north up Whitehall Way, as the record drawing (reference number P1) is nearly illegible. This area showed some upstream capacity issues that could be influenced by this lack of information. GHD used the invert information from Route 28 as a conservative assumption in the model based on input from the Town.

5.2 Pumping Station and Force Main (FM) Results

Table 5-2 summarizes the pumping station information including FM size, existing design flow (gpm), number of pumps, and estimated existing and future flows to the station (gpm) based on sewershed data and upstream stations. It should be noted that the system does not model the vacuum sewer system located along Bearses Way and Route 28, therefore that station is not listed in the table below.

Flow estimates were based on GIS water data for existing and future conditions and the existing service areas connected to the collection system as discussed in Section 4.3. Future flows do not consider future expansion outside of the existing collection system area, therefore stations like Lincoln Road show significant available capacity as it was designed for future expansion to serve areas not currently within the sewersheds/service areas shown on Figure 5-1.

Estimated peak flows listed in Table 5-2 for pumping stations include the flow to that station from its immediate service area and flows from upstream pumping stations. The SewerCAD model can calculate estimated pumping rates from each station based on available pump information and force main information; however, that can lead to an over or under estimation of pumping flow depending on the reliability of the record information. Therefore, each station was examined to consider the estimated pumping rate, the design pumping rate (based on existing available data), the estimated flow within each sewershed to each station, and future flow projections. Some station information was unavailable, for example Bryant, Settlers Lane, and Sudbury; and estimates were based on the GIS data for the service area and not run through the SewerCAD model and therefore are not included in Table 5-2.

Table 5-2 compiles this data and estimates flows as follows:

- Each station with no upstream station, flows estimated based on service area projections.
- Each station with one upstream station, flows estimated based on service area projections plus the design pumping rate of that upstream station.
- Main Street Pumping Station: flow estimated based on service area projection plus design pump rate from Sudbury and service area flow from Marston Ave. However, as Marston Ave connections increase, the Main Street Pumping Station capacity will need to be evaluated as the flows under existing conditions would exceed the design pumping rate if both upstream stations pump at the same time.
- Old Colony Pumping Station: was considered a special case and flow estimates were based on the service area projections plus the design flows from Kalmus and Sea Street (who's service area approached their design flows) plus the sewershed flow estimates for Hyannis Youth Center and Baxter Road (who's flows were projected to be less than 15 percent of the design pumping rates for those last two stations).

Table 5-2 Modeled Pumping Stations

Pumping Station [1]	Design Flow (gpm) Each Pump [2]	Number of Pumps	Estimated Existing Peak Flow (gpm)[3]	Estimated Future Peak Flow (gpm)[3]	Force Main Size (inch)
Baxter	200	2	20	28	4
Bay Shore	450	2	340	362	8 transition to 10
Bryant	80	2	N/A [4]	N/A	4
Bearses Way[5]	**735**	**3**	**906**	**1,996**	**12**
Estey	**400**	**2**	**392**	**434**	**8**
Freezer Road	2 at 1,460 and 1 at 750	3	590	721	12 dual
Gosnold	220	2	70	94	6 & 10 (future)
Hyannis Youth Center	125	2	19	19	4
Independence	230	2	63	149	6
Kalmus	450	2	437	444	8
Lincoln Road	600	2	117	250	8 & 12 dual
720 Main Street	650	2	716	974	8 & 14 (future)
Marks Path	**330 (Town notes indicate 300)**	**2**	**438**	**508**	**6**

Pumping Station [1]	Design Flow (gpm) Each Pump [2]	Number of Pumps	Estimated Existing Peak Flow (gpm)[3]	Estimated Future Peak Flow (gpm)[3]	Force Main Size (inch)
Marston Ave	150	2	12	57	4
Oak Neck	120	2	60	88	4
Ocean Street	380	2	70	249	10
Old Colony	**2300 (2,900 with two pumps in service)**	**3**	**2,285**	**5,359**	**16 transition to 20 (with alternate cross connect to 10 on Ocean)**
Periwinkle	125	2	16	21	4
Rendezvous Lane (ejector station)	75	2 (pots)	42	53	4
Route 6A	350	2	111	131	8
Sea Street Beach	100	2	27	42	4
Sea Street	**200**	**2**	**200**	**260**	**4**
Seameadow	100	2	35	36	4
Sudbury	100	2	60	65	4
Toby	170	2	150	158	6

Notes:

1. Table does not include Bearses Way Vacuum Station (not modeled in SewerCAD) or Settlers Lane (data not available).
2. Data originally compiled from 1993 Needs Assessment Report Table 8-3 and 2011 CWMP Needs Assessment Table 4-4 and Hyannis WPCF-provided spreadsheet of pumping station equipment information.
3. Estimated flows are flows projected to enter the wet well from the upstream service area.
4. N/A = data not available
5. Enterprise Drive has three pumps sufficient to handle existing peaked flow.
6. Stations in **bold** indicate estimated flows into the station exceeding the design pumping rate (either under existing or future conditions or both).

The following stations were identified as approaching or exceeding capacity under existing or future conditions:

- **Bearses Way**: shows the need to handle a large flow in the future, as a result the station will need to be evaluated as the service area approaches those future flows. The evaluation should look at the flow conditions, I/I and pumping rates, and storage capacity to determine if an upgrade is necessary. Based on the station's proximity to the WPCF, this may require a pump drawdown test to verify its

pumping rate with two pumps in service, as depending on its hydraulics may be sufficient to handle the future flows with one pump out of service as required by TR-16.

- **Old Colony:** the same is true for Old Colony Station, which is anticipated to see a significant increase in flow based on the future flow values provided by the Town, and currently appears to be operating near capacity under peak conditions.
- **Marks Path**: is the only station that is considered over capacity under both existing and future conditions.
- **720 Main Street:** is highly influenced by Marston Ave and Sudbury PS. At this time both of those upstream stations are operating well below their design pumping rate, and therefore this station is likely operating within the design flows, however as Marston Ave service area increases connections, the Town should consider an evaluation of this station to verify its current pumping rate.
- **Sea Street, Estey, Toby, and Kalmus**: each appears to be operating near or at their capacity under existing peak conditions and each is influenced by upstream stations; however Sea Street is highly influenced by the Periwinkle Station which has a very small service area relative to its design pumping rate and therefore may be operating well within its capacity. The flow rate from Periwinkle drives the Sea Street Station to appear over capacity, however under future condition only sees 21 gpm from its service area (well below its design pumping rate of 125 gpm).

Several stations (like Lincoln Road and the vacuum sewer station) are designed such that they can be upgraded with the replacement or addition of pumps or use of larger or parallel force mains in the future. In addition, the following stations are equipped with dual (parallel) force mains which also allow for future expansion capacity or redundancy:

- **720 Main Street Pumping Station**: 8-inch and 14-inch DI force mains to WPCF. Future flow conditions may be addressed by pump modifications (pump impeller change or pump replacement) to increase pumping rates and possible consideration of use of the 14-inch FM in the future.
- **Freezer Road Pumping Station**: has dual force mains, however the vacuum sewer station is tied into one of the force mains at the WPCF site. (Cross connected so either station can pump to either force main.)

6 FLOW TIE-INS

Four potential “tie-in” areas were identified as part of initial discussions when the project began and are identified below. It is noted that these scenarios have not been fully run as there have been a number of changes regarding the Town’s current planning efforts and therefore as the Town works through recent changes in the Cape Cod Commission’s newly approved 208 Plan, different areas may be considered. Therefore it was decided to delay proceeding with modeling any potential “tie-in” scenarios at this time until the Town has further defined their wastewater management strategies. However this model will provide an excellent tool for evaluating those potential connection points and alternatives.

Potential connection areas identified previously:

- North of Route 28 along Yarmouth Road and Willow Street.

- Potential connection from Yarmouth.
- Areas south of the Lincoln Road Pumping Station.
- Areas west of the Lincoln Road Pumping Station (Long Pond/Southern Lake Wequaquet).

The model results as currently developed, as shown on Figures 5-3 and 5-4, show the significantly limited capacity at the Old Colony station; this will impact proposed connections from:

- North of Route 28 along Yarmouth Road and Willow Street.
- Potential connection from Yarmouth.

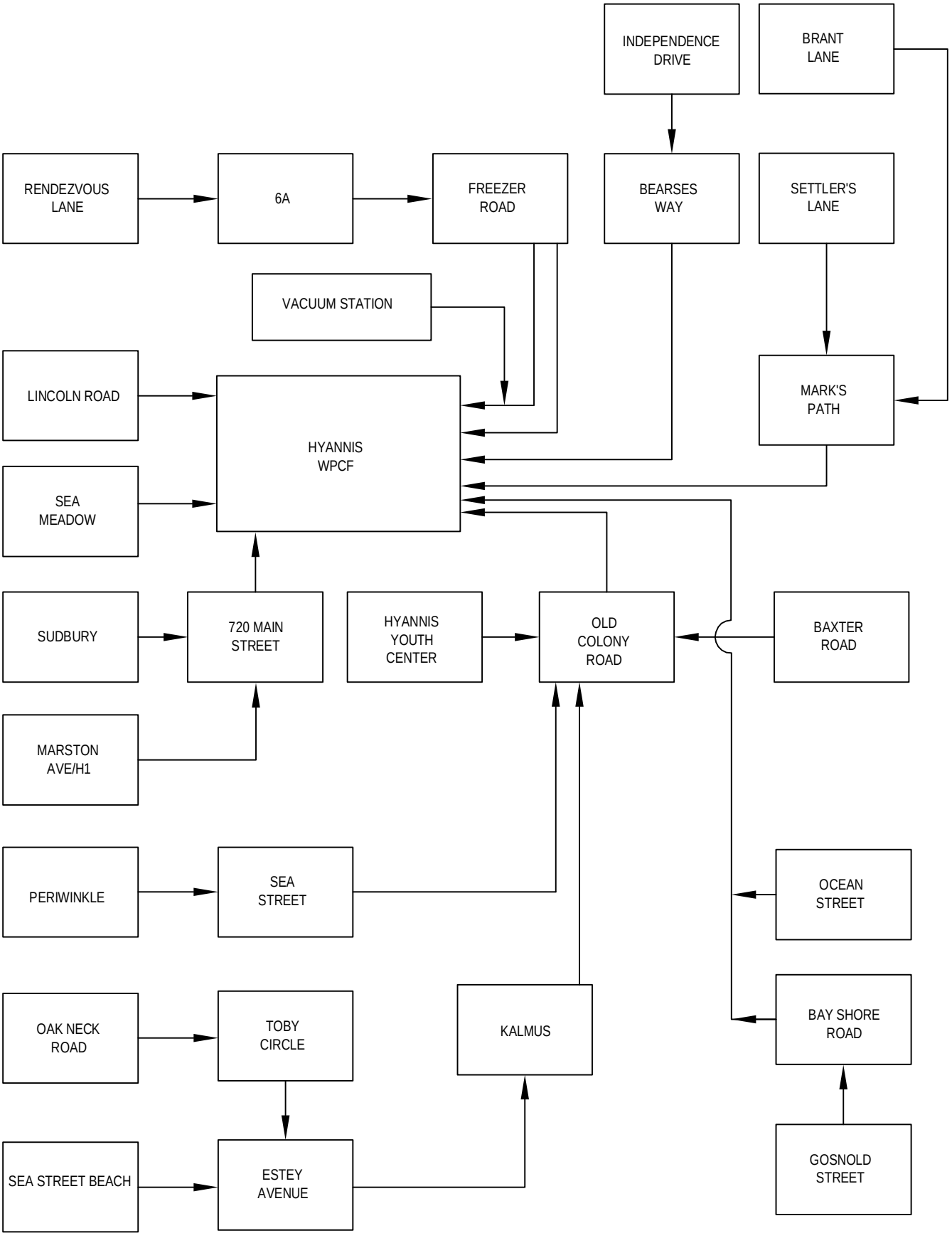
Each of these areas may require direct connection to the WPCF, which could be problematic as that would likely require work on Iyannough Road or Route 28 or both and connection to the vacuum sewer on Route 28 would not be possible based on the system limitations of the vacuum sewer system at its extremities.

The proposed connections to the Lincoln Road station can still be modelled within the system as there is sufficient capacity at that station.

7 REFERENCES AND DATA SOURCES

1. Technical Memorandum: *"Downtown Hyannis SewerCAD Modeling",* Stearns & Wheler, LLC, November 2005.
2. Report: "Wastewater Facilities Plan, Phase I, Needs Assessment Report, Town of Barnstable Massachusetts." Stearns & Wheler, LLC and Town of Barnstable DPW, December 1993.
3. Report: "Comprehensive Wastewater Management Planning (CWMP) Project, Needs Assessment Report, Volume 1 and 2." GHD Inc., May 2011.
4. Record Drawings: Scanned Record/As-built Drawings Cataloged by the Town of Barnstable as "A-Plans through W-Plans", various authors and dates.
5. GIS Data: as provided by Town of Barnstable GIS Department (James Benoit), water usage existing and future.

Figures



NOTE: PRIVATE BUSINESS PUMPING STATIONS NOT SHOWN OR MODELED

Town of Barnstable, MA
Nutrient Management Project - SewerCAD

PUMP STATION/ FORCE MAIN SCHEMATIC

Job Number	86-16263
Revision	A
Date	Mar 2016

Figure 3-1

1545 Iyannough Road, Hyannis Massachusetts 02601 USA **T** 1 774 470 1630 **F** 1 774 470 1631 **E** hyamail@ghd.com **W** www.ghd.com

Plot Date: 31 March 2016 - 4:02 PM Cad File No: G:\86\16263\GIS\Maps\MXD_Deliverables\Report Maps\24x36\BARSTABLE FLOW CHART.dwg

RENDEVOUS LANE

RTE 6A

FREEZER ROAD

BEARSES WAY

INDEPENDENCE DRIVE

SCHOONER VILLAGE
(TO VACUUM SEWER)

BRANT WAY

MARKS PATH

VACUUM SEWER

OLD COLONY
ROAD

BAXTER ROAD

OCEAN STREET

BAY SHORE ROAD

720 MAIN STREET

SEA STREET

TOBY CIRCLE

GOSNOLD

PERIWINKLE

OAK NECK ROAD

ESTEY AVENUE

KALMUS

SEA STREET BEACH

SUDBURY

LINCOLN ROAD

WW-Rendevous
WW-Freezer
WW-Route 6A
WW-Independence Dr.
WW-Settlers Lane
WW-Brant
WW-Bearses Way
WW_Vacuum Station
WW-Marks
WW-Baxter
WW-Sudbury
WW-Hyannis Youth Center
WW-Lincoln Rd.
WW-Old Colony
WW-720 Main St
WW-Ocean
WW-Bay Shore
WW-Oak Neck
WW-Toby
WW-Sea Street
WW-Gosnold
WW-Periwinkle
WW-Estey
WW-Marston
WW-Sea Street Beach
WW-Kalmus

Legend

Gravity Sewer
DIAMETER (Inches)

6
8
10
12
14
15
16
18
20
21

Sewersheds

Name

- SCHOONER VILLAGE
- 720 MAIN STREET
- BAXTER ROAD
- BAY SHORE ROAD
- BEARSES WAY
- BRANT WAY
- ESTEY AVENUE
- FREEZER ROAD
- GOSNOLD
- INDEPENDENCE DRIVE
- KALMUS
- LINCOLN ROAD
- MARKS PATH
- MARSTON AVE
- OAK NECK ROAD
- OCEAN STREET
- OLD COLONY ROAD
- PERIWINKLE
- RENDEVOUS LANE
- RTE 6A
- SEA STREET
- SEA STREET BEACH
- SUDBURY
- TOBY CIRCLE
- VACUUM SEWER

- Pump Station
- Sewer Manhole
- Low Pressure
- Vacuum Sewer
- Force Main

** Inactive Gravity Sewer Pipe and Manhole. Facilities were not included in Model but Wastewater Flows have been accounted for.

- ** Manhole
- **Gravity Sewer

Paper Size ARCH D

0 950 1,900 3,800 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

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Town of Barnstable, MA
Nutrient Management - SewerCAD

SEWERSHEDS AND PIPE DIAMETERS

Job Number 86-16263
Revision A
Date 31 Mar 2016

Figure 5-1

G:\86\16263\GIS\Maps\MXD_Deliverables\Report Maps\8616263 F5-1.mxd
1545 Iyannough Road, Hyannis Massachusetts 02601 USA **T** 1 774 470 1644 **F** 1 774 470 1631 **E** hyamail@ghd.com **W** www.ghd.com
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Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien

RENDEVOUS LANE

RTE 6A

FREEZER ROAD

BEARSES WAY

INDEPENDENCE DRIVE

SCHOONER VILLAGE (TO VACUUM SEWER)

BRANT WAY

MARKS PATH

VACUUM SEWER

OLD COLONY ROAD

BAXTER ROAD

SUDBURY

OCEAN STREET

LINCOLN ROAD

720 MAIN STREET

BAY SHORE ROAD

SEA STREET

TOBY CIRCLE

GOSNOLD

PERIWINKLE

OAK NECK ROAD

ESTEY AVENUE

KALMUS

SEA STREET BEACH

WW-Rendevous
WW-Freezer
WW-Route 6A
WW-Independence Dr.
WW-Settlers Lane
WW-Brant
WW-Bearses Way
WW-Vacuum Station
WW-Marks
WW-Sudbury
WW-Lincoln Rd.
WW-Hyannis Youth Center
WW-Baxter
WW-Old Colony
WW-720 Main St
WW-Ocean
WW-Bay Shore
WW-Oak Neck
WW-Toby
WW-Sea Street
WW-Gosnold
WW-Periwinkle
WW-Estey
WW-Marston
WW-Sea Street Beach
WW-Kalmus

Legend

Gravity Sewer

Pipe Material

- Asbestos Cement
- Ductile Iron
- PVC
- Vitrified Clay Pipe

Sewersheds

Name

- SCHOONER VILLAGE
- 720 MAIN STREET
- BAXTER ROAD
- BAY SHORE ROAD
- BEARSES WAY
- BRANT WAY
- ESTEY AVENUE
- FREEZER ROAD
- GOSNOLD
- INDEPENDENCE DRIVE
- KALMUS
- LINCOLN ROAD
- MARKS PATH
- MARSTON AVE
- OAK NECK ROAD
- OCEAN STREET
- OLD COLONY ROAD
- PERIWINKLE
- RENDEVOUS LANE
- RTE 6A
- SEA STREET
- SEA STREET BEACH
- SUDBURY
- TOBY CIRCLE
- VACUUM SEWER

- Pump Station
- Sewer Manhole
- Low Pressure
- Vacuum Sewer

** Inactive Gravity Sewer Pipe and Manhole. Facilities were not included in Model but Wastewater Flows have been accounted for.

- ** Manhole
- **Gravity Sewer

Paper Size ARCH D

0 950 1,900 3,800 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

Town of Barnstable, MA
Nutrient Management - SewerCAD

EXISTING GRAVITY SEWER PIPE MATERIAL

Job Number 86-16263
Revision A
Date 31 Mar 2016

Figure 5-2

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Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien

Gravity Sewer Pipe (Existing Capacity)

Pipe Capacity

- > 50% Capacity
- Between 15% and 50% Capacity Remaining
- Less Than 15% Capacity Remaining
- Pipe Is Surcharged

RENDEVOUS LANE
RTE 6A
FREEZER ROAD
BEARSES WAY
INDEPENDENCE DRIVE
SCHOONER VILLAGE (TO VACUUM SEWER)
BRANT WAY
MARKS PATH
VACUUM SEWER
OLD COLONY ROAD
BAXTER ROAD
SUDBURY
LINCOLN ROAD
720 MAIN STREET
OCEAN STREET
BAY SHORE ROAD
SEA STREET
TOBY CIRCLE
GOSNOLD
PERIWINKLE
OAK NECK ROAD
ESTEY AVENUE
KALMUS
SEA STREET BEACH

WW-Rendevous
WW-Route 6A
WW-Freezer
WW-Independence Dr.
WW-Settlers Lane
WW-Bearses Way
WW-Vacuum Station
WW-Brant
WW-Marks
WW-Sudbury
WW-Baxter
WW-Hyannis Youth Center
WW-Old Colony
WW-Lincoln Rd.
WW-720 Main St
WW-Ocean
WW-Bay Shore
WW-Oak Neck
WW-Toby
WW-Sea Street
WW-Gosnold
WW-Periwinkle
WW-Estey
WW-Marston
WW-Sea Street Beach
WW-Kalmus

Sewersheds

Name

- SCHOONER VILLAGE
- 720 MAIN STREET
- BAXTER ROAD
- BAY SHORE ROAD
- BEARSES WAY
- BRANT WAY
- ESTEY AVENUE
- FREEZER ROAD
- GOSNOLD
- INDEPENDENCE DRIVE
- KALMUS
- LINCOLN ROAD
- MARKS PATH
- MARSTON AVE
- OAK NECK ROAD
- OCEAN STREET
- OLD COLONY ROAD
- PERIWINKLE
- RENDEVOUS LANE
- RTE 6A
- SEA STREET
- SEA STREET BEACH
- SUDBURY
- TOBY CIRCLE
- VACUUM SEWER

- Pump Station
- Sewer Manhole
- Force Main
- Vacuum Sewer
- Low Pressure

** Inactive Gravity Sewer Pipe and Manhole. Facilities were not included in Model but Wastewater Flows have been accounted for.

- ** Manhole
- **Gravity Sewer

Paper Size ARCH D

0 950 1,900 3,800 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

Town of Barnstable, MA
Nutrient Management - SewerCAD

PIPE CAPACITY
EXISTING CONDITIONS

Job Number 86-16263
Revision A
Date 31 Mar 2016

Figure 5-3

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Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien

Gravity Sewer Pipe (Future Capacity)

- > 50% Capacity
- Between 15% and 50% Capacity Remaining
- Less Than 15% Capacity Remaining
- Pipe is Surcharged

RENDEVOUS LANE
RTE 6A
FREEZER ROAD
BEARSES WAY
INDEPENDENCE DRIVE
SCHOONER VILLAGE (TO VACUUM SEWER)
BRANT WAY
MARKS PATH
VACUUM SEWER
BAXTER ROAD
OLD COLONY ROAD
SUDBURY
OCEAN STREET
LINCOLN ROAD
720 MAIN STREET
BAY SHORE ROAD
SEA STREET
TOBY CIRCLE
GOSNOLD
PERIWINKLE
OAK NECK ROAD
ESTEY AVENUE
KALMUS
SEA STREET BEACH

WW-Rendevous
WW-Freezer
WW-Route 6A
WW-Independence Dr.
WW-Settlers Lane
WW-Brant
WW-Bearses Way
WW-Vacuum Station
WW-Marks
WW-Baxter
WW-Sudbury
WW-Hyannis Youth Center
WW-Lincoln Rd.
WW-Old Colony
WW-720 Main St
WW-Ocean
WW-Bay Shore
WW-Oak Neck
WW-Toby
WW-Sea Street
WW-Gosnold
WW-Periwinkle
WW-Estey
WW-Marston
WW-Sea Street Beach
WW-Kalmus

Sewersheds

Name

- SCHOONER VILLAGE
- 720 MAIN STREET
- BAXTER ROAD
- BAY SHORE ROAD
- BEARSES WAY
- BRANT WAY
- ESTEY AVENUE
- FREEZER ROAD
- GOSNOLD
- INDEPENDENCE DRIVE
- KALMUS
- LINCOLN ROAD
- MARKS PATH
- MARSTON AVE
- OAK NECK ROAD
- OCEAN STREET
- OLD COLONY ROAD
- PERIWINKLE
- RENDEVOUS LANE
- RTE 6A
- SEA STREET
- SEA STREET BEACH
- SUDBURY
- TOBY CIRCLE
- VACUUM SEWER

- Pump Station
- Sewer Manhole
- Vacuum Sewer
- Low Pressure
- Force Main

** Inactive Gravity Sewer Pipe and Manhole. Facilities were not included in Model but Wastewater Flows have been accounted for.

- ** Manhole
- **Gravity Sewer

Paper Size ARCH D

0 950 1,900 3,800 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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Town of Barnstable, MA
Nutrient Management - SewerCAD

PIPE CAPACITY
FUTURE CONDITIONS

Job Number	86-16263
Revision	A
Date	31 Mar 2016

Figure 5-4

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Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien

Legend

- Gravity Sewer
- Slope less than TR16 Standard
- Slope less than TR16 Standard (Highlighted)

RENDEVOUS LANE

RTE 6A

FREEZER ROAD

BEARSES WAY

INDEPENDENCE DRIVE

SCHOONER VILLAGE (TO VACUUM SEWER)

BRANT WAY

MARKS PATH

VACUUM SEWER

OLD COLONY ROAD

BAXTER ROAD

SUDBURY

OCEAN STREET

LINCOLN ROAD

720 MAIN STREET

BAY SHORE ROAD

SEA STREET

TOBY CIRCLE

GOSNOLD

PERIWINKLE

OAK NECK ROAD

ESTEY AVENUE

KALMUS

SEA STREET BEACH

WW-Rendevous
WW-Freezer
WW-Route 6A
WW-Independence Dr.
WW-Settlers Lane
WW-Bearses Way
WW-Vacuum Station
WW-Brant
WW-Marks
WW-Sudbury
WW-Lincoln Rd.
WW-Hyannis Youth Center
WW-Baxter
WW-Old Colony
WW-720 Main St
WW-Ocean
WW-Bay Shore
WW-Oak Neck
WW-Toby
WW-Sea Street
WW-Gosnold
WW-Periwinkle
WW-Estey
WW-Marston
WW-Sea Street Beach
WW-Kalmus

Sewersheds						
Name	BAY SHORE ROAD	GOSNOLD	MARSTON AVE	RENDEVOUS LANE	TOBY CIRCLE	
SCHOONER VILLAGE	BEARSES WAY	INDEPENDENCE DRIVE	OAK NECK ROAD	RTE 6A	VACUUM SEWER	
720 MAIN STREET	BRANT WAY	KALMUS	OCEAN STREET	SEA STREET		
BAXTER ROAD	ESTEY AVENUE	LINCOLN ROAD	OLD COLONY ROAD	SEA STREET BEACH		
	FREEZER ROAD	MARKS PATH	PERIWINKLE	SUDBURY		

- Sewer Manhole
- Pump Station
- Force Main
- Low Pressure
- Vacuum Sewer

** Inactive Gravity Sewer Pipe and Manhole. Facilities were not included in Model but Wastewater Flows have been accounted for.

- ** Manhole
- **Gravity Sewer

Paper Size ARCH D

0 950 1,900 3,800 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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Town of Barnstable, MA
Nutrient Management - SewerCAD

Job Number 86-16263
Revision A
Date 31 Mar 2016

ADVERSE PIPE SLOPES

Figure 5-5

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 774 470 1644 F 1 774 470 1631 E hyamail@ghd.com W www.ghd.com

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Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien

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Appendix GG

BWPCD Groundwater Discharge Permit

Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

Southeast Regional Office • 20 Riverside Drive, Lakeville MA 02347 • 508-946-2700

Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Matthew A. Beaton
Secretary

Martin Suuberg
Commissioner

November 5, 2018

Mr. Daniel Santos, Director
Department of Public Works
382 Falmouth Road
Hyannis, Massachusetts 02601

RE: BARNSTABLE – BRP WP 12,
Barnstable Water Pollution Control
Facility
Permit No.: 21-1
Transmittal No.: X280981

Dear Mr. Santos:

In response to your application for a permit to discharge into the ground a treated effluent from the treatment works at the above referenced location and after due public notice, I hereby issue the attached final permit.

Since no comments were received by the Department during the public comment period related to the terms of the permit, in accordance with 310 CMR 2.08, the permit becomes effective at issuance.

Parties aggrieved by the issuance of this permit are hereby advised of their right to request an Adjudicatory Hearing under the provisions of Chapter 30A of the Massachusetts General Laws and 314 CMR 1.00, Rules for the Conduct of Adjudicatory Proceedings. Unless the person requesting the adjudicatory hearing requests and is granted a stay of the terms and conditions of the permit, the permit shall remain fully effective.

This information is available in alternate format. Contact Michelle Waters-Ekanem, Director of Diversity/Civil Rights at 617-292-5751.
TTY# MassRelay Service 1-800-439-2370
MassDEP Website: www.mass.gov/dep
Printed on Recycled Paper

If you should have any questions on any information provided with this letter please contact me at (508) 946-2814.

Sincerely,

Brian A. Dudley, Section Chief
Wastewater Management – Cape & Islands

D/BAD
Enclosures

cc: Mr. Thomas McKean, Director
Health Division
200 Main Street
Hyannis, MA. 02601
Enclosure (Permit)

ecc: DEP/Boston/Wastewater Management

DEP/SERO
Attn: Lisa Ramos

Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

Southeast Regional Office • 20 Riverside Drive, Lakeville MA 02347 • 508-946-2700

Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Matthew A. Beaton
Secretary

Martin Suuberg
Commissioner

INDIVIDUAL GROUNDWATER DISCHARGE PERMIT

Name and Address of Applicant: Town of Barnstable, Department of Public Works, 382 Falmouth Road, Hyannis, Massachusetts 02601

Date of Application:

Application/Permit No. 21-1

Date of Issuance: November 5, 2018
Date of Expiration: November 5, 2023

Effective Date: November 5, 2018

AUTHORITY FOR ISSUANCE

Pursuant to authority granted by Chapter 21, Sections 26-53 of the Massachusetts General Laws, as amended, 314 CMR 2.00, and 314 CMR 5.00, the Massachusetts Department of Environmental Protection (the Department or MassDEP) hereby issues the following permit to: **Town of Barnstable, Department of Public Works** (hereinafter called "the permittee") authorizing discharges to the ground from the on site wastewater treatment facility located at **Barnstable Water Pollution Control Facility (BWPCF), Bearses Way, Hyannis** such authorization being expressly conditional on compliance by the permittee with all terms and conditions of the permit hereinafter set forth.

Brian A. Dudley, Section Chief
Wastewater Management – Cape and Islands

NOVEMBER 5, 2018
Date

This information is available in alternate format. Contact Michelle Waters-Ekanem, Director of Diversity/Civil Rights at 617-292-5751.
TTY# MassRelay Service 1-800-439-2370
MassDEP Website: www.mass.gov/dep

Printed on Recycled Paper

I. SPECIAL CONDITIONS

A. Department Plan Approval of the BWPCF

This Permit authorizes, subject to the terms and conditions set forth in the Permit, the continued operation of the BWPCF with a discharge capacity of 2.7 million gallons per day (MGD) maximum daily flow and a treatment capacity of 4.2 MGD maximum daily flow subject to the Department's review and approval as provided below.

The Permittee shall evaluate the capacity of the current infiltration beds, including consideration of adverse downgradient impacts, and evaluate options for wastewater disposal outside the Lewis Bay watershed. Prior to accepting wastewater above 2.7 MGD, the Permittee shall submit an engineering report and plans, if required, demonstrating adequate capacity for up to 4.2 MGD which shall include calculations of nitrogen loading to any watersheds to which effluent is discharged. The Permittee shall obtain the Department's approval to operate the expanded BWPCF prior to operating at a capacity in excess of 2.7 MGD maximum daily flow at which time the Department may impose alternate mass loading limits.

B. Effluent Limits

1) The permittee is authorized to discharge into the ground from the wastewater treatment facilities for which this permit is issued a treated effluent whose characteristics shall not exceed the following values:

Effluent Characteristics	Current Discharge Limitations	Expanded Discharge Limitations
Flow	2.7 MGD(maximum)	4.2 MGD (maximum)
Biochemical Oxygen Demand, 5-day at 20°C (BOD_5)	30 mg/L	30 mg/L
Total Suspended Solids	30 mg/l	30 mg/l
Total Dissolved Solids	1000 mg/L	1000 mg/L
Nitrate Nitrogen	10 mg/l	10 mg/l
Total Nitrogen (NO_2 + NO_3 + TKN)	10 mg/l and not to exceed 49,315 pounds per calendar year	10 mg/l
Oil & Grease	15 mg/l	15 mg/l
Fecal Coliform	200 colonies/100 ml	200 colonies/100 ml
Total Residual Chlorine	1 mg/L	1 mg/L

a) 10 mg/L represents the maximum daily limit. 49,315 pounds per year represents the mass load at a maximum daily flow of 2.7 MGD and an annual average Total Nitrogen concentration of 6 mg/L.

b) The pH of the effluent shall not be less than 6.5 nor greater than 8.5 at any time or not more than 0.2 standard units outside the naturally occurring range.

c) The discharge of the effluent shall not result in any demonstrable adverse effect on the groundwater or violate any water quality standards that have been promulgated.

d) The monthly average concentration of BOD and TSS in the discharge shall not exceed 15 percent of the monthly average concentrations of BOD and TSS in the influent into the permittee's wastewater treatment facility.

e) When the average annual flow exceeds 80 percent of the permitted flow limitations, the permittee shall submit a report to the Department describing what steps the permittee will take in order to remain in compliance with the permit limitations and conditions, inclusive of the flow limitations established in this permit.

C. Monitoring and Reporting

1) The permittee shall monitor and record the quality of the **influent** and the quality and quantity of the **effluent** prior to discharge to the leaching facilities according to the following schedule and other provisions:

INFLUENT:

Parameter	Minimum Frequency of Analysis	Sample Type
pH	Daily	Grab
Septage (quantity)	Daily	report
TSS	Weekly	24-hr Composite
BOD_5	Monthly	24-hr Composite
Oil & Grease	Monthly	Grab
Total Nitrogen ($NO_2 + NO_3 + TKN$)	Monthly	24-hr Composite
Sodium	Monthly	Grab
Volatile Organic Compounds US EPA Method #624	Quarterly	Grab

a) Sampling location to be at the influent channel atop the headworks

EFFLUENT:

Parameter	Minimum Frequency of Analysis	Sample Type
Flow	Daily	Continuous reading and/or calculation
pH	Daily	Grab
BOD_5	2 x Monthly	24-hr Composite
Total Nitrogen (NO_2+NO_3+TKN)	2 x Monthly	24-hr Composite
Nitrate - Nitrogen (NO_3)	2 x Monthly	24-hr Composite
NH_3 as Nitrogen	2 x Monthly	24-hr Composite
Total Suspended Solids	Weekly	24-hr Composite
Total Solids	Weekly	Grab
Oil & Grease	Monthly	Grab
Fecal Coliform	Monthly	Grab
Total Phosphorus	Quarterly	Grab
Orthophosphate	Quarterly	Grab
Total Residual Chlorine	Daily	Grab
Volatile Organic Compounds	Quarterly	Grab

a) Grab samples shall be collected immediately following the chlorine contact chamber. 24-hr composite samples shall be taken immediately prior to the chlorine contact chamber.

b) After one full year of monitoring the Total Phosphorus and Orthophosphate results, the Department may determine, upon the request of the permittee, that the frequency of monitoring may be reduced if, in the judgment of the Department, the results of the sampling indicate that existing phosphorus levels will not adversely impact downgradient receptors. If the Department reduces the frequency of monitoring for Total Phosphorus and Orthophosphate, the Department reserves the right to resume more frequent monitoring if the Department determines that phosphorus levels are impacting downgradient receptors.

2) The permittee shall monitor, record and report the quality of water in the approved upgradient monitoring well BC -1 and downgradient monitoring wells BA-1, BA-2, BA-3, BB-1, BB-2, BB-3, BD-1 and BE-1 (as shown on the accompanying map) according to the following schedule and other provisions:

Parameter	Frequency of Analysis
Static Water Level	Quarterly
Specific Conductance	Quarterly
pH	Quarterly
Total Nitrogen($NO_2 + NO_3 + TKN$)	Quarterly
Ammonia Nitrogen ($NH_3 - N$)	Quarterly
Nitrate Nitrogen (NO_3-N)	Quarterly
Alkalinity	Quarterly
Chloride	Quarterly
Copper	Quarterly
Iron	Quarterly
Manganese	Quarterly
Sodium	Quarterly
Sulfate	Quarterly
Total Phosphorus	Quarterly
Orthophosphate	Quarterly
Total Residual Chlorine	Quarterly
Volatile Organic Compounds	2 x Annually

a) Static Water Level shall be expressed as an elevation and shall be referenced to the surveyed datum established for the site. It shall be calculated by subtracting the depth to the water table from the surveyed elevation of the top of the monitoring well's PVC well casing/riser.

b) After one full year of monitoring the Total Phosphorus and Orthophosphate results, the Department may determine, upon the request of the permittee, that the frequency of monitoring may be reduced if, in the judgment of the Department, the results of the sampling indicate that existing phosphorus levels will not adversely impact downgradient receptors. If the Department reduces the frequency of monitoring for Total Phosphorus and Orthophosphate, the Department reserves the right to resume more frequent monitoring if the Department determines that phosphorus levels are impacting downgradient receptors.

3) Any grab sample or composite sample required to be taken less frequently than daily shall be taken during the period of Monday through Friday inclusive. All composite samples shall be taken over the operating day.

4) The permittee shall submit all monitoring reports within 30 days of the last day of the reporting month to MassDEP using the eDEP data submission system.

To register for electronic submission go to:
http://www.mass.gov/eea/agencies/massdep/service/online/edep-online-filing.html
and to the Board of Health, 200 Main Street, Hyannis, MA. 02601

D. Supplemental Conditions

1) By December 31, 2021, the Permittee shall submit a Comprehensive Wastewater Management Plan (CWMP) or equivalent to the Department for its review and approval. The CWMP shall include, but not be limited to, the following items:
   a. assessment of future capacity of the BWPCF based on the needs of the town to meet Total Maximum Daily Loads (TMDL) in watersheds within Town jurisdiction;
   b. evaluation and assessment of necessary effluent treatment limits to meet TMDLs;
   c. identification and assessment of alternate effluent recharge locations outside the Lewis Bay watershed;
   d. evaluation of community partnership opportunities with communities sharing watersheds with the Town, with immediate emphasis on Lewis Bay; and
   e. demonstrate consistency with the Cape Cod Commission's 208 Plan Update.

2) By December 31, 2019 the Permittee shall submit an engineering report and plans for Department review and approval to install an effluent flow meter. Installation of the flow meter shall be completed by December 31, 2020.

3) The permittee shall notify the Department at least thirty (30) days in advance of any proposed transfer of ownership of the facility for which this permit is written. Said notification shall include a written agreement between the existing and new permittees containing a specific date for transfer of permit, responsibility, coverage and liability between them.

4) A staffing plan for the facility shall be submitted to the Department once every two years and whenever there are staffing changes. The staffing plan shall include the following components:

   a) The operator(s)'s name(s), operator grade(s) and operator license number(s);
   b) The number of operational days per week;
   c) The number of operational shifts per week;
   d) The number of shifts per day;
   e) The required personnel per shift;
   f) Saturday, Sunday and holiday staff coverage;
   g) Emergency operating personnel

5) The permittee is responsible for the operation and maintenance of all sewers, pump stations, and treatment units for the permitted facility, which shall be operated and maintained under the direction of a properly certified wastewater operator.

6) Operation and maintenance of the proposed facility must be in accordance with 314 CMR 12.00, "Operation and Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Discharges", and, 257 CMR 2.00, "Rules and Regulations for Certification of Operators of Wastewater Treatment Facilities".

a) The facility has been rated (in accordance with 257 CMR 2.00), to be a Grade 6 facility. Therefore, the permittee shall provide for oversight by a Massachusetts Certified Wastewater Treatment plant operator (Chief Operator) Grade 6 or higher. The permittee will also provide for a backup operator who shall possess at least a valid Grade 6 license.

b) The date and time of the operator's inspection along with the operator's name and certification shall be recorded in the log book on location at the treatment facility. All daily inspection logs consistent with the O&M Manual requirements shall be kept at the facility for a period of three (3) years.

c) Records of operation of wastewater treatment facilities or disposal systems required by the Department shall be submitted on forms supplied by the Department or on other forms approved by the Department for such use. Monthly reports shall be certified by the wastewater treatment plant operator in charge and shall be included in the discharge monitoring reports submitted each month.

If the operation and maintenance of the facility is contracted to a private concern, the permittee shall submit a copy of the contract, consistent with what is required by the approved Operation & Maintenance manual and signed only by the contractor, to the appropriate MassDEP Regional Office within thirty (30) days of permit issuance. Along with the contract, a detailed listing of all contract operation obligations of the proposed contractor at other facilities shall also be submitted.

7) All tests or analytical determinations to determine compliance with permit standards and requirements shall be done using tests and procedures found in the most recent version of *Standard Methods for the Examination of Water and Wastewater* and shall be performed by a Massachusetts Certified laboratory.

8) The permittee shall notify the appropriate MassDEP Regional Office, in writing, within thirty (30) days of the following events:

a) The date of treatment plant start up.
b) Any interruption of the treatment system operation, other than routine maintenance.
c) Final shutdown of the treatment system.

9) The permittee shall contract to have any and all solids and sludges generated by the treatment system for which this permit is issued removed off site by a properly licensed waste hauler for disposal at an EPA/MassDEP approved facility. The name and license number of the hauler along with the quantity of wastes removed and the date(s) of removal shall be reported by the permittee in writing to the appropriate MassDEP Regional Office.

10) Simultaneously with the permit renewal application in 2023, the permittee shall submit an engineering report prepared by a registered professional engineer to the Department for its review and approval that outlines in sufficient detail what modifications (if any) to

the facility or other changes are required to insure that the facility can remain in compliance with its GWDP and other applicable requirements through the next 5 year permit term (year 2028) and beyond.

11) In the event that effluent limits are not met, or the discharge is determined to impair groundwater quality in accordance with 314 CMR 5.16(1), the permittee may be obligated to modify, supplement or replace the permitted treatment process so as to ensure that the discharge does not impair the ability of the groundwater to act as an actual or potential source of potable water.

12) Pursuant to M.G.L. Chapter 21A, section 18(a), and 310 CMR 4.03, holders of this Permit may be subject to annual compliance assurance fees as assessed each year on July 1st and invoiced by MassDEP. Failure of the Permit holder to pay applicable annual compliance assurance fees shall result in the automatic suspension of the permit by operation of law under the statute. If fee non-payment continues for sixty days or more, MassDEP has the statutory option of revoking the Permit, denying any other pending permit applications filed by the Permit holder or taking other enforcement action. Permit holders are required to notify MassDEP in writing if they wish to relinquish or transfer a permit. Failure to do so will result in the continued assessment of fees.

E. Appeal Rights

During the thirty (30) day period following issuance of this permit, a Notice of Claim for an Adjudicatory Appeal may be sent by any person aggrieved (the "Petitioner") by the issuance to:

Case Administrator
Office of Appeals and Dispute Resolution
Department of Environmental Protection
One Winter Street/2nd Floor
Boston, MA 02108

310 CMR 1.01(6)(b) requires the Notice of Claim to: include sufficient facts to demonstrate aggrieved person status; state the facts which are grounds for the appeal specifically, clearly and concisely; and, state relief sought. The permit shall become or remain effective at the end of the 30 day appeal period unless the person filing the Notice of Claim requests, and is granted, a stay of its terms and conditions. If a permit is modified under 314 CMR 2.10, only the modified terms and conditions may be subject to an Adjudicatory Appeal. All other aspects of the existing permit shall remain in effect during any such Adjudicatory Appeal.

Per 310 CMR 4.06, the hearing request to the Commonwealth will be dismissed if the filing fee is not paid. Unless the Petitioner is exempt or granted a waiver, a valid check payable to the Commonwealth to Massachusetts in the amount of $100.00 must be mailed to:

Commonwealth of Massachusetts
Department of Environmental Protection
P.O. Box 4062
Boston, MA 02211

The filing fee is not required if the Petitioner is a city, town, county, or district of the Commonwealth, federally recognized Indian tribe housing authority effective January 14, 1994, or any municipal housing authority; or, per MGL 161A s. 24, the Massachusetts Bay Transportation Authority. The Department may waive the adjudicatory hearing filing fee for a Petitioner who shows that paying the fee will create an undue financial hardship. A Petitioner seeking a waiver must file, along with the hearing request, an affidavit setting forth the facts believed to support the claim of undue financial hardship.

II. GENERAL PERMIT CONDITIONS

5.16: General Conditions

The following conditions apply to all individual and general permits:

(1) No discharge authorized in the permit shall cause or contribute to a violation of 314 CMR 4.00: *Massachusetts Surface Water Quality Standards*. Upon promulgation of any amended standard, the permit may be modified to comply with such standard in accordance with the procedures in 314 CMR 2.10: *Modification, Suspension, Revocation and Renewal of Permits and General Permit Coverage* and 314 CMR 5.12. Except as otherwise provided in 314 CMR 5.10(3)(c), 5.10(4)(a)2. and 5.10(9), no discharge authorized in the permit shall impair the ability of the ground water to serve as an actual or potential source of potable water. Evidence that a discharge impairs the ability of the ground water to serve as an actual or potential source of potable water includes, without limitation, analysis of samples taken in a downgradient well that demonstrates one or more exceedances of the applicable water quality based effluent limitations set forth in 314 CMR 5.10. In those cases where it is shown that a measured parameter exceeds the applicable water quality based effluent limitations set forth in 314 CMR 5.10 at the upgradient monitoring well, evidence that a discharge impairs the ability of the ground water to serve as an actual or potential source of potable water is deemed to exist if a measured parameter in any downgradient well exceeds the level of that same measured parameter in the upgradient well for the same sampling period. A statistical procedure approved by the Department shall be used to determine when a measured parameter exceeds the allowable level.

(2) Duty to Comply. The permittee shall comply at all times with the terms and conditions of the permit, 314 CMR 5.00, M.G.L. c. 21, §§ 26 through 53, and all applicable state and federal statutes and regulations.

(3) Standards and Prohibitions for Toxic Pollutants. The permittee shall comply with effluent standards or prohibitions established by § 307(a) of the Federal Act, 33 U.S.C. § 1317(a), for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.

(4) Proper Operation and Maintenance. The permittee shall at all times properly operate and maintain all facilities and equipment installed or used to achieve compliance with the terms and conditions of the permit, 314 CMR 12.00: *Operation and Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Discharges*, and 257 CMR 2.00: *Certification of Operators of Wastewater Treatment Facilities*. All equipment shall be maintained in an acceptable condition for its intended use.

(5) Duty to Halt or Reduce Activity. Upon reduction, loss, or failure of the treatment facility, the permittee shall, to the extent necessary to maintain compliance with its permit, control production, discharges, or both, until the facility is restored or an alternative method of treatment is provided. A permittee may not raise as a defense in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of the permit.

(6) Power Failure. In order to maintain compliance with the effluent limitations and prohibitions of the permit, the permittee shall either:

(a) provide an alternative power source sufficient to operate the wastewater control facilities; or

(b) halt, reduce or otherwise control production or all discharges upon the reduction, loss, or failure of the primary source of power to the wastewater control facilities.

(7) Duty to Mitigate. The permittee shall take all reasonable steps to minimize or prevent any adverse impact on human health or the environment resulting from non-compliance with the permit. Additionally, the permittee shall take all necessary steps to prevent an operational upset of the PWTF or POTW.

(8) Duty to Provide Information. The permittee and any operator of the permitted facility shall furnish to the Department within a reasonable time as specified by the Department any information which the Department may request to determine whether cause exists for modifying, suspending, revoking and reissuing, or terminating the permit, or to determine whether the permittee is complying with the terms and conditions of the permit.

(9) Inspection and Entry. The permittee shall allow the Department or its authorized representatives to:

(a) Enter upon the permittee's premises where a regulated facility or activity is located or conducted, or where records required by the permit are kept;

(b) Have access to and copy, at reasonable times, any records that must be kept under the conditions of the permit;

(c) Inspect at reasonable times any facilities, equipment, practices, or operations regulated or required under the permit; and

(d) Sample or monitor at reasonable times for the purpose of determining compliance with the terms and conditions of the permit.

(9A) The permittee shall physically secure the treatment works and monitoring wells and limit access to the treatment works and monitoring wells only to those personnel required to operate, inspect and maintain the treatment works and to collect samples.

(9B) The permittee shall identify each monitoring well by permanently affixing to the steel protective casing of the well a tag with the identification number listed in the permit.

(10) Monitoring. Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity. Monitoring must be conducted according to test procedures approved under 40 CFR Part 136 unless other test procedures are specified in the permit.

(11) Recordkeeping. The permittee shall retain records of all monitoring information, including all calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by the permit, and all records of all data used to complete the application for the permit, for a period of at least five years from the date of the sample, measurement, report or application. This period may be extended by request of the Department at any time. Records of monitoring information shall include without limitation:

(a) The date, exact place, and time of sampling or measurements;
(b) The individual(s) who performed the sampling or measurement;
(c) The date(s) analyses were performed;
(d) The individual(s) who performed the analyses;
(e) The analytical techniques or methods used; and
(f) The results of such analyses.

(12) Prohibition of Bypassing. Except as provided in 314 CMR 5.16(13), bypassing is prohibited and the Department may take enforcement action against a permittee for bypassing unless:

(a) The bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;

(b) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if the permittee could have installed adequate backup equipment to prevent a bypass which occurred during normal periods of equipment downtime or preventive maintenance; and

(c) The permittee submitted notice of the bypass to the Department:

1. In the event of an anticipated bypass, at least ten days in advance, if possible; or

2. In the event of an unanticipated bypass, as soon as the permittee has knowledge of the bypass and no later than 24 hours after its first occurrence.

(13) Bypass not Exceeding Limitations. The permittee may allow a bypass to occur which does not cause effluent limitations to be exceeded, but only if necessary for the performance of essential maintenance or to assure efficient operation of treatment facilities.

(14) Permit Actions. The permit may be modified, suspended, or revoked for cause. The filing of a request by the permittee for a permit modification, reissuance, or termination, or a notification of planned changes or anticipated non-compliance does not stay any permit condition.

(15) Duty to Reapply. If the permittee wishes to continue an activity regulated by the permit after the expiration date of the permit, the permittee must apply for and obtain a new permit. The permittee shall submit a new application at least 180 days before the expiration date of the existing permit, unless permission for a later date has been granted by the Department in writing.

(16) Property Rights. The permit does not convey any property rights of any sort or any exclusive privilege.

(17) Other Laws. The issuance of a permit does not authorize any injury to persons or property or invasion of other private rights, nor does it relieve the permittee of its obligation to comply with any other applicable Federal, State, or local law, or regulation.

(18) Oil and Hazardous Substance Liability. Nothing in the permit shall be construed to preclude the institution of any legal action or relieve the permittee of any responsibilities, liabilities, or penalties to which the permittee is or may be subject under § 311 of the Federal

Act, 33 U.S.C. § 1321, and M.G.L. c. 21E.

(19) Removed Substances. Solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters shall be disposed in a manner consistent with applicable Federal and State laws and regulations including, but not limited to, the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26 through 53, and the Federal Act, 33 U.S.C. § 1251 *et seq.*, the Massachusetts Hazardous Waste Management Act, M.G.L. c. 21C, and the Federal Resource Conservation and Recovery Act, 42 U.S.C. § 6901, *et seq.*, 310 CMR 19.000: *Solid Waste Management* and 310 CMR 30.000: *Hazardous Waste*.

(20) Reporting Requirements.

(a) Monitoring Reports. Monitoring results shall be reported on a Discharge Monitoring Report (DMR) at the intervals specified in the permit. If a permittee monitors any pollutant more frequently than required by the permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the DMR. Beginning on December 2, 2017, a permittee shall submit all DMRs electronically, using the electronic reporting system designated by the Department. A permittee may seek a waiver of this requirement by submitting a written request for the Department's approval.

(b) Compliance Schedules. Reports of compliance or non-compliance with, or any progress reports on interim and final requirements contained in any compliance schedule in the permit shall be submitted no later than 14 days following each schedule date.

(c) Planned Changes. The permittee shall give notice to the Department as soon as possible of any planned physical alterations or additions to the permitted facility or activity which could significantly change the nature or increase the quantity of pollutants discharged. Unless and until the permit is modified, any new or increased discharge in excess of permit limits or not specifically authorized by the permit constitutes a violation.

(d) Anticipated Non-compliance. The permittee shall give advance notice to the Department of any planned changes in the permitted facility or activity which may result in non-compliance with permit requirements.

(e) 24 Hour Reporting. The permittee shall report any non-compliance which may endanger health or the environment. Any information shall be communicated orally within 24 hours of the time the permittee becomes aware of the circumstances. A written submission shall also be provided within five days of the time the permittee becomes aware of the circumstances. The written submission shall contain: a description of the non-compliance, including exact dates and times, and if the non-compliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the non-compliance. The following shall be included as information which must be reported within 24 hours:

1. Any unanticipated bypass which exceeds any effluent limitation in the permit; and
2. Any violation of a maximum daily discharge limitation for any of the pollutants required by the permit to be reported within 24 hours.

(f) Other Non-compliance. The permittee shall report all instances of non-compliance not reported under 314 CMR 5.16(20)(a), (b), or (e) at the time monitoring reports are submitted. The reports shall contain the information listed in 314 CMR 5.16(20)(e).

(g) Toxics. All manufacturing, commercial, mining, or silvicultural dischargers must notify

the Department as soon as they know or have reason to believe:

1. That any activity has occurred, or will occur, that would result in the discharge of any toxic pollutant listed in 314 CMR 3.17: *Appendix B - Toxic Pollutants* not limited by the permit, if that discharge will exceed the highest of the following notification levels:

a. 100 micrograms per liter (100 ug/l);

b. 200 micrograms per liter (200 ug/l) for acrolein and acrylonitrile, 500 micrograms per liter (500 ug/l) for 2,4-dinitrophenol, and for 2-methyl-4,6-dinitrophenol, and one milligram per liter (1 mg/l) for antimony;

c. Five times the maximum concentration value reported for that pollutant in the permit application; or

2. That they have begun or expect to begin to use or manufacture as an intermediate or final product or byproduct any toxic pollutant which was not reported in the permit application.

(h) Indirect Dischargers. All Publicly Owned Treatment Works shall provide adequate notice to the Department of the following:

1. Any new introduction of pollutants into the POTW from an indirect discharger which would be subject to § 301 or § 306 of the Federal Act, 33 U.S.C. § 1311 or 1316, if it were directly discharging those pollutants; and

2. Any substantial change in the volume or character of pollutants being introduced into the POTW by a source introducing pollutants into the POTW at the time of issuance of the permit.

(i) Information. Where a permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application or in any report to the Department, it shall promptly submit the relevant facts or correct information.

(j) The permittee shall notify the Department in writing within seven days of any change in contract operators.

(21) Signatory Requirement. All applications, reports, or information submitted to the Department shall be signed and certified in accordance with 314 CMR 5.14 and 5.15.

(22) Severability. The provisions of the permit are severable. If any provision of the permit, or the application of any provision of the permit to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of the permit, shall not be affected thereby.

(23) Reopener Clause. The Department reserves the right to make appropriate revisions to the permit to establish any appropriate effluent limitations, schedules of compliance, or other provisions, as authorized by the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26 through 53, or the Federal Act, 33 U.S.C. § 1251 *et seq.*, to bring all discharges into compliance with these statutes.

(24) Approval of Treatment Works. All discharges and associated treatment works authorized in 314 CMR 5.00 shall remain in compliance with the terms and conditions of the permit. Any modification of the approved treatment works shall require written approval of the Department prior to the construction of the modification.

(25) Transfer of Permits.

(a) RCRA Facilities. Any permit which authorizes the operation of a RCRA facility subject to the requirements of 314 CMR 8.07: *Standards for all other RCRA Facilities* shall be valid only for the person to whom it is issued and may not be transferred.

(b) Transfers by Modification. Except as provided in 314 CMR 5.16(25)(a) and (c), a permit may be transferred by the permittee to a new permittee if the permit has been modified or revoked and reissued in accordance with 314 CMR 5.12(2), or a minor modification is made to identify the new permittee in accordance with 314 CMR 5.12(3) and (4).

(c) Automatic Transfers. For facilities other than Privately Owned Wastewater Treatment Facilities (PWTFs) that treat at least some sewage from residential uses, hospitals, nursing or personal care facilities, residential care facilities, or assisted living facilities, PWTFs that have been required to establish, fund and maintain financial assurance mechanism(s) pursuant to 314 CMR 5.15(6), and RCRA facilities subject to the requirements of 314 CMR 8.07: *Standards for all other RCRA Facilities*, a permit may be automatically transferred in accordance with 314 CMR 5.12(5).

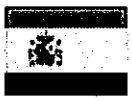
(26) Permit Compliance Fees and Inspection Information. Except as otherwise provided, any permittee required to obtain a ground water discharge permit pursuant to M.G.L. c. 21, § 43, and 314 CMR 5.00 shall submit the annual compliance assurance fee established in accordance with M.G.L. c. 21A, § 18 and 310 CMR 4.00: *Timely Action Schedule and Fee Provisions*, as provided in 314 CMR 2.12: *Applications, Fees and Inspection Information.* The requirement to submit the annual compliance fee does not apply to any local government unit other than an authority. Any permittee required to obtain a ground water discharge permit pursuant to M.G.L. c. 21, § 43 and 314 CMR 5.00, may be required to submit inspection information annually, as provided in 314 CMR 2.12.

Massachusetts Department of Environmental Protection
One Winter Street, Boston MA 02108 • Phone: 617-292-5751
Communication For Non-English Speaking Parties - 310 CMR 1.03(5)(a)



1 English:

This document is important and should be translated immediately. If you need this document translated, please contact MassDEP's Diversity Director at the telephone numbers listed below.



2 Español (Spanish):

Este documento es importante y debe ser traducido inmediatamente. Si necesita este documento traducido, por favor póngase en contacto con el Director de Diversidad MassDEP a los números de teléfono que aparecen más abajo.



3 Português (Portuguese):

Este documento é importante e deve ser traduzida imediatamente. Se você precisa deste documento traduzido, por favor, entre em contato com Diretor de Diversidade da MassDEP para os números de telefone listados abaixo.



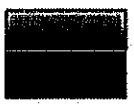
4(a) 中國（傳統）(Chinese (Traditional):

本文件非常重要，應立即翻譯。如果您需要翻譯這份文件，請用下面列出的電話號碼與MassDEP的多樣性總監聯繫。



4(b) 中国（简体中文）(Chinese (Simplified):

本文件非常重要，应立即翻译。如果您需要翻译这份文件，请用下面列出的电话号码与MassDEP的多样性总监联系。



5 Ayisyen (franse kreyòl) (Haitian) (French Creole):

Dokiman sa-a se yon bagay enpòtan epi yo ta dwe tradui imedyatman. Si ou bezwen dokiman sa a tradui, tanpri kontakte Divèsite Direktè MassDEP a nan nimewo telefòn ki nan lis pi ba a.



6 Việt (Vietnamese):

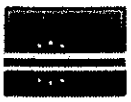
Tài liệu này là rất quan trọng và cần được dịch ngay lập tức. Nếu bạn cần dịch tài liệu này, xin vui

lòng liên hệ với Giám đốc MassDEP đa dạng tại các số điện thoại được liệt kê dưới đây.



7 ប្រទេសកម្ពុជា (Kmer (Cambodian):

ឯកសារនេះគឺមានសារៈសំខាន់និងគួរត្រូវបានបកប្រែភ្លាម។ ប្រសិនបើអ្នកត្រូវបានបកប្រែ ឯកសារនេះសូមទំនាក់ទំនងឆ្ពោតជានាយក MassDEP នៅលេខទូរស័ព្ទដែលបានរាយខាងក្រោម។



8 Kriolu Kabuverdianu (Cape Verdean):

Es documento é importante e deve ser traduzido imidiatamente. Se bo precisa des documento traduzido, por favor contacta Director de Diversidade na MassDEP's pa es numero indicode li d'boche.



9 Русский язык (Russian):

Этот документ является важным и должно быть переведено сразу. Если вам нужен этот документ переведенный, пожалуйста, свяжитесь с директором разнообразия MassDEP по адресу телефонных номеров, указанных ниже.



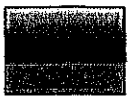
10 العربية **(Arabic):**

هذه الوثيقة الهامة وينبغي أن تترجم على الفور. اذا كنت بحاجة الى هذه الوثيقة المترجمة، يرجى الاتصال مدير التنوع في MassDEPعلى أرقام الهواتف المدرجة أدناه.



11 한국어 **(Korean):**

이 문서는 중요하고 즉시 번역해야합니다. 당신이 번역이 문서가 필요하면 아래의 전화 번호로 MassDEP의 다양성 감독에 문의하시기 바랍니다.



12 հայերեն **(Armenian):**

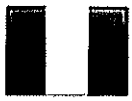
Այս փաստաթուղթը շատ կարեւոր է եւ պետք է թարգմանել անմիջապես. Եթե Ձեզ անհրաժեշտ է այս փաստաթուղթը թարգմանվել դիմել MassDEP բազմազանությունը տնօրեն է հեռախոսահամարների թվարկված են ստորեւ.



13 فارسی **(Farsi (Persian):**

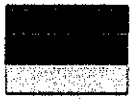
این سند مهم است و باید فورا ترجمه شده است.

اگر شما نیاز به این سند ترجمه شده، لطفا با ما تماس تنوع مدیر MassDEP در شماره تلفن های ذکر شده در زیر.



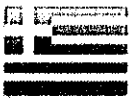
14 Français (French):

Ce document est important et devrait être traduit immédiatement. Si vous avez besoin de ce document traduit, s'il vous plaît communiquer avec le directeur de la diversité MassDEP aux numéros de téléphone indiqués ci-dessous.



15 Deutsch (German):

Dieses Dokument ist wichtig und sollte sofort übersetzt werden. Wenn Sie dieses Dokument übersetzt benötigen, wenden Sie sich bitte Diversity Director MassDEP die in den unten aufgeführten Telefonnummern.



16 Ελληνική (Greek):

Το έγγραφο αυτό είναι σημαντικό και θα πρέπει να μεταφραστούν αμέσως. Αν χρειάζεστε αυτό το έγγραφο μεταφράζεται, παρακαλούμε επικοινωνήστε Diversity Director MassDEP κατά τους αριθμούς τηλεφώνου που αναγράφεται πιο κάτω.



17 Italiano (Italian):

Questo documento è importante e dovrebbe essere tradotto immediatamente. Se avete bisogno di questo documento tradotto, si prega di contattare la diversità Direttore di MassDEP ai numeri di telefono elencati di seguito.

18 Język Polski (Polish):



Dokument ten jest ważny i powinien być natychmiast przetłumaczone. Jeśli potrzebujesz tego dokumentu tłumaczone, prosimy o kontakt z Dyrektorem MassDEP w różnorodności na numery telefonów wymienionych poniżej.



19 हिन्दी (Hindi):

यह दस्तावेज महत्वपूर्ण है और तुरंत अनुवाद किया जाना चाहिए. आप अनुवाद इस दस्तावेज़ की जरूरत है, नीचे सूचीबद्ध फोन नंबरों पर MassDEP की विविधता निदेशक से संपर्क करें.

Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection
Southeast Regional Office • 20 Riverside Drive, Lakeville MA 02347 • 508-946-2700

Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Matthew A. Beaton
Secretary

Martin Suuberg
Commissioner

Individual Groundwater Discharge Permit
Fact Sheet

I. APPLICANT, FACILITY INFORMATION, and DISCHARGE LOCATION

Name and Address of Applicant: Town of Barnstable, Department of Public Works

Name and Address of Facility where discharge occurs: Barnstable Water Pollution Control Facility, Bearses Way, Hyannis

Discharge Information:

Groundwater Discharge Permit Number: 21 - 1

The Groundwater Discharge Permit will continue to allow the applicant discharge up to 2.7 million gallons per day of treated sanitary wastewater from an existing publicly owned treatment works to groundwaters of the Commonwealth.

The discharge is within a Zone II of a public water supply well and within the Lewis Bay watershed for which a Total Maximum Daily Load (TMDL) has been approved (FINAL Lewis Bay System and Halls Creek Total Maximum Daily Loads For Total Nitrogen (Report # 96-TMDL-18 Control #314), issued March 3, 2015).

II. LIMITATIONS AND CONDITIONS

Discharge permit limitations are as listed in the ground water permit and are in conformance with 314 CMR 5.00, the Groundwater Discharge Permit Program.

III. PERMIT BASIS AND EXPLANATION OF EFFLUENT LIMITATIONS

An Individual Groundwater Discharge permit is required for this discharge in accordance with the Massachusetts Clean Water Act, M.G.L. c. 21, s. 26-53 and 314 CMR 5.03.

This information is available in alternate format. Contact Michelle Waters-Ekanem, Director of Diversity/Civil Rights at 617-292-5751.
TTY# MassRelay Service 1-800-439-2370
MassDEP Website: www.mass.gov/dep
Printed on Recycled Paper

Effluent limitations are based upon the location of the discharge, the level of treatment, consideration of human health protection criteria and protection of the groundwaters of the Commonwealth.

This is a renewal for a permit that expired in 1985 but could not be issued pending the Town's receipt of a Secretary's Certificate for a Comprehensive Wastewater Management Plan (CWMP). In the interim, the Town embarked on significant upgrades to the plant in the 1990s and early 2000s in anticipation of new discharge limits and has been operating the plant as if those limits were in effect.

The draft permit sets effluent limits of 30 mg/l of 5 – Day Biochemical Oxygen Demand (BOD_5) and Total Suspended Solids (TSS) and 10 mg/L of Nitrate – Nitrogen (NO_3 – N) and Total Nitrogen (TN). In addition, the draft permit sets a mass loading limit of 49,315 lbs/year of TN based on an annual average concentration of 6 mg/L TN at a maximum day flow of 2.7 MGD. The permit allows the plant to retain a treatment capacity of 4.2 MGD, but recognizes limitations at the infiltration beds which limit current discharge capability to 2.7 MGD.

While located in a Zone II, the facility is not required to meet more stringent technology based limits due to an allowed exemption under 314 CMR(4A)(e).

The permit also requires an updated evaluation of the capacity of the current infiltration beds and analysis of options for disposal outside the Lewis Bay watershed. Furthermore, the Town has three (3) years to complete to complete an updated CWMP to address further nitrogen mitigation both in the Lewis Bay watershed and for other nitrogen impaired watersheds within its jurisdiction including a requirement to investigate community partnerships with towns sharing watersheds. The CWMP will also have to demonstrate consistency with the Cape Commission's 208 Plan Update.

IV. COMMENT PERIOD, HEARING REQUESTS, AND PROCEDURES FOR FINAL DECISIONS

The public comment period for this permit is thirty (30) days following public notice in *The Environmental Monitor*. The public notice for this Individual Groundwater Discharge Permit occurred on [DATE].

[In addition, this permit contains "Special Effluent Limitations" pursuant to 314 CMR 5.10(9). Therefore, in accordance with 314 CMR 2.06(4)(a) public notice was also published in [Newspaper] on [DATE].]

Requests for an adjudicatory hearing must be submitted within thirty (30) days of the issuance/denial of the permit, by any person who is aggrieved by such issuance/denial.

A final decision on the issuance/denial of this permit will be made after the public notice period, and review of any comments received during this period.

V. STATE CONTACT INFORMATION

Additional information concerning the draft permit may be obtained between the hours of 9:00 a.m. and 5:00 p.m. Monday through Friday excluding holidays, from:

Brian A. Dudley
Wastewater Management Program

NOVEMBER 5, 2018
Date

Appendix HH

Marstons Mills Wastewater Treatment Facility Groundwater Discharge Permit

MassDEP
Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection
Southeast Regional Office • 20 Riverside Drive, Lakeville MA 02347 • 508-946-2700

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Governor

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Lieutenant Governor

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Martin Suuberg
Commissioner

Individual Groundwater Discharge Permit
Fact Sheet

I. APPLICANT, FACILITY INFORMATION, and DISCHARGE LOCATION

Name and Address of Applicant:
Town of Barnstable, 367 Main Street, Hyannis, Massachusetts 02601.

Name and Address of Facility where discharge occurs:
Horace Mann Charter School, 730 Osterville – West Barnstable Road, Marstons Mills, Massachusetts.

Discharge Information:
Groundwater Discharge Permit Number: 576 - 3

The Groundwater Discharge Permit will allow the applicant to continue to discharge 42,900 gallons per day of treated sanitary wastewater to groundwaters of the Commonwealth (school with a population of 1,751 and a 30 unit affordable housing development). The discharge is located in a sensitive area such as a Zone II wellhead protection area of a public water supply (greater than 2 years travel time between the discharge and the well). The discharge meets the criteria set forth in 314 CMR 5.10 (4A) (e).

II. LIMITATIONS AND CONDITIONS

Discharge permit limitations are as listed in the ground water permit and are in conformance with 314 CMR 5.00, the Groundwater Discharge Permit Program.

III. PERMIT BASIS AND EXPLANATION OF EFFLUENT LIMITATIONS

An Individual Groundwater Discharge permit is required for this discharge in accordance with the Massachusetts Clean Water Act, M.G.L. c. 21, s. 26-53 and 314 CMR 5.03.

Effluent limitations are based upon the location of the discharge, the level of treatment, consideration of human health protection criteria and protection of the groundwaters of the Commonwealth.

This information is available in alternate format. Contact Michelle Waters-Ekanem, Director of Diversity/Civil Rights at 617-292-5751.
TTY# MassRelay Service 1-800-439-2370
MassDEP Website: www.mass.gov/dep

Printed on Recycled Paper

IV. COMMENT PERIOD, HEARING REQUESTS, AND PROCEDURES FOR FINAL DECISIONS

The public comment period for this permit is thirty (30) days following public notice in *The Environmental Monitor*. The public notice for this Individual Groundwater Discharge Permit occurred on January 9, 2019.

Requests for an adjudicatory hearing must be submitted within thirty (30) days of the issuance/denial of the permit, by any person who is aggrieved by such issuance/denial.

A final decision on the issuance/denial of this permit will be made after the public notice period, and review of any comments received during this period.

V. STATE CONTACT INFORMATION

Additional information concerning the draft permit may be obtained between the hours of 9:00 a.m. and 5:00 p.m. Monday through Friday excluding holidays, from:

Christos Dimisioris
DEP /SERO
20 Riverside Drive
Lakeville, MA 02347
(508) 946-2736

Brian A. Dudley, Chief
Wastewater Management – Cape and Islands

February 19, 2019
Date

P:\My Documents\12\576 - 3 - Barnstable - Horace Mann Charter School Fact Sheet.docx

Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

Southeast Regional Office • 20 Riverside Drive, Lakeville MA 02347 • 508-946-2700

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Secretary

Martin Suuberg
Commissioner

INDIVIDUAL GROUNDWATER DISCHARGE PERMIT

Name and Address of Applicant: ***Town of Barnstable, 367 Main Street, Hyannis, Massachusetts 02601.***

Date of Application:	***August 20, 2018***
Application/Permit No.	***576 - 3***
Date of Issuance:	***February 19, 2019***
Date of Expiration:	***February 19. 2024***
Effective Date:	***February 19, 2019***

AUTHORITY FOR ISSUANCE

Pursuant to authority granted by Chapter 21, Sections 26-53 of the Massachusetts General Laws, as amended, 314 CMR 2.00, and 314 CMR 5.00, the Massachusetts Department of Environmental Protection (the Department or MassDEP) hereby issues the following permit to: **Town of Barnstable** (hereinafter called "the permittee") authorizing discharges to the ground from the on site wastewater treatment facility located at the **Horace Mann Charter School, 730 Osterville – West Barnstable Road, Marstons Mills, Massachusetts** (school with a population of 1,751 and a 30 unit affordable housing development), such authorization being expressly conditional on compliance by the permittee with all terms and conditions of the permit hereinafter set forth.

Brian A. Dudley, Chief
Wastewater Management – Cape and Islands

February 19, 2019
Date

This information is available in alternate format. Contact Michelle Waters-Ekanem, Director of Diversity/Civil Rights at 617-292-5751.
TTY# MassRelay Service 1-800-439-2370
MassDEP Website: www.mass.gov/dep

Printed on Recycled Paper

I. SPECIAL CONDITIONS

A. Effluent Limits

1) The permittee is authorized to discharge into the ground from the wastewater treatment facilities for which this permit is issued a treated effluent whose characteristics shall not exceed the following values:

Effluent Characteristics	Discharge Limitations
Flow	42,900 GPD
Oil and grease	15 mg/l
Total Suspended Solids (TSS)	10 mg/l
Total Nitrogen ($NO_2 + NO_3 + TKN$)	10 mg/l
Nitrate-Nitrogen	10 mg/l
Biochemical Oxygen Demand, 5-day @20°C (BOD_5)	30 mg/l
Turbidity	5 NTU
Fecal Coliform	200 colonies / 100 ml

a) The pH of the effluent shall not be less than 6.5 nor greater than 8.5 at any time or not more than 0.2 standard units outside the naturally occurring range.

b) The discharge of the effluent shall not result in any demonstrable adverse effect on the groundwater or violate any water quality standards that have been promulgated.

c) The monthly average concentration of BOD and TSS in the discharge shall not exceed 15 percent of the monthly average concentrations of BOD and TSS in the influent into the permittee's wastewater treatment facility.

d) When the average annual flow exceeds 80 percent of the permitted flow limitations, the permittee shall submit a report to the Department describing what steps the permittee will take in order to remain in compliance with the permit limitations and conditions, inclusive of the flow limitations established in this permit.

B. Monitoring and Reporting

1) The permittee shall monitor and record the quality of the **influent** and the quality and quantity of the **effluent** prior to discharge to the leaching facilities according to the following schedule and other provisions:

INFLUENT:

Parameter	Minimum Frequency of Analysis	Sample Type
BOD_5	Monthly	24-Hour Composite
Total Suspended Solids	Monthly	24-Hour Composite
Total Solids	Monthly	24-Hour Composite
Ammonia Nitrogen	Monthly	24-Hour Composite

EFFLUENT:

Parameter	Minimum Frequency of Analysis	Sample Type
Flow	Daily	Meter reading Report: Min – Max - Average
pH	Continuous recording	Continuous
UV Intensity	Continuous recording	Continuous
Total Suspended Solids	Weekly	24-Hour Composite
Oil & Grease	Monthly	Grab
BOD_5	Weekly	24-Hour Composite
Nitrate Nitrogen	Weekly	24-Hour Composite
Total Nitrogen ($NO_2 + NO_3$ + TKN)	Weekly	24-Hour Composite
Turbidity	Continuous recording	Continuous

Fecal Coliform	2 / Week	Grab
Total Phosphorus (as P)	Quarterly	Grab
Orthophosphate (as P)	Quarterly	Grab
Volatile Organic Compounds	Annually	Grab

a) After one full year of monitoring the Total Phosphorus and Orthophosphate results, the Department may determine, upon the request of the permittee, that the frequency of monitoring may be reduced if, in the judgment of the Department, the results of the sampling indicate that existing phosphorus levels will not adversely impact downgradient receptors. If the Department reduces the frequency of monitoring for Total Phosphorus and Orthophosphate, the Department reserves the right to resume more frequent monitoring if the Department determines that phosphorus levels are impacting downgradient receptors.

2) The permittee shall sample the upgradient monitoring well GWMW# 8 and the downgradient monitoring wells GWMW# 5, GWMW# 6, GWMW# 4, GWMW# 3 and GWMW# 2 as shown on a plan titled "Existing Site Plan, Marstons Mills Middle School, Barnstable, Massachusetts" dated August, 2003, submitted by Stearns & Wheler, LLC. Labels identifying each monitoring well's identification in accordance with the above-referenced approved plans shall be affixed to the steel protective casing of each monitoring well.

The permittee shall monitor, record and report the quality of water in the approved monitoring wells according to the following schedule and other provisions:

Parameter	**Minimum Frequency of Analysis**
Static Water Level	Monthly
Specific Conductance	Monthly
pH	Monthly
Total Nitrogen (NO_2+NO_3+TKN)	Quarterly
Nitrate-Nitrogen	Quarterly
Total Phosphorus (as P)	Quarterly
Orthophosphate (as P)	Quarterly
Volatile Organic Compounds	Annually

a) Static Water Level shall be expressed as an elevation and shall be referenced to the surveyed datum established for the site. It shall be calculated by subtracting the depth to the water table from the surveyed elevation of the top of the monitoring well's PVC well casing/riser.

b) After one full year of monitoring the Total Phosphorus and Orthophosphate results, the Department may determine, upon the request of the permittee, that the frequency of monitoring may be reduced if, in the judgment of the Department, the results of the sampling indicate that existing phosphorus levels will not adversely impact downgradient receptors. If the Department reduces the frequency of monitoring for Total Phosphorus and Orthophosphate, the Department reserves the right to resume more frequent monitoring if the Department determines that phosphorus levels are impacting downgradient receptors.

3) Any grab sample or composite sample required to be taken less frequently than daily shall be taken during the period of Monday through Friday inclusive. All composite samples shall be taken over the operating day.

4) The permittee shall submit all monitoring reports within 30 days of the last day of the reporting month to MassDEP and to the Barnstable Public Health Division, 200 Main Street, Hyannis, MA 02601. All discharge monitoring reports submitted to MassDEP must be submitted through eDEP. To register for electronic submission go to: http://www.mass.gov/eea/agencies/massdep/service/online/edep-online-filing.html

C. Supplemental Conditions

1) The permittee shall notify the Department at least thirty (30) days in advance of the proposed transfer of ownership of the facility for which this permit is written. Said notification shall include a written agreement between the existing and new permittees containing a specific date for transfer of permit, responsibility, coverage and liability between them.

2) A staffing plan for the facility shall be submitted to the Department once every two years and whenever there are staffing changes. The staffing plan shall include the following components:

a) The operator(s)'s name(s), operator grade(s) and operator license number(s);
b) The number of operational days per week;
c) The number of operational shifts per week;
d) The number of shifts per day;
e) The required personnel per shift;
f) Saturday, Sunday and holiday staff coverage;
g) Emergency operating personnel

3) The permittee is responsible for the operation and maintenance of all sewers, pump stations, and treatment units for the permitted facility, which shall be operated and maintained under the direction of a properly certified wastewater operator.

4) Operation and maintenance of the proposed facility must be in accordance with 314 CMR 12.00, "Operation and Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Discharges", and, 257 CMR 2.00, "Rules and Regulations for Certification of Operators of Wastewater Treatment Facilities".

   a) The facility has been rated (in accordance with 257 CMR 2.00), to be a Grade **4** facility. Therefore, the permittee shall provide for oversight by a Massachusetts Certified Wastewater Treatment plant operator (Chief Operator) Grade **4** or higher. The permittee will also provide for a backup operator who shall possess at least a valid Grade **3** license.

   b) The date and time of the operator's inspection along with the operator's name and certification shall be recorded in the log book on location at the treatment facility. All daily inspection logs consistent with the O&M Manual requirements shall be kept at the facility for a period of three (3) years.

   c) Records of operation of wastewater treatment facilities or disposal systems required by the Department shall be submitted on forms supplied by the Department or on other forms approved by the Department for such use. Monthly reports shall be certified by the wastewater treatment plant operator in charge and shall be included in the discharge monitoring reports submitted each month.

5) If the operation and maintenance of the facility is contracted to a private concern, the permittee shall submit a copy of the contract, consistent with what is required by the approved Operation & Maintenance manual and signed only by the contractor, to the appropriate MassDEP Regional Office within thirty (30) days of permit issuance. Along with the contract, a detailed listing of all contract operation obligations of the proposed contractor at other facilities shall also be submitted.

6) Any additional connections to the sewer system, beyond the flow as described on page 1 of the facility of this permit (including any connections using the reserve capacity) shall be approved by MassDEP and the local Board of Health prior to the connection.

7) All tests or analytical determinations to determine compliance with permit standards and requirements shall be done using tests and procedures found in the most recent version of *Standard Methods for the Examination of Water and Wastewater* and shall be performed by a Massachusetts Certified laboratory.

8) The permittee shall notify the appropriate MassDEP Regional Office, in writing, within thirty (30) days of the following events:

   a) Any interruption of the treatment system operation, other than routine maintenance.

b) Final shutdown of the treatment system.

9) The permittee shall contract to have any and all solids and sludges generated by the treatment system for which this permit is issued removed off site by a properly licensed waste hauler for disposal at an EPA/MassDEP approved facility. The name and license number of the hauler along with the quantity of wastes removed and the date(s) of removal shall be reported by the permittee in writing to the appropriate MassDEP Regional Office.

10) Simultaneously with the next permit renewal application, the permittee shall submit two reports to the Department for its review and approval:

a) An engineering report, prepared by a registered professional engineer, that outlines in sufficient detail what modifications (if any) to the facility or other changes are required to insure that the facility can remain in compliance with its GWDP and other applicable requirements through the next 5 year permit term (year 2028) and beyond.

b) A financial plan that contains the cost estimates for implementing the facility modifications or other changes identified in the engineering report, and describes and demonstrates, how and when the permittee will finance the needed facility modifications or other changes

11) In the event that effluent limits are not met, or the discharge is determined to impair groundwater quality in accordance with 314 CMR 5.16(1), the permittee may be obligated to modify, supplement or replace the permitted treatment process so as to ensure that the discharge does not impair the ability of the groundwater to act as an actual or potential source of potable water.

12) Pursuant to M.G.L. Chapter 21A, section 18(a), and 310 CMR 4.03, holders of this Permit may be subject to annual compliance assurance fees as assessed each year on July 1st and invoiced by MassDEP. Failure of the Permit holder to pay applicable annual compliance assurance fees shall result in the automatic suspension of the permit by operation of law under the statute. If fee non-payment continues for sixty days or more, MassDEP has the statutory option of revoking the Permit, denying any other pending permit applications filed by the Permit holder or taking other enforcement action. Permit holders are required to notify MassDEP in writing if they wish to relinquish or transfer a permit. Failure to do so will result in the continued assessment of fees.

E. Appeal Rights

During the thirty (30) day period following issuance of this permit, a Notice of Claim for an Adjudicatory Appeal may be sent by any person aggrieved (the "Petitioner") by the issuance to:

Case Administrator
Office of Appeals and Dispute Resolution
Department of Environmental Protection
One Winter Street/2nd Floor
Boston, MA 02108

310 CMR 1.01(6)(b) requires the Notice of Claim to: include sufficient facts to demonstrate aggrieved person status; state the facts which are grounds for the appeal specifically, clearly and concisely; and, state relief sought. The permit shall become or remain effective at the end of the 30 day appeal period unless the person filing the Notice of Claim requests, and is granted, a stay of its terms and conditions. If a permit is modified under 314 CMR 2.10, only the modified terms and conditions may be subject to an Adjudicatory Appeal. All other aspects of the existing permit shall remain in effect during any such Adjudicatory Appeal.

Per 310 CMR 4.06, the hearing request to the Commonwealth will be dismissed if the filing fee is not paid. Unless the Petitioner is exempt or granted a waiver, a valid check payable to the Commonwealth to Massachusetts in the amount of $100.00 must be mailed to:

Commonwealth of Massachusetts
Department of Environmental Protection
P.O. Box 4062
Boston, MA 02211

The filing fee is not required if the Petitioner is a city, town, county, or district of the Commonwealth, federally recognized Indian tribe housing authority effective January 14, 1994, or any municipal housing authority; or, per MGL 161A s. 24, the Massachusetts Bay Transportation Authority. The Department may waive the adjudicatory hearing filing fee for a Petitioner who shows that paying the fee will create an undue financial hardship. A Petitioner seeking a waiver must file, along with the hearing request, an affidavit setting forth the facts believed to support the claim of undue financial hardship.

II. GENERAL PERMIT CONDITIONS

5.16: General Conditions

The following conditions apply to all individual and general permits:

(1) No discharge authorized in the permit shall cause or contribute to a violation of 314 CMR 4.00: *Massachusetts Surface Water Quality Standards*. Upon promulgation of any amended standard, the permit may be modified to comply with such standard in accordance with the procedures in 314 CMR 2.10: *Modification, Suspension, Revocation and Renewal of Permits and General Permit Coverage* and 314 CMR 5.12. Except as otherwise provided in 314 CMR 5.10(3)(c), 5.10(4)(a)2. and 5.10(9), no discharge authorized in the permit shall impair the ability of the ground water to serve as an actual or potential source of potable water. Evidence that a discharge impairs the ability of the ground water to serve as an actual or potential source of potable water includes, without limitation, analysis of samples taken in a downgradient well that

demonstrates one or more exceedances of the applicable water quality based effluent limitations set forth in 314 CMR 5.10. In those cases where it is shown that a measured parameter exceeds the applicable water quality based effluent limitations set forth in 314 CMR 5.10 at the upgradient monitoring well, evidence that a discharge impairs the ability of the ground water to serve as an actual or potential source of potable water is deemed to exist if a measured parameter in any downgradient well exceeds the level of that same measured parameter in the upgradient well for the same sampling period. A statistical procedure approved by the Department shall be used to determine when a measured parameter exceeds the allowable level.

(2) Duty to Comply. The permittee shall comply at all times with the terms and conditions of the permit, 314 CMR 5.00, M.G.L. c. 21, §§ 26 through 53, and all applicable state and federal statutes and regulations.

(3) Standards and Prohibitions for Toxic Pollutants. The permittee shall comply with effluent standards or prohibitions established by § 307(a) of the Federal Act, 33 U.S.C. § 1317(a), for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.

(4) Proper Operation and Maintenance. The permittee shall at all times properly operate and maintain all facilities and equipment installed or used to achieve compliance with the terms and conditions of the permit, 314 CMR 12.00: *Operation and Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Discharges*, and 257 CMR 2.00: *Certification of Operators of Wastewater Treatment Facilities*. All equipment shall be maintained in an acceptable condition for its intended use.

(5) Duty to Halt or Reduce Activity. Upon reduction, loss, or failure of the treatment facility, the permittee shall, to the extent necessary to maintain compliance with its permit, control production, discharges, or both, until the facility is restored or an alternative method of treatment is provided. A permittee may not raise as a defense in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of the permit.

(6) Power Failure. In order to maintain compliance with the effluent limitations and prohibitions of the permit, the permittee shall either:

(a) provide an alternative power source sufficient to operate the wastewater control facilities; or

(b) halt, reduce or otherwise control production or all discharges upon the reduction, loss, or failure of the primary source of power to the wastewater control facilities.

(7) Duty to Mitigate. The permittee shall take all reasonable steps to minimize or prevent any adverse impact on human health or the environment resulting from non-compliance with the permit. Additionally, the permittee shall take all necessary steps to prevent an operational upset of the PWTF or POTW.

(8) Duty to Provide Information. The permittee and any operator of the permitted facility shall

furnish to the Department within a reasonable time as specified by the Department any information which the Department may request to determine whether cause exists for modifying, suspending, revoking and reissuing, or terminating the permit, or to determine whether the permittee is complying with the terms and conditions of the permit.

(9) Inspection and Entry. The permittee shall allow the Department or its authorized representatives to:

(a) Enter upon the permittee's premises where a regulated facility or activity is located or conducted, or where records required by the permit are kept;
(b) Have access to and copy, at reasonable times, any records that must be kept under the conditions of the permit;
(c) Inspect at reasonable times any facilities, equipment, practices, or operations regulated or required under the permit; and
(d) Sample or monitor at reasonable times for the purpose of determining compliance with the terms and conditions of the permit.

(9A) The permittee shall physically secure the treatment works and monitoring wells and limit access to the treatment works and monitoring wells only to those personnel required to operate, inspect and maintain the treatment works and to collect samples.

(9B) The permittee shall identify each monitoring well by permanently affixing to the steel protective casing of the well a tag with the identification number listed in the permit.

(10) Monitoring. Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity. Monitoring must be conducted according to test procedures approved under 40 CFR Part 136 unless other test procedures are specified in the permit.

(11) Recordkeeping. The permittee shall retain records of all monitoring information, including all calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by the permit, and all records of all data used to complete the application for the permit, for a period of at least five years from the date of the sample, measurement, report or application. This period may be extended by request of the Department at any time. Records of monitoring information shall include without limitation:

(a) The date, exact place, and time of sampling or measurements;
(b) The individual(s) who performed the sampling or measurement;
(c) The date(s) analyses were performed;
(d) The individual(s) who performed the analyses;
(e) The analytical techniques or methods used; and
(f) The results of such analyses.

(12) Prohibition of Bypassing. Except as provided in 314 CMR 5.16(13), bypassing is prohibited and the Department may take enforcement action against a permittee for bypassing unless:

(a) The bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;
(b) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if the permittee could have installed adequate backup equipment to prevent a bypass which occurred during normal periods of equipment downtime or preventive maintenance; and
(c) The permittee submitted notice of the bypass to the Department:
1. In the event of an anticipated bypass, at least ten days in advance, if possible; or
2. In the event of an unanticipated bypass, as soon as the permittee has knowledge of the bypass and no later than 24 hours after its first occurrence.

(13) Bypass not Exceeding Limitations. The permittee may allow a bypass to occur which does not cause effluent limitations to be exceeded, but only if necessary for the performance of essential maintenance or to assure efficient operation of treatment facilities.

(14) Permit Actions. The permit may be modified, suspended, or revoked for cause. The filing of a request by the permittee for a permit modification, reissuance, or termination, or a notification of planned changes or anticipated non-compliance does not stay any permit condition.

(15) Duty to Reapply. If the permittee wishes to continue an activity regulated by the permit after the expiration date of the permit, the permittee must apply for and obtain a new permit. The permittee shall submit a new application at least 180 days before the expiration date of the existing permit, unless permission for a later date has been granted by the Department in writing.

(16) Property Rights. The permit does not convey any property rights of any sort or any exclusive privilege.

(17) Other Laws. The issuance of a permit does not authorize any injury to persons or property or invasion of other private rights, nor does it relieve the permittee of its obligation to comply with any other applicable Federal, State, or local law, or regulation.

(18) Oil and Hazardous Substance Liability. Nothing in the permit shall be construed to preclude the institution of any legal action or relieve the permittee of any responsibilities, liabilities, or penalties to which the permittee is or may be subject under § 311 of the Federal Act, 33 U.S.C. § 1321, and M.G.L. c. 21E.

(19) Removed Substances. Solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters shall be disposed in a manner consistent with applicable Federal and State laws and regulations including, but not limited to, the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26 through 53, and the Federal Act, 33 U.S.C. § 1251 *et seq.*, the Massachusetts Hazardous Waste Management Act, M.G.L. c. 21C, and the Federal Resource Conservation and Recovery Act, 42 U.S.C. § 6901, *et seq.*, 310 CMR 19.000: *Solid Waste Management* and 310 CMR 30.000: *Hazardous Waste*.

(20) Reporting Requirements.

(a) Monitoring Reports. Monitoring results shall be reported on a Discharge Monitoring Report (DMR) at the intervals specified in the permit. If a permittee monitors any pollutant more frequently than required by the permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the DMR. Beginning on December 2, 2017, a permittee shall submit all DMRs electronically, using the electronic reporting system designated by the Department. A permittee may seek a waiver of this requirement by submitting a written request for the Department's approval.

(b) Compliance Schedules. Reports of compliance or non-compliance with, or any progress reports on interim and final requirements contained in any compliance schedule in the permit shall be submitted no later than 14 days following each schedule date.

(c) Planned Changes. The permittee shall give notice to the Department as soon as possible of any planned physical alterations or additions to the permitted facility or activity which could significantly change the nature or increase the quantity of pollutants discharged. Unless and until the permit is modified, any new or increased discharge in excess of permit limits or not specifically authorized by the permit constitutes a violation.

(d) Anticipated Non-compliance. The permittee shall give advance notice to the Department of any planned changes in the permitted facility or activity which may result in non-compliance with permit requirements.

(e) 24 Hour Reporting. The permittee shall report any non-compliance which may endanger health or the environment. Any information shall be communicated orally within 24 hours of the time the permittee becomes aware of the circumstances. A written submission shall also be provided within five days of the time the permittee becomes aware of the circumstances. The written submission shall contain: a description of the non-compliance, including exact dates and times, and if the non-compliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the non-compliance. The following shall be included as information which must be reported within 24 hours:

1. Any unanticipated bypass which exceeds any effluent limitation in the permit; and
2. Any violation of a maximum daily discharge limitation for any of the pollutants required by the permit to be reported within 24 hours.

(f) Other Non-compliance. The permittee shall report all instances of non-compliance not reported under 314 CMR 5.16(20)(a), (b), or (e) at the time monitoring reports are submitted. The reports shall contain the information listed in 314 CMR 5.16(20)(e).

(g) Toxics. All manufacturing, commercial, mining, or silvicultural dischargers must notify the Department as soon as they know or have reason to believe:

1. That any activity has occurred, or will occur, that would result in the discharge of any toxic pollutant listed in 314 CMR 3.17: *Appendix B - Toxic Pollutants* not limited by the permit, if that discharge will exceed the highest of the following notification levels:
    a. 100 micrograms per liter (100 ug/l);
    b. 200 micrograms per liter (200 ug/l) for acrolein and acrylonitrile, 500 micrograms per liter (500 ug/l) for 2,4-dinitrophenol, and for 2-methyl-4,6-dinitrophenol, and one milligram per liter (1 mg/l) for antimony;

c. Five times the maximum concentration value reported for that pollutant in the permit application; or

2. That they have begun or expect to begin to use or manufacture as an intermediate or final product or byproduct any toxic pollutant which was not reported in the permit application.

(h) Indirect Dischargers. All Publicly Owned Treatment Works shall provide adequate notice to the Department of the following:

1. Any new introduction of pollutants into the POTW from an indirect discharger which would be subject to § 301 or § 306 of the Federal Act, 33 U.S.C. § 1311 or 1316, if it were directly discharging those pollutants; and

2. Any substantial change in the volume or character of pollutants being introduced into the POTW by a source introducing pollutants into the POTW at the time of issuance of the permit.

(i) Information. Where a permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application or in any report to the Department, it shall promptly submit the relevant facts or correct information.

(j) The permittee shall notify the Department in writing within seven days of any change in contract operators.

(21) Signatory Requirement. All applications, reports, or information submitted to the Department shall be signed and certified in accordance with 314 CMR 5.14 and 5.15.

(22) Severability. The provisions of the permit are severable. If any provision of the permit, or the application of any provision of the permit to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of the permit, shall not be affected thereby.

(23) Reopener Clause. The Department reserves the right to make appropriate revisions to the permit to establish any appropriate effluent limitations, schedules of compliance, or other provisions, as authorized by the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26 through 53, or the Federal Act, 33 U.S.C. § 1251 *et seq.*, to bring all discharges into compliance with these statutes.

(24) Approval of Treatment Works. All discharges and associated treatment works authorized in 314 CMR 5.00 shall remain in compliance with the terms and conditions of the permit. Any modification of the approved treatment works shall require written approval of the Department prior to the construction of the modification.

(25) Transfer of Permits.

(a) RCRA Facilities. Any permit which authorizes the operation of a RCRA facility subject to the requirements of 314 CMR 8.07: *Standards for all other RCRA Facilities* shall be valid only for the person to whom it is issued and may not be transferred.

(b) Transfers by Modification. Except as provided in 314 CMR 5.16(25)(a) and (c), a permit may be transferred by the permittee to a new permittee if the permit has been modified or revoked and reissued in accordance with 314 CMR 5.12(2), or a minor

modification is made to identify the new permittee in accordance with 314 CMR 5.12(3) and (4).

(c) Automatic Transfers. For facilities other than Privately Owned Wastewater Treatment Facilities (PWTFs) that treat at least some sewage from residential uses, hospitals, nursing or personal care facilities, residential care facilities, or assisted living facilities, PWTFs that have been required to establish, fund and maintain financial assurance mechanism(s) pursuant to 314 CMR 5.15(6), and RCRA facilities subject to the requirements of 314 CMR 8.07: *Standards for all other RCRA Facilities*, a permit may be automatically transferred in accordance with 314 CMR 5.12(5).

(26) Permit Compliance Fees and Inspection Information. Except as otherwise provided, any permittee required to obtain a ground water discharge permit pursuant to M.G.L. c. 21, § 43, and 314 CMR 5.00 shall submit the annual compliance assurance fee established in accordance with M.G.L. c. 21A, § 18 and 310 CMR 4.00: *Timely Action Schedule and Fee Provisions*, as provided in 314 CMR 2.12: *Applications, Fees and Inspection Information.* The requirement to submit the annual compliance fee does not apply to any local government unit other than an authority. Any permittee required to obtain a ground water discharge permit pursuant to M.G.L. c. 21, § 43 and 314 CMR 5.00, may be required to submit inspection information annually, as provided in 314 CMR 2.12.

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Appendix II

Popponesset Bay Watershed Inter-municipal Agreement

Popponesset Bay Watershed Permitting
Pursuant to the Massachusetts Clean Waters Act
Intermunicipal Agreement
Between
The Towns of Barnstable, Mashpee, and Sandwich

This Intermunicipal Agreement ("Agreement") is entered into as of November 13, 2017 (the "Effective Date") by and among the Towns of Barnstable, Mashpee, and Sandwich, each one a municipal corporation acting through their respective chief executive officers (collectively, with their successors and assigns, the "Parties").

RECITALS

WHEREAS, municipalities are authorized in accordance with G.L. c. 40, §4A to enter into intermunicipal agreements for the purpose of performing jointly, or on behalf of each other, activities or undertakings which any of the municipalities are authorized by law to perform; and

WHEREAS, Mashpee and Sandwich have been authorized to enter into this Agreement as evidenced by the execution of this Agreement by their respective Boards of Selectmen; and

WHEREAS, the Town of Barnstable Town Manager is authorized to enter into this Agreement; and

WHEREAS, the Commonwealth of Massachusetts has, pursuant to the Federal Clean Water Act §208(b) (3) and 40 C.F.R. 130.6(e), prepared and certified the Cape Cod Water Quality Management Plan Update ("208 Plan Update") developed by the Cape Cod Commission, which was certified by the Governor of the Commonwealth on June 10, 2015, and submitted to the United States Environmental Protection Agency, Region 1 ("USEPA"); and

WHEREAS, USEPA approved the 208 Plan Update on September 15, 2015: and

WHEREAS, Section 2A of Chapter 259 of the Acts of 2014 requires MassDEP "to develop a watershed permitting approach to address and optimize nitrogen management measures intended to restore water quality to meet applicable water quality standards in watersheds included in an approved area wide nitrogen management plan developed pursuant to section 208 of the federal Clean Water Act," and

WHEREAS, the 208 Plan Update includes a number of recommendations for improving water quality in the estuaries and embayments on Cape Cod; and

WHEREAS, one of the most significant recommendations contained in the 208 Plan Update is the development of a watershed-based permit program ("Permit") pursuant to Section 2A of Chapter 259 of the Acts of 2014; and

WHEREAS, the estuaries and embayments of the Popponesset Bay system have experienced greatly increased anthropogenic loads of nitrogen delivered to the water through surface and groundwater sources from the increasingly developed watershed, and that this increase in nitrogen has increased the rate of eutrophication of the waters causing adverse aesthetic, water quality and habitat impacts that result in violation of state water quality standards, all as documented in the Massachusetts Estuary Project ("MEP") report entitled, "Popponesset Bay, Total Maximum Daily Loads for Total Nitrogen (Report #96-TMDL-4, Control #217.0), MADEP, April 10, 2006."; and

WHEREAS, Mashpee, Barnstable, and Sandwich recognize that increased nitrogen loads to the embayment come from surface and groundwater sources in the watershed shared by the Parties; and

WHEREAS, the Parties believe that it is in their mutual best interests to apply jointly for a Permit for the following reasons: (1) such a Permit will provide more flexibility to achieve TMDL compliance by authorizing additional nitrogen mitigation measures beyond a traditional groundwater discharge permit issued by MassDEP; (2) a Permit will authorize opportunities for achieving compliance with the Clean Water Act through non-traditional nitrogen management approaches; and (3) the Parties will have an opportunity to share resources to achieve the mutual goal of nitrogen reduction in Popponesset Bay ("Bay"); and

WHEREAS, the Massachusetts Department of Environmental Protection (MassDEP) has developed and the USEPA has approved the Total Maximum Daily Load (TMDL) limitations for nitrogen discharges to the Bay;

WHEREAS, the Parties agree that wastewater, fertilizer, and stormwater are the prime source of controllable nitrogen causing impairment of the embayment and that, as a result, a joint effort is required to restore and protect beneficial uses and aquatic resources of the Bay and its tributaries; and

WHEREAS, each of the Parties have, to varying degrees, established or are in the process of preparing a Comprehensive Wastewater Management Plan ("CWMP") or equivalent plan, pursuant to the requirements of the MassDEP; and

WHEREAS, Attachment A to this Agreement provides the current status of the CWMP planning process for each of the Parties to this Agreement; and

WHEREAS, Mashpee, Barnstable, and Sandwich believe that it is in their mutual best interests to work cooperatively in seeking a Permit for nitrogen discharge as recommended in the 208 Plan Update, and believe that this Agreement represents the best opportunity to establish a framework of cooperation to achieve that goal.

NOW, THEREFORE, in consideration of the promises and mutual benefits to be derived by the Parties hereto, the Parties agree as follows:

1. The Parties agree that the most cost-effective means in terms of total cost, of meeting the TMDL requirements and attaining water quality and beneficial use goals may be a regional, watershed-based approach to mitigate the nitrogen at locations within the watershed where the contributing loads are the greatest and the methods useful for nitrogen reduction are the most effective.

2. Each Party will continue to develop and/or implement its own MassDEP approved CWMP or Targeted Watershed Management Plan, but shall include in their respective plan, if appropriate, any joint efforts undertaken by the Parties pursuant to this Agreement.

3. The Parties agree to jointly apply for a Permit for the Bay pursuant to the 208 Plan Update and Chapter 259 of the Acts of 2014, and any future requirements for such Permits established by MassDEP pursuant to 315 C.M.R. 5.00. If necessary and feasible, the Parties shall be joint Permittees. The joint permit application will include provisions that Mashpee will implement its plan in 5 year blocks in accordance with its approved CWMP and that Sandwich and Barnstable agree to propose a schedule that enables them to respectively complete their respective CWMP's as set forth in Attachment A, and then incorporate their planning implementation schedule in the watershed permit.

4. As the Party having the largest allocated load of nitrogen, Town of Mashpee shall serve as the fiscal agent under this Agreement and, as such, shall receive, hold, and expend any funds appropriated by the Parties for joint actions required in the implementation of this Agreement as well as any grant funds awarded to the Parties for the purpose of pursuing, securing, and implementing a Permit. Unless otherwise provided in the watershed permit or an amendment to this Agreement is made, capital projects undertaken individually by any one of the Parties pursuant to an approved CWMP or Targeted Watershed Plan shall be the sole responsibility of that Party. On December 31st and June 30th of each Fiscal Year during the term of this Agreement, Mashpee shall provide an accounting of the expenditure of funds as the fiscal agent. Any Party to this Agreement may request that Mashpee include an audit of the funds held under this Agreement as part of Mashpee's regular annual audit.

5. The Parties hereby establish a Popponesset Bay Watershed Work Group ("Work Group"), comprised of three members from each Town. The three members from each Town shall consist of the Town Manager from each Town, a member of the Town Council from Barnstable and a member of the Board of Selectmen from Mashpee and Sandwich, and a technical representative appointed by the Town Manager in each Town. Appointments shall be made in accordance with any applicable local Charter and bylaw provisions. The purposes of the Work Group will be to:

a. Administer the day-to-day joint activities of the Parties under this Agreement;

b. Coordinate with the various departments and boards of their respective towns to apply for and implement a Permit for the Bay, subject to approval by each of the Parties prior to filing;

c. Share or develop engineering and economic studies and evaluations to define means of meeting the Parties' respective nitrogen reduction targets and to develop cost-performance relationships that define most cost-effective technologies and practices for the removal of nitrogen;

d. Develop and propose for adoption amendments to this IMA, if necessary, or other forms of agreement that will define and require the action of each Party to implement agreed-upon plans to apply for and implement, a Permit;

e. The Work Group has no authority to bind one or more of the Parties. Its role shall be solely administrative in nature and to make recommendations to the Parties for actions required to implement such recommendations. The incurrence of any obligation under this Agreement by any Party shall be subject to the approval of the chief executive officer of each Party and the legislative body, if required, to implement such recommendations.

The Work Group shall be considered a public body subject to the Open Meeting Law. As the fiscal agent, Mashpee shall be responsible for posting meetings as well as preparing and distributing meeting minutes.

6. The Parties have determined that it is in their mutual best interests to establish a nitrogen allocation formula for the purpose of allocating certain costs in a fair and reasonable manner. The parties believe that the watershed permitting responsibilities should be allocated on the basis of unattenuated and attenuated nitrogen loadings. Unattenuated loads consist of the nitrogen load from the watershed contributed by septic systems, wastewater effluent, fertilizer application, storm water runoff, golf course operations, landfill activities, and natural sources. Attenuated loads are the nitrogen loadings that reach Popponesset Bay after natural attenuation in wetlands, ponds or streams, as measured at the Sentinel Testing Station. The Technical Memorandum, attached hereto as Attachment B, sets forth the technical basis agreed to by the parties for establishing the nitrogen loading allocation formulas for both unattenuated and attenuated loads as follows:

	Unattenuated	Attenuated
Barnstable	12.6%	16.0%
Mashpee	65.4%	74.5%
Sandwich	22.0%	9.5%
Total	100%	100%

The unattenuated load percentages will be used to calculate each Party's responsibility for TMDL compliance and for the tracking and accounting of implementation measures. The attenuated load percentages will be used to calculate watershed-based shared expenses including administrative costs, sentinel station monitoring costs, watershed permit application costs, watershed permit compliance costs and updates, and MEP confirmatory model runs, and such other watershed-based costs that the Parties may agree to in the future.

The allocation formula shall be reviewed every five years and will be adjusted based on any revisions to the TMDL or in accordance with a revised formula that the Towns mutually determine to be appropriate.

7. The Parties agree to adopt a fair and practical methodology for implementing the most cost-effective watershed-wide approach, in order to comply with any permits issued by MassDEP, and to share on a fair and equitable basis the capital, operating, administrative, legal, operational, and other ancillary costs associated with a regional, watershed-based wastewater and/or nutrient management system. The Towns further agree to individually fund those measures expected to achieve control of their respective share of the load identified in Paragraph 6 above unless they mutually agree to joint efforts to mitigate nitrogen.

8. The Parties agree to develop, if deemed mutually beneficial based on comparison of other wastewater management options of each Town, a fair and practical methodology for a reasonable nitrogen trading mechanism, including metrics for determining a nitrogen credit trading "currency" in terms of dollars per pound or other trading metric, as a means to implement a watershed-based plan.

9. The Parties agree to adopt, as a fair and practical methodology for monitoring the water quality of the watershed following the implementation of regional, watershed-based wastewater and/or nutrient management approaches, and the allocation of costs as agreed to in Paragraph 6 above.

10. Each Party shall cooperate with the other Parties and other entities as appropriate to identify, apply for, secure, manage and fairly allocate federal, state and other funding sources, as such may become available, to finance the planning and implementation of multi-town or regional nutrient management plans resulting from the cooperative efforts of the Parties under this Agreement.

11. Effective Date of Agreement – The effective date of this Agreement shall be the date upon which this Agreement is entered into as first written above.

12. Term of Agreement – Pursuant to G.L. c. 40, §4A, the maximum term of this Agreement shall be 25 years, recognizing, however, that any permit issued by MassDEP will likely be for a term of twenty years in 4 five year increments. Notwithstanding the foregoing, this Agreement will be reassessed at intervals of five years, or, if more stringent, in accordance with any permit renewal requirements established by the MassDEP and may be modified by mutual agreement of the Parties through an amendment of this Agreement, if necessary, to achieve permit renewal and compliance.

13. Termination – This Agreement may be terminated by any one Party upon sixty (60) days notice to the other Parties, provided, however, that any obligations created by a joint Permit issued by the MassDEP shall continue for each of the Parties unless the Permit is modified pursuant to a joint application filed by all of the Parties.

14. Dispute Resolution – In the event of a dispute arising out of or in relation to the terms of this Agreement, representatives of the Parties shall meet and endeavor to settle the dispute in an amicable manner through mutual consultation. If such persons are unable to resolve the dispute in a satisfactory manner within thirty (30) calendar days, either party may seek assistance of an independent third party, mutually-agreeable to both or all Parties.

15. Assignment - Any Party may assign to another governmental entity established for the purpose of addressing wastewater issues in the Town the responsibility in whole or in part for implementing the watershed permitting activities contemplated in the Agreement.

16. Amendment of this Agreement – This Agreement may be changed or modified through a mutually agreed upon written Amendment executed by each and all of the Parties to this Agreement. Any Amendment shall be attached to and shall become part of this Agreement.

17. Mutual Indemnification – Each party to this Agreement shall indemnify and hold harmless each and all other Parties to this Agreement, their officers, agents, consultants, employees and assigns for all liability arising out of the activities under this Agreement.

18. Subject to Appropriation – The obligations of each of the Parties shall be subject to appropriation and the availability of funds.

19. No Remuneration – Parties to this Agreement shall be solely responsible for any and all costs incurred by themselves, their agents, their employees, committee members, consultants or other persons or entities resulting from activities undertaken pursuant to this Agreement.

20. Governance – This Agreement shall be governed by, construed under and enforced in accordance with the laws of the Commonwealth of Massachusetts.

21. Severability – If any provision of this Agreement is determined to be illegal, unenforceable, or void, then all Parties shall be relieved of their obligations under that provision, provided, however, that the remainder of the Agreement shall remain in full effect.

22. Entire Agreement - This Agreement constitutes the entire agreement between the Parties.

IN WITNESS THEREOF, the Parties hereto have executed this Agreement as of the first date written above.

Town of Mashpee
By its Board of Selectmen

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_____

Town of Barnstable
By its Town Manager

Mark S. Ells

Town of Sandwich,
By its Board of Selectmen

_____

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_____

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595247v.1/Sand/0373

IN WITNESS THEREOF, the Parties hereto have executed this Agreement as of the first date written above.

Town of Mashpee
By its Town Manager

_____

RATIFIED BY BOS 11/13/2017

Town of Barnstable
By its Town Manager

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Town of Sandwich,
By its Board of Selectmen

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595247v.1/Sand/0373

IN WITNESS THEREOF, the Parties hereto have executed this Agreement as of the first date written above.

Town of Mashpee
By its Board of Selectmen

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Town of Barnstable
By its Town Manager

_____

Town of Sandwich,
By its Board of Selectmen

Susan R. James

_____

_____

_____

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595247v.1/Sand/0373

ATTACHMENT A

Attachment A
Town of Barnstable
CWMP Status

The Town of Barnstable has been implementing its CWMP under MEPA certificates issued on May 18, 2007, and July 20, 2012.

With the advent, in 2013, of an update of the Section 208 Water Quality Plan under the Cape Cod Commission, the Barnstable Town Council established a Water Resources Advisory Committee (WRAC) to advise the Council regarding compliance with Section 208 of the Clean Water Act relative to the Town's CWMP.

The WRAC has developed a watershed-based plan that not only addresses nutrient issues related to coastal estuaries, but the entirety of wastewater management issues throughout the Town. The Town's plan includes developing relationships with neighboring Town's with which we have shared watersheds, which include Mashpee, Sandwich, and Yarmouth.

The WRAC Plan was presented to the Town Council in July 2017.

The schedule for implementation of the plan is under advisement and discussion among Town staff and officials. Attachment A will be amended as additional information becomes available.

Memorandum

October 24, 2017

To:	Town of Mashpee, MA	Ref. No.:	11110988
From:	J. Jefferson Gregg, P.E., BCEE	Tel:	774-470-1640
cc:	File		
Subject:	**IMA – DRAFT Attachment B – Mashpee Planning Status**		

1. BACKGROUND

The Town of Mashpee, MA (Town) initiated its formal Watershed Nitrogen Management Planning (WNMP) effort in 1999 to address the Town's need for reducing nitrogen impacts to its coastal embayments and to evaluate options for restoring their water quality. At that time, the Town, through its Sewer Commission, hired GHD Inc (formerly Stearns & Wheler, LLC) to perform this planning work.

The following documents were generated as part of the planning process:

1. **Needs Assessment Report** (NAR)—issued in April 2007
2. **Technology Screening Report**—issued in November 2007
3. **Draft Alternative Scenarios Analysis and Site Evaluation Report**—issued in March 2008
4. **Two (2) Notices of Project Change**—the first issued in 2007 and the second in 2012
5. **Alternatives Screening Analysis Report** (ASAR)—issued in August 2013
6. **Draft Recommended Plan/Draft Environmental Impact Report** (DRP/DEIR)—issued in June 2014
7. **Final Recommended Plan/Final Environmental Impact Report** (FRP/FEIR)—issued May 2015

2. APPROVALS AND STATUS

Subsequent to the submittal of the above referenced documents through the Massachusetts Environmental Policy Act / Cape Cod Commission Development of Regional Impact (MEPA/DRI) review process (a joint review by State and local regulatory agencies), the following most recent approvals were received:

1. Certificate of the Secretary of Energy and Environmental Affairs on the Final Environmental Impact Report – Comprehensive Watershed Nitrogen Management Plan – EEA # 12615 – Dated July 31, 2015. This document stated that the above submitted documents: "adequately and properly complies with the Massachusetts Environmental Policy Act (MEPA) (M.G.L. c. 30, ss.61-62I) and its implementing regulations (301 CMR 11.00). No further MEPA review is required."
2. Cape Cod Commission Consistency Letter for Phase 1 of the CWNMP dated October 16, 2015. This letter states the activities proposed in Phase 1 of this document "are consistent with the 208 Plan Update and should be implemented for the benefit of the town and the region." The letter states that a formal 208 Consistency document will be forthcoming as the Cape Cod Commission (CCC) had yet

to issue formal guidance setting forth the requirements for a town to obtain 208 Plan Update consistency determination.

3. CURRENT STATUS AS OF OCTOBER 2017

The CCC has extended its DRI Public Hearing Period in anticipation of the development of a Draft Watershed Permit.

The Town of Mashpee has initiated Phase 1 of its plan as follows:

1. Initiated IMA / Watershed Permit Discussions with the neighboring communities of Barnstable and Sandwich regarding the Popponesset Bay Watershed: June 2016 to Present.
2. Initiated Feasibility Studies:
    a. Quashnet / Moonakis River Evaluation—flushing and shellfish/fin fish habitat restoration: June 2016 to Present.
    b. Mashpee Commons and Wampanoag Private WWTF evaluations: March 2016 to Present.
3. Shellfish aquaculture/propagation/restoration—Phase 1 expansion: 2016 to present.
    a. Mashpee River / Shoestring Bay—oysters.
    b. Great River / Jehu Pond / Little River / Hamblin Pond—quahogs.
    c. Department reconfiguration and expansion of personnel.
    d. Monitoring per MEP protocols with additional water quality meters deployed.

ATTACHMENT A

POPPONESSET BAY INTER-MUNICIPAL AGREEMENT
STATUS OF WASTEWATER-RELATED PLANNING FOR TOWN OF SANDWICH
25 October 2017

Sandwich has been developing its Comprehensive Water Resources Management Plan (CWRMP) since October 2012. Sandwich completed its CWRMP Needs Assessment (draft March 2012, updated draft October 2016) and its CWRMP Alternatives Analysis (draft April 2013, updated draft October 2016). Sandwich has submitted the Draft CWRMP to the Massachusetts Department of Environmental Protection for technical review and to the Cape Cod Commission for a "208 Plan Update Consistency Review". These reviews are on-going. The CWRMP will be updated to address review comments and finalized in December 2017. The CWRMP is funded by a grant received from the Commonwealth Natural Resources Damages Assessment fund and this grant expires December 31, 2017.

The Town received town meeting approval in May 2017 for an initial appropriation of $150,000 for continued planning efforts, including items such as pre-design activities, Massachusetts Environmental Policy Act (MEPA) review, Development of Regional Impact (DRI) review (if applicable). Sandwich has been, and will continue to be, involved in discussions with Joint Base Cape Cod (JBCC) and other municipal and quasi-municipal entities regarding sewer treatment capacity at the existing JBCC wastewater collection, treatment and disposal facilities.

ATTACHMENT B

ATTACHMENT B

EXHIBIT A TO INTER-MUNICIPAL AGREEMENT
TECHNICAL BASIS FOR NITROGEN LOADING ALLOCATION
Towns of Barnstable MA, Mashpee MA and Sandwich MA

Date: March 1, 2017; rev. March 14, 2017; rev. May 2, 2017
Prepared by: J. Jefferson Gregg, PE,BCEE – GHD Inc; Edward J. Leonard, PE, Wright-Pierce

BACKGROUND AND PURPOSE

Watershed nitrogen loadings to Popponesset Bay have been studied and reported on numerous times by various authors since 2000, including the studies identified below:

- MEP "Technical Report" (and associated "data disk") [Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts, Commonwealth of Massachusetts, Department of Environmental Protection, Massachusetts Estuaries Project, Final Report – September 2004]

- DEP "Revised TMDL" [Popponesset Bay Total Maximum Daily Loads for Total Nitrogen, Report #96-TMDL-4, Control #217.0, Department of Environmental Protection, December 5, 2006]

- DEP "Pilot Project Report" [Inter-Municipal Watershed Planning and TMDL Implementation to Restore Embayment Water Quality on Cape Cod, Massachusetts Department of Environmental Protection, Massachusetts Estuaries Project, Nov 2008]

- MEP "Unified Database" Memorandum [MEP Technical Memorandum, Report on Unified Database and Requested MEP Scenarios for the (a) Popponesset Bay Estuary and (b) Eastern Basins of the Waquoit Bay System, December 15, 2009]

- Mashpee "Watershed Nitrogen Management Plan (WNMP)" [Watershed Nitrogen Management Plan, Final Recommended Plan/Environmental Impact Report, GHD, May 2015]

- CCC "208 Plan Update" [208 Plan, Cape Cod Area Wide Water Quality Management Plan Update, Cape Cod Commission, June 2015]

- GHD "Allocation Memo" ["Popponesset Bay Load Allocation Approach", GHD Memorandum, May 19, 2016]

- Sandwich "CWRMP Needs Assessment" [Updated Draft Report, Wright-Pierce, October 2016]

- Sandwich "CWRMP Alternatives Analysis" [Updated Draft Report, Wright-Pierce, October 2016]

Each of these reports contributes to the body of data available for planning and implementation of watershed solutions for the Popponesset Bay system. The purpose of this memorandum is to summarize the watershed nitrogen loadings that will serve as the basis for an inter-municipal agreement (IMA) between the Towns of Barnstable, Mashpee and Sandwich.

INTRODUCTION

On June 16, 2016, representatives from the Towns of Barnstable, Mashpee and Sandwich held a kickoff meeting at the Mashpee Town Hall to discuss the development of an Inter-municipal Agreement (IMA) and the potential development of an application for a Watershed Permit as part of the effort of all three communities to address Total Nitrogen (TN) Total Maximum Daily Loads (TMDLs) for Popponesset Bay. These TMDLs were established by MassDEP and the USEPA based on the efforts of the ongoing Massachusetts Estuaries Project (MEP).

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The key component in establishing the IMA is the agreement of each community on their share of the nitrogen load migrating to Popponesset Bay estuary through the watersheds that feed this system and include portions of each of the three communities. Following the Town of Mashpee's completion of their Comprehensive Planning efforts and the completion of the Cape Cod Commission's (CCC) recent 208 Planning efforts, GHD Inc was retained to compare three nitrogen load allocation approaches and propose an allocation that could be used in an IMA.

GHD prepared a memorandum dated May 19, 2016 entitled "Popponesset Bay Load Allocation Approach" presenting the analysis and recommendations for further discussion among the communities. This information was presented to each of the three communities and discussed during several joint meetings held on June 16, 2016, June 30, 2016, August 11, 2016 and February 15, 2017. The memorandum reviewed some previously presented allocations of nitrogen load under unattenuated and attenuated conditions and both "existing" or "baseline" conditions (considered the condition established in the MEP technical reports) and "future" conditions (build-out conditions). The Memorandum then summarized an approach of averaging such values.

During the February 15, 2017 and April 27, 2017 meetings, that included representatives of each community, the following items were agreed upon:

- CCC wMVP values would not be utilized because existing, watershed-specific information is already available (i.e., MEP original data disk and MEP "unified database").
- MEP approach (i.e., land use, water use, unattenuated loads, natural attenuation, attenuated loads and hydrodynamic assessments) is a reasonable approach.
- Allocation of responsibility would use average percent allocations based on the percent allocations established as part of the DEP Pilot Project and those established by the WNMP under the "existing" conditions. The difference between these values ranged from 0.1% to 1.0%, depending on the condition (attenuated or unattenuated) and on the community.
- Underlying data for the MEP approach will be re-evaluated in the future in the context of a watershed permit.
- Both unattenuated and attenuated loads should be presented in the IMA.
    - The purpose of presenting unattenuated loads is to provide a benchmark to allow for tracking and accounting of nitrogen reductions which result from implemented measures.
    - The purpose of presenting attenuated loads is to provide a benchmark for comparison of improvements to water quality based on implemented measures. Attenuated load is what is 'received in the estuary'.
- The allocation of responsibility for existing loads should be considered the baseline year identified in the MEP/DEP work projects (i.e., 2000/2001).
- The average values of the comparable results of the DEP Pilot Project and the Mashpee WNMP/Unified Database would be used to establish the baseline loads for the IMA.
- The parcels which have been developed or redeveloped since the baseline year represent "future conditions" in terms of TMDL compliance (i.e., there has been at least 16 years of growth since the baseline year).
- The allocation of responsibility for development or redevelopment that has occurred since the baseline year will be the responsibility of the municipality that the growth occurred in.

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BRIEF DESCRIPTION OF NITROGEN LOADING MODELS

The tables below include the average "existing" (i.e., baseline) TN load based on the loads presented in the "rainbow"[1] spreadsheets used in the MEP analysis and those estimated based on the "unified"[2] database used in the Mashpee WNMP analysis. The primary differences in the loading estimates using the "unified" database are associated with build-out, which was the focus of the WNMP analysis in achieving TMDL compliance. However, as part of the development of the IMA, GHD was requested to generate existing loadings related to allocation estimates. In generating those numbers, two primary differences were identified in the GHD analysis when comparing to the original MEP analysis, which may have contributed to the slight increase in nitrogen load values under existing conditions:

- GHD analysis of assigning parcels to watersheds were based on the "centroid" method in GIS (where the centroid is the geometrical center of a parcel) vs. the MEP analysis where parcels were "split" and the location of septic system leaching areas relative to watershed lines were used.
- GHD used conservative average performance concentrations (for planning purposes) at the existing WWTFs in the watershed. Concentrations of either 5 mg/L or 10 mg/L TN were applied depending on the size of the facility. Estimated wastewater generation from parcels connected to each WWTF were used to estimate flows, whereas the MEP analysis used flows and concentration values for WWTFs based on "Town of Mashpee Board of Health/Planning Dept." records (per the notes provide on the "factors" worksheet in the "rainbow" spreadsheet data).

NITROGEN LOAD ALLOCATION

As part of the DEP Pilot Project, an approach was presented that if each community removed 49.2% of their share of the load, the TN TMDL could be achieved in Popponesset Bay at the sentinel station. Table 1 presents this approach, however since the Pilot Project only estimated the maximum total unattenuated load to "sustain" the threshold concentration at the sentinel station (as presented in Figure 2.15 of the Pilot Project Report), an attenuated load had to be estimated as part of this effort. This attenuated value was estimated by calculating the average attenuation by Town using the results of the analysis performed by Brian Dudley of MassDEP during the Pilot Project study. During the MassDEP effort, each Town's contribution according to the MEP dataset was divided out such that an estimated contribution by Town could be established (as that was not done as part of the original MEP efforts).

It should be noted that the Pilot Project like the WNMP and MEP technical reports all present different ways to achieve TMDL compliance by targeting different amounts of nitrogen in different subwatersheds. The Pilot Project simply attempted to streamline the process for communities using the approximately 50% reduction across the board. Therefore, it is understood that this approach may be conservative and the ultimate effectiveness of any approach will only be realized during the periodic monitoring and modeling necessary to demonstrate compliance and that will need to be defined in the Watershed Permit.

The following tables have been prepared to summarize the pertinent data from the MEP Technical Report and the DEP Pilot Project (Table 1), the WNMP/MEP Unified Database (Table 2) and the Basis for the IMA (Table 3).

Each table uses the TMDL value of 40.3 kg/day (14,710 kg/year) as the maximum attenuated load which can remain in the watershed and which would be expected to achieve the Massachusetts Water Quality Criteria, based on Table 2-5 of the TMDL Report dated December 10, 2006.

[1] Popponesset Data Disk, MEP, "Poppy_summary_public.xls"
[2] MEP Technical Memo: "Report on Unified Database and Requested MEP Scenarios for the: (a) Popponesset Bay Estuary and (b) Eastern Basins of Waquoit Bay System", SMAST, December 15, 2009

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Table 1 – MEP Technical Report/DEP Pilot Project Report

	Unattenuated (Baseline 2000/2001)				Attenuated (Baseline 2000/2001)			
	Applied Load[1]	TMDL Load to Sustain[2]	Load to Remove[2]	% Load[1]	Applied Load[1]	TMDL Load to Sustain[4]	Load to Remove[4]	% Load[1]
Barnstable	6,224	3,162	3,062	12.8%	5,199	2,398	2,801	16.3%
Mashpee	31,705	16,106	15,599	65.4%	23,811	10,981	12,830	74.7%
Sandwich	10,585	5,377	5,208	21.8%	2,886	1,331	1,555	9.0%
Total	48,514	24,645	23,869	100%	31,896	14,710[3]	17,187	100%

Notes:

1. Values as reported in MEP Pilot Project Report Table 2.8.
2. Values as reported in MEP Pilot Project Report Figure 2.15.
3. Value reported in Popponesset Bay TMDL Report Table 2-5.
4. Values "Prorata" (in relation to TMDL value and % load), except as noted above.

Table 2 – Watershed Nitrogen Management Plan (Mashpee/GHD)

	Unattenuated (Baseline 2000/2001)				Attenuated (Baseline 2000/2001)			
	Applied Load[1]	TMDL Load to Sustain[3]	Load to Remove[1]	% Load[1]	Applied Load[1]	TMDL Load to Sustain[3]	Load to Remove[3]	% Load[1]
Barnstable	6,239	3,045	3,194	12.4%	5,263	2,300	2,963	15.6%
Mashpee	33,054	16,133	16,921	65.5%	25,022	10,935	14,087	74.3%
Sandwich	11,200	5,467	5,733	22.2%	3,373	1,474	1,899	10.0%
Total	50,493	24,645[2]	25,848	100%	33,658	14,710[4]	18,949	100%

Notes:

1. Values developed as part of the Town of Mashpee, MA Watershed Nitrogen Management Planning (WNMP) efforts, except as noted.
2. Value as reported in MEP Pilot Project Report Figure 2.15.
3. Values "Prorata" (in relation to TMDL value and % load), except as noted above.
4. Value reported in Popponesset Bay TMDL Report Table 2-5.

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Table 3 – Basis for Inter-Municipal Agreement (IMA)[1][2]

	Unattenuated (Baseline 2000/2001)				Attenuated (Baseline 2000/2001)			
	Applied Load	TMDL Load to Sustain	Load to Remove	% Load	Applied Load	TMDL Load to Sustain	Load to Remove	% Load
Barnstable	6,230	3,100	3,130	12.6%	5,230	2,350	2,880	16.0%
Mashpee	32,380	16,120	16,260	65.4%	24,420	10,960	13,460	74.5%
Sandwich	10,890	5,420	5,470	22.0%	3,130	1,400	1,730	9.5%
Total	49,500	24,640	24,860	100%	32,780	14,710	18,070	100%

Notes:

1. **Values represent the average of Tables 1 and 2.**
2. **Values are rounded to the nearest 10kg/yr.**

Appendix JJ

Feasibility Analysis of Shared Wastewater Treatment and Effluent Recharge between Barnstable, MA and Yarmouth, MA

Memorandum

To: *Town of Yarmouth*

From: *Kara M. Johnston, P.E.*
Hannah C. Sullivan
David F. Young, P.E.

Date: *July 2, 2019 (updated)*

Subject: *Feasibility Analysis of Shared Wastewater Treatment and Effluent Recharge between Barnstable, MA and Yarmouth, MA*

Funded by the Massachusetts Efficiency and Regionalization Grant Program and the Massachusetts Best Practices Grant Program

The Town of Yarmouth was awarded in 2018 an Efficiency and Regionalization Grant from the State's Community Compact Program. A portion of this grant was used to analyze the feasibility of shared wastewater treatment and effluent recharge between the Towns of Barnstable and Yarmouth. The Town of Harwich was awarded a Best Practices Grant in 2019 on behalf of the towns of Dennis, Harwich, Yarmouth, and Barnstable. A portion of this grant was allocated for continued analysis of wastewater treatment and effluent recharge between Barnstable and Yarmouth. The two towns share the Lewis Bay watershed and have taken the initiative to assess reducing nitrogen loading to embayments through shared commitment.

Both towns are at different phases in their Comprehensive Wastewater Management Plans. The Town of Barnstable has an existing Water Pollution Control Program which manages a collection, treatment, and recharge system, including the operation and maintenance of a secondary Water Pollution Control Facility (WPCF), 30 sewage pumping stations, and 55 miles of sewer lines. The Town is currently planning their next phases of their wastewater management plan to meet Total Maximum Daily Loads (TMDLs) for nitrogen throughout watersheds in Barnstable.

The Town of Yarmouth has been working to update their Comprehensive Wastewater Management Plan (CWMP). In 2011, the Town received state approval of their CWMP. The Town is now incorporating the Bass River Watershed into the plan and is evaluating partnership options with neighboring communities. The Town's goal is to identify a recommended program that meets the unique wastewater management challenges and economic growth goals of Yarmouth. The Town's Water Resources Advisory Committee (WRAC) is updating the CWMP and the Town plans to file a Notice of Project Change (NPC) with the Massachusetts Environmental Policy Act (MEPA) Office and the Cape Cod Commission (CCC) for regulatory review in 2019.

The purpose of this memorandum is to present the various alternatives that have been developed for the towns to coordinate shared wastewater treatment and effluent recharge. There are numerous potential routes to convey Yarmouth's wastewater from the Lewis Bay Watershed to Barnstable's Water Pollution Control Facility. Upon treatment at the existing WPCF, the effluent could be conveyed to a town-owned site on Buck Island Road in Yarmouth where it would be recharged into the ground. Two potential routes were evaluated from the WPCF to the Buck Island Road Recharge Site. The towns developed 8 alternatives with varying factors that include:

- The locations where redundant force mains could be installed;
- The wastewater conveyance routes from the Lewis Bay Watershed in Yarmouth to the WPCF in Barnstable; and
- The treated effluent conveyance routes from the Barnstable WPCF to the Buck Island Road Recharge Site in Yarmouth.

The majority of these alternatives account for 365,000 gpd of flow from the Lewis Bay Watershed in West Yarmouth and 100,000 gpd of flow from a potential new sewer area in Barnstable off of Yarmouth Road.

The Barnstable WPCF has a current treatment capacity of 4.2 million gallons per day (MGD) maximum day and effluent discharge capacity of 2.7 MGD maximum day. It is estimated based on transient groundwater modeling that the Buck Island Road Recharge Site has a capacity of 870,000 gpd to 1.2 MGD, depending on the concentration of total nitrogen (TN) in the effluent to be discharged. It is assumed in the alternatives below that Barnstable could purchase the remaining capacity not used by Yarmouth at the Buck Island Road Recharge Site.

1.0 Pipe Conveyance Redundancy Scenarios

When evaluating pipe conveyance routes between the communities, the towns discussed the need for force main redundancy for both the wastewater force main and the effluent force main. The Town of Barnstable prefers that a redundant pipe be installed alongside all force mains within the town. Barnstable has expressed concern that the Town would not be able to recharge the Barnstable/Yarmouth effluent in town in the event of an effluent pipe force main break on its way to the Yarmouth Buck Island Road Recharge Site. An effluent force main repair carrying treated effluent would be similar to a water main repair and CDM Smith anticipates that the line could be fixed fairly quickly. In accordance with this discussion between the communities, two redundancy scenarios have been analyzed for each route option that is discussed in Sections 2 and 3. The communities would need to discuss the redundancy impacts on costs and future operations.

Redundancy Scenario 1: All force mains installed in both Barnstable and Yarmouth include a redundant pipe installed in the same trench. This includes both the force main conveying wastewater to the Barnstable WPCF, as well as the force main conveying treated effluent to the Buck Island Road Recharge Site.

Redundancy Scenario 2: Only the force main that conveys wastewater to the Barnstable WPCF in Barnstable and Yarmouth includes a redundant pipe installed in the same trench. Force main conveying treated effluent to the Buck Island Road Recharge Site include a single pipe in both towns.

2.0 Wastewater Conveyance Routes from Yarmouth to Barnstable

In order to convey a portion of Yarmouth's wastewater from the Lewis Bay watershed to the Barnstable WPCF for treatment, various potential routes have been analyzed for cost and efficiency. Routes were developed in discussions between Barnstable and Yarmouth representatives. All four of the routes begin by collecting 365,000 from the Yarmouth Pumping Station on Route 28 in the Lewis Bay Watershed and end at the Barnstable WPCF on Bearses Way in Barnstable. Options 2A and 3 collect an additional 100,000 gpd of buildout flow from the area of Barnstable that is north of Route 28 and east of Yarmouth Road. Attachment A includes figures for the conveyance options that are described in more detail below, along with a summary figure showing all the wastewater and effluent conveyance options.

2.1 Wastewater Conveyance Option 1 - Direct Route

Conveyance Option 1 is to convey the wastewater along the most direct route within Route 28, a state-owned roadway. The wastewater would be pumped via a 6" force main from the Yarmouth Pumping Station west along Route 28 and up Bearses Way to the Barnstable WPCF for treatment. The total length of force main installed would be approximately 2.5 miles, with 2.3 miles of that on a state road. The cost to install force main along a state roadway is significantly higher than on a local road due to the necessity of additional police detail, state backfill and paving requirements, permitting, and potential required nightwork. The potential flow proportion between Barnstable and Yarmouth was developed based on the percentage of flow that each town would contribute to each pipe segment. Figure 1 in Attachment A shows this wastewater conveyance route.

2.2 Wastewater Conveyance Option 2A – via Existing Gravity Sewer System and Old Colony Pumping Station with Barnstable Flow

The second option for conveying wastewater to the Barnstable WPCF makes use of Barnstable's existing gravity sewer system. The wastewater would be pumped from the Yarmouth Pumping Station, west along Route 28, up Camp Street, and down Mill Pond Village to the shared B/Y Pumping Station facility via a 6" force main. From there, the wastewater would be pumped down Yarmouth Road via a 6" force main where it would then tie into Barnstable's existing 8" gravity sewer at the intersection of Yarmouth Road and Camp Street. The wastewater would then flow by gravity through the existing collection system to Barnstable's Old Colony Pumping Station at the corner of South Street and Old Colony Road. From there, the wastewater would be pumped through a new 10" force main down South Street, up High School Road, and up Bearses Way to the WPCF for treatment. The additional flow from the two towns of approximately 465,000 gpd into Barnstable's existing collection and conveyance system would likely require some necessary pipe size upgrades. Figure 2 in Attachment A shows this wastewater conveyance route.

2.3 Wastewater Conveyance Option 2B – via Existing Gravity Sewer System and Old Colony Pumping Station without Barnstable Flow

Similar to Conveyance Option 2A, this alternative incorporates Barnstable's existing gravity sewer system into the shared wastewater conveyance plan. However, instead of installing a force main up to Ferndoc Street to the proposed shared pumping station, a force main would be installed from the Yarmouth Pumping Station, west along Route 28 to Main Street in Barnstable where it would tie into Barnstable's existing 8" gravity sewer. In this Option 2B, the shared pumping station on Ferndoc Street would not be installed and the new collection system in the area of Barnstable north of Route 28 and east of Yarmouth Road would be conveyed separately through Barnstable's sewer system. Therefore, the only additional wastewater conveyed to the Barnstable WPCF would be the 365,000 gpd of buildout flow from Yarmouth.

Once tying into the existing collection system, the wastewater would flow by gravity to the Old Colony Pumping Station where it would then be pumped through the existing 10" force main down South Street, up High School Road, and up Bearses Way to the WPCF. To accommodate the additional 365,000 gpd of buildout flow in the collection and conveyance system, some upgrades to the gravity sewers and force main would likely be necessary. Figure 3 in Attachment A shows this wastewater conveyance route.

2.4 Wastewater Conveyance Option 3 – via Municipally Owned Roads (through Airport and Shopping Center)

Option 3 was developed with the intent of avoiding the additional permitting and costs associated with installing new pipe on the state-owned Route 28. The Town of Barnstable owns the Hyannis Airport property and the adjacent shopping center. The Town of Barnstable proposed that the airport access road and adjacent shopping center parking lot be used in place of Route 28 between Yarmouth Road and Airport Road. In this case, wastewater would be pumped from the Yarmouth Pumping Station, west along Route 28, up Camp Street and down Mill Pond Village to the proposed shared B/Y Pumping Station on Ferndoc Street. The wastewater would flow down Yarmouth Road for a short distance until turning west at 326 Yarmouth Road and continue along a cross country route through the municipally owned airport land to the airport service road. It would then follow the service road until reaching Barnstable Road which connects the airport to the municipal owned shopping plaza parking lot. Upon crossing through the parking lot, the force main would turn down Airport Road to Route 132 where it would then follow the state road for approximately a tenth of a mile. Next, it would turn down Independence Drive to Enterprise Road until reaching Bearses Way where the Barnstable WPCF is located. Although this route is approximately 1.3 miles longer than the direct route, there would be no work on Route 28 in Barnstable. Figure 4 in Attachment A shows this wastewater conveyance route.

2.5 Wastewater Conveyance Route Options Summary

All conveyance route options were analyzed under both redundancy scenarios. However, since both scenarios require redundant wastewater force main, the total wastewater conveyance cost remains the same under both scenarios for each of the route options discussed in this section. A cost estimate for each of the four wastewater conveyance route options has been developed and is

presented in Table 1. All costs are projected to Year 2022 with an estimated Engineering News Record (ENR) Construction Cost Index of 12,400. The ENR Index is an industry standard index for tracking costs over time. Force main cost estimates include temporary trench width paving followed by mill and overlay, costs for jack and boring beneath railroad crossing where applicable, and consider additional costs for work on a state road where applicable. The potential flow proportion split between Barnstable and Yarmouth was developed based on the percentage of flow that each town would contribute to each pipe segment. Flow proportions are just one potential cost sharing method for discussion; other potential methods would be further discussed and negotiated between the communities.

Table 1 - Wastewater Conveyance Options Opinion of Probable Cost (For Redundancy Scenarios 1 and 2)

	Total Cost[1]	Potential Flow Proportions		Potential Flow Proportion Percentages for Shared Infrastructure	
		Barnstable	Yarmouth	Barnstable	Yarmouth
OPTION 1 - DIRECT ROUTE VIA ROUTE 28	$7.87 Million	0 gpd	365,000 gpd	0%	100%
OPTION 2A – VIA OLD COLONY PUMPING STATION W/ BARNSTABLE FLOW	$14.44 Million	100,000 gpd	365,000 gpd	22%	78%
OPTION 2B – VIA OLD COLONY PUMPING STATION W/O BARNSTABLE FLOW	$10.26 Million	0 gpd	365,000 gpd	0%	100%
OPTION 3 – VIA MUNICIPALLY OWNED ROADS THROUGH AIRPORT AND SHOPPING CENTER	$11.50 Million	100,000 gpd	365,000 gpd	22%	78%

[1]The cost of the Yarmouth Mill Creek Pumping Station and associated force main is included in the total costs in Table 1, but is not assumed to be shared infrastructure with Barnstable.

3.0 Treated Effluent Conveyance Routes from Barnstable to Yarmouth

Similar to wastewater conveyance, there are multiple potential routes for the treated effluent conveyance from the Barnstable WPCF to the Buck Island Road Recharge Site in Yarmouth. The figures in Attachment A depict the two routes developed for the conveyance of the treated effluent. Both of these effluent conveyance options were analyzed under each of the redundancy scenarios. Scenario 1 includes effluent force main redundancy whereas Scenario 2 includes a single effluent force main. As discussed in Section 1, the communities will need to discuss the redundancy impacts on costs and future operations.

3.1 Effluent Conveyance Option 1 - Direct Route

Effluent Conveyance Option 1 is to convey the effluent along the most direct route. This is essentially the reverse of the wastewater conveyance Option 1 route; however, the force main continues to the Buck Island Road Recharge Site. The effluent force main would travel from the Barnstable WPCF, east on Route 28. From there, the effluent force main would turn up Town Brook Road and follow Buck Island Road to the Buck Island Road Recharge Site. The total cost and the

potential flow proportion percentages between the two towns for sending the effluent to the Buck Island Road Recharge Site is shown in Table 2.

Table 2 - Treated Effluent Conveyance Option 1 (Direct Route via Route 28) Opinion of Probable Cost

	Total Cost	Potential Flow Proportions[1]		Potential Flow Proportion Percentages	
		Barnstable	Yarmouth	Barnstable	Yarmouth
Redundancy Scenario 1 *(Redundant sewer and effluent force main in Barnstable and Yarmouth)*	$12.87 Million	835,000 gpd	365,000 gpd	70%	30%
Redundancy Scenario 2 *(Redundant sewer force main in Barnstable and Yarmouth only)*	$6.77 Million	835,000 gpd	365,000 gpd	70%	30%

[1]Effluent Conveyance Option assumes nitrogen upgrade to Barnstable WPCF to TN discharge of 3 mg/L.

If either wastewater conveyance Option 2A or 2B is selected in conjunction with effluent conveyance Option 1, then an additional cost would be included for pipe jacking at the railroad crossing.

3.2 Effluent Conveyance Option 2- via Municipally Owned Roads (through Airport and Shopping Center)

Similar to wastewater conveyance Option 3, this route was developed to avoid work on state owned Route 28 by way of the municipally owned airport service road and shopping plaza parking lot. The route is the reverse of the wastewater Option 3 route until reaching Camp Street where it would then follow Buck Island Road to the Buck Island Road Recharge Site. Table 3 shows the total cost under each redundancy scenario for this effluent conveyance route option as well as the potential flow proportion percentages based on the amount of additional flow in each pipe segment.

Table 3 - Treated Effluent Conveyance Option 2 (via Municipally Owned Roads) Opinion of Probable Cost

	Total Cost	Potential Flow Proportions[1]		Potential Flow Proportion Percentages	
		Barnstable	Yarmouth	Barnstable	Yarmouth
Redundancy Scenario 1 *(Redundant sewer and effluent force main in Barnstable and Yarmouth)*	$14.77 Million	835,000 gpd	365,000 gpd	70%	30%
Redundancy Scenario 2 *(Redundant sewer force main in Barnstable and Yarmouth only)*	$7.78 Million	835,000 gpd	365,000 gpd	70%	30%

[1]Effluent Conveyance Option assumes nitrogen upgrade to Barnstable WPCF to TN discharge of 3 mg/L.

4.0 Barnstable Water Pollution Control Facility (WPCF)

The Barnstable WPCF has a current average daily flow of 1.57 million gallons per day (MGD). The Town has hired a consultant to create a BioWin model of the plant to evaluate its treatment capacities and is awaiting the results of the study. The current estimates are that the town has about 1.0-2.0 MGD of treatment capacity available, and about 1.0 MGD of disposal capacity available, some of which is currently allocated for future sewer phases in Barnstable. Additionally, Barnstable is currently evaluating its pumping stations throughout town to estimate the capacity, condition, and needs assessment for each station.

The Town of Barnstable has plans for future phases to meet their nitrogen TMDL goals. It is not anticipated that the wastewater flow from Yarmouth would significantly impact future Barnstable flows at the WPCF. The Town of Barnstable's permitted flow from their November 5, 2018 issued discharge permit is 2.7 MGD, with the an associated mass loading limit based on an annual average of 6 mg/L Total Nitrogen. The maximum daily limit of Total Nitrogen permitted is 10 mg/L.

Because of the studies underway, the costs for upgrades at the Barnstable WPCF are unknown at this time and are not included in the cost estimates in this memorandum. The need for pumps and wet well storage to pump effluent to the Buck Island Road Recharge Site are also unknown at this time and are not included in the cost estimates in this memorandum.

5.0 Buck Island Road Recharge Site in Yarmouth

Once the wastewater has been treated and conveyed to the Buck Island Road Recharge Site, the highly treated effluent would be recharged into the ground via infiltration basins. The Buck Island Road Site was selected as a potential recharge site for a variety of reasons:

- Site is outside of any Zone II areas, meaning the aquifer at this site does not contribute to a drinking water well;
- Site is owned by the Town of Yarmouth;
- Subsurface soil characteristics are desirable for infiltration of the recharge into the groundwater as prior investigations have shown the subsurface is predominately sandy soil and not dense clay.

The Town of Yarmouth has assessed the nitrogen balance of the Parkers River watershed in their sewer plan, including the widening of the Parkers River Bridge on Route 28 which will provide increased flushing. Under the Town's current plan, the Upper Parkers River subwatershed where the Buck Island Road Effluent Recharge Site is located is planned to be fully sewered to meet the watershed's TMDL. If Barnstable and Yarmouth recharge effluent at the Buck Island Road Recharge Site, additional nitrogen from the effluent will enter the groundwater in the Parkers River Watershed and will need to be removed to meet the watershed's TMDL.

The Buck Island Road Recharge Site was previously analyzed to quantify the recharge capacity of the site. The 10-acre site is estimated to be able to hydraulically recharge a total of 1.2 MGD of

effluent at a WPCF nitrogen discharge of 3 mg/L. A permeable reactive barrier (PRB) has been proposed to achieve additional nitrogen removal surrounding the Buck Island Road Recharge Site after treatment, reducing the nitrogen discharge of 3 mg/L to 1 mg/L. The Cape Cod Commission's Section 208 Plan provides an estimate nitrogen removal for PRBs at 75-90% removal. CDM Smith performed a PRB analysis in Falmouth, MA where an 80% nitrogen removal rate was found to be anticipate through a PRB based on literature citations. For the Buck Island Road Recharge Site, an 80% nitrogen removal rate is expected to be achieved through a PRB, meaning a WPCF TN discharge of 3 mg/L would be lowered to approximately 1 mg/L. Based off the site capacity of 1.2 MGD, the barrier would stretch approximately 2,600 linear feet.

Per the Individual Groundwater Discharge Permit issued to the Barnstable WPCF on November 5, 2018, the treatment facility has a current nitrogen maximum daily effluent discharge limit of 10 mg/l and is not to exceed 49,315 pounds per calendar year based on a maximum daily flow of 2.7 MGD and an annual average Total Nitrogen concentration of 6 mg/l. It is assumed that a PRB could remove 80% of additional nitrogen from the effluent discharge. If there were no nitrogen upgrades at the Barnstable WPCF and the effluent is treated to the annual average TN concentration of 6 mg/l, the 10-acre Buck Island Site has a recharge capacity of approximately 870,000 gpd. Approximately 365,000 gpd of the flow under this option with a TN discharge of 6 mg/L would be contributed from the Town of Yarmouth, and the remaining 505,000 gpd of the flow could be contributed from the Town of Barnstable.

The Barnstable WPCF would need to be upgraded to meet an effluent limit of 3 mg/L Total Nitrogen in order to discharge 1.2 MGD of effluent in the Upper Parkers River subwatershed. Because the costs to upgrade the Barnstable WPCF are unknown at this time, the costs associated with meeting an effluent limit of 3 mg/L TN are also unknown and are not included in the cost estimates in this memorandum.

All alternatives have been analyzed with 365,000 gpd of flow from Yarmouth being sent to the WPCF and ultimately to the Buck Island Road Recharge Site for recharge. Under the current WPCF's average TN discharge of 6 mg/L, Barnstable could contribute 505,000 gpd of effluent recharge at the Buck Island Road Recharge Site. If the WPCF is upgraded to a TN discharge of 3 mg/L the Town of Barnstable could contribute up to 875,000 gpd.

The costs for the lease of the Yarmouth Buck Island Road Recharge Site are unknown at this time and are not included in the estimates below or in this memorandum. Table 4 shows the total cost and the potential flow proportion percentages for the effluent recharge site based on the 1.2 MGD site capacity if the Barnstable WPCF upgraded to treat to 3 mg/L TN.

Table 4 - Effluent Recharge Site Opinion of Probable Cost

Item	Total Cost	Potential Flow Proportions		Potential Flow Proportion Percentages	
		Barnstable	Yarmouth	Barnstable	Yarmouth
Buck Island Road Recharge Site	$6.05 Million	835,000 gpd	365,000 gpd	70%	30%
PRB	$8.10 Million	835,000 gpd	365,000 gpd	70%	30%

6.0 Operation and Maintenance Costs

In addition to the capital cost, the operations and maintenance costs have been estimated for all the alternatives. The unit costs to operate and maintain each component of the wastewater management plan are shown in Table 5.

Table 5 - Unit O&M Costs

Item	Unit	Unit Cost
Gravity Main	linear foot	$2.00
Sewer Force Main	linear foot	$1.00
Effluent Force Main	linear foot	$1.00
Pumping Station	each	$62,500.00
Effluent Recharge O&M	square foot	$0.17
PRB O&M	each	$55,000.00

Because the costs to upgrade the Barnstable WPCF are unknown at this time, the O&M costs associated with these upgrades are also unknown and are not included in the cost estimates in this memorandum.

7.0 Summary & Recommendation

The various alternatives for treatment and recharge of Barnstable and Yarmouth flow each provide various advantages and disadvantages. A summary table of the total cost and potential flow proportion percentages for both Barnstable and Yarmouth in each scenario and conveyance option is shown in Table 6.

Table 6 - Overall Cost Summary Table

		Scenario 1 - Redundant Sewer Force Main and Effluent Force Main	Scenario 2 - Redundant Sewer Force Main
OPTION 1 - DIRECT ROUTE VIA ROUTE 28	Capital Cost	$34.9 Mil	$28.8 Mil
	O & M Cost	$297,550	$270,750
	Barnstable Wastewater Flow Proportion	0%	0%
	Yarmouth Wastewater Flow Proportion	100%	100%
OPTION 2A - VIA EXISTING GRAVITY SEWER SYSTEM, W/ BARNSTABLE FLOW	Capital Cost	$41.6 Mil	$35.5 Mil
	O & M Cost	$411,100	$332,200
	Barnstable Wastewater Flow Proportion	22%	22%
	Yarmouth Wastewater Flow Proportion	78%	78%
OPTION 2B - VIA EXISTING GRAVITY SEWER SYSTEM NO BARNSTABLE FLOW	Capital Cost	$37.4 Mil	$31.4 Mil
	O & M Cost	$334,800	$310,800
	Barnstable Wastewater Flow Proportion	0%	0%
	Yarmouth Wastewater Flow Proportion	100%	100%
OPTION 3 - VIA MUNICIPALLY OWNED ROADS THROUGH AIRPORT AND SHOPPING CENTER	Capital Cost	$40.4 Mil	$33.4 Mil
	O & M Cost	$350,850	$322,550
	Barnstable Wastewater Flow Proportion	78%	78%
	Yarmouth Wastewater Flow Proportion	22%	22%

After further evaluation of the current flows at the Old Colony Pumping Station, the Town of Barnstable's preference is to not convey additional flow to the Old Colony Pumping Station. Therefore, the wastewater conveyance options 2A and 2B are not recommended at this time.

Conveyance and Effluent Recharge Option 1 provides the most direct and cost-effective route, but includes work on Route 28 in both communities. Conveyance Option 3 (with Effluent Recharge Conveyance Option 2) takes advantage of Barnstable-owned property to avoid work on Route 28, but is more costly due to the longer pipe distance, and the inclusion of a shared Barnstable/Yarmouth pumping station to accommodate an additional 100,000 gpd of wastewater flow from the Town of Barnstable.

If Barnstable and Yarmouth choose to move forward with a partnership, community leaders will need to discuss the implications of both of these options. Considerations will need to review:

- Capital costs;
- Operations;
- Force main redundancy;
- Impacts to state/town roads;

- Impacts to the Barnstable WPCF;
- Nitrogen impacts in the Parker's River Watershed.

An intermunicipal agreement (IMA) could be considered to formalize the partnership. The costs associated with nitrogen upgrades at the WPCF, costs for the effluent pumping station at the WPCF and for utilizing the Buck Island Road recharge site would all need to be further discussed.

As part of this grant, a series of meetings were held between Barnstable and Yarmouth to discuss the alternatives described above. Minutes from these meetings are included in Attachment B.

cc: Town of Barnstable
DHY Clean Waters Community Partnership

Attachments:
Attachment A: Figure 1
Attachment A: Figure 2
Attachment A: Figure 3
Attachment A: Figure 4
Attachment A: Figure 5
Attachment B: Meeting Minutes



N

Barnstable WPCF/ Recharge Routes

WPCF Route 1

Recharge Route 1

Barnstable - Yarmouth, MA

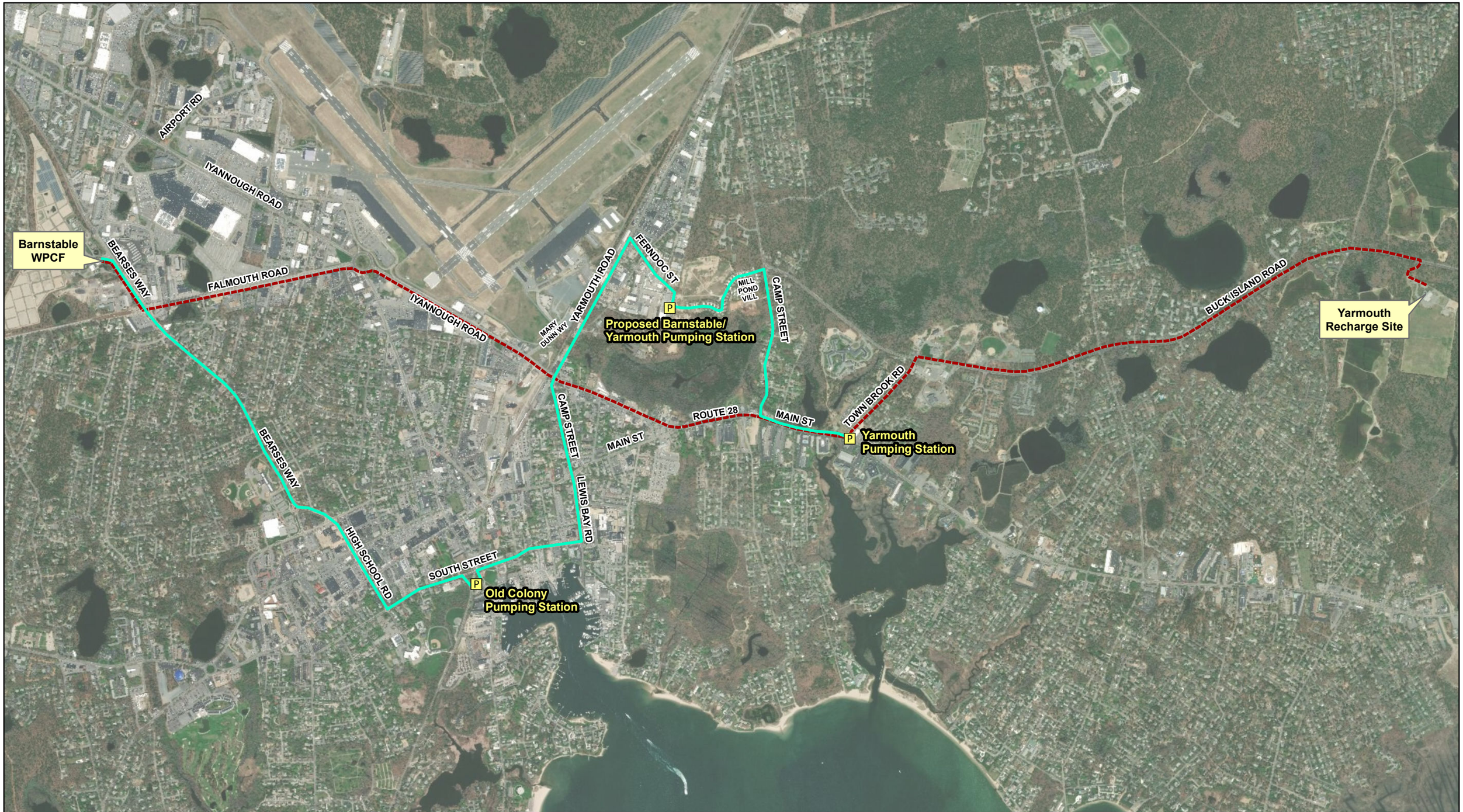
0 1,000 2,000 3,000 Feet

WPCF Route Option 1 and Recharge
Route Option 1 - June 2019

Figure 1

CDM Smith

NEWELLJD F:\Yarmouth_MA\Yarmouth_Barnstable_WWTP_Routes_Ortho_Figure1.mxd 6/19/2019



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Barnstable WPCF/ Recharge Routes

WPCF Route 2A

Recharge Route 1

Barnstable - Yarmouth, MA

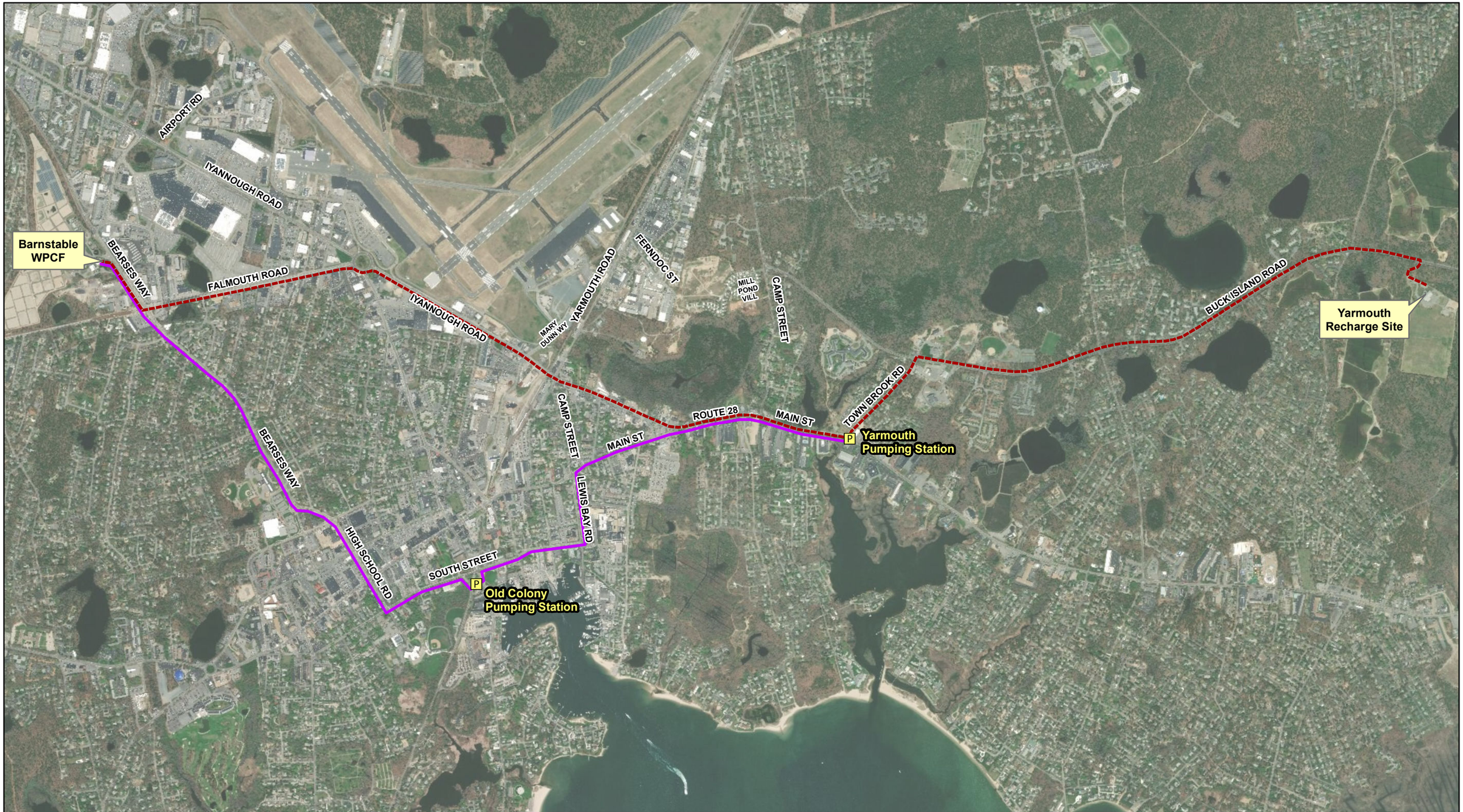
0 1,000 2,000 3,000 Feet

WPCF Route Option 2A and Recharge Route Option 1 - June 2019

Figure 2

CDM Smith

NEWELLJD F:\Yarmouth_MA\Yarmouth_Barnstable_WWTP_Routes_Ortho_Figure2.mxd 6/19/2019



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Barnstable WPCF/ Recharge Routes

- WPCF Route 2B
- Recharge Route 1

Barnstable - Yarmouth, MA

0 1,000 2,000 3,000 Feet

WPCF Route Option 2B and Recharge Route Option 1 - June 2019

Figure 3

CDM Smith

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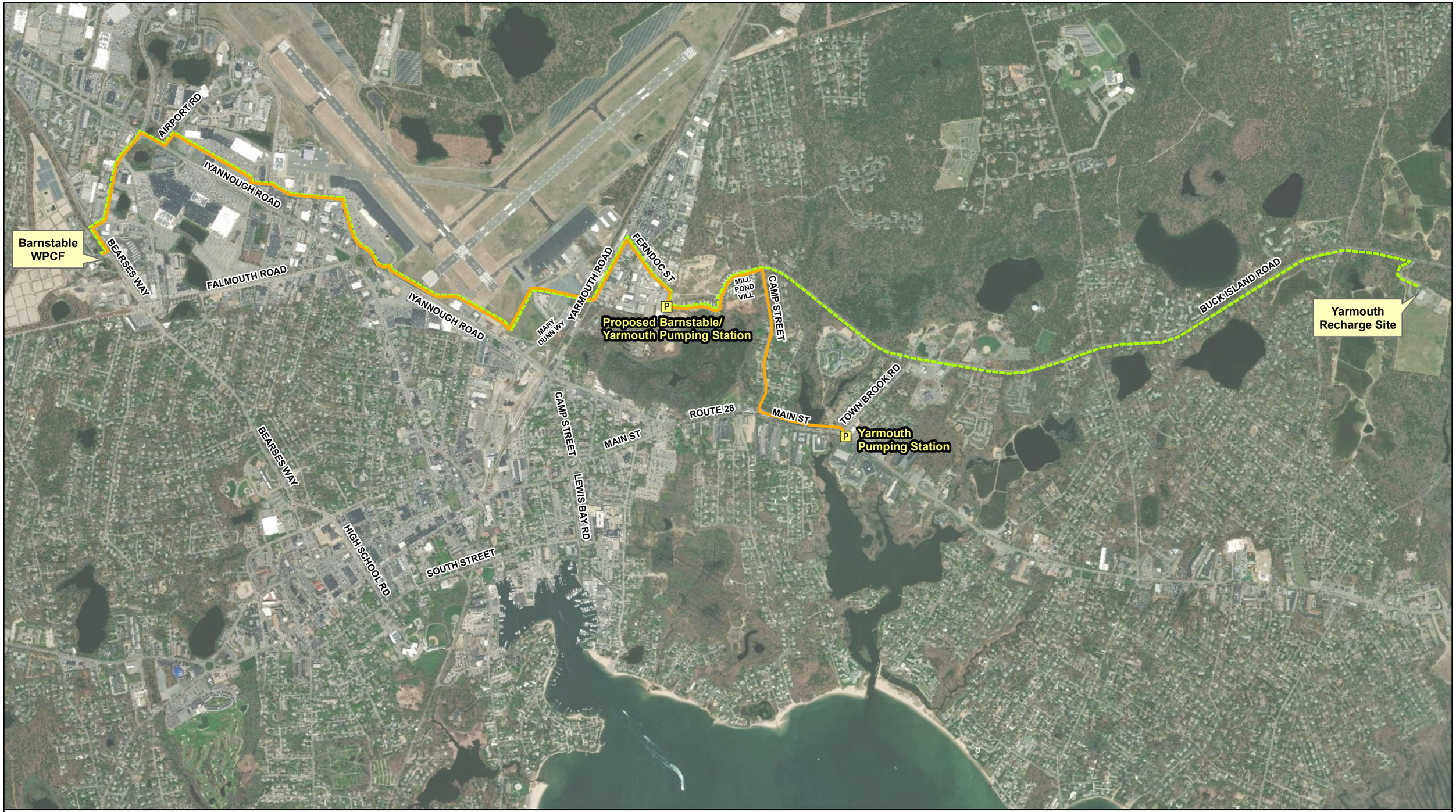

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Barnstable WPCF/ Recharge Routes

WPCF Route 3

Recharge Route 2

Barnstable - Yarmouth, MA

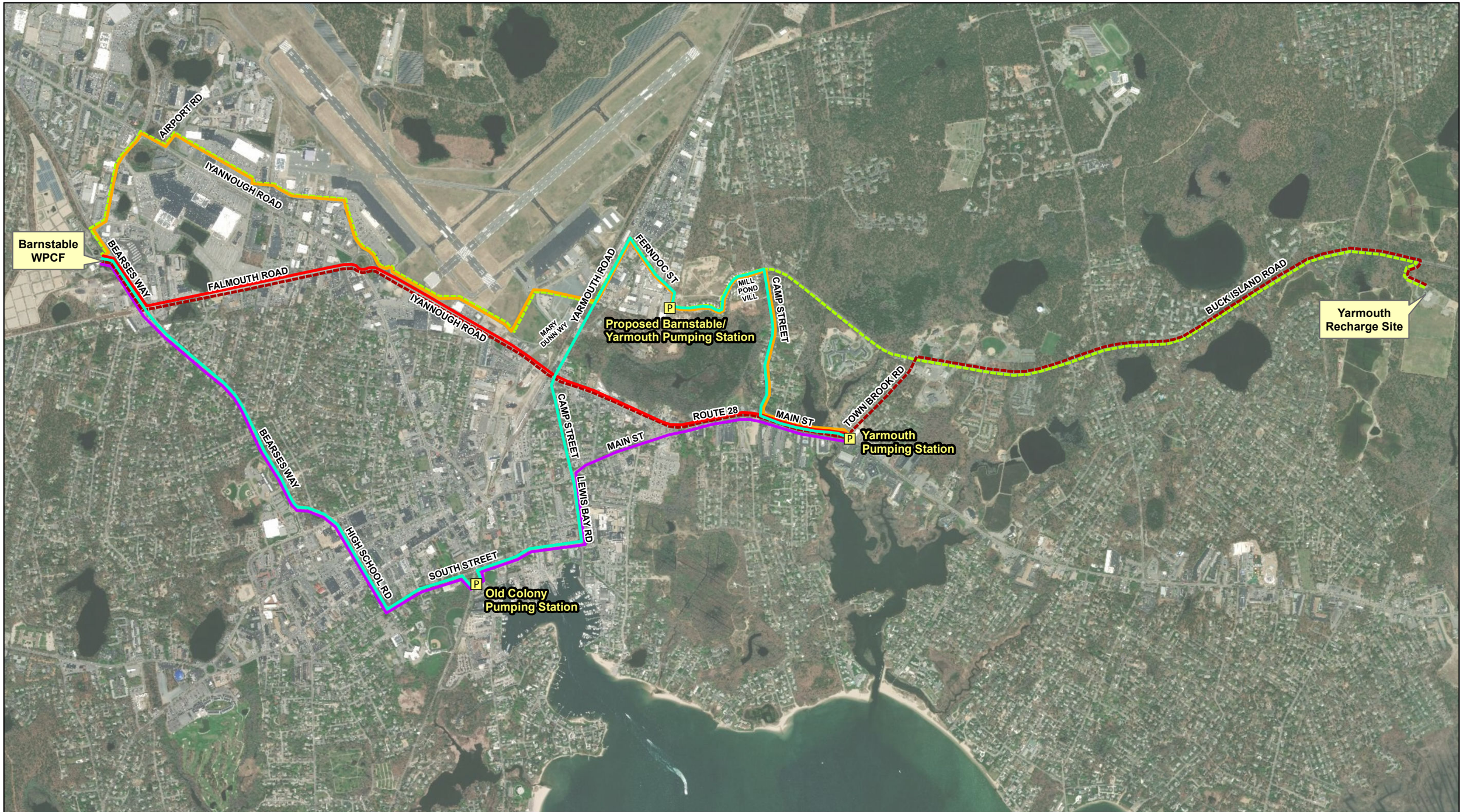
0 1,000 2,000 3,000 Feet

WPCF Route Option 3 and Recharge Route Option 2 - June 2019

Figure 4

CDM Smith

NEWELLJD F:\Yarmouth_MA\Yarmouth_Barnstable_WWTP_Routes_Ortho_Figure4.mxd 6/27/2019



N

Barnstable WPCF/ Recharge Routes

- WPCF Route 1
- WPCF Route 2A
- WPCF Route 2B
- WPCF Route 3
- Recharge Route 1
- Recharge Route 2

Barnstable - Yarmouth, MA

0 1,000 2,000 3,000 Feet

Summary of Options for Wastewater Treatment and Effluent Recharge - June 2019

Figure 5

CDM Smith

NEWELLJD F:\Yarmouth_MA\Yarmouth_Barnstable_WWTP_Routes_Ortho_Figure5.mxd 6/27/2019

Meeting Minutes

05-31-2018	Barnstable-Yarmouth Wastewater Meeting
07-16-2018	Barnstable-Yarmouth Wastewater Meeting
11-02-2018	Barnstable-Yarmouth Wastewater Meeting
11-08-2018	Barnstable-Yarmouth Wastewater Meeting
06-21-2019	Barnstable-Yarmouth Wastewater Meeting

Barnstable - Yarmouth Wastewater Meeting Minutes

Date: 05/31/2018
Time: 2:00 PM
Location: Barnstable DPW
Attendees: Griffin Beaudoin, Andy Boule, Elizabeth Jenkins, Amanda Ruggerio, Dan Santos, Rob Stein (Barnstable)

Rich Bienvenue, Jeff Colby, Kelly Grant, Karl von Hone (Yarmouth)

Kara Johnston, Dave Young (CDM Smith)

1. Grant Overview: Barnstable – Yarmouth Subtasks ($50,000)
2. Wastewater Discussions
    a. Barnstable - Current WWTP and Effluent Recharge Capacity
        i. Current and future flows
        ii. Collection system/pump station capacity for potential Yarmouth tie-in location: embarking on a comprehensive evaluation of pump stations. The will be kicked off next month and the final evaluation report will be issued in the Spring of 2019.
        iii. Flows that would trigger a treatment plant expansion + associated costs of component expansions/upgrades. Barnstable hired a consultant to create a BioWin model of the plant to estimate its treatment capacities. This model is expected to be completed in October 2018. Additionally, Barnstable is working with DEP on a new Permit for the facility which may have bearing on the issue.
    b. Yarmouth – Buck Island Road Effluent Recharge Capacity
    c. Barnstable – Current and Future Flows
    d. West Yarmouth – Anticipated Buildout Flows

MEETING MINUTES

Barnstable – Yarmouth Wastewater

Date: July 16, 2018
Time: 1:30 PM
Location: Town of Barnstable Department of Public Works

Attendees: Griffin Beaudoin, Andy Boule– Town of Barnstable

Jeff Colby – Town of Yarmouth

Kara M. Johnston, David F. Young – CDM Smith

Meeting Summary:

- Buck Island Road Effluent Recharge Site Capacity: 1.2 – 2.0 MGD (Additional testing will be required to reach higher range)
- Hospital ties into Old Colony Pumping Station. Barnstable currently evaluating the station's upgrades needs.
- Mill Pond Affordable Housing in Yarmouth owned by a private developer. Potential to discuss easement on this site with owner for a shared pumping station. Developer wants to add more units.
- Potential Routes between Yarmouth and Barnstable (for wastewater treatment and effluent recharge):
  - Option 1: Route 28 (straight shot)
  - Option 2: Tying into existing collection system and Old Colony Pumping Station (collection system and pumping station would both require upgrades)
  - Option 3: Through Airport and Kmart Plaza (town owned), Route 132, Enterprise Road
- Barnstable to review force main redundancy policy
- Barnstable to review town policy for access at airport for O&M
- CDM Smith to confirm flows from Yarmouth / Lewis Bay area
- Barnstable WWTP:
  - 2 MGD current
  - 2.7 MGD with all of Phase 1
  - Nitrogen: 6-10 ppm
  - Aeration train upgrade may be needed with additional flow from Yarmouth
  - Upgrading solids handling in approximately 5 years. Yarmouth evaluating anaerobic digester at septage facility.
- Triangle Sewer Area – approx. 0.3 MGD at full buildout
- Buck Island – may need a reserve capacity for Yarmouth septage plant + Yarmouth Flow from Yarmouth to Barnstable + Remaining portion of site capacity would be available for Barnstable

- Need to check nitrogen balance if additional sewering would be required in Parkers River for effluent recharge added at Buck Island

Assigned To	Action Item
CDM Smith	Send PDF of Ongoing/Future MassDOT Projects
Barnstable	Send PDF of Barnstable System Map - "Figure 5-2"
Barnstable	Review Town Policy for force main/redundancy
Barnstable	Review Town Policy for airport access/future O&M – any restrictions?
Barnstable	Confirm flow from "triangle sewer area" (current and buildout)
Barnstable	Provide Old Colony Pumping Station capacity information and pipe sizes for collection system requiring upgrades between Yarmouth and WWTP through Old Colony Pumping Station

MEETING MINUTES

Barnstable – Yarmouth Wastewater

Date: November 2, 2018
Location: CDM Smith – Yarmouth Office

Attendees: Jeff Colby – Town of Yarmouth

Kara M. Johnston, David F. Young – CDM Smith

Meeting Summary:

- Review of Scenarios and Options for Barnstable/Yarmouth Wastewater:
  - Option 1 – Direct via Route 28
  - Option 2 – Via Old Colony PS
  - Option 3 – Via Airport Road
  - Scenario 1 – Redundant Sewer Force Main and Effluent Force Main in Barnstable and Yarmouth
  - Scenario 2 – Redundant Sewer Force Main in Barnstable and Yarmouth
  - Scenario 3 – Redundant Sewer Force Main in Barnstable Only

- Timing of Barnstable triangle sewer area?
- P.S. on Route 28 in Barnstable? East Main Street?
- Discussion of sleeves under railroad line
- Schedule meeting with Barnstable to review scenarios and options

MEETING MINUTES

Barnstable – Yarmouth Wastewater

Date: November 8, 2018
Location: Town of Barnstable Department of Public Works

Attendees: Griffin Beaudoin, Andy Boule– Town of Barnstable

Jeff Colby – Town of Yarmouth

Kara M. Johnston, David F. Young – CDM Smith

Meeting Summary:

- Review of Scenarios and Options
  - Option 1 – Direct via Route 28
  - Option 2 – Via Old Colony PS
  - Option 3 – Via Airport Road
  - Scenario 1 – Redundant Sewer Force Main and Effluent Force Main in Barnstable and Yarmouth
  - Scenario 2 – Redundant Sewer Force Main in Barnstable and Yarmouth
  - Scenario 3 – Redundant Sewer Force Main in Barnstable Only

- Discussion of new "Option 2B" where Yarmouth would tie into Barnstable sewer system off of Main Street

Assigned To	Action Item
CDM Smith	Add "Option 2B"

MEETING MINUTES

Barnstable – Yarmouth Wastewater

Date: June 21, 2019

Location: Town of Barnstable Department of Public Works

Attendees: Griffin Beaudoin, Andy Boule, Rob Steen– Town of Barnstable
Jeff Colby – Town of Yarmouth
Kara Johnston, David Young – CDM Smith

Meeting Summary:

- Discussion of comments from Town of Barnstable:
  - Remove potential cost allocations from tables– to be discussed by community leaders at a later date.
  - Effluent pipe redundancy is important for Barnstable since effluent that would be sent to Yarmouth could not be recharged at other sites in Barnstable in the event of a force main break. However, CDM Smith suggested that like a water main repair effluent force main could be fixed fairly quickly.
  - The draft memo will be updated to reflect these comments, and others discussed during 6/21/2019 meeting.
- Grant Update:
  - The Efficiency and Regionalization Grant previously obtained by the Town of Yarmouth has been closed out. A draft of the Barnstable-Yarmouth Memo was sent to the agency, but memo is still a working document and has not been finalized.
  - The Town of Harwich obtained an additional grant on behalf of the four towns through the MA Best Practices Grant Program. $40,000 for DHY and $10,000 for Barnstable-Yarmouth.
- Review of Route Options:
  - Option 1: Revised "direct route" along Route 28.
  - Option 2A: Old Colony Pumping Station is no longer a preferred route for Barnstable. CDM Smith will add language in memo to further explain. High flows to the station currently, and potential for future hospital expansion.
  - Option 2B: Old Colony Pumping Station is no longer a preferred route for Barnstable. CDM Smith will add language in memo to further explain. High flows to the station currently, and potential for future hospital expansion.
  - Option 3: Revise to avoid Route 28 altogether. Griffin will send preferred route to Airport Road (received 6-26-19).
- Cost Allocation Discussion:
  - Remove reference to cost allocation between communities in the tables. Change to percentage flow proportions instead.
  - Future cost allocations would be discussed and negotiated at a later date.

- Redundancy Scenarios Discussion:
  - Scenario 1 includes full redundancy of sewer and effluent force mains.
  - Scenario 2 includes redundancy of sewer force mains, and not of effluent force main.
  - Scenario 3 will be removed from the memo (effluent force main redundant in Barnstable, and not in Yarmouth).
  - Additional language will be added to memo to describe Barnstable's preference for redundancy of effluent force main. In the event of a force main break, Barnstable expressed concern they would not be able to recharge the Barnstable/Yarmouth effluent in town. However, CDM Smith suggested that like a water main repair effluent force main could be fixed fairly quickly.
- Discussion of recharge at the Buck Island Road Recharge Site and nitrogen loading in the Parkers River Watershed:
  - At Total Nitrogen level of 3 mg/l WPCF discharge, the Buck Island Road Recharge Site can accept 1.2 MGD.
  - The potential capacity at the Buck Island Road Recharge Site at 6 mg/l of Total Nitrogen at WPCF discharge was further evaluated by CDM Smith after the meeting on 06/21/2019. With the assumption of additional nitrogen removal by a permeable reactive barrier (PRB), the Buck Island Road Recharge capacity at 6mg/l Total Nitrogen is estimated to be 870,000 gpd. Revisions will be made to the memo to reflect the assumptions associated with this calculation. The recharge at 3mg/l Total Nitrogen is 1.2 mgd.
  - CDM Smith will revise memo to discuss Barnstable's current max day permit level of 10 mg/l Total Nitrogenas.
  - Barnstable has discussed denitrification filters at the WPCF, but is still evaluating.
- Review of Griffin's comment email from 5/29/2019:
  - *Barnstable Question 1:* "As noted, WPCF cannot currently treat to 3 mg/L. The average daily TN from WPCF is 6 mg/L. At 6 mg/L, what is the disposal capacity of the Buck Island disposal site?"
  - *Response 1:* A paragraph has been added to Section 5 of the Memo to discuss this in more detail. Further edits will be made in the memo to discuss the potential capacity at the Buck Island Road Recharge Site with additional nitrogen removal from a PRB.
  - *Barnstable Question 2:* "Cost allocation assumptions should be removed. Total project costs should be presented. Cost allocation is an item that would be negotiated at a later date."
  - *Response 2:* Cost allocations will be removed from the memo. A percent of "flow proportion" will be shown in its place.
  - *Barnstable Question 3:* "The Route 28 scenario ("straight shot") discussed at the 7/16/18 meeting is not reflected as a wastewater conveyance scenario. This scenario should be included in the analysis."
  - *Response 3:* Route Option 1 has been revised to include this scenario.
  - *Barnstable Question 4:* "Redundancy Scenario 3: A redundant force main in one town only is an operational issue. Suggest removing this scenario and replacing with a redundancy scenario analyzing redundant effluent force mains only instead. If a single effluent force main were to be damaged, there would be no option for disposal above the permitted capacity of the WPCF beds."

- *Response 4:* Redundancy Scenario 3 will be removed from the memo. Scenario 1 includes sewer and effluent force main redundancy. As discussed at previous meetings, the costs will be shown for redundant sewer and single effluent force main. Additional language will be added to the memo to describe Barnstable's desire for redundant force main to the effluent recharge site since there is no other available recharge locations within Barnstable for that flow if the pipe couldn't be fixed quickly.
- *Barnstable Question 5:* "Is the cost of the proposed Barnstable / Yarmouth Pumping Station included in the cost estimates?"
- *Response 5:* Yes
- *Barnstable Question 6:* "Utilizing Old Colony Pump Station is not our preferred scenario at this time."
- *Response 6:* Further language has been added to the memo Summary Section 7 to describe this.
- Barnstable Question 7: "The wastewater and effluent force mains should follow the same routes under the recommended scenario."
- *Response 7:* Route Option 3 will be revised to avoid Route 28.
- *Barnstable Question 8:* "WPCF's nitrogen permit level is not 6 mg/L as suggested. The permit level is 10 mg/L. The nitrogen mass load is based upon an average of 6 mg/L at 2.7 MGD."
- *Response 8:* Language revised to match Barnstable's permit. 10 mg/L max day permit level for Total Nitrogen to be added to the memo as well.
- *Barnstable Question 9:* Recommend modifying the Potential Routes figure as it is difficult to follow.
- *Response 9:* Separate figures created for each route option.

▪ CDM Smith will revise memo and send to the group for further comments.

Assigned To	Action Item
CDM Smith	Remove reference to potential cost allocations and show flow proportions as percentages
Griffin Beaudoin	Send preferred route through Airport Road
CDM Smith	Revise Route Option 3 with revised Airport Road access (text and figures)
CDM Smith	Remove Redundancy Scenario 3
CDM Smith	Add "10 mg/l max day Total Nitrogen Permit Level" to memo
CDM Smith	Add language on Old Colony Pumping Station as no longer being a feasible route
CDM Smith	Revise memo and send to group for further comments
CDM Smith	Send 6/21/2019 meeting minutes to the group for comment

Appendix KK

JBCC Wastewater Evaluation, December 2014

JOINT BASE CAPE COD
WATER AND WASTEWATER SYSTEM EVALUATION

for the

Massachusetts Development Finance Agency

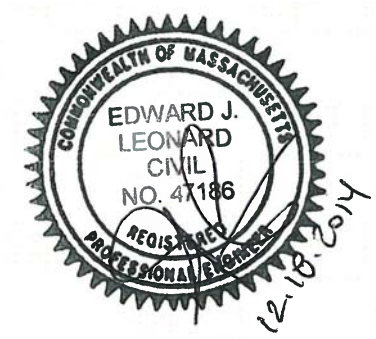
December 2014

WRIGHT-PIERCE
Engineering a Better Environment

In association with Water Resources Associates

JOINT BASE CAPE COD
WATER AND WASTEWATER SYSTEM EVALUATION
for the
Massachusetts Development Finance Agency

December 2014



Prepared By:
Wright-Pierce
Andover, MA

In association with:
Water Resources Associates
Osterville, MA

JBCC WATER AND WASTEWATER SYSTEM EVALUATION

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APPENDIX D	MATERIALS SUPPORTING WATER SYSTEM ANALYSIS

1 EXECUTIVE SUMMARY

1.1 BACKGROUND

Joint Base Cape Cod (JBCC) has a wastewater collection, treatment and disposal system which provides service to the cantonment area on the base. The JBCC wastewater system is owned by the United States Air Force (USAF) and is operated by the Massachusetts Air National Guard (ANG) and serves approximately 3,500 users.

The JBCC collection system includes 11 pumping stations and approximately 36 miles of sewers. The collection system was constructed between the 1940s and the present. The current wastewater treatment facility (WWTF) is an extended aeration activated sludge facility with biological nitrogen removal and disinfection. The WWTF was constructed in 1996 and is located at the southeast edge of JBCC. WWTF effluent is pumped approximately 11 miles to a rapid infiltration basin (RIB) disposal system located at the northwest edge of JBCC. The locations of the wastewater system components are shown on **Figure ES-1**.

WWTF effluent must meet standards set forth in state water quality regulations. The WWTF effluent quality requirements are contained in a Groundwater Discharge Permit (GWDP) which is issued by the Massachusetts Department of Environmental Protection (DEP). The JBCC wastewater system is permitted to discharge an annual average flow of 360,000 gpd to the rapid infiltration basins. Current effluent flows are approximately 130,000 gpd and, therefore, unused treatment and disposal capacity is available.

JBCC also has a water production, treatment and distribution system which is owned by the USAF and operated by the ANG. The JBCC water system consists of two elevated water storage tanks and approximately 49 miles of buried water distribution mains. Water is supplied to the system from two sources: a gravel-packed well owned and operated by the JBCC (referred to as the "J-Well"); and a metered interconnection from the Upper Cape Regional Water Supply Cooperative (UCRWSC). The locations of the water system components are shown on **Figure ES-2**.

FIGURE ES-1
JBCC WASTEWATER SYSTEM

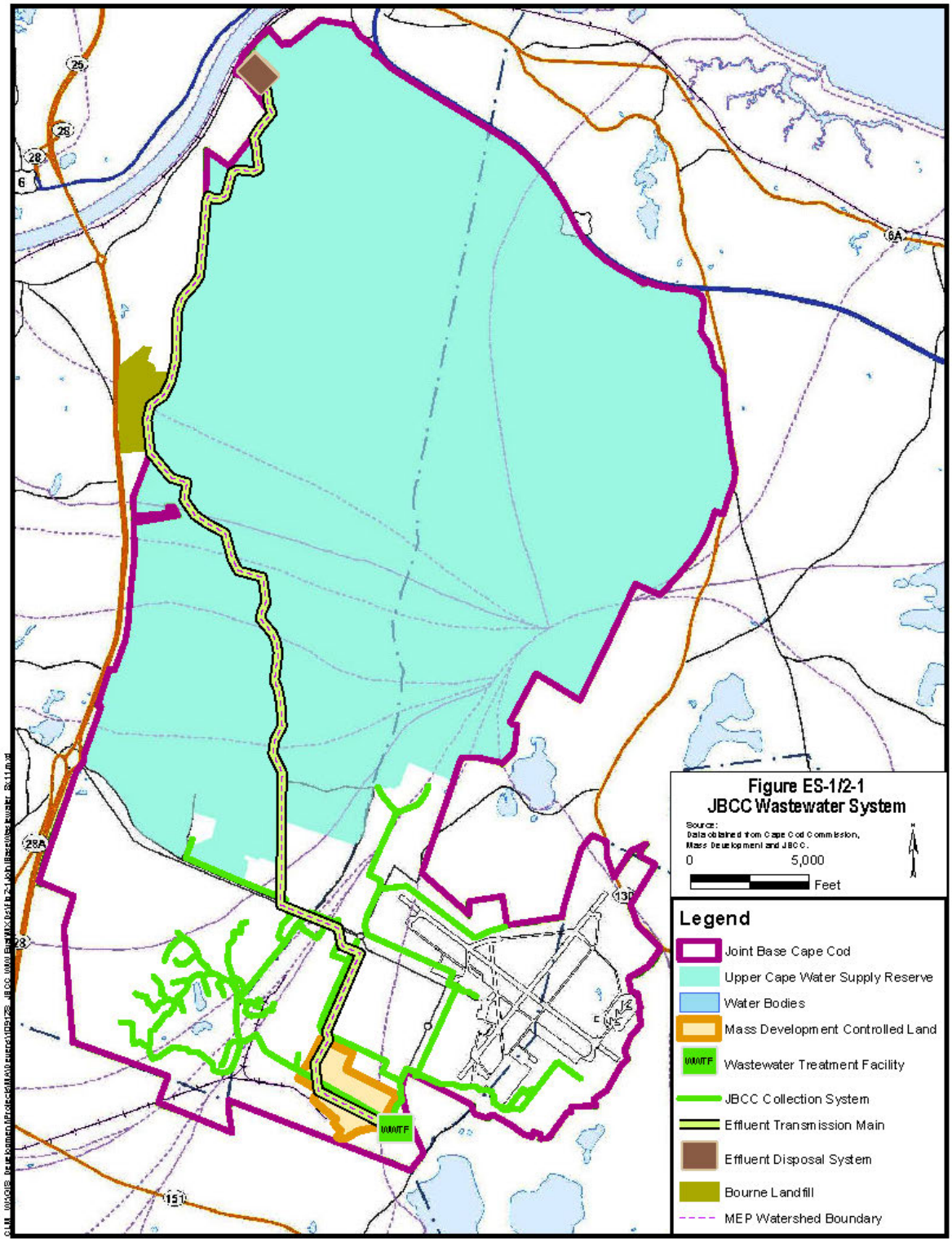
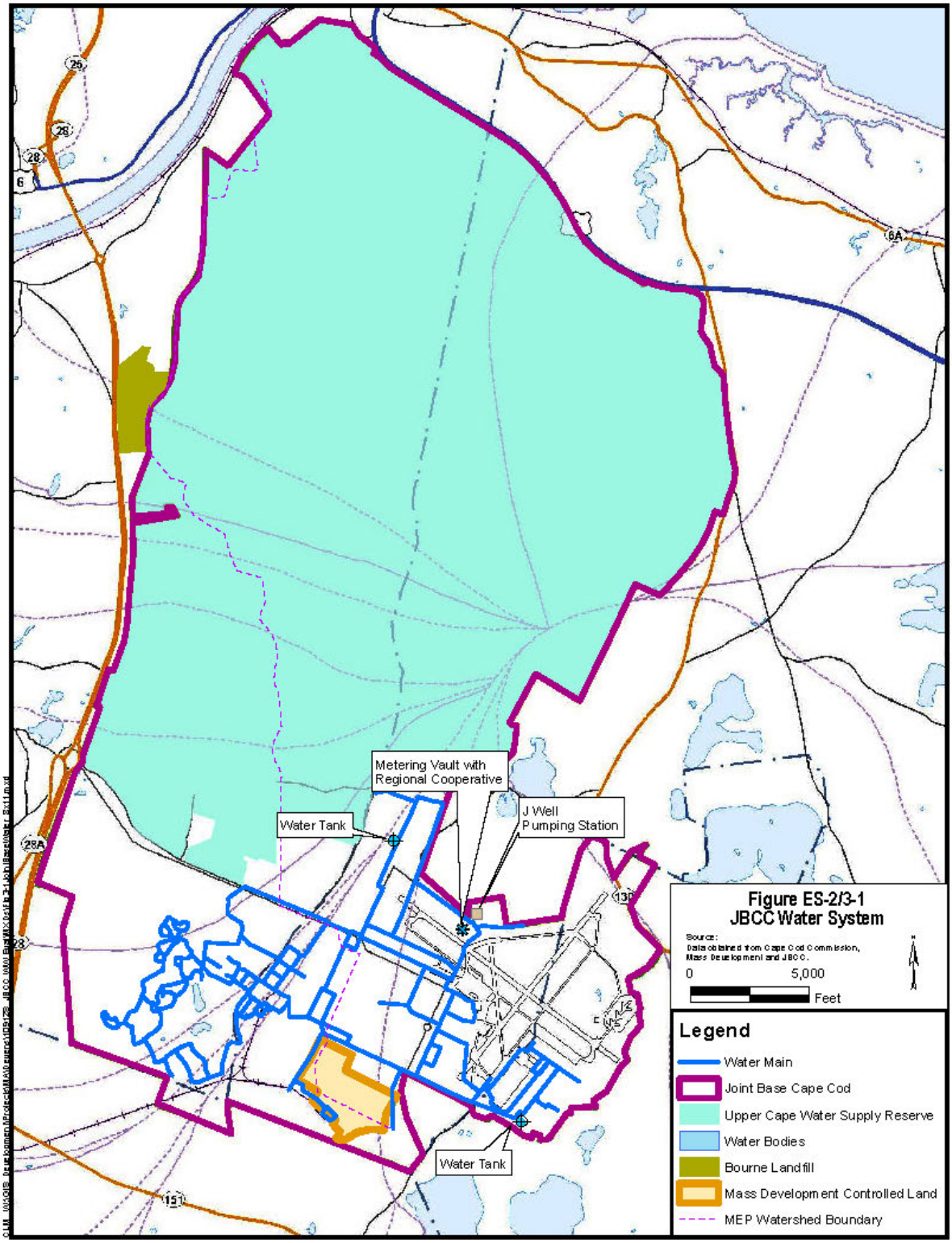


FIGURE ES-2
JBCC WATER SYSTEM



The Massachusetts Development Finance Agency (MassDevelopment) has been asked by the USAF and ANG to consider taking over the ownership and operation of the JBCC wastewater and water systems. Accordingly, MassDevelopment is interested in developing a full understanding of the financial implications and feasibility of ownership and management of the wastewater facilities and in developing a preliminary business case that evaluates the full range of cost and revenue options.

1.2 PROJECT PREMISE

1.2.1. Wastewater System

The primary purposes of this evaluation are to: develop an understanding of existing conditions; determine the financial implications of take-over; and position MassDevelopment for negotiations with the USAF and ANG. If MassDevelopment were to take over the wastewater system, it has two stated goals: provide for "military preservation" through rate stabilization; and provide service for other regional users. The JBCC is ideally suited for a potential regional use of the wastewater system by neighboring towns that could benefit the business case evaluation in a positive manner. We have identified the following potential alternatives for the wastewater system which should be evaluated:

1. **Existing WWTF with Minimal Capital Upgrades**

   This alternative will consist of utilizing the existing capacity to increase revenues and customer base by adding users for sewage (i.e., sanitary wastewater received by way of dedicated sanitary sewers), septage (i.e., trucked waste removed from residential and commercial septic tanks) and/or effluent disposal (i.e., treated wastewater from a separate wastewater treatment facility conveyed to the existing JBCC effluent disposal system). This alternative will explore "minimal capital upgrades".

2. **Existing WWTF with Moderate Capital Upgrades to Expand Capacity**

   This alternative will consist of a 50% capacity expansion to WWTF and RIBs while remaining in the existing fence lines. This alternative will involve more significant capital upgrades than Alternative 1 but will allow for greater revenues.

3. **New Regional WWTF**

   This alternative would consist of an "order of magnitude expansion" (i.e., 12 times the existing capacity) or replacement of the WWTF as outlined in the 2012 CH2M-Hill report.

4. **New Regional WWTF with Energy and/or Nutrient Recovery Capabilities**

   This alternative would expand upon Alternative 3 to include regional biosolids composting, regional energy recovery related to regional food waste (source separated organics) and/or regional nutrient recovery related to regional urine collection. These enhancements are consistent with the opportunities identified in the Cape Cod Commission's 2013 Joint Land Use Study Update report and 2014 Draft 208 Cape Cod Area-Wide Water Quality Management Plan.

The scope of our current project for the wastewater system (Delivery Order #12) includes only Alternative 1 and Alternative 2, as described above. We have structured our work so it can be expanded to address Alternatives 3 and 4 later.

1.2.2. Water System

If MassDevelopment were to take over the water system, it has one primary goal – provide for military preservation through rate stabilization. The JBCC water system could also represent a regional use opportunity; however, this is perhaps less likely than for the wastewater system. The scope of our current project for the water system (Delivery Order #11) includes evaluation of the system under a "status quo" arrangement (i.e., take ownership and operate the system as it is today, including the storage tanks, the J-well and the UCRWSC interconnection).

1.3 REPORT ORGANIZATION

This report is divided into the following sections: 1) Executive Summary; 2) Wastewater System; 3) Business Case Analysis for Wastewater Alternatives; 4) Assessment and Management of Risks; 5) Water System; 6) Conclusions and Recommendations; and 7) References. A list of commonly used acronyms and abbreviations is provided in **Table ES-1**.

TABLE ES-1
LIST OF COMMONLY USED ACRONYMS AND ABBREVIATIONS

ACEC	Area of Critical Environmental Concern
ANG	Air National Guard, Massachusetts (102nd Intelligence Wing)
BOD_5	Biochemical Oxygen Demand
CCC	Cape Cod Commission
Current	Covering the dates 2009 to 2013, applied to population, wastewater flow or nitrogen load conditions
CWMP	Comprehensive Wastewater Management Plan
D/B/O	Design/Build/Operate contract delivery method
DEIR	Draft Environmental Impact Report
DEP	Department of Environmental Protection (Massachusetts)
DRI	Developments of Regional Impact
EIR	Environmental Impact Report
EENF	Expanded Environmental Notification Form
EOEEA	Executive Office of Energy and Environmental Affairs (Massachusetts)
ESA	Environmentally Sensitive Area
FEIR	Final Environmental Impact Report
Future	Referring to population, wastewater flows or nitrogen loads, expected in the future
GIS	Geographic Information System
gpd	Gallons Per Day
gpd/sf	Gallons Per Day Per Square Foot
I/I	Infiltration and Inflow
ISO	Insurance Services Organization
HCF	Hundred Cubic Feet
Hp	Horsepower
JBCC	Joint Base Cape Cod (aka Massachusetts Military Reservations, Otis Air Force Base)
kg/day	Kilograms Per Day
kgal	Thousand Gallons
lb/yr	Pounds Per Year
MEP	Massachusetts Estuaries Project
MCL	Maximum Contaminant Level
MEPA	Massachusetts Environmental Policy Act
Mgal	Million gallons
Mgal/yr	Million gallons per year
mgd	Million gallons per day
mg/l	Milligrams per liter
MOU	Memorandum of Understanding
NHESP	Natural Heritage and Endangered Species Program
NPV	Net Present Value
O&M	Operations and Maintenance
RIB	Rapid Infiltration Basins
SCADA	Supervisory Control and Data Acquisition system (computer control system)
SEIR	Single Environmental Impact Report
SMAST	School of Marine Science and Technology, University of Massachusetts at Dartmouth
SRF	State Revolving Fund (administered by Massachusetts Department of Environmental Protection)
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TSS	Total Suspended Solids
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
USGS	United States Geologic Survey
VFD	Variable Frequency Drive
VOC	Volatile Organic Compound
WWTF	Wastewater Treatment Facility

2 WASTEWATER SYSTEM

2.1 INTRODUCTION

This section of the report describes the existing wastewater system and summarizes current wastewater flows and loadings, compliance history, staffing levels, and condition assessment for the JBCC wastewater system. This section of the report also summarizes potential future flows and loadings, as well as the alternatives analysis and costs for potential wastewater system upgrades.

2.2 CURRENT CONDITIONS

2.2.1. Wastewater Flows and Loads

The wastewater flows and loads for the period 2008 to 2012 are summarized in **Table 2-1** (CH2M-Hill, 2012). We also requested and received data for the period January 2012 to April 2014. These data are also summarized in **Table 2-1**. Based on this information, the WWTF is operating at just under 50% of its design capacity. **Figure 2-1** and **Figure 2-2** show daily effluent flows and daily effluent nitrogen concentrations, respectively.

2.2.2. Overall System

The existing JBCC wastewater system provides service for on-base facilities. It is currently owned by the United States Air Force (USAF) and is currently operated and maintained by the Massachusetts Air National Guard 102nd Intelligence Wing (ANG). The major components of the existing wastewater treatment system are summarized in **Table 2-2**. A detailed listing of the system components is provided in Appendix A of the 2012 CH2M-Hill report.

The WWTF and all of the collection system are located within the Cantonment Area, which comprises 25% of JBCC. Most of the effluent forcemain and the entire effluent disposal system are located in the Upper Cape Water Supply Reserve, which comprises the northerly 75% of JBCC. The existing JBCC wastewater system is shown on **Figure ES-1**.

TABLE 2-1
CURRENT WWTF FLOWS AND LOADINGS

Parameter	Condition	Design Rating	Permit Value	Current 2008 to 2012	Current 2012 to 2014
Flow (gpd)	Annual Average	300,000	360,000 (1)	143,000	131,000
	Maximum Month	430,000	-	248,500	210,000
	Maximum Day	800,000	840,000	555,600	390,000
	Peak Hourly	1,380,000	-	-	-
BOD Load (lb/day)	Annual Average	690	-	337	-
	Maximum Month	990	-	548	-
	Maximum Week	1840	-	948	-
TSS Load (lb/day)	Annual Average	550	-	272	-
	Maximum Month	790	-	453	-
	Maximum Week	1470	-	884	-
TKN Load (lb/day)	Annual Average	125	-	60	-
	Maximum Month	180	-	104	-
	Maximum Week	335	-	233	-
Ammonia Load (lb/day)	Annual Average	90	-	43	-
	Maximum Month	125	-	76	-
	Maximum Week	235	-	163	-

Note: 1) 12-month rolling average daily flow.

TABLE 2-2
WASTEWATER SYSTEM COMPONENTS

Component	Quantity
Collection & Conveyance	161,000 linear feet sewers, 595 manholes
Pump Stations	11
Wastewater Treatment Facility	300,000 gpd (design); 360,000 gpd (permit)
Effluent Forcemain	55,280 linear feet
Rapid Infiltration Disposal Beds (RIBs)	4 cells, 6 acres
Monitoring Wells (for RIBs):	7
Composting Facilities (abandoned)	25,290 square feet

FIGURE 2-1
JBCC WWTF EFFLUENT FLOW

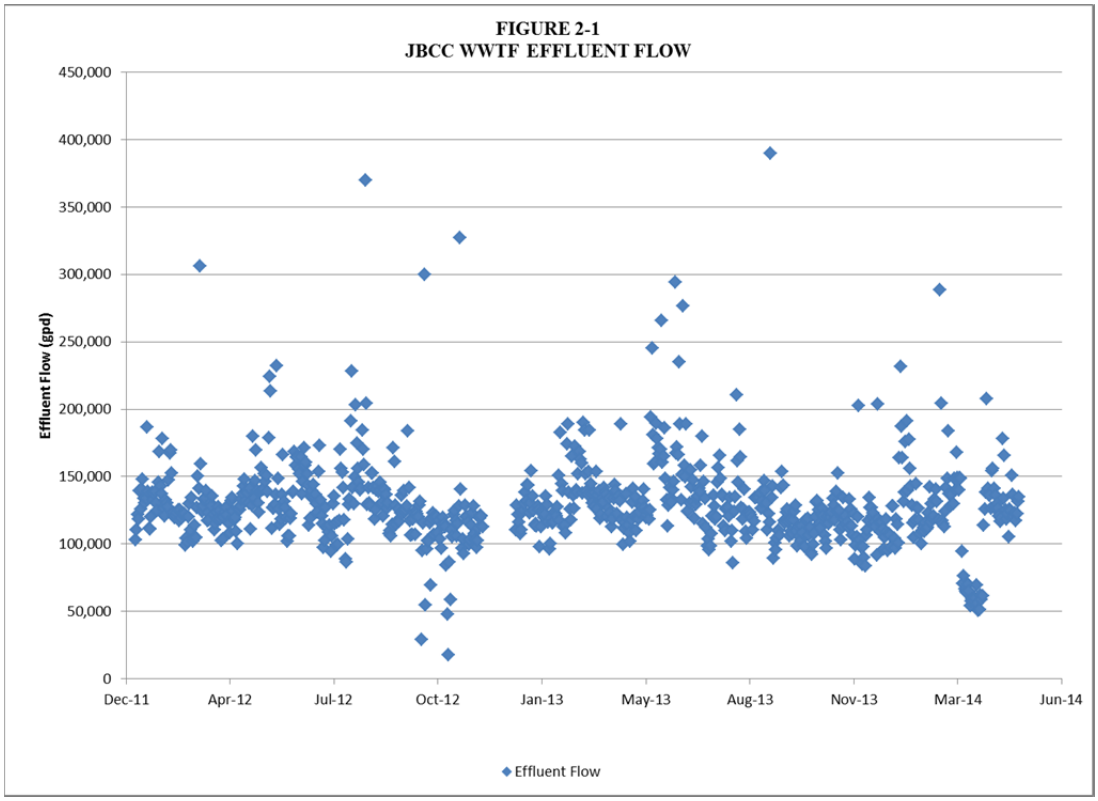
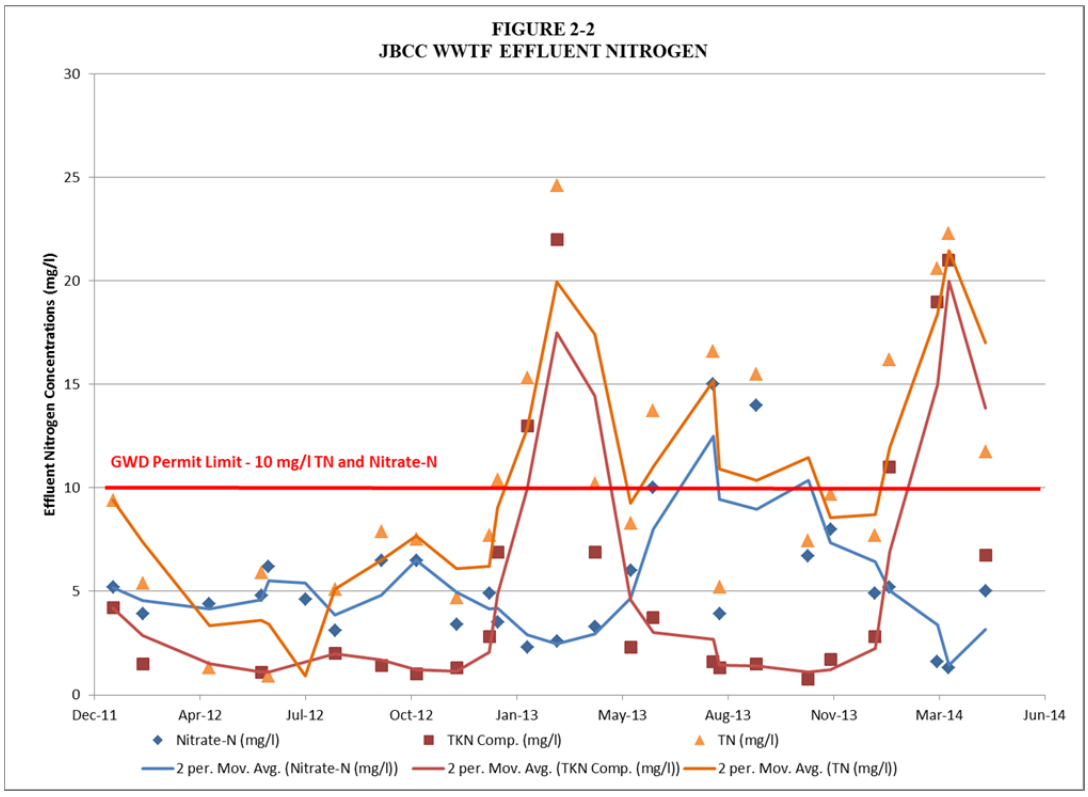
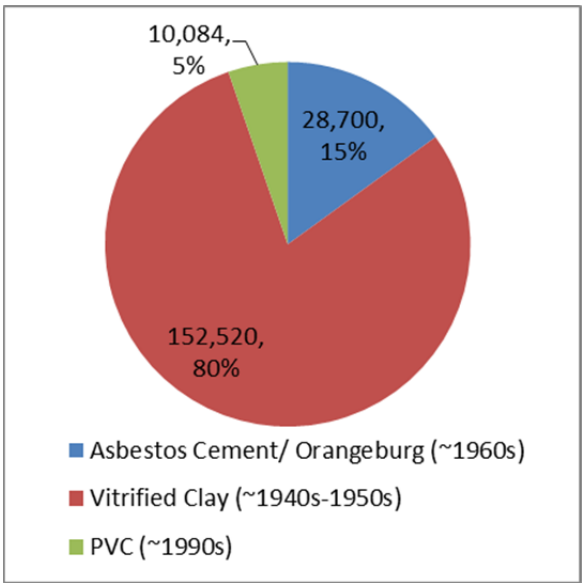


FIGURE 2-2
JBCC WWTF EFFLUENT NITROGEN



2.2.3. Collection System

The collection system was built when there were 70,000 users on-site; whereas, there are currently approximately 3,500 users (JBCC Base Population Survey, 2009). The collection system includes approximately 36 miles of sewers ranging in size from 6-inch to 24-inch diameter including several pipe materials. The asbestos cement and orangeburg pipe materials will exceed their design lives in the next 10 years. A summary of the pipe types and lengths is provided in the inset figure.



Length of Pipe (feet)

2.2.4. Wastewater Treatment Facility

The WWTF is an extended aeration activated sludge facility (biological nitrogen removal) with disinfection that was constructed in 1996. The WWTF design capacity is 300,000 gpd (annual average) with a design maximum day flow of 800,000 gpd.

Major unit processes at the WWTF include:

- Preliminary Treatment (screening and grit removal)
- Advanced secondary treatment (biological nutrient removal)
- Disinfection
- Effluent Pumping
- Sludge Holding and Aeration
- Sludge Decanting
- Biosolids hauling (for off-site processing and disposal)

The WWTF equipment is in good condition; however, upgrades will be needed to address regulatory compliance issues as well as to maintain existing reliability.

2.2.5. Effluent Forcemain

The existing effluent forcemain is a 12-inch diameter ductile iron pipe that runs from the WWTF, through the Reserve, to the Rapid Infiltration Basins. The forcemain is shown on the design drawings entitled "Effluent Forcemain and Infiltration Basins" (CDM/SAIC, 1993). The forcemain is hydraulically complex and has approximately 20 air and/or vacuum relief valves. The operators reported capacity limitations when more than one effluent pump is running (i.e., overflow at the static head manhole located at Frank Perkins Road, near pipeline station 245+00, about 45% of the way from the WWTF to the RIBs). This situation requires further evaluation.

2.2.6. Rapid Infiltration Basins

The existing effluent disposal facility consists of four rapid infiltration basins (RIBs), with a total surface area of 259,160 square feet. The RIBs were constructed on the basis of design drawings entitled "Effluent Forcemain and Infiltration Basins" (CDM/SAIC, 1993) as well as a *Hydrogeologic Investigation and Design Effluent Infiltration Basins* technical memorandum (CDM/SAIC, 1993). The operators reported that the RIBs work very well and the only significant concern is the vegetation growth with the RIBs. As described later in this section, inflow in the collection system limits the available effluent disposal capacity. This situation warrants further evaluation and potentially re-rating of the RIBs.

2.2.7. Groundwater Discharge Permit Requirements

The WWTF effluent quality requirements are contained in a Groundwater Discharge Permit (GWDP) which is issued by the Massachusetts Department of Environmental Protection (DEP). The GWDP (Application/Permit No. 41-3) allows for disposal of suitable quality effluent up to 360,000 gpd on a 12-month rolling average basis and up to a maximum of 840,000 gpd on any given day (so-called "maximum day flow"). It is important to note that disposal capacity provided under the GWDP is greater than the design capacity indicated in WWTF design documentation. The GWDP is included in Appendix A and its requirements for the WWTF effluent are summarized in **Table 2-3**. The GWDP requirements for groundwater monitoring at the RIB site are summarized in **Table 2-4**.

TABLE 2-3
WWTF EFFLUENT LIMITS AND MONITORING REQUIREMENTS

Parameter	Discharge Limitation	Minimum Frequency
Flow, 12-month moving average	360,000 gpd	Daily
Flow, maximum day	840,000 gpd	Daily
Oil and grease	15 mg/l	Monthly
Total Suspended Solids (TSS)	30 mg/l	Monthly
Total Nitrogen (NO2-N + NO3-N + TKN)	10 mg/l	Monthly
Nitrate-Nitrogen (NO3-N)	10 mg/l	Monthly
Biochemical Oxygen Demand, 5-day at 20°C (BOD_5)	30 mg/l	Monthly
Fecal Coliform	200 colonies/ 100 ml	Monthly
pH	6.5 to 8.5	Daily
Total Solids	Report	Monthly
Total Phosphorus (as P)	Report	Monthly
Orthophosphate (as P)	Report	Monthly
Volatile Organic Compounds	Report	Monthly

TABLE 2-4
GROUNDWATER MONITORING REQUIREMENTS

Parameter	Discharge Limitation	Minimum Frequency
Static Water Level	Report	Monthly
Specific Conductance	Report	Monthly
pH	Report	Monthly
Total Nitrogen (NO2-N + NO3-N + TKN)	Report	Quarterly
Nitrate-Nitrogen (NO3-N)	Report	Quarterly
Total Phosphorus (as P)	Report	Quarterly
Orthophosphate (as P)	Report	Quarterly
Volatile Organic Compounds	Report	Quarterly

2.2.8. Compliance History

During our site tour on June 4, 2014, the WWTF operators identified some operational concerns related to highly variable influent flows (due to base activities), inflow-related wet weather peak flows, and winter denitrification. A review of the current data provided by JBCC indicates that GWDP limits for nitrate and/or total nitrogen were exceeded in 11 of the last 27 months between January 2012 and April 2014. Capital improvements are warranted to improve performance.

2.2.9. Staffing

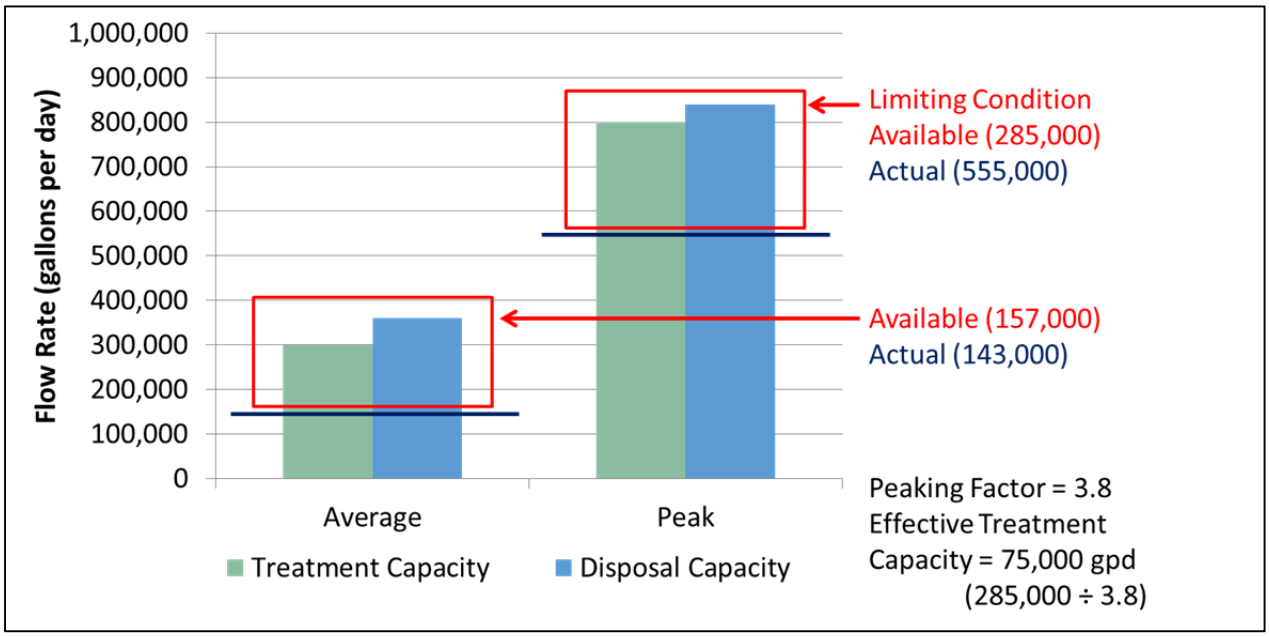
The GWDP permit rates the WWTF as a Grade 5 facility in accordance with 257 CMR 2.00 and requires that the existing WWTF be overseen by a Grade 5 (or higher) operator with a backup Grade 5 operator available. JBCC reported that there are 5 operators that are shared between the water and wastewater systems. Based on our initial assessment, this appears appropriate for the WWTF and the water wells but appears to be understaffed for the wastewater collection system and the water distribution system.

2.2.10. Estimate of Existing Available Capacity

Based on the WWTF design capacity and the 2008 to 2012 flows and loads, the WWTF has approximately **157,000 gpd (annual average)** of residual capacity which can be made available to neighboring communities or users on the base.

On an annual average basis, the effluent disposal system has approximately 157,000 gpd of additional capacity. On a peak day basis (due to the impacts of inflow), the effluent disposal system has approximately 285,000 gpd of additional capacity. Given that the existing peaking factor for peak to average flows is 3.8:1 (again, due primarily to the impacts of inflow), the *effective capacity* is approximately **75,000 gpd (annual average basis)**. It is important to note this *effective capacity* is less than that available at the WWTF. Without inflow control, available treatment capacity will go unused due to the limitations inherent in the GWDP. The capacity and effective capacity is illustrated on **Figure 2-3**.

FIGURE 2-3
ESTIMATE OF EXISTING AVAILABLE CAPACITY



This existing available capacity can be made available to neighboring communities or to new users which may be located on JBCC. From a potential revenue perspective, it is very important to maximize the available capacity. This available capacity can be maximized by one or more of the following methods:

- Aggressively investigating and removing collection system inflow sources;
- Securing customers with low wastewater flow "peaking factors" (i.e., customers with a peak flow that is similar to the average flow);
- Providing influent flow equalization at the WWTF;
- Addressing the effluent forcemain capacity limitation; and/or
- Increasing the capacity of the RIBs by re-rating the site and revising the GWDP with DEP review and approval.

2.3 FUTURE CONDITIONS

The 2012 CH2M-Hill report identified future flows from various military users as well as adjacent municipalities. This section summarizes the future flows used in this analysis.

2.3.1. Future Flows for Existing Users (Sewage)

There are 10 military and non-military users on the existing system with an estimated wastewater flow of 140,000 gpd (CH2M-Hill, 2012). Future flow from military and non-military users was estimated to be 7,000 gpd (CH2M-Hill, 2012). This future flow was utilized herein.

2.3.2. Future Flows for MassDevelopment (Sewage)

MassDevelopment indicated that it has the ability to develop up to 250 acres of land at the southern end of JBCC (in the vicinity of the WWTF) and has provided development goals for this land as follows: Warehousing/Storage Facility – estimated 24 employees (daytime only), located near the WWTF; and Cape Cod Community College Extension Facility – estimated 35 students and faculty (daytime only), located near the airfield and fire station. Based on Title 5 (310 CMR 15.203), this amounts to approximately 880 gpd (i.e., 15 gpd/person for Warehouse/ Dry Storage Space without Cafeteria as well as 15 gpd/person for Secondary/Middle School with cafeteria but no gymnasium or showers). It was agreed that an allowance of 5,000 gpd for MassDevelopment would be used in the analysis moving forward.

2.3.3. Future Flows for Neighboring Municipalities (Sewage)

Neighboring municipalities identified the following wastewater management needs (annual average flows) which could potentially be served by JBCC (CH2M-Hill, 2012):

- Bourne: If capacity were available, potential future flows to JBCC – 1,836,000 gpd.
- Sandwich: If capacity were available, potential future flows to JBCC – 1,080,000 gpd.
- Mashpee: If capacity were available, potential future flows to JBCC – 816,000 gpd.

Bourne and Sandwich have not completed additional wastewater management planning since 2012; however, Mashpee has refined its wastewater management planning. Mashpee is currently projecting potential future flows to JBCC at 200,000 gpd (GHD, 2014). Wastewater flows from

Mashpee should be considered in the near-term future of the JBCC wastewater system; whereas, wastewater flows from Bourne and Sandwich should be considered in the longer-term future given the status of their respectively planning efforts.

2.3.4. Future Flows for Regional Septage

Septage is trucked waste which is periodically removed from residential and commercial septic tanks. There have been several previous estimates of septage volumes produced on Cape Cod, both at present and in the future. As a part of this evaluation, we updated estimates of current and future septage volumes. These prior and current estimates are summarized in **Table 2-5**.

Currently about 8 Mgal/yr is received at the Falmouth WWTF, and perhaps 5 to 10 Mgal/yr is hauled off-Cape. Falmouth may benefit from sending its septage to JBCC, because it would reduce the effluent nitrogen loading to West Falmouth Harbor (by the equivalent of 20,000 gpd at the typical effluent nitrogen concentration of 3 to 4 mg/l) and make capacity available for influent flows from areas of Falmouth needing sewers.

Based on this evaluation, we recommend that the financial planning for JBCC wastewater facilities consider the potential receipt of up to 20 to 25 Mgal/yr of septage (as well as sludge from small-scale, satellite wastewater treatment plants with current revenue of up to $2.0 to $2.5 million per year.

TABLE 2-5
ESTIMATES OF REGIONAL SEPTAGE VOLUMES

Study	Estimate of Current Annual Septage Volumes	Estimate of Future Annual Septage Volumes
Tri-Town Facility Evaluation Wright-Pierce, 2005	59 Mgal	87 to 89 Mgal
Orleans CWMP Wright-Pierce, 2010	54 Mgal	-
Regional Wastewater Mgmt Plan Cape Cod Commission, 2012	-	53 to 78 Mgal
JBCC Evaluation, Wright-Pierce, 2014 Total (See Note 1) Less than 10 miles to JBCC Less than 15 miles to JBCC	 50 to 65 Mgal 14 to 18 Mgal (28%) 18 to 23 Mgal (36%)	 30 to 40 Mgal 8 to 12 Mgal (28%) 10 to 14 Mgal (36%)

Notes:
1) Estimates exclude the 1 to 2 Mgal/year from the 50 satellite WWTFs on Cape Cod, 22 of which are in Bourne, Falmouth, Sandwich and Mashpee. Estimates exclude grease volumes.

2.3.5. Future Flows for Effluent Disposal

Two municipalities have expressed interest in discharging effluent to the JBCC disposal system (i.e., connecting to the effluent forcemain and not to the WWTF). Each is summarized below.

- Bourne has expressed interest in discharging treated landfill leachate. Currently Bourne collects the leachate in a holding tank and trucks it off-Cape for treatment and disposal. Published reports indicate that the annual volume hauled by Bourne has varied from 6.0 to 16.0 Mgal/year (Joyce Engineering, 2009; Commonwealth Resource Management Corporation, 2011). The preliminary proposal is for Bourne to construct a treatment facility and connect to the JBCC effluent forcemain at an average daily flow rate of 40,000 gpd (14.6 Mgal/year) (CH2M-Hill, 2012).
- Falmouth has expressed interest in discharging treated municipal wastewater. Currently Falmouth discharges effluent to rapid infiltration beds located in the West Falmouth Harbor watershed. This watershed currently exceeds its nitrogen threshold and, therefore, nitrogen must be removed from the watershed. The preliminary proposal is for Falmouth to construct an effluent forcemain and connect to the JBCC effluent forcemain at an average daily flow rate of 200,000 gpd (CH2M-Hill, 2012).

2.3.6. Future Permit Limits

The current GWDP is focused primarily on addressing conventional parameters (BOD, TSS, bacteria) as well as nutrients (nitrogen, phosphorus). Over time, additional parameter or more stringent effluent limits may be imposed.

- Nitrogen – DEP has not indicated any intention to revise the JBCC nitrogen limits at this time. There is no Total Maximum Daily Load (TMDL) Study completed or planned because the effluent disposal site is not located in a nitrogen sensitive watershed. Given the location of the discharge, the imposition of a more stringent nitrogen limit is unlikely.
- Phosphorus – DEP has not indicated any intention to add a phosphorus limit at this time. Given the location of the discharge, the imposition of a phosphorus limit is very unlikely.
- Compounds of emerging concern (CECs) – CECs encompass a wide variety of compounds including endocrine disrupting compounds, pharmaceuticals, flame

retardants, hormones, industrial solvents and surfactants, metals, pesticides, and personal care products. CECs have been found in wastewater for decades; however, they have recently reached the forefront of regulatory and public concern, and there is currently a great deal of research on CECs. One of the difficulties associated with addressing this topic is the large number and wide array of substances that can be classified as CECs. EPA and DEP have not established effluent standards for CECs to date, and have not indicated any intention to regulate CECs in the near term. Given that the location of the discharge is outside water supply recharge areas, the imposition of CEC limits is very unlikely.

While capital upgrades would be required if the GWDP requirements were made more stringent, this eventuality appears unlikely within a 10 to 20 year timeframe.

2.4 ALTERNATIVES ANALYSIS

Recalling the Project Premise described in Section 1, the purpose of this evaluation is to estimate the costs and revenues associated with Alternative 1 (use of existing capacity) and Alternative 2 (50% capacity expansion). Based on the estimated future flows available from each wastewater category (i.e., sewage, septage, effluent), it is apparent that the future wastewater management needs in the Upper Cape region easily exceed the capacity available at the existing JBCC wastewater system and may also exceed the capacity available with a 50% expansion.

In order to provide a framework for the business case analysis (**Section 3**), we have developed eight upgrade alternatives for the JBCC wastewater facilities, as follows:

- Alternative 1A – Baseline Improvements
- Alternative 1B – Baseline Improvements plus Septage Receiving
- Alternative 1C – Baseline Improvements plus Effluent Disposal
- Alternative 1D – Baseline Improvements plus Septage and Effluent Disposal
- Alternative 2A – Expansion
- Alternative 2B – Expansion plus Septage Receiving
- Alternative 2C – Expansion plus Effluent Disposal

- Alternative 2D – Expansion plus Septage and Effluent Disposal

We have utilized the future flows, organized by alternative and by wastewater category, indicated on **Table 2-6**. Each of the alternatives is described below.

TABLE 2-6
FUTURE FLOWS FOR ALTERNATIVES ANALYSIS

	Existing	Additional			Future
	Sewage (gpd)	Sewage (gpd)	Septage (gpd)	Effluent (gpd)	Total (gpd)
Alternative 1A	140,000	160,000	0	0	300,000
Alternative 1B	140,000	12,000	20,000	0	172,000
Alternative 1C	140,000	160,000	0	40,000	340,000
Alternative 1D	140,000	12,000	20,000	40,000	212,000
Alternative 2A	140,000	310,000	0	0	450,000
Alternative 2B	140,000	160,000	20,000	0	320,000
Alternative 2C	140,000	310,000	0	40,000	490,000
Alternative 2D	140,000	160,000	20,000	40,000	360,000

Notes:
1. Growth allowance for existing military and non-military users is from CH2M-Hill, 2012.
2. Growth allowance for MassDevelopment is described herein.
3. Septage allowance is based on treatment and GWDP. Septage revenues are based on 15,000 gpd annual average (5.5Mgal/year).
4. Effluent allowance is based on Bourne landfill leachate effluent (14.6Mgal/year).

2.4.1.1 Alternative 1A – Baseline Improvements (Sewage Only)

This alternative consists of constructing minimal upgrades to address permit compliance, increase peak flow capacity and reduce O&M costs related to liquid sludge disposal. These upgrades include:

- Add an off-line influent equalization tank and a pump station to help with peak flow management. Set equalization volume at 100,000 gallons (note: this is approximately the same size as each anoxic basin).
- Add a small supplemental carbon system including 500-gallon storage tank, one chemical feed pump, instrumentation interface with SCADA and electrical feeds.

- Add a rotary disc or drum thickener over the existing Sludge Storage Tanks and enclose it in a small building. Automate sludge wasting and polymer feed system to pre-thicken waste sludge prior to storage.
- Replace existing sludge feed pumps (progressing cavity) with higher rate sludge feed pumps (rotary lobe) to convey thickened sludge to a tanker truck at high rate (say 200 gpm) to allow for shorter truck fill times. Add new truck fill piping with quick-connect to building exterior.
- Upgrade the effluent forcemain (i.e., increase the pipe from 8"-inch to 18-inch from Static Head Structure No. 1 to Hydraulic Distribution Structure, replace all existing air/vacuum release valves, add a surge tank at the Frank Perkins Road Static Head Structure).

This scenario would allow for approximately 160,000 gpd from new sewer users to the WWTF. This would address the needs of JBCC military/non-military and MassDevelopment as well as most of the needs identified by Mashpee.

2.4.1.2 Alternative 1B – Baseline Improvements (Sewage and Septage)

This alternative consists of constructing minimal upgrades to address permit compliance, increase peak flow capacity and reduce O&M costs. These upgrades include:

- All upgrades identified in Alternative 1A.
- Construct additional upgrades to allow for up to 20,000 gpd septage capacity, including: new mechanical septage screening unit (400-gpm, outdoor rated, insulated); new septage storage tank (40,000-gallon tank) with decant provisions; new septage aeration system (coarse bubble diffusers and 2 blowers); new piping to connect from septage storage tank to sludge feed pumps (to load a liquid tanker truck); and decant pump station (20,000-gallon storage volume) with force main to headworks.

This scenario would allow for approximately 12,000 gpd from new sewer users to the WWTF. This would address the needs of JBCC military/non-military and MassDevelopment. Additional treatment capacity would be used for septage treatment.

2.4.1.3 Alternative 1C – Baseline Improvements (Sewage and Effluent)

This alternative consists of constructing minimal upgrades to address permit compliance, increase peak flow capacity and reduce O&M costs. These upgrades include:

- All upgrades identified in Alternative 1A.
- Receive Bourne landfill leachate effluent via a forcemain connection to the existing effluent forcemain. It is assumed that there are no capital improvements required by MassDevelopment/JBCC for the physical connection.
- Re-rate the RIBs to allow for additional capacity.

This scenario would allow for approximately 160,000 gpd from new sewer users to the WWTF. This would address the needs of JBCC military/non-military and MassDevelopment as well as most of the needs identified by Mashpee. Additional disposal capacity would be used for the effluent disposal needs of Bourne.

2.4.1.4 Alternative 1D – Baseline Improvements (Sewage, Septage and Effluent)

This alternative consists of constructing minimal upgrades to address permit compliance, increase peak flow capacity and reduce O&M costs. These upgrades include:

- All upgrades identified in Alternative 1A.
- Construct additional upgrades to allow for up to 20,000 gpd septage capacity, including: new mechanical septage screening unit (400-gpm, outdoor rated, insulated); new septage storage tank (40,000-gallon tank) with decant provisions; new septage aeration system (coarse bubble diffusers and 2 blowers); new piping to connect from septage storage tank to sludge feed pumps (to load a liquid tanker truck); and decant pump station (20,000-gallon storage volume) with force main to headworks.
- Receive Bourne landfill leachate effluent via a forcemain connection to the existing effluent forcemain. It is assumed that there are no capital improvements required by MassDevelopment/JBCC for the physical connection.
- Re-rate the RIBs to allow for additional capacity.

This scenario would allow for approximately 12,000 gpd from new sewer users to the WWTF. This would address the needs of JBCC military/non-military and MassDevelopment. Additional disposal capacity would be used for the effluent disposal needs of Bourne.

2.4.1.5 Alternative 2A – Expansion (Sewage Only)

This alternative consists of comprehensive upgrades to address permit compliance, increase peak flow capacity, reduce O&M costs and expand the WWTF capacity. These upgrades include:

- All upgrades identified in Alternative 1A.
- Construct additional upgrades to allow for additional overall treatment capacity within the fencelines of the WWTF and Effluent Disposal sites, including: new third Carrousel oxidation ditch; new third secondary clarifier; and new fourth sludge storage tank.
- Upgrade the effluent forcemain (i.e., increase the pipe from 8"-inch to 18-inch from Static Head Structure No. 1 to Hydraulic Distribution Structure, replace all existing air/vacuum release valves, add a surge tank at the Frank Perkins Road Static Head Structure) and re-rate/upgrade the effluent disposal beds to gain additional capacity (i.e., Hydrogeologic testing to re-rate the RIBs, add segmentation of RIBs within the existing footprint, add wicks).

This scenario would allow for approximately 310,000 gpd from new sewer users to the WWTF. This would address the needs of JBCC military/non-military, MassDevelopment and Mashpee. Additional capacity could be utilized for other municipalities.

2.4.1.6 Alternative 2B – Expansion (Sewage and Septage)

This alternative consists of comprehensive upgrades to address permit compliance, increase peak flow capacity, reduce O&M costs and expand the WWTF capacity. These upgrades include:

- All upgrades identified in Alternative 2A and in Alternative 1B.

This scenario would allow for approximately 160,000 gpd from new sewer users to the WWTF. This would address the needs of JBCC military/non-military and MassDevelopment as well as

most of the needs identified by Mashpee. Additional treatment capacity would be used for septage treatment.

2.4.1.7 Alternative 2C – Expansion (Sewage and Effluent)

This alternative consists of comprehensive upgrades to address permit compliance, increase peak flow capacity, reduce O&M costs and expand the WWTF capacity. These upgrades include:

- All upgrades identified in Alternative 2A and in Alternative 1C.

This scenario would allow for approximately 310,000 gpd from new sewer users to the WWTF. This would address the needs of JBCC military/non-military, MassDevelopment and Mashpee. Additional capacity could be utilized for other municipalities. Additional disposal capacity would be used for the effluent disposal needs of Bourne.

2.4.1.8 Alternative 2D – Expansion (Sewage, Septage and Effluent)

This alternative consists of comprehensive upgrades to address permit compliance, increase peak flow capacity, reduce O&M costs and expand the WWTF capacity. These upgrades include:

- All upgrades identified in Alternative 2A and in Alternative 1D.

This scenario would allow for approximately 160,000 gpd from new sewer users to the WWTF. This would address the needs of JBCC military/non-military and MassDevelopment as well as most of the needs identified by Mashpee. Additional treatment capacity would be used for septage treatment and for the effluent disposal needs of Bourne.

2.5 EXISTING ANNUAL O&M COSTS

The existing wastewater O&M costs for the past 5 years are summarized in **Table 2-7**. This summary was prepared based on information provided by JBCC.

TABLE 2-7
EXISTING ANNUAL O&M BUDGETS

Budget Item	2009	2010	2011	2012	2013
Chemicals (Hypochlorite, Bisulfite)	$25,851	$6,710	$22,451	$20,719	$22,905
Enzymes	$6,495	$130	$856	$228	$571
Biosolids Disposal	$24,792	$26,830	$30,000	$38,480	$22,000
Collection System (Degreasers)	$129	$0	$0	$0	$0
Lab Testing and Supplies	$19,882	$1,644	$3,273	$1,301	$1,301
Supplies and Shop Stock	$10,632	$42,709	$40,845	$62,187	$55,598
Parts and Equipment	$64,961	$25,987	$13,105	$0	$26,393
Service Contracts	$0	$12,573	$24,597	$35,142	$32,769
Projects (Sustainment, Repair, Modernization)	$0	$33,832	$0	$0	$39,655
Natural Gas	$5,739	$6,514	$7,776	$5,830	$7,615
Electricity	$85,733	$101,315	$105,827	$102,050	$99,263
Total Annual Costs (excl. Labor)	**$244,213**	**$258,244**	**$248,729**	**$265,937**	**$308,070**
Annual Volume Treated (Mgal)	54.82	52.04	51.11	48.64	47.68
Unit Cost (excl. Labor)	$4.50	$4.96	$4.87	$5.47	$6.46
Annual Labor with Benefits	-	-	-	$342,300	$356,000
Est. Labor for Wastewater (66%)	-	-	-	$225,920	$234,960
Total Annual Costs (incl. Labor)	-	-	-	**$491,860**	**$543,030**
Est. Unit Cost (incl. Labor)	-	-	-	$10.11	$11.39
Charges to Typ. Military User	-	-	-	$5.47	$6.46
Charges to Typ. Non-Military User	-	-	-	$9.24	$10.57

Notes
1. Annual budget data provided by JBCC. Typical user service agreements provided by JBCC
2. Biosolids hauling and disposal cost is $0.11/gallon per current contract according to JBCC.
3. Annual labor with fringe benefits for 2013 was provided by JBCC.
4. Unit costs are per thousand gallons of wastewater.
5. Existing labor allocation between wastewater and water utilities was estimated at 66% and 34%, respectively.

2.6 ESTIMATED COSTS FOR UPGRADES

Regardless of which alternative is selected, MassDevelopment will be faced with costs in two categories. The first category is "capital cost", which include the cost to design and construct the needed facilities. The second category is "operation and maintenance costs", which include the on-going annual expenses to run the facilities.

2.6.1. Capital Costs

The planning-level costs were developed using standard cost estimating procedures consistent with industry standards utilizing conceptual layouts, unit cost information, and planning-level cost curves, as necessary. Total project capital costs include allowances of 40% of the estimated construction costs to account for construction contingency, design and construction engineering, permitting, as well as financing, administrative and legal expenses. Many factors arise during final design (e.g. foundation conditions, owner-selected features and amenities, code issues, etc.) that cannot be definitively identified and estimated at this time. These factors are typically covered by the allowances described above; however, this allowance may not be adequate for all circumstances. The project cost information presented herein is in current dollars and is based on ENR Construction Cost Index 9870 (October 2014). Planning-level project costs have been prepared for the various alternatives are presented in **Table 2-8**.

The costs presented herein do not include costs for new sewer users or new effluent disposal users to plan, design or construct infrastructure to convey their flows to the JBCC wastewater system. It is assumed that the new users will be responsible for these costs.

2.6.2. Annual Operating and Maintenance Costs

Annual O&M costs were prepared for each of the alternatives based on the estimated increase and decrease in the existing WWTF budget line items. The current budget and the current flows and loads were considered the baseline. Future staffing requirements have been estimated using criteria established by EPA Publication MO-1 ("Estimated Staffing for Municipal Wastewater Treatment Facilities"). The estimated annual O&M costs as well as the anticipated additional staff are presented in **Table 2-9**.

TABLE 2-8
ESTIMATED CAPITAL COSTS FOR ALTERNATIVES

	Construction Cost	Project Cost
Alternative 1A	$2,350,000	$3,290,000
Alternative 1B	$2,790,000	$3,910,000
Alternative 1C	$2,350,000	$3,290,000
Alternative 1D	$2,790,000	$3,910,000
Alternative 2A	$6,510,000	$9,110,000
Alternative 2B	$7,590,000	$10,630,000
Alternative 2C	$6,510,000	$9,110,000
Alternative 2D	$7,590,000	$10,630,000

Notes:
1. ENR CCI 9870 (October 2014)
2. Project costs include a planning-level allowance of 40% of construction cost to account for contingency, technical services, legal and administrative costs.

TABLE 2-9
ESTIMATED ANNUAL O&M COSTS FOR ALTERNATIVES

	Annual O&M Cost	New Staff
Alternative 1A	$680,000	1
Alternative 1B	$670,000	1
Alternative 1C	$690,000	1
Alternative 1D	$670,000	1
Alternative 2A	$930,000	2
Alternative 2B	$940,000	2
Alternative 2C	$930,000	2
Alternative 2D	$940,000	2

Notes:
1. ENR CCI 9870 (October 2014)
2. Annual O&M Costs exclude MassDevelopment administrative costs, contract operator overhead, reserve accounts and debt service.

These estimates are based on the following assumptions:

- Utility rates as well as chemical and biosolids disposal unit costs were held constant.
- Flows and loads were assumed to be at full design capacity.
- Additional staff were assumed to be added at current labor costs.
- The "Supplies and Stock", "Parts and Equipment" and "Projects-SRM" line items were reduced based on the future use of reserve accounts to fund repair and replacement (i.e., spare parts) and special projects.
- The "Service Contracts" line was also reduced slightly based on MassDevelopment in-house engineering capabilities and Contract Operations in-house engineering capabilities.

2.6.3. Areas of Uncertainty Related to Costs

Due to the time and scope constraints of this project, there are several areas that could not be explored in greater detail. These items represent areas of uncertainty related to the capital cost estimates. Specific areas of uncertainty consist of the following items:

- WWTF Operational factors – Limited operational data were provided; underlying factors may not have been discovered as a part of this preliminary evaluation.
- Effluent forcemain – Limited information was provided on the reasons for effluent forcemain capacity limitations. More extensive upgrades than those included herein may be required in order to obtain sufficient capacity.
- Rapid Infiltration Basin capacity – Additional capacity may not be approved by DEP.

These areas of uncertainty should be refined as soon as possible.

2.6.4. Additional Costs for Potential Customers

In addition to the costs related to obtaining service from the JBCC wastewater system, potential customers will also need to collect and transport wastewater (or in some cases treated wastewaters) to the JBCC system. This additional infrastructure is costly and may influence the likelihood of the connection materializing. The potential connection costs were estimated as a part of the 2012 CH2M-Hill effort and are summarized in **Table 2-10**. Beyond the connection cost, there may also be costs associated with wastewater collection and/or treatment in the

community served. For example, Bourne would need to construct a landfill leachate treatment facility and effluent forcemain to the JBCC forcemain. Falmouth already has collection, treatment and disposal facilities, so it would have no costs in addition to transport. Mashpee and Sandwich would need sewer systems in order to collect the wastewater volumes. We have estimated these costs "qualitatively" in terms of whether the additional costs are "none", "millions of dollars" or "tens of millions of dollars" to provide some perspective. These qualitative estimates are also summarized in **Table 2-10**. Each community would need to estimate its total costs to connect to JBCC and compare that option to other local options.

TABLE 2-10
ESTIMATED ADDITIONAL COSTS FOR POTENTIAL CUSTOMER COMMUNITIES

Community	Annual Average Flow (gpd) (1)	Cost for Transport to JBCC (1,2)	Cost for Collection (3)	Cost for Treatment (3)	Total Cost (3,4)
Bourne (effluent)	40,000	$	$	$$	$$
Falmouth (effluent)	200,000	$9.6M	n/a	n/a	$$
Mashpee (sewage)	158,000	$4.9M	$$$	n/a	$$$
Sandwich (sewage)	156,000	$8.0M	$$$	n/a	$$$

Notes:
1. Flows are from Section 4.3.2 (Option B) for Bourne and from Section 4.3.4 (Option D) for Falmouth, Mashpee and Sandwich. (CH2M-Hill, 2012)
2. Costs from 2012 CH2M-Hill, Table 4-3 (2012 dollars, say ENR CCI 9400)
3. $ - hundreds of thousands of dollars; $$ - millions of dollars; $$$ - tens of millions of dollars.
4. Total costs include cost for collection, treatment and transport to JBCC, as applicable.

2.7 REGULATORY CONSIDERATIONS

There are numerous potential regulatory issues that MassDevelopment may face in the take-over and upgrading of JBCC wastewater and water facilities. In general, the regulatory issues at JBCC are determined by the location on the base where activities will take place. As noted previously, in broad terms, JBCC has two major components: the Upper Cape Water Supply Reserve; and the Cantonment area. These two areas are shown on **Figure ES-1**.

The Upper Cape Water Supply Reserve consists of approximately 15,000 acres on the north side of the base. It was formally established by the Massachusetts Legislature through Chapter 42 of the Acts of 2002, enacted in March of 2002. The purpose of the Reserve is to protect water

supplies and preserve wildlife habitat. Activities in the Reserve are governed by a detailed set of performance standards that were established in a Memorandum of Agreement between the Commonwealth and the Army and National Guard in 2001. Some revisions in those performance standards were made in 2007. Activities within the Reserve are administered by the DEP Environmental Management Commission.

The Cantonment area includes about 5,000 acres of land on the south side of the base where most of the military activities take place. Activities within the Cantonment are administered by the military. The existing water and wastewater infrastructure is largely located within the Cantonment area, with the following notable exceptions: the wastewater effluent disposal system; the pipeline leading to the wastewater effluent disposal system; and the water pipeline between the three wells owned by the UCRWSC and the Cantonment area.

Beyond normal operations and maintenance activities, modifications to these facilities in the Reserve will require substantial coordination and environmental study in light of the water supply and wildlife habitat protection measures that have been put in place. Additional regulatory requirements from specific regulatory agencies are summarized below.

2.7.1.1 Federal Programs

Based on discussions with MassDevelopment, we are not aware of any federal program requirements for the activities identified in Alternatives 1 and 2. It is conceivable that Alternatives 3 or 4 could trigger a federal Environmental Impact Statement.

2.7.1.2 State – Article 97

The Reserve is considered "Article 97 land", conservation land established under Article 97 of the state constitution. Any attempt to put that land to use for other than conversation purposes requires a two-thirds vote of the state legislature, a very high hurdle. This would make expansion of the RIBs beyond the existing fenceline difficult.

2.7.1.3 State – Massachusetts Environmental Policy Act

The Massachusetts Environmental Policy Act (MEPA) requires that the project proponents study the environmental consequences of their actions, including permitting and financial assistance. It

also requires the proponent to take all feasible measures to avoid, minimize, and mitigate damage to the environment. MEPA review provides the mechanism through which this information collection and mitigation mandate is executed, and it empowers the Secretary of the Executive Office Energy & Environmental Affairs (EOEEA) to oversee the review process. The process is public and encourages comments from citizens and from state, regional and local agencies. MEPA review will be required if MEPA thresholds are exceeded. There have been MEPA reviews of recent military projects, both within and outside the Reserve. The Section 61 findings associated with the 2001 Environmental Impact Report establish more stringent MEPA thresholds for activities within the Reserve. Among other things, MEPA review is triggered by any new wastewater infrastructure there.

2.7.1.4 State – Massachusetts DEP

DEP would need to review and approve the transfer of the Groundwater Discharge Permit from the Air Force/Air National Guard to MassDevelopment. It is expected that the current GWDP would be transferred to Mass Development with few or no substantive changes, following the 30-day notice to DEP of the pending transfer of ownership. A few additional regulatory items are worth noting:

- Sewer Use Ordinance and Industrial Pretreatment Programs would be required by the permit based on MassDevelopment ownership. This would need to in place before ownership transfer.
- A Contract Operator would be required. The selected contract operator must execute an operational contract before the discharge permit can be transferred.
- Potential permit modifications would need to be reviewed and approved by DEP.
- MassDevelopment should request that the phosphorus monitoring requirement be eliminated.
- MassDevelopment should conduct investigation and request a re-rating of the RIB disposal system.
- With an Industrial Pretreatment Program in place, new development on the base could be connected to the wastewater system without the need for a sewer extension permit.

- Similarly, receipt of municipal wastewater from nearby towns would not require a sewer extension permit, assuming no new treatment or disposal capacity is needed;
- If septage receiving facilities were constructed at the treatment plant, DEP approval would be sought via a BRP WP 68 submittal and a request for GWD permit modification;
- Receipt of non-JBCC effluent at the existing rapid infiltration site would require a GWD permit modification, following detailed discussions among Mass Development, DEP and the entity seeking disposal capacity (for, say, effluent from the Falmouth wastewater treatment facility, or effluent from a leachate treatment system at the Bourne landfill).

2.7.1.5 State – Natural Heritage and Endangered Species Program

This program will apply to activities that disrupt wildlife habitat. This will not likely have much impact on Alternative 1 or 2 projects.

2.7.1.6 State – Historic/Archaeological

The requirements of the Massachusetts Historical Commission will apply to new construction, especially related to archeological resources. This will not likely have much impact on Alternative 1 or 2 projects.

2.7.1.7 County – Development of Regional Impact (DRI)

The Commission's DRI process does not apply to state agencies, so DRI review would not occur for Mass Development-initiated projects that exceed DRI thresholds. However, it appears that DRI approval could be needed for large-scale development on Mass Development-controlled land if that land were transferred to a private company.

2.7.1.8 County – 208 Plan

The Cape Cod Commission's Draft 208 Water Quality Plan requests that development at the base be "nitrogen neutral"; that is, new development should not add to the current nitrogen load in nitrogen-sensitive watersheds in a way that increases the cost burden of the towns in the watersheds that have TMDLs. The Cape Cod Commission's Draft 208 Plan also requests that un-used wastewater capacity be provided to satisfy exiting municipal needs and not be used to

promote economic development. MassDevelopment should consider the implications of these requirements and whether it can be compelled to meet the Commission goals.

2.7.1.9 Local Programs

It is unlikely that the Towns of Bourne, Falmouth, Mashpee and Sandwich have any jurisdiction, in a formal permitting sense, for activities to be conducted by Mass Development on the base.

2.8 ALLOCATION OF CAPACITY

The existing JBCC treatment and disposal capacity represents a significant asset on the Upper Cape. As a part of allocation this capacity, MassDevelopment should consider the following important factors:

1. On-Base Sewerage Needs: The existing infrastructure should serve JBCC military and non-military needs/missions.
2. Off-Base Sewerage Needs: Several Upper Cape municipalities have wastewater management needs based on the requirements of the Massachusetts Estuaries Project technical reports. We suggest that MassDevelopment prioritize the capacity allocated to the towns based on the following reasons for "off-site wastewater management", listed in suggested order of "most important" to "least important":
    a. Ensuring sanitary conditions
    b. Protecting public and private water supplies
    c. Protecting surface waters
    d. Allowing for targeted growth (e.g., industrial parks, etc.)
    e. Allowing for general growth
    f. Addressing convenience or aesthetics concerns

3. Trucked Wastes: The existing treatment and disposal capacity is very valuable because the disposal area is not located in a nitrogen-sensitive watershed. Trucked wastes should be used to generate supplemental revenue until such time as sewerage needs infill the remaining capacity. To the extent that a sewerage needs exists, trucked wastes should be encouraged to go "off-Cape" in the mid-term to longer-term.

4. Effluent Disposal: Due to the existing issues associated with I/I, effluent disposal users should be contractually required to "temporarily shut down" upon demand based on weather conditions and peak flows. The user(s) must be able to store or dispose of their flow elsewhere (i.e., to their existing disposal locations or to an alternative trucked waste location) for short-term durations with limited notice.

3 BUSINESS CASE ANALYSIS FOR WASTEWATER ALTERNATIVES

The primary purpose of this evaluation is to conduct a "business case analysis" of various scenarios to determine the risks, costs and revenues associated with MassDevelopment taking ownership of the JBCC wastewater system. The analysis was intended to answer the question *does it make business sense to acquire the JBCC wastewater system and to sell existing capacity to maintain sustainable user rates*? The analysis presented in this section does not include the JBCC water system.

3.1 STEADY STATE BALANCE SHEET ANALYSIS

In order to determine which of the various scenarios presented in Section 2 are most advantageous, Wright-Pierce developed a steady state "balance sheet analysis" for each scenario. On the cost side, the following items were included: current annual O&M costs, debt service associated with potential capital upgrades, new annual O&M associated with MassDevelopment take-over (administration and reserves), new annual O&M associated with the sale of reserve capacity. On the revenue side, the following items were included: existing revenues as well as new revenues from the sale of reserve capacity for sewage, septage and effluent disposal. This analysis is presented in current dollars and does not account for inflation. This analysis also assumes that there is no cost for the transfer of the capital assets from the USAF/ANG to MassDevelopment. The balance sheet analysis is presented in **Table 3-1**.

For this analysis, the rates were set as follows:

- Military: $10/kgal
- Non-Military: $11 to $11.50/kgal
- Septage: $110/kgal
- Effluent: $7.50/kgal

TABLE 3-1
STEADY-STATE FINANCIAL ANALYSIS

	Now	Scenario 0	Scenario 1A	Scenario 1B	Scenario 1C	Scenario 1D	Scenario 2A	Scenario 2B	Scenario 2C	Scenario 2D
Sale of reserve capacity										
Sewage treatment			√	√	√		√	√	√	√
Septage treatment				√		√		√		√
Effluent disposal					√	√			√	√
Influent Flow to WWTF (gpd)	**140,000**	**140,000**	**300,000**	**172,000**	**300,000**	**172,000**	**450,000**	**320,000**	**450,000**	**320,000**
Total Flow to Disposal (gpd)	**140,000**	**140,000**	**300,000**	**172,000**	**340,000**	**212,000**	**450,000**	**320,000**	**490,000**	**360,000**
Project Capital Costs, $1000										
Total	0	0	3,300	3,910	3,300	3,910	9,120	10,640	9,120	10,640
Annual costs and revenues, $1000										
Current O&M Costs	510	460	410	410	410	410	410	410	410	410
Added O&M Costs--"Base Case" (10 year average)										
Total	0	250	250	250	250	250	275	275	275	275
Debt service in order to sell reserve capacity (2%, 20yrs)										
Total	0	0	202	239	202	239	558	651	558	651
Added O&M resulting from sale of reserve capacity										
Total	0	0	270	260	280	270	520	520	530	530
Rate Stabilization Subsidy for Military	0	0	0	0	0	0	0	0	0	0
Projected Costs, Total	**510**	**710**	**1,132**	**1,159**	**1,142**	**1,169**	**1,763**	**1,856**	**1,773**	**1,866**
Revenue from existing users	510	710	537	537	537	537	537	537	537	537
Revenue from sale of reserve capacity										
Total	0	0	614	622	724	732	1,272	1,244	1,381	1,354
Projected Revenues, Total	**510**	**710**	**1,151**	**1,159**	**1,260**	**1,268**	**1,808**	**1,781**	**1,918**	**1,891**
Net Balance (Revenues minus Costs)	0	0	19	(0)	119	99	46	(75)	145	25
Amount to Subsidize Military Rate or to Supplement Reserves										

Based on this steady state analysis, we conclude that:

- Taking over the JBCC wastewater system will be a financial burden to MassDevelopment ("base case" or Scenario 0) unless capital investments are made and the user base is expanded (i.e., "selling reserve capacity" or Scenarios 1A/B/C/D and 2A/B/C/D). The added O&M costs associated with MassDevelopment take-over, as described above, would create a deficit of $200,000 per year or would require a 40% rate increase to existing customers in order to break even (i.e. from $10.00/kgal to $13.80/kgal).
- The capital investments identified herein allow for MassDevelopment to sell reserve capacity in order to generate revenues from up to four distinct sources: existing sewer users; new sewer users; septage sources; and effluent disposal sources. Scenarios 1A/B/C/D and 2A/B/C/D, which accept various combinations of flow and revenues from each source, are described in detail in **Section 2**.
- Existing sewer user rates charged by JBCC to the existing users do not appear to fully account for the labor associated with operations and maintenance of the wastewater system. Federal organizations at JBCC are not charged for labor because it is already included in the federal budget. Non-federal organizations are charged based on approximately 1 full-time equivalent worker. Moving forward, MassDevelopment should adjust user rates to appropriately account for labor costs since these are "real" costs currently being incurred by the government for provision of wastewater services. When the cost of WWTF operations labor is accounted for, the existing user rate is approximately $11.39/kgal).
- When the cost of WWTF operations labor is accounted for, the existing user rates (approximately $11/kgal) are higher than the "market rate" charged by nearby Cape Cod towns (approximately $5/kgal in Barnstable to approximately $8 to $9/kgal in Falmouth and Chatham). This is due, in part, to higher electrical utility costs as well as the fact that some of the costs for these municipal facilities were covered through grants or through contributions from general municipal taxation.
- The market rate for septage disposal on Cape Cod is between $100 and $110/kgal. We are not aware of any other local circumstances with "effluent disposal users", therefore,

we are not aware of a market rate for effluent disposal. We have established a preliminary effluent disposal rate of $7.50/kgal herein based on an assessment of the value of the effluent disposal capacity to others.

- Based on our steady-state financial analysis as summarized in **Table 3-1** most of the alternatives are expected to generate positive revenue based on the 10-year average of the baseline additional O&M costs associated with MassDevelopment ownership. It is important to note that all rates and costs are presented in current dollars (October 2014, ENR Construction Cost Index 9870).
- In Alternatives 1A through 1D, MassDevelopment take-over plus capital projects would add $620,000 to $660,000 per year in new debt service and O&M costs; however, sale of that reserve capacity would generate $640,000 to $760,000 in annual revenue (i.e., 3% to 15% greater than costs).
- Similarly, in Alternatives 2A through 2D, MassDevelopment take-over plus capital projects would add $1,050,000 to $1,160,000 per year in new debt service and O&M costs; however, sale of that reserve capacity would generate $1,100,000 to $1,180,000 in annual revenue (i.e., 2% to 4% greater than costs).
- Septage (Alternative 1D and 2D) and effluent disposal (Alternative 1C, 1D, 2C and 2D) represent the best opportunities to raise revenue from the sale of reserve capacity. Capacity dedicated to septage in the early years could be converted to additional sewage capacity if/when the neighboring municipalities construct wastewater collection systems under prior agreement with JBCC to receive flow from such facilities. Surplus revenues generated from the sale of reserve capacity should be used to create and fund reserve accounts necessary for asset management, I/I reduction and rate stabilization.
- The net revenue potential for Alternatives 1C/2C is higher than that for Alternatives 1D/2D. This is primarily due to the fact that there are additional capital costs associated with the septage receiving elements of Alternatives 1D/2D. That said, Alternatives 1D/2D provide service to more “categories of users” which MassDevelopment indicates is important. Alternatives 1D/2D represent a more reliable near-term revenue source that could be converted to Alternatives 1C/2C over time if desired. For this reason, Alternatives 1D/2D are carried forward as the recommended alternatives for this

evaluation. It makes financial sense to use or construct capacity that can be utilized for septage in the near term and then converted to wastewater use in the future.

- MassDevelopment should expect to provide significant subsidy to the operation in the early years, until such time as the revenues fully fund the operation by way of new users and "value pricing" of the service. Significant factors related to the subsidy in the early years are the need to establish appropriate reserve accounts, the need to carry fixed costs until new sewage users connect to the system and the need to fund professional services for technical, financial and legal input up to and during the transfer.
- It is important to note that the financial analysis is very sensitive to the rates charged and to whether rates are fixed with or without inflation. Committing to fixed user rates for the military for an extended period of time may require additional subsidy.
- If MassDevelopment can support the capital investments described herein, then then we recommend moving forward with take-over of the wastewater facilities.

3.2 DESCRIPTION OF BUSINESS CASE ANALYSIS

In order to generate the business case analysis, Water Resources Associates was retained to develop a time-variable analysis of costs and revenues for Scenario 1D and 2D. The time-variable business case analysis is described below.

3.2.1. Existing Rate System

The USAF and ANG are not able to fund reserve accounts due to the nature of the accounting system utilized by the federal government. Accordingly, emergency repairs, projects and spare parts must be funded in the "current year" budget. As shown in **Table 2-7**, there is substantial year-to-year variability in the budget. It is also important to note that ANG only charges military users for the "out-of-pocket" costs to run the utility and the labor to operate the facility is treated as a "sunk cost" that is not recouped from the other military sewer users. The ANG does charge a different (and higher) sewer user rate to the Barnstable County Sheriff's Office/Correctional Facility which includes a portion of the labor cost associated with operating the JBCC wastewater system.

3.2.2. Model Inputs and Assumptions

Numerous assumptions are needed to develop a model of this nature. Key assumptions are identified below.

- The assumed timing of the transfer and upgrade activities is:
  - 2015 – activities to transfer ownership of the wastewater system from USAF/ANG to MassDevelopment
  - 2016 – preparation of design plans and specifications for facility upgrades, start receiving sewage from MassDevelopment sources which are already connected to the sewer system
  - 2017 to 2018 – construction and start-up of WWTF upgrade, start receiving limited septage, start receiving effluent disposal
  - 2019 – start loan repayment, start connecting new sewer users
- User Rate assumptions:
  - The user rate paid by military entities will be $10.00/kgal. It is assumed that MassDevelopment's contract with the military will include an annual escalation clause to cover inflation. [Note that some of the scenarios described herein do not inflation of costs, rates or revenues.]
  - It is assumed that the Non-Military user rate will be fixed at $11.00 per 1000 gallons, with the same escalation clause in contracts as discussed above.
  - It is assumed that MassDevelopment and new users of the system (e.g. neighboring towns) would pay actual, annually escalated costs for system services used (e.g. treatment and disposal, treated effluent disposal only)
- Transfer price: to be determined, currently assumed to be "no cost"
- Reserve and operating account requirements:
  - Operating reserve – Two months operating cost, establish over 5 years
  - Debt service reserve – 115% of annual debt service, establish over 5 years
  - Working capital reserve – "single contingency failure" method
  - Pump Station/Collection System asset management reserves - $50,000 per year.
  - I/I Investigation reserves - $25,000

- Sewer Use Ordinance & Industrial Pretreatment Program management - $25,000 per year.

- Interest and inflation rates:
  - Inflation rate (CPI Boston) – 2.0%
  - Interest rate (on reserve accounts) – 0.5%
  - Interest rate on CWSRF Loan – 2.0% (20 year term)
- Costs associated with wastewater system transfer to MassDevelopment:
  - Legal – $30,000
  - Engineering – $400,000 (Includes Project Evaluation Form application, facilities planning, permitting and permit negotiation, program management and contract operations procurement)
  - MassDevelopment Administration – $50,000
  - Financial consulting - $5,000
  - Sewer Use Ordinance and Industrial Pre-treatment Program - Assumed developed by new contract operator of system
  - Engineering design - $472,000 (assuming Design-Bid-Build with contract operations, not Design-Build-Operate procurement)
  - Construction and construction management costs associated with the Baseline Alternative – estimated and financed as documented above.
- Costs associated with <u>future transfer</u> from MassDevelopment to other:
  - None, assumed to be covered out of operating reserves

3.2.3. Net Present Value

A present value analysis is a standard economic evaluation method that allows the calculation of a single "cost" to represent the combination of capital costs and annual expenses for operation and maintenance over an established period of time. In this analysis, the "net present value" (NPV) represents the current value or worth of the net revenue from potential MassDevelopment investments, considering all components of cost and revenues including purchase costs, initial capital costs for upgrade or expansion, capital repair and replacement costs (asset management), annual operating expenses, subsidies fulfill rate guarantees to users, revenues from sale of

capacity and services to system users and other costs and revenues over the 20-year planning period. For the purposes of this study, the NPV has been computed assuming a 2% discount rate for various planning periods (5-year, 10-year and 20-year). The higher the NPV, the greater the potential for generating net revenue from the given investment.

The following parameters were calculated using the business case model in order to provide MassDevelopment with a range of metrics that will be important in considering the financial implications of the decision to acquire the JBCC system:

- NPV to MassDevelopment: 1st five years
- NPV to MassDevelopment: 1st ten years
- NPV to MassDevelopment: 20 year planning period
- Amount of Subsidy by MassDevelopment to the Military Users: 1st five years
- Amount of Subsidy by MassDevelopment to the Military Users: 20 year average
- Amount of Subsidy by MassDevelopment to the Non-Military Users: 1st five years
- Amount of Subsidy by MassDevelopment to the Non-Military Users: 20 year average

A graphical depiction of the time-variable annual costs, annual revenues, reserve account values, WWTF flow rates and user rates are presented in **Figure 3-1** and **Figure 3-2**, respectively. **Table 3-2** presents a summary of these key financial metrics for Scenario 1D and 2D.

It is clear from the model output and this summary table, that the revenue from septage and treated effluent disposal, commencing in year 2018 under the current assumptions, are the factors that drive the intermediate and long-term financial benefit of the project. The NPV of the project would be negative $197,500 through the first 5 years of the project (that is, the costs of the investments will exceed the associated revenue); however, the NPV for the 10-year and 20-year horizons are positive $632,000 and $1,997,000, respectively (that is, the investment turns profitable in the later years to more than offset the "unprofitable" early years). Scenario 2D has a similar trend in the financial metrics, except that it is "more negative" in the first 5 years and "less positive" at the 10-year and 20-year horizons.

FIGURE 3-1: TIME-VARIABLE FINANCIAL ANALYSIS
ALTERNATIVE 1D (BASELINE)

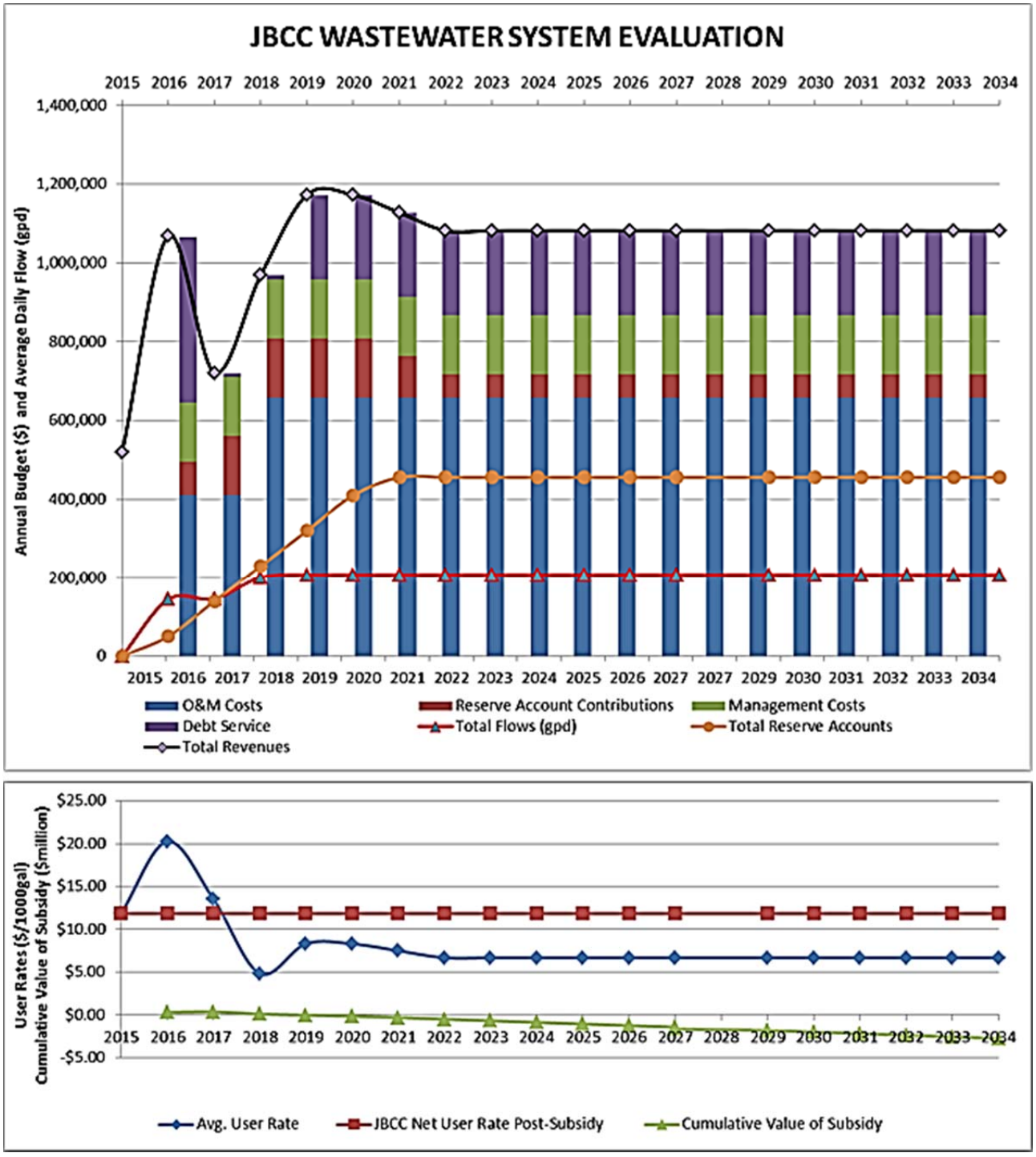
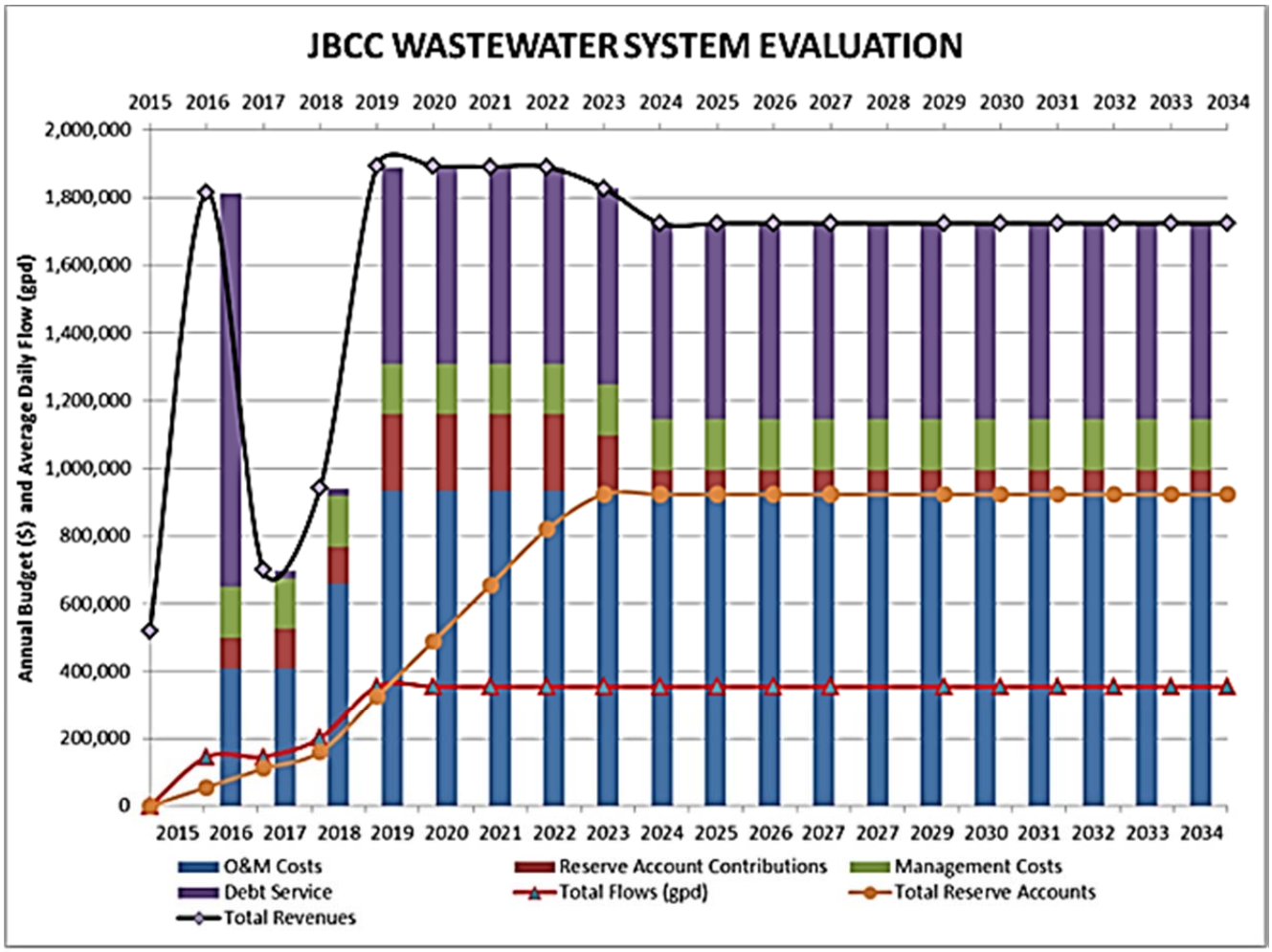


FIGURE 3-2: TIME-VARIABLE FINANCIAL ANALYSIS ALTERNATIVE 2D (EXPANSION)



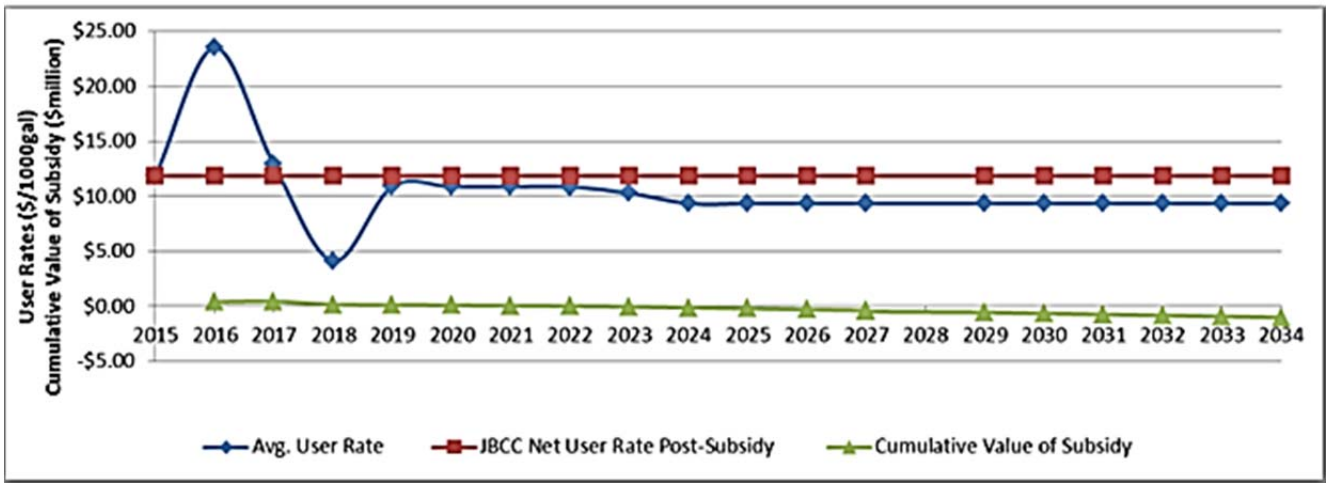


TABLE 3-2
FINANCIAL METRICS FROM TIME-VARIABLE BUSINESS CASE MODEL

Scenario Metrics	Scenario	1D	2D
	JBCC Wastewater	X	X
	Septage	X	X
	Landfill Leachate	X	X
	Regional Wastewater		X
MassDevelopment-Military Subsidy, 1st 5 years (Cumulative)		$ 171,500	$ 422,800
MassDevelopment-Military Subsidy, 20-yr Annual Average		$ (74,800)	$ 12,000
MassDevelopment-Non-Military Subsidy, 1st 5 years (Cumulative)		$ 8,700	$ 130,800
MassDevelopment- Non-Military Subsidy, 20-yr Annual Average		$ (50,600)	$ (9,100)
Net Present Value, 1st 5 Years - MassDevelopment (Cumulative)		$ (197,500)	$ (547,700)
Net Present Value, 1st 10 Years - MassDevelopment (Cumulative)		$ 632,000	$ (259,900)
Net Present Value, 20 year - MassDevelopment (Cumulative)		$ 1,997,200	$ 630,200
MilitaryProjected Rate/1st 10 years ($/kgal)		$ 10.00	$ 10.00
Military Current Projected Rate/No Subsidy/10 Years ($/kgal)		$ 11.85	$ 11.85
MilitaryProjected Rate/1st 10 years/Excess Revenue to Military Rate ($/kgal)		$ 8.66	$ 10.00
Non-Military Projected Rate/1st 10 years ($/kgal)		$ 11.00	$ 11.00

3.2.4. Sensitivity Analysis

The time-variable model was used to conduct a number of sensitivity analyses for Scenario 1D in order to compare the "baseline case" (i.e., no inflation) to several other conditions. These analyses are described below. The results of the sensitivity analyses are presented in **Table 3-3**.

3.2.4.1 Analysis of Fixed Military User Rate – Current Full Rate

The assumed military user rate of $10.00/kgal has been used. As described previously, the current user rates do not appear to include the full labor cost associated with running the facility and the estimated user rate including labor is $11.39/kgal (in 2013 dollars). If this rate is escalated by 2% per year, the current rate would be $11.85/thousand gallon (in 2015 dollars). If this rate is used as the starting military rate, along with a similar increase in the non-military rate, the NPV improves significantly. This additional revenue can be used to fund system improvement such as I/I reduction and asset management.

TABLE 3-3
SENSITIVITY ANALYSIS FROM TIME-VARIABLE BUSINESS CASE MODEL

Scenario Modification	NPV 5 years	NPV 10 years	Military Rate 10 yr avg	Non-Military Rate 10 yr avg
Baseline: No inflation, Initial User Rates	$ (197,500)	$ 632,000	$ 10.00	$ 11.00
Military Rate at **Current Full Rate** ($11.85/kgal)	$ 256,800	$ 1,510,000	$ 11.85	$ 12.85
Military Rate - **Breakeven Subsidy**	$ 35,200	$ 1,081,000	$ 10.95	$ 11.95
Baseline: No inflation, Initial User Rates	$ (197,500)	$ 632,000	$ 10.00	$ 11.00
Baseline: Initial User Rates **2% annual inflation on all costs and revenues**	$ (87,500)	$ 1,019,000	$ 11.17	$ 12.29
Baseline: Initial User Rates **3% annual inflation on all costs and revenues**	$ (30,300)	$ 1,229,000	$ 11.81	$ 12.99
Baseline: No inflation, Initial User Rates **Septage Tipping Fee** = $110/kgal	$ (197,500)	$ 632,000	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Septage Tipping Fee** = $130/kgal	$ 106,000	$ 1,403,000	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Septage Tipping Fee** = $100/kgal	$ (349,300)	$ 246,500	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Effluent Disposal Fee** = $7.50/kgal	$ (197,500)	$ 632,000	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Effluent Disposal Fee** = $10.00/kgal	$ (96,353)	$ 889,053	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Effluent Disposal Fee** = $6.00/kgal	$ (258,200)	$ 477,900	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates	$ (197,500)	$ 632,000	$ 10.00	$ 11.00
Baseline: Optimized Best Case Military Rate: Current Full Rate = $11.85/kgal Septage Rate = $120/kgal Effluent Disposal Fee = $8.50/kgal	$ 598,700	$ 2,540,000	$ 11.85	$ 12.85

3.2.4.2 Analysis of Fixed User Rate – Breakeven Subsidy

The baseline case assumes that the military and non-military rates are set at $10.00/kgal and $11.00/kgal, respectively, are "held constant" over the planning period. Positive net revenue will be retained by MassDevelopment and can be used to fund system improvements such as I/I reduction and asset management. The baseline case shows that Scenario 1D will have net

positive revenue approximately 7 years after MassDevelopment takes over. The implications of this point are that, in transfer negotiations in order to provide a more favorable financial internal balance sheet over the first 5 to 7 years, MassDevelopment could guarantee the military users the current rate, escalated as discussed above, but ***as averaged over the 20-year period***. This would provide higher Military rates during the first 10 years with reduced rates in subsequent years, providing the overall goal of constant rates. It would also allow MassDevelopment to "break-even" for the first few years, rendering the transfer more financially attractive to MassDevelopment. The business model was also run to determine the military and non-military rates at which the subsidy by MassDevelopment for the first five years would be zero. As shown on **Table 3-3**, the break-even subsidy rates are $10.95/kgal and $11.95/kgal for the military and non-military customers, respectively, only about 9% higher than the baseline rates.

3.2.4.3 Analysis of the Impact of Inflation

Table 3-3 shows the key financial metrics assuming 2% inflation per year and 3% inflation per year applied to all user fees, revenues and costs, including capital repair and replacement costs (starting with the initial user fees of $10.00/kgal and $11.00/kgal for military and non-military customers, respectively). The tests for inflation show that the NPV improves under both cases. The 10-year average user rate increases to $11.17/kgal and $12.29/kgal for military and non-military users, respectively, under the 2% inflation scenario. The 10-year average user rate increases to $11.81/kgal and $12.99/kgal for military and non-military users, respectively, under the 3% inflation scenario.

3.2.4.4 Analysis of Septage Tipping and Effluent Disposal Fees

Table 3-3 shows the key financial metrics at variable septage tipping fees and effluent disposal fees. An increase in the septage tipping fee from $110/kgal to $130/kgal (an 18% increase) improves the NPV by 122%; whereas a decrease in the septage tipping fee to $100/kgal (a 9% decrease) reduces the NPV by 61%. This analyses shows that the viability of the project is very sensitive to septage tipping fees. Similarly, an increase in the effluent disposal fee from $7.50/kgal to $10.00/kgal (a 33% increase) improves the NPV by 41%; whereas a decrease in the effluent disposal fee to $6.00/kgal (a 20% decrease) reduces the NPV by 21%. This analysis

shows that the NPV and subsidies are not as sensitive to effluent disposal fees as they are to septage disposal tipping fees, and illustrates the need to closely monitor the markets for disposal of these wastes.

3.2.4.5 Optimized Best Case

The results of these analyses show that the baseline case is conservative and that the net present worth improves (or does not worsen) if the user rates and operations costs are increased with inflation. We considered a scenario that is referred to as the "optimized best case": a combination of a modest increase in the initial full user rate to be charged to the military ($11.85/kgal vs $10/kgal) and non-military customers ($12.85/kgal), a small increase in the septage tipping fee ($120/kgal vs $110/kgal) and effluent disposal fee ($8.50/kgal vs $7.50/kgal). In summary, this produces a financially attractive project (NPV of $2.5 million) that would provide significant revenues for system management and risk resolution.

3.2.5. Summary and Recommendations

If MassDevelopment can support the capital investments described herein and if MassDevelopment can secure binding commitments from potential new users (commitment to connect, financially contribute, pay user rates and abide by the sewer use ordinance), then then we recommend implementing **Alternative 1D** (i.e., baseline improvements with upgrades to accept some new sewage as well as septage and effluent disposal). Alternative 1D has a higher net present value, has less risk and fewer regulatory, institutional and financial complexities. This could be expanded to **Alternative 2D** (i.e., 50% capacity expansion with upgrades to accept new sewage, septage and effluent disposal) if Mashpee can secure Town Meeting approval(s) to proceed with its CWMP. Key conclusions from this analysis are:

- Subsidy is required in the first 5 years, declining from the first to the fifth year.
- For Alternative 1D, the net present value is positive between Year 6 and 8.
- For Alternative 2D, the net present value is positive between Year 12 and 14.
- In order to minimize risk to MassDevelopment, it will be important to get formal commitments from potential users (i.e., municipalities) with regard to the capital costs for upgrades as well as to the proposed user rates. Potential customer municipalities will

need to compare the proposed user rates versus their other wastewater management alternatives.

3.2.6. Other Potential Revenue Sources

MassDevelopment may want to consider the following additional mechanisms to raise revenue as a means to further develop reserve accounts and to mitigate risk:

- Connection Fees – Develop connection fees based, in part, on the existing value of the system that was paid for by others.
- Host Fees – MassDevelopment could charge "host fees" to "customer towns". These fees could be a flat fee or a variable fee and would be in addition to the user fees associated with actual flows and loads discharged to the treatment system.
- Infiltration/Inflow Fees – I/I fees could be utilized as a cost-based incentive to have facility/building owners remove I/I sources from their facility/building (e.g., roof leaders, sump pumps, etc.). If the facility/building owner is unwilling or unable to remove the I/I source, then the fee would be charged.
- Industrial Pre-Treatment Program Fees – It is common for sewer users in the Industrial Pre-Treatment Program pay additional fees to cover the additional administrative and monitoring costs associated with this category of user.
- Loading Surcharges – It is common for sewer users that discharge high-strength wastewaters to pay loading surcharges to cover the additional processing costs associated with this type of wastewater.

Each of the above fee types has advantages, disadvantages and challenges (e.g., public acceptance, administrative complexity, etc.). Analysis of these factors is beyond the scope of this study but should be considered in greater detail prior to advancing towards implementation.

4 ASSESSMENT AND MANAGEMENT OF RISKS

There are numerous potential risks associated with the take-over of a wastewater utility such as the JBCC wastewater system; however, it is important to understand that these risks are inherent to sewerage infrastructure and are similar to those faced by many small municipal wastewater systems throughout New England. A summary of these risks is presented in **Table 4-1**. In general, these risks can be satisfactorily addressed through:

- Well-crafted transfer documents;
- Proactive utility management;
- Thorough Sewer Use Ordinances and Industrial Pre-treatment Programs;
- Dedicated reserve accounts;
- Clear delineation of ownership of building - specific pump stations and service laterals;
- On-going and intensive condition assessments in the collection system;
- Well-operated and maintained treatment and disposal facilities; and
- User rates and connection fees established to provide for sustainable revenues to adequately fund operations and reserve accounts.
- Service agreements with new users that set a minimum annual revenue value.

There are several JBCC-specific items which MassDevelopment should consider in its negotiations with USAF/ANG, including:

- Segregating liability related to legacy pollutants;
- Obtaining consent for “right of access to inspect” through the Sewer Use Ordinance and Industrial Pre-Treatment Program;
- Coordinating access and pipe routing issues associated with each potential “revenue source” (e.g., sewer connections to the WWTF, septage haulers to the WWTF, effluent disposal connection to the existing effluent forcemain).
- Coordinating with JBCC commanders to identify opportunities to reduce the extent of the collection system (i.e., abandon piping when consistent with the JBCC mission);

- Coordinating “ownership” of service laterals and small pumping stations with the existing sewer users and documenting in the Sewer Use Ordinance.
- JBCC is not able to fund reserve accounts due to the nature of the budgeting and accounting approach utilized by the federal government. Accordingly, planned maintenance, emergency repairs and special projects must be funded in the “current year budget”. This produces relatively large year-to-year variability in the budget. If MassDevelopment were to take-over the wastewater collection system, MassDevelopment would have to increase O&M costs in order to address administration costs and reserve account funding.

TABLE 4-1
IDENTIFICATION AND MANAGEMENT OF RISKS

Risk	Potential Cost	Likelihood Near-Term (0 to 5 yrs)	Likelihood Long-Term (10 to 20 yrs)	Management Strategy
Legacy pollutants are identified	Unknown	Medium	Medium	• Craft transfer documents to exclude liability for legacy pollutants related to easements and/or real property
Collection system piping failures and/or pump station failures	$$	Medium	High	• Conduct condition survey • Craft transfer documents to leave "service piping" and/or "private pump stations" with the existing owners. • Establish reserve accounts to fund asset management • Reduce extent of system
MassDevelopment expends costs to conduct studies and facilitate transfer but transfer does not happen	$ to $$	Medium	Low	• Execute MOU with interested towns to share in evaluation and implementation costs • Secure OEA funding.
Cost-effective I/I removal not found	$	Low	Medium	• Reduce extent of system, construct influent equalization
Increased RIB capacity not approved by DEP	$	Medium	Low	• Obtain DEP approval prior to committing to new customers
Military Users and/or Effluent Users do not comply with SUO/IPP	$	Low	Low	• Require acceptance certification as a part of transfer documents • Utilize escrow account in lieu of fines
Septage haulers don't use facility	$$	Low	Low	• Lower septage tipping fee to below market rate to increase use
New users don't agree to rates	$$	Medium	Low	• Require commitment prior to advancing acquisition
New users fail to connect	$$	Medium	Low	• Require IMA or MOU prior to constructing upgrades
Fixed user rates are not adequate	$	Medium	Low	• Establish rate stabilization reserves, raise rates if necessary
DEP imposes more stringent GWDP requirements	$$$	Low	Low	• Confirm GWDP requirements prior to expanding WWTF. • Raise revenue to construct upgrades

Notes: $ - tens of thousands of dollars; $$ - hundreds of thousands of dollars; $$$ - millions of dollars

5 WATER SYSTEM

5.1 INTRODUCTION

This section of the report describes the existing water works, water demands, and adequacy of supply. This section of the report also provides an alternatives analysis and costs for potential water system upgrades.

5.2 DESCRIPTION OF EXISTING WATER SYSTEM

A brief description of the waterworks facilities and how the system operates and is maintained is presented below. The facilities, distribution system and other features of the JBCC are shown in **Figure ES-2**.

5.2.1. JBCC Water Supply

The JBCC is supplied public drinking water from two supplies: 1) the J-Well located on the JBCC, and 2) wholesale interconnection with the Upper Cape Regional Water Supply Cooperative. The system also maintains an emergency interconnection with the Mashpee Water District. This interconnection is rarely used. A brief description of the limitations of the two primary sources of supply and operation of the system is presented below.

5.2.1.1 Interconnection with the Upper Cape Regional Water Supply Cooperative

The primary source of supply for the JBCC is the Upper Cape Regional Water Supply Cooperative (UCRWSC). The primary point of interconnection is located in a vault near the JBCC's other source of supply, the J-Well. The Upper Cape Regional Water Supply Cooperative (UCRWSC) was established in 2000 by the Massachusetts Legislature (Chapter 352 of the Acts of 2000). A copy of the enabling legislation is included in Appendix D. The UCRWSC is governed by a Board of Managers with representatives from the Bourne Water District, Town of Falmouth, Sandwich Water District and the Mashpee Water District.

The UCRWSC has three groundwater supplies referred to as Well No. 1, Well No. 2 and Well No. 3. The Water Management Act (WMA) permit and the enabling legislation allocates maximum daily volume reserves to each participating water system as well as a little over 500,000 gallons per day (gpd) reserved for use by the JBCC. Each well is restricted to a maximum daily withdrawal of 1.5 million gallons per day (mgd) and an average daily withdrawal of 1.0 mgd (3.0 mgd total). Each of the remaining participating water systems has a daily maximum allocation of 500,000 gpd, except Falmouth, which has a reserve allocation of 1.0 mgd.

The UCRWSC is the preferred supply for the JBCC because of its higher quality and lower cost. Presently, the JBCC uses far less water than the allocated reserve volume from the UCRWSC because of low demands. The pH of the UCRWSC supply is adjusted with potassium carbonate to match the finished water conditions of the J-Well as described below. The JBCC contract price for water from the UCRWSC is $1.0 per thousand gallons purchased.

5.2.1.2 J-Well Groundwater Supply (PWS ID #4096001)

The J-Well is an active gravel-packed well supply located in the JBCC service area. The well is operated in accordance with a Certificate of Registration issued by the Massachusetts DEP. A copy of the DEP Registration Statement is included in Appendix D. The registration statement allows a maximum annual withdrawal volume of 197.1 million gallons (Mgal) and an average daily withdrawal volume of 540,000 gpd. The single well is equipped with a 150 horsepower vertical turbine well pump powered by a variable frequency drive unit. The pump can produce approximately 1,400 gallons per minute. A new pump motor was installed in the 1990s.

The J-Well site contains four primary structures; the pumping station which houses the well pump and chemical feed equipment, a chemical injection vault, an inactive carbon contactor building constructed in 1998 and a generator building housing a gas-fired auxiliary generator.

The generator, chemical injection vault and carbon contactor building were installed in the 1990's. The pumping station is in relatively good condition for a building of this age. The

chemical systems are compact and situated in very close proximity to electrical and control equipment. Any major renovations of this space would likely trigger building and life safety codes and require repurposing this space. The well pump discharges through a basement level to an exterior chemical injection vault before entering the distribution system through two parallel 10-inch diameter water mains. Both locations are confined space areas.

The J-Well is much more costly to treat and pump to the distribution system than wholesale purchase of bulk water from the UCRWSC. The source is treated with three chemicals: sodium hypochlorite for disinfection; potassium carbonate for corrosion control and pH adjustment; and sodium fluoride for tooth decay prevention.

The natural low pH of the water and the depth to the water table are the two primary factors driving the cost of production at the J-Well. The chemical feed systems were overhauled in the late 1990's. The J-Well is normally only operated one day per week. The production cost for the J-Well is high because of the large pump horsepower of the well and substantial chemical feed requirements. The well is oversized for the demands and water-use patterns at JBCC. The present well capacity is approximately 2.0 mgd. Average-day demands ranged from 176,700 gallons/day to 189,100 gallons/day over the past three years. Operators also report that intermittent operation of the well improves water quality from stagnant water and accumulation of metals in the piping and well casing during downtimes. Operation of the well on an infrequent basis also reduces the risk of the MassDEP declaring the well inactive.

The future viability of the J-Well as a source of supply for the JBCC is discussed later in the assessment. In the 1990s, VOCs were detected in the J-Well. A granular activated carbon (GAC) adsorption system was constructed to remove the contaminant following issuance of an administrative consent order by the DEP. GAC contactors were constructed in a pre-engineered metal building located adjacent to the pumping station. This system is reported to be inactive.

5.2.1.3 Water Quality

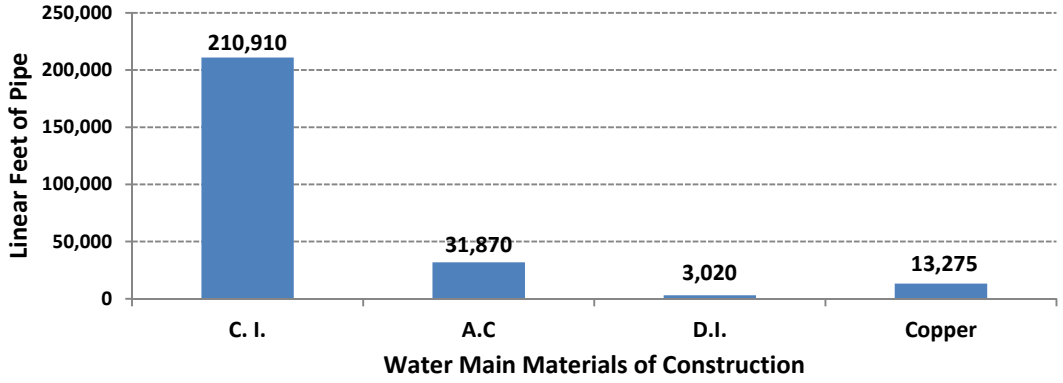
Maintaining high quality, delivered water to the customer's tap has been an issue in the system at certain times. Finished water meets all state and federal maximum contaminant levels (MCLs). Operators report that treated water has an apparent color range of 5 to 10 color units. Staining of bathroom fixtures is common is some facilities. Some service connections have installed cartridge filters to improve water quality and to reduce oxidized iron and manganese in the system. The change in water quality from the sources of supply to the customer's tap is likely a combination of unlined cast iron piping and a polyphosphate feed system that is not optimized to completely sequester the metals from the well supply. The water quality issues appear to be aesthetic in nature and not a concern for public health.

5.2.2. Water Distribution

The original water distribution system was constructed in 1940 to 1941. This original system consisted of about 144,000 lineal feet of unlined cast iron water main ranging in size from 2-inch to 12-inch in diameter. The next major expansion of the water distribution system occurred from 1955 to 1960 consisting of an additional 112,000 lineal feet of new mains, as the core system expanded outwardly to encompass the current Coast Guard Housing and Coast Guard Non-Housing areas. Most of this new main consisted of cement lined cast iron main plus the addition of approximately 32,900 feet of asbestos cement (transite) mains in the main base area. The asbestos cement water mains have been a source of repairs and maintenance issues in recent years. Operators report that much of the asbestos cement pipe is brittle and soft. Repairs to this older pipe are increasingly a problem in the system. The asbestos cement pipe does not have vinyl chloride linings and as such does not require bleeders to maintain water quality. Small amounts of modern copper and ductile iron pipe are present, but the quantities are small and limited. The distribution system has been virtually unchanged since the 1960's with the exception of pipe repairs, and replacement or addition of isolated valves and hydrants.

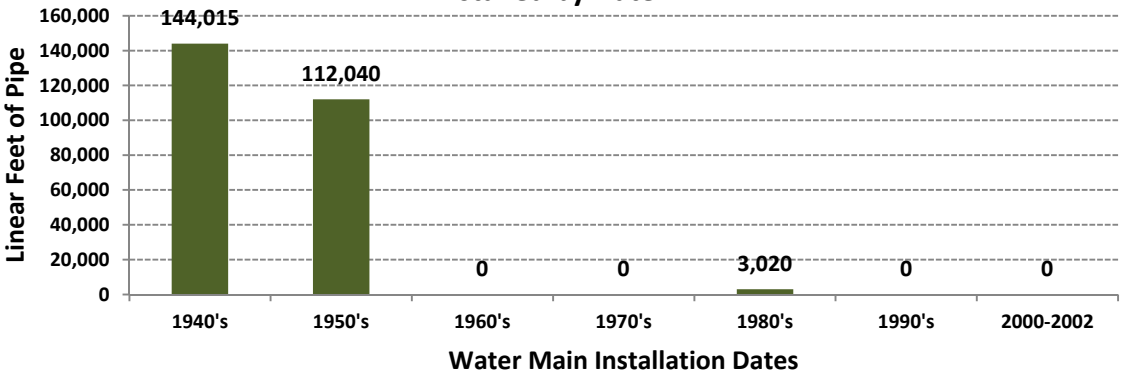
The total length of mains in the JBCC water distribution system is approximately 259,000 feet or 49 miles. The distribution of the water mains by pipe material type is presented in **Figure 5-1**.

Figure 5-1 - JBCC Water Distribution System - Linear Feet of Main by Material Type



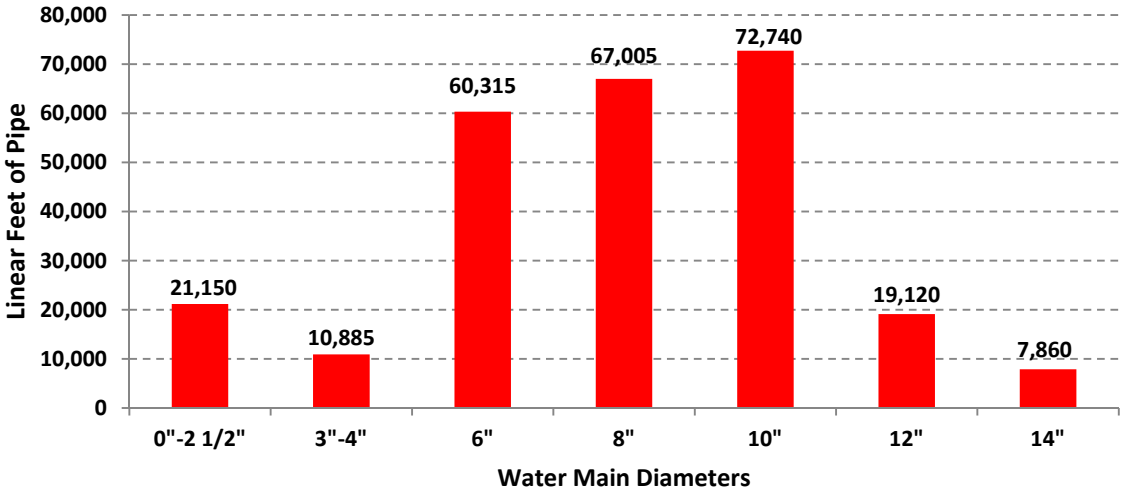
The distribution of the mains in the system by year of installation is presented in **Figure 5-2**. As discussed above, the vast majority of piping was installed prior to 1961.

Figure 5-2 - JBCC Water Distribution System - Linear Feet of Main Installed by Date



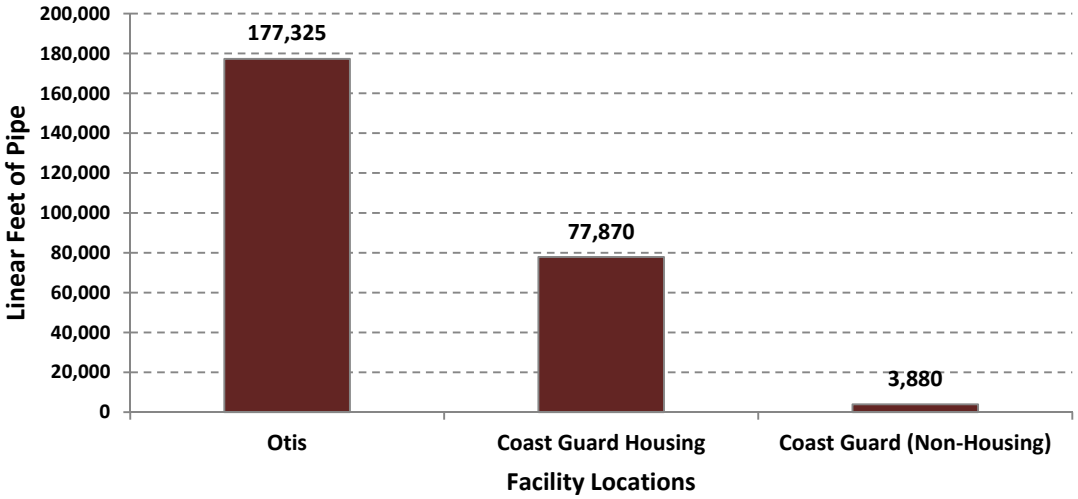
The distribution of the mains in the system by pipe diameter is presented in **Figure 5-3**. The primary core of the distribution system contains 6-inch, 8-inch and 10-inch water mains.

Figure 5-3 - JBCC Water Distribution System - Linear Feet of Main by Pipe Diameter



The distribution of the mains in the system by primary location in the JBCC is presented in **Figure 5-4**. The majority of the piping is located within the main base area.

Figure 5-4 - JBCC Water Distribution System - Linear Feet of Main by Location



A hydraulic model of the distribution system does not exist so simulated available fire flows at each hydrant are not available. However, the prevalence of 6-inch and 8-inch mains suggest that hydrant flows throughout much of the service area will be limited and likely below Insurance Services Organization (ISO) recommendations for the type of large structures found on the JBCC.

5.2.3. Service Connections, Metering and Backflow Prevention

The base maintains an active cross connection control program and has 4 licensed backflow testing technicians on staff. Presently, the system maintains an inventory of devices and has a formal policy of specifying devices and billing the tenants for the installation, maintenance and testing of the devices. Individual structures are not individually metered. Water bills are generated based on a usage algorithm that was not made available.

It is understood that each individual structure will require an individual flow meter, corner horn for mounting the meter, and a backflow prevention device (reduced pressure zone (RPZ) or double check valve) depending on the nature of the service connection. The cost to install a meter assembly should be relatively fixed for each existing service connection. The cost could be funded through a one-time assessment or through water rates.

MassDevelopment has requested a plan to provide water meters at each service connection. Flow meters are sized based on the diurnal water-use pattern at the service connection. A preliminary service count was obtained by counting existing structures with service connections from the GIS mapping. About 380 services to occupied buildings are shown in the database. For the purposes of this evaluation, the costs to extend metering to each service have been evaluated. A fixed cost allocation of $3,000 per service connection has been assumed to provide a meter, meter cornerhorn, radio read or touchpad devise and for an initial surveillance of the properties to determine best location for the equipment. It is recognized that the meter size will vary by location, but for planning purposes a fixed budget cost to account for some variation from service to service is reasonable.

Our cost assumptions to install service meters in the JBCC system are as follows:

- Estimated cost to install 380 service meters $1,140,000 (2014 dollars)
- Number of meters - $380 ranging in size from 5/8" to 2"
- Average Cost per Service Installation- $3,000
- Funding Period – 20 years
- Annual inflation rate – 2%
- Interest rate – 2 %

5.2.4. Water Storage and Fire Protection

Fire storage in the water system is provided by two, 400,000-gallon elevated water storage tanks. One tank is located off Shelton Road (Facility 2302) and the other tank is located off Granville Road (Facility 2303). The tanks were constructed in 1942, dating back to the origin of the water system. Both tanks were refurbished in the early 1990s with new cathodic protection systems, obstruction lighting, new interior and exterior coatings and repair of various structural components. Both tanks will have a new maintenance cycle completed by the end of 2015.

Both tanks are reported to be equipped with 12-inch altitude valves located in buried vaults at each facility. It is not known if the valves are operational or if the control point is set below the overflow elevation to control overflow events at the tanks. The valves and vaults were added to the system as part of the rehabilitation projects in the early 1990's.

The system contains about 270 fire hydrants dispersed through of the distribution system for fire protection. Many of the hydrants date back the original distribution system or were added with the expansion in the 1950's. The condition, operability and presence of adequate branch valves to isolate hydrants are not known at this time.

Operating pressures are reported to range from a low of about 40 psi to high pressure of 70 psi. This data would suggest that the tanks are about 100 feet high. Record drawings were not made available to confirm the operating parameters, height and bowl dimensions of the two storage tanks.

Both tanks are approaching 75 years old and both are constructed using an older, high maintenance technology for water storage. Since the tanks are nearly 75 years old, we have assumed that the structures are fully depreciated with no remaining residual value. An analysis of the adequacy of this storage system to meet projected demands and fire requirements at the JBCC is discussed later in the report.

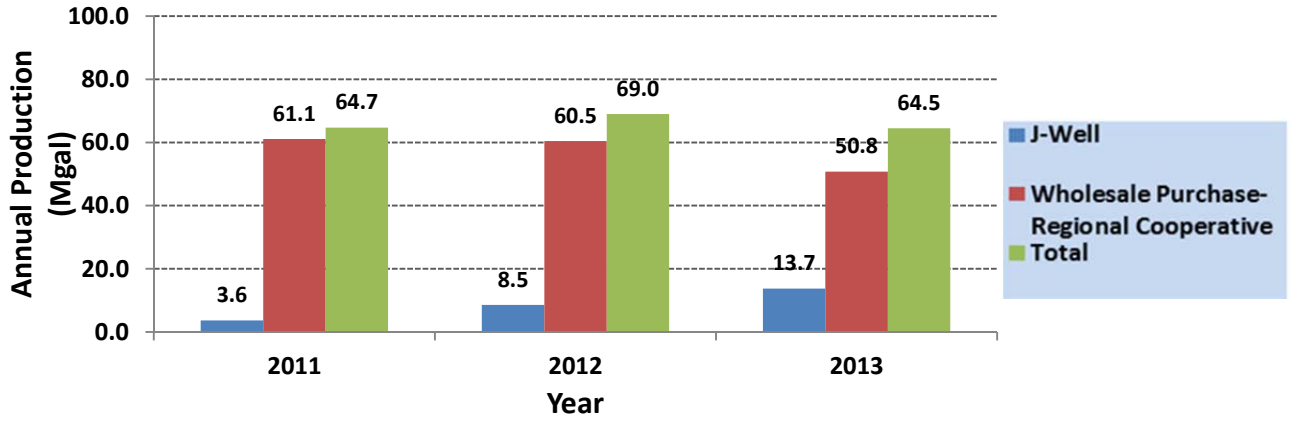
5.2.5. Water System Classification

The JBCC is classified as a Class I public water treatment system. The person with responsibility for making process system integrity decisions about water quality or quantity that affect public health, and having active field supervision of treatment activities must hold the appropriate Grade 1T or higher grade treatment certificate. The JBCC is classified as a Class II public water distribution system. The person with responsibility for making process system integrity decisions about water quality or quantity that affect public health, and having active field supervision of the distribution system activities must hold the appropriate Grade 2D or higher grade treatment certificate.

5.3 EXISTING DEMANDS AND WATER USE

The annual water usage at JBCC over the past three years is presented in **Figure 5-5**. The figure also shows the apportionment of demands between purchased water from the Regional UCRWSC and production from the J-Well. The J-Well has produced between 6% and 21% of the total demands in the system over the past three years.

Figure 5-5 – Water Demands in JBCC for the Period 2011-2013



The data suggests that the use of the J-well has diminished in importance over the last several years because of the much higher production cost. The J-well continues to be used however for a small portion of the production for several reasons; (1) Intermittent use of the well is needed to maintain water quality and prevent high concentration of iron and manganese in the well and (2) To maintain the well in active status with the MassDEP for redundancy to the preferred water from the UCRWSC.

Unaccounted-for water in the JBCC system is understood to be high. Routine leak detection surveys have not been completed and consumption is not metered. However, flow data from the wastewater treatment facility does provide some insights into lost water in the system.

Water production (J-Well plus purchased water from the UCRWSC) has averaged 64.5 Mgal/year or approximately 176,500 gallons/day over the past three years. Average influent at the wastewater treatment facility has averaged approximately 131,000 gallons/day (See Table 2-1) over the same period, including contributions from inflow and infiltration (I/I) in the sewer collection system. These data suggest that unaccounted for water has averaged at least 45,000 gallons/day or 25.5% of water demands plus contributions of I/I.

5.4 ADEQUACY OF STORAGE AND SUPPLY

5.4.1. Supply Evaluation

The adequacy of the JBCC supply was evaluated for the following conditions:

- Adequacy of Supply to meet projected average-day demand conditions
- Ability of supply to meet maximum-day conditions
- Ability of supply to comply with Massachusetts Water Management Act

For the purposes of this evaluation, the capacity constraints of the wastewater treatment facility are important. Although it is likely that sufficient development will not occur within the JBCC service area to absorb any capacity through growth, our analysis will consider this condition only from the supply adequacy perspective.

5.4.1.1 Average-Day Demands

The present average-day demands in the JBCC system have been 176,500 gallons/day or 64.5 Mgal/year over the past three years. The J-Well and UCRWSC agreement are both constrained on annual yield or contract limits to supply the needs of the JBCC.

The UCRWSC agreement allows for a maximum-day purchase of 500,000 gallons on any given day during the year. On an annual basis, this equates to approximately 183 Mgal/year. For the J-Well, the Water Management Act registration statement limits the annual withdrawal volume from the well to 197.1 Mgal/year.

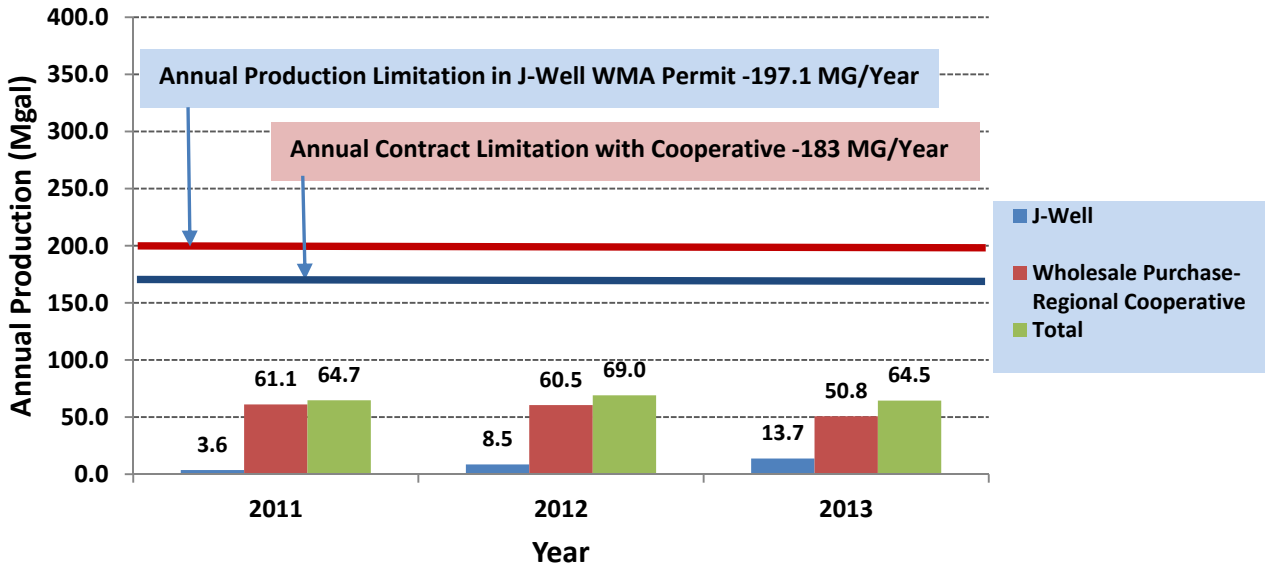
The JBCC wastewater treatment facility has an annual average design flow rating of 300,000 gallons/day, so the water supply from either the J-Well or the UCRWSC is sufficient to meet the entire available capacity at the wastewater treatment facility.

In summary, JBCC can meet all the required demands in the system with either the J-Well or the UCRWSC interconnection. Both of the sources are not needed other than providing complete redundancy.

If the JBCC choose to consume the remaining capacity of the water supply through development, the constraint on the water supply would be the capacity of the current wastewater treatment facility not the permit or purchase agreement with the UCRWSC.

The annual production values from each source, as well as the annual production/contract limits from each source, are presented in **Figure 5-6**.

Figure 5-6 – Annual Production Limitations for J-Well and UCRWSC



5.4.1.2 Maximum-Day Demands

Maximum-day demands or production from the two water supplies were not made available for review. From a water supply perspective, the UCRWSC agreement allows for a maximum-day purchase of 500,000 gallons on any given day during the year as previously described.

For the J-Well, the Water Management Act registration statement has no limits on maximum-day pumpage as long as the annual withdrawal volume of 197.1 Mgal is not exceeded. The maximum-day production rate from the J-Well is constrained by the well capacity and pump, currently limited to about 1,400 gpm or 2.0 mgd. If the well pump is operating at maximum speed and the full allocation from the UCRWSC is used, the JBCC supply can produce 2.5 mgd.

The maximum-day capacity of the JBCC wastewater treatment is about 800,000 gal/day. If the JBCC chooses to consume the remaining capacity of the wastewater treatment facility through development, the J-Well would be required as a peaking source to meet these demands. At this juncture, the demands in the system can be met under this design condition with either source of supply under average-day demand conditions.

5.4.1.3 Conditional Assessment of J-Well

The J-Well was substantially renovated in the 1990's. The well now requires routine maintenance to chemical feed systems, maintenance of the building and routine cleaning of the well screen. No major capital investment is needed over the next 20 years to comply with new regulations or for a major rehabilitation of the pumping station.

5.4.1.4 Supply Redundancy

The UCRWSC is supplied by three wells. The UCRWSC supply has inherent supply and well redundancy to the wholesale customers including the JBCC. Although the J-Well does provide direct mechanical redundancy, the well is not needed to meet the projected demands in the JBCC system. The well also provides redundancy back to the UCRWSC and is a registered water supply with likely regional value.

The J-Well has much greater value as a potential regional water supply source. It is recommended that this be explored further to assess the true value of this asset. Strictly from a water supply perspective the J-Well is costly and is not needed to meet the projected demands.

5.4.2. Storage Evaluation

5.4.2.1 Storage Quantity Required

The JBCC owns and operates two distribution storage facilities as previously described. System storage is necessary for the following reasons:

- Storage should be designed to provide all demands which exceed the maximum day average flow rate. The volume of storage which is depleted during the daytime, peak flow periods is refilled during the lower demand, early morning hours.
- Storage is provided for fire protection. If a fire occurred during the maximum day demand, all the water used to fight the fire would be drawn from storage volume.
- Storage provides water during emergency situations such as power failures, transmission main breaks, etc.
- Storage provides additional volume for pumping during off-peak electrical periods.
- Operating storage is used for cycling pumps during normal daily operation.

All storage components described above should be available while still providing at least 20 psi of pressure in the each pressure zone. This pressure is equivalent to the volume of water stored 46 feet above the highest service. This storage volume is referred to as the available or active storage.

To determine the adequacy of the existing storage volume, an analysis of each of the storage components described was made using projected demands. At this juncture, a projected maximum-day demand of about 390,000 gallons/day was assumed based on observed peaking factors at the wastewater treatment facility. A worst case scenario would dictate that for a fire on the maximum day, the fire flow and hourly fluctuation volume of the available storage should be available simultaneously.

The required storage in the JBCC can be calculated as follows:

1. *Fire Protection Storage Volume* - The volume which should be stored for fire protection should be capable of providing 3,500 gpm for 3 hours or 630,000 gallons. This is the Insurance Services Office (ISO) recommended maximum amount of fire protection necessary for a public water purveyor to supply for a large commercial building. This flow is appropriate for the JBCC.

2. *Equalization Storage for Peak-Hour Storage Fluctuation* - The storage volume necessary to provide the system hourly fluctuation demands was estimated to be 20 percent of the maximum day total demand in total for the entire water system. This equates to a volume of about 80,000 gallons or about twenty percent of the estimated maximum-day demand approximately 390,000 gallons for the entire water system.

3. *Emergency Storage* - Storage should be available to meet emergencies. Because JBCC is interconnected to the UCRWSC and Mashpee and has an emergency generator at the J-Well, the system can meet domestic demands in an emergency without supplemental storage.

The total required active storage volume for the three components described above is 710,000 gallons. The existing active storage volume in the JBCC system is about 800,000 gallons in the storage tanks. Based on this analysis, the JBCC system appears to have adequate storage volume

if both tanks are retained. A brief discussion follows on the condition of the storage tanks and appropriate financial planning and capital reserves to eventually replace these two structures with a similar storage volume.

5.4.2.2 Conditional Assessment and Life Cycle Cost Analysis

The JBCC storage tanks are approaching the end of their useful lives. Although both structures have been recently rehabilitated, the storage tanks are 72 years old and will likely require replacement approaching the next painting cycle in 15 to 20 years.

A recommended approach for storage planning is to allocate a capital reserve account as a sinking fund for maintenance. At this juncture, we would recommend a plan that retains both storage tanks in their current location, which is advantageous for fire flows, and reserve an appropriate amount to rehabilitate both 400,000 gallon facilities. If after 15 years, the condition of the facilities has continued to deteriorate, than the accumulated funds can be supplemented with capital borrowing and the two facilities replaced with a standpipe or elevated tank of similar active storage volume.

Our cost assumptions in establishing the annual maintenance fund, are as follows:

- Estimated cost to rehabilitate each tank $750,000 (2014 dollars)
- Annual inflation rate – 2%
- Anticipated Painting Cycle – 15 years
- Interest rate – 2 %

On this basis, an annual capital reserve amount of $57,000 per tank or $114,000 in total would be required annual to build sufficient funds with inflation to rehabilitate the tanks in 15 years (2029).

5.4.2.3 Storage System Recommendations

On this basis, the JBCC would need to establish a sinking fund in the amount of $57,000/year per storage tank to have sufficient funds to rehabilitate the two storage tanks in 2029 (15 years). At that point in the time, the tanks would be reassessed and either rehabilitated or replaced with supplemental capital funds.

5.5 ALTERNATIVES ANALYSIS

5.5.1. Existing Annual Budget

The existing water O&M costs for the past three years are summarized in **Table 5-1**. This summary was prepared based on information provided by JBCC and includes an adjustment for labor costs. Refer to Sections 1 and 2 for additional information on how labor is accounted for in the budgeting process.

Small capital projects are in this table as O&M expenses. This line item changes year to year based on actual needs at the facility and would typically include such items as contract well cleaning, and other capital items. Routine maintenance items such as chemical feed pump replacement, small mechanical improvements and other similar incidentals are shown as supplies, parts and shop items in the table. Again, the budget for these items will tend to fluctuate year to year based on actual need in a given year.

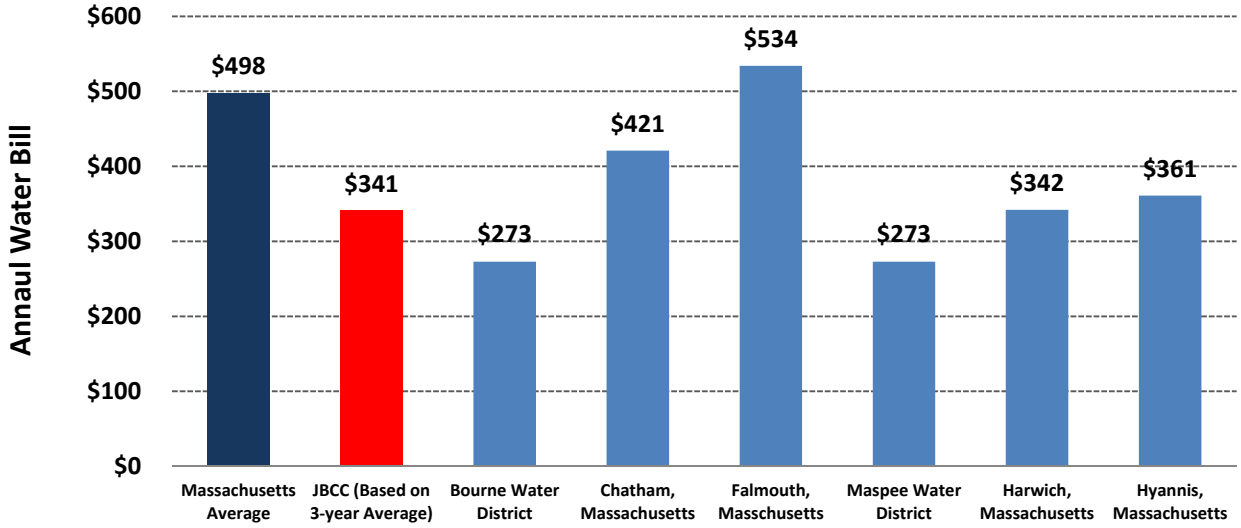
TABLE 5-1
ANNUAL O&M COSTS FOR WATER SYSTEM

Budget Item	2011	2012	2013
Potassium Carbonate	-	$42,553	$17,731
Sodium Hypochlorite	$856	-	-
Sodium Fluoride	$19,903	-	$27,320
Supplies, Parts and Shop Stock	$3,116	$13,799	$13,912
Wholesale Water from UCRWSC	$57,993	$60,461	$50,788
Projects – Sustainment, Repair, Modernization	$12,160	-	$39,655
Natural Gas	$252	$1,070	$982
Electricity	$41,085	$1,746	$3,314
Labor	Not Incl.	Not Incl.	Not Incl.
Total Annual Costs (excl. Labor)	**$141,395**	**$119,628**	**$153,692**
Annual Production (Mgal)	64.7	69.02	64.49
Average-day (gallons/day)	177,300	189,100	176,700
Unit Cost per Mgal (excl. Labor)	$2.18	$1.73	$2.38
Annual Labor with Benefits	-	$342,300	$356,000
Est. Labor for Water (33%)	-	$112,900	$117,500
Total Annual Costs (incl. Labor)	**-**	**$232,500**	**$271,200**
Unit Cost per Mgal (incl. Labor)	-	$3.37	$4.21
Average Unit Cost per Mgal (incl. Labor)	-	$3.79	

5.5.2. Benchmarking Current Production Costs

A biannual water rate survey is conducted in Massachusetts to track municipal water rates in each public or quasi-public water system in the Commonwealth. The last survey was conducted in 2012. The survey tracks residential water costs based on an average annual usage of 120 hundred cubic feet (HCF) or 90,000 gallons per year. In 2012, the average residential water bill in the Commonwealth was $498/year. The median water cost was $476/year. The average operation costs in the last two years including labor is approximately $3.79/Mgal or $341/120 HCF of usage as shown in **Figure 5-7**. It is important to note that this value does not include capital reserves for painting or replacing storage tanks, distribution main replacement costs, projected capital needs at the J-well or debt service to acquire the assets at the JBCC.

Figure 5-7 – Comparison to Annual Water Bills based on 120 HCF of Usage (Existing)



In general, water costs are lower in Cape Cod communities because most communities use groundwater, which is of high quality and requires minimal treatment. Figure 3-8 compares water rates at the JBCC with several local cape communities and with the average residential water-use bill in Massachusetts.

5.5.3. Scenario 2 – Fund Tank Replacement Reserve

Under this scenario, the JBCC would create a sinking fund in the amount of $114,000 annually as a fixed payment for eventual rehabilitation of the two existing storage tanks in year 2029 (15 years). The data suggests that the cost per Mgal will increase to approximately $5.50 per Mgal when this cost is included in the operations budget. This cost would increase the average water bill to about $495 per 120 HCF, close to the state average residential water bill.

5.5.4. Scenario 3 – Fund Service Meter Installation Reserve

The estimated cost to install service meters at each current service connection would be approximately $1,140,000 as previously discussed. If funded over a 20-year period, the annual debt service would be approximately $69,500 at an interest rate of 2% per year. The data suggest that the cost per Mgal will increase to approximately $4.82 per Mgal when this cost is included in the operations budget, assuming no tank reserve. This cost would increase the average water bill to about $434 per 120 HCF, close to the state average residential water bill.

5.5.5. Scenario 4 – Fund Main Replacement Reserve

The JBCC water distribution system contains about 260,000 lineal feet of water mains. The majority of the distribution system mains are 6-inch, 8-inch and 10-inch diameter cast iron and asbestos cement as previously described. Most cast iron water mains have useful lives in excess of 75 years if routinely flushed and maintained. The asbestos cement mains are much less durable but likely have useful lives of about 75 years as well. The useful life of a cast iron main can be extended substantially by installing have new cement liners. For the purposes of this evaluation, we will assume that the entire distribution system will require eventually replacement over a 100-year period, or 1% of the total length of the system per year, or about 2,600 lineal feet of main replacement per year.

Water mains smaller than 8-inch, are normally not installed any longer, because of the small cost differential to increase to 8-inch diameter pipe. An 8-inch diameter main provides tremendous flow benefits over 6-inch diameter mains. Similarly, 10-inch mains are an atypical main size, normally replaced with a 12-inch pipeline. Based on recent bid pricing, our cost model assumes that an average 8-main complete with road restoration, new hydrants, and fittings will cost about $135/foot including engineering and contingencies. On this basis, an annual main replacement budget of $351,000 would be required without annual escalators for inflation.

The data suggests that the cost per Mgal will increase to approximately $9.15 per Mgal when this cost is included in the operations budget, excluding other identified needs such as metering and tank rehabilitation costs. This cost would increase the average water bill to about $823 per 120 HCF, well above the average public water costs in Massachusetts.

It should be recognized that many public water systems do not meet his high standard for full replacement of all pipelines very 100 years or 1% per year. Should the water system assets be required, the rate of pipe replacement should be subject to further discussion. These high costs illustrate the challenge with acquiring and modernizing the JBCC water distribution system. The mains are almost fully depreciated and will now require a routine pipe replacement program to modernize the piping network without the benefit of an existing sinking fund. The analysis

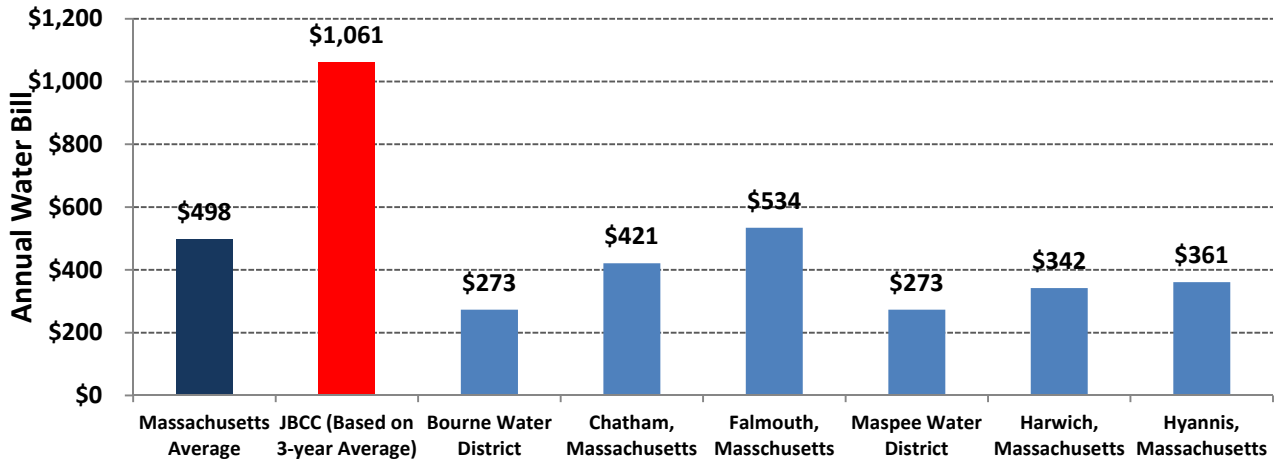
assumes no new debt service to acquire the system and assumes that progressing replacement or rehabilitation of all piping would be completed over the next 100 years at a rate of 2,600 feet per year. It is recommended that a leak detection survey of the entire system be completed initially so that break history and poor quality pipes can be prioritized early in the program.

If the water system were to be acquired, MassDevelopment could establish a rate goal or target water rate for the water system as a way to determine what level of subsidy would be required to fund the needed capital investment in the system.

5.5.6. Scenario 5 – Fund All Recommended Improvements

Scenario 5 includes all the investments included in Scenarios 2 through 4 as well as current operating costs captured in Scenario 1. Under this all-encompassing approach, the cost per Mgal purchased would increase to approximately $11.79 including capital reserve accounts, pipe replacement and metering. Again this cost would exclude any debt service to acquire the water system assets. These data suggest that to properly maintain and operate the current assets, a subsidy from the seller would likely be needed to support revenue requirements if a rate goal somewhat typical for the Commonwealth is desired. Refer to **Figure 5-8** for a comparison to annual water bills in other communities if Scenario 5 was implemented.

Figure 5-8 – Comparison to Annual Water Bills based on 120 HCF for Scenario 5



5.5.7. Summary of Alternatives

Data from the 5 investment alternatives are summarized in **Table 5-2** below. In customary water utility rate making, revenue projections are used to develop a graduated rate scale or cost blocks for various user classes. Normally an increasing block structure is preferred to penalize water high water use and to incentivize water conservation.

TABLE 5-2
PROJECTED ANNUAL REVENUE REQUIREMENT FOR ALTERNATIVES

	Scenario 1 Existing Conditions	Scenario 2 Tank Replacement Reserve	Scenario 3 Meter Installation Reserve	Scenario 4 Main Replacement Reserve	Scenario 5 All Improvements
Current Operating Costs	$251,900	$251,900	$251,900	$251,900	$251,900
Additional Annual Costs Investment	-	$114,000	$69,500	$351,000	$534,500
Total Annual Costs	$251,900	$365,900	$321,400	$602,900	$786,400
Projected Cost per Mgal	$3.79	$5.50	$4.82	$9.04	$11.79
Projected Total Annual Cost per 120 HCF Usage	$341	$495	$434	$823	$1,061

A rate study would develop an appropriate rate schedule and allocate cost based on various cost categories such as minimum quarterly charges, use of consumption costs, meter installation charges and other techniques to distribute and allocate cost. A rate study would be needed if the water system is privatized to determine how the owner of the system wishes to create incentives to encourage or discourage water use. If MassDevelopment intends to take this system over, a more detailed rate study is recommended.

5.5.8. Net Present Value Calculations for Each Scenario

Net present value (NPV) is a useful analysis for comparing the life cycle cost of alternative investments. However, the annual revenue requirements to operate a system and debt service are

what must be supported through water rates. The data in **Table 5-3** are based on the following assumptions:

- Acquire assets at no cost
- 20-year period
- Discount factor of 2%
- No annual escalators included for inflation
- Annual operating costs after year 20 are not included
- No residual value was included for J-Well, storage tanks or distribution system piping

This data will be useful in determining if a subsidy from the JBCC may be needed to support a sustainable water system at water rates that are marketable to outside parties and fair and reasonable when compared to similar water systems.

TABLE 5-3
PROJECTED NET PRESENT VALUE FOR ALTERNATIVES

Improvement Scenario	Projected Annual Revenue Requirements	Estimated Net Present Value (NPV)	Net Increase in NPV from Baseline
Scenario 1 – Baseline Conditions, No Improvements	$251,900	$4,112,000	-
Scenario 2 – Establish Sinking Find for Tank Rehabilitation in 15-years	$365,900	$5,978,000	$1,866,000
Scenario 3 – Install Service Meters on All services	$321,400	$5,254,000	$1,143,000
Scenario 4 – Replace 2,600 feet of Water Mains Each Year	$602,900	$9,986,000	$5,874,000
Scenario 5 – All Improvements made for Scenarios 2-4	$786,400	$12,843,000	$8,731,000

The following strategies should be explored to reduce operating costs and/or to increase revenue to help fund the recommended reserve accounts:

- Reducing reliance on the J-Well to lower operating costs (note that this will be sufficient to cover the additional revenue needs).
- Marketing surplus water from the J-Well to outside partners to generate revenue.

- Transferring ownership of the J-Well and appurtenances to the UCRWSC in exchange for a higher water allowance and a lower "wholesale" rate.

Business case analysis of the water system is beyond the scope of Delivery Order #11 and #12. Based on evaluations to date, it appears that it will be more difficult to fund the water system budget shortfalls given that there is not a large regional water demand (as compared to the anticipated wastewater demand). If MassDevelopment intends to take over the water system, we recommend that it be incorporated into the business case model developed for the wastewater system in order to better assess the necessary user rates.

5.6 REGULATORY CONSIDERATIONS

From a regulatory perspective, the JBCC water supply appears secure for the future. The UCRWSC agreement was enacted through specific legislation and the J-Well supply is registered as a supply with the DEP. Transfer of ownership of the J-Well or sale of water to outside parties may trigger the inter-basin transfer regulations and MEPA and should be investigated before any of these actions are pursued. Refer **Section 2.7** for further discussion of regulatory issues.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 WASTEWATER SYSTEM

Based on our evaluations, we offer the following conclusions and recommendations regarding the JBCC wastewater system:

- The collection system is reportedly in fair to poor condition.
    a. Based on pipe material and age, approximately 15% of the collection system piping will exceed its design life in the next 10 years (i.e., asbestos cement and orangeburg pipe) and an additional 80% of the collection system piping will exceed its design life within 20 years (i.e., vitrified clay). The system will require consistent investment over time to maintain the current level of service.
    b. The collection system is extensive and was built when there were 70,000 users on-site; whereas, there are currently approximately 3,500 users. The extent of the collection is much larger than is currently needed; however, the system is adequate to meet the existing JBCC needs. Portions of the system could be capped, if desired, to minimize long-term asset management costs.
    c. The collection system exhibits evidence of *inflow* (i.e., water entering the system typically during and immediately following storm events), which reduces available capacity, as noted below.
    d. Staffing limitations force the operators to focus on the WWTF and not on the collection system. The operators appear to have lesser knowledge of the condition of the collection system.

- The WWTF is in good condition.
    a. The WWTF has approximately **157,000 gpd (annual average)** of unused capacity.
    b. Effluent from the WWTF has exceeded the GWDP limits for nitrate and/or total nitrogen in 11 of the 27 months between January 2012 and April 2014. These

exceedences are related to the variability of influent wastewater temperatures, flows and loads associated with base operations and with infiltration/inflow.

c. Some capital improvements (i.e., influent equalization and supplemental carbon feed systems) are warranted in order to improve operational flexibility for GWDP compliance.

d. The WWTF remaining capacity could be made available to additional users on JBCC, to neighboring municipalities or to septage haulers after baseline capital improvements are implemented to accept additional flows.

- The effluent forcemain piping and structures are reportedly in good physical condition; however, based on operator input, the effluent forcemain appears to have capacity limitations related to apparent hydraulic transient conditions which occur when more than one effluent pump is running. Capital improvements may be needed in order to restore/provide additional capacity. At a minimum, additional study is warranted to determine the specific cause of the capacity limitations. We have included costs for additional study and for limited capital improvements to address forcemain capacity concerns.

- The effluent disposal system is in good condition.

  a. The effluent disposal system has approximately 157,000 gpd of additional capacity on an annual average basis. On a maximum day basis (due to the impacts of inflow), the effluent disposal system has approximately 285,000 gpd of additional capacity. Given that the existing peaking factor for peak to average flows is 3.8:1 (again, due primarily to the impacts of inflow), the *effective capacity* is approximately **75,000 gpd (annual average)**. Refer to **Section 2** for additional information. Available capacity can be made available to neighboring communities or users on the base.

  b. The *effective capacity* can be increased back to the full unused capacity with aggressive inflow control**.** The *effective capacity* at the effluent disposal system can also be increased within the existing GWDP by: addressing the effluent

forcemain capacity limitations; bringing on customers with low wastewater flow peaking factors; and/or by providing equalization at the WWTF. It is expected that DEP would be receptive to these types of measures.

c. The capacity could potentially be further increased by re-rating the RIBs through a GWDP revision. This would require hydrogeologic study and DEP review and approval. Re-rating the RIBs will be more difficult to attain than addressing the effective capacity as described above.

- There are numerous potential risks associated with the take-over of a wastewater utility such as the JBCC wastewater system; however, it is important to understand that these risks are inherent to sewerage infrastructure and are similar to those faced by many small municipal wastewater systems throughout New England. A summary of these risks is presented in **Table 4-1**.

- There are several JBCC-specific items which MassDevelopment should consider in its negotiations with USAF/ANG, including items such as segregating liability related to legacy pollutants, obtaining consent for "right of access to inspect" through the Sewer Use Ordinance and Industrial Pre-Treatment Program, etc. These are described in **Section 4**.

- MassDevelopment has a goal of creating a sustainability utility and rate structure within a 10-year timeframe. MassDevelopment also has a goal of ultimately transferring ownership to another municipal or quasi-municipal entity; however, MassDevelopment intends to own and operate the wastewater system until such time as the subsequent owner is identified and asset transfer is completed.

- Based on the steady-state balance sheet analysis described in **Section 3**, MassDevelopment should not pay for the wastewater system assets. Additional information and conclusions are presented in Section 3. Key conclusions from this analysis are:

a. A subsidy is required in the first 5 years, declining from the first to the fifth year.
b. For Alternative 1D, net surplus revenue begins between Year 6 and 8.
c. For Alternative 2D, net surplus revenue begins between Year 12 and 14.
d. A sensitivity analysis shows that the net surplus revenue generated from the various scenarios will improve (or not worsen) if the user rates and operational costs are increased with inflation.

- If MassDevelopment can support the capital investments described herein, then then we recommend implementing **Alternative 1D** (i.e., baseline improvements with upgrades to accept some new sewage as well as septage and effluent disposal). Alternative 1D has a higher net present value, has less risk and fewer regulatory, institutional and financial complexities.

- If MassDevelopment can secure binding commitments from potential new users (commitment to connect, financially contribute, pay user rates and abide by the sewer use ordinance), then the JBCC wastewater system could be expanded to **Alternative 2D** (i.e., 50% capacity expansion with upgrades to accept new sewage, septage and effluent disposal) now or in the future. One example would be Mashpee securing Town Meeting approval(s) to proceed to implementation of its CWMP.

6.2 WATER SYSTEM

Based on our evaluations, we offer the following conclusions and recommendations regarding the JBCC water system:

- Water Supply
    a. The J-well and appurtenances are in good condition and should be serviceable for another 15 to 20 years without the need for major capital expenditures.
    b. The UCRWSC interconnection meter and appurtenances were not inspected but are relatively new and it is our understanding that they are in good working order. The meter should be calibrated every 3 to 5 years.

c. The J-Well and the interconnection with the UCRWSC are each sufficient to meet the needs of the JBCC. Having both supplies available provides redundancy and protects the JBCC system from having the J-Well declassified as an "inactive supply" through lack of use.

d. The J-Well is a large, relatively high quality supply operating through a DEP Registration Statement. MassDevelopment could sell reserve supply capacity to other surrounding local utilities as a source of revenue without compromising safe delivery of water within the JBCC geographic boundaries. Alternatively, MassDevelopment could transfer ownership of the J-well to the UCRWSC in exchange for a higher water supply allocation through the interconnection. The needs of the UCRWSC and the surrounding municipalities, utilities and/or industrial/commercial partners should be assessed.

- Water Storage Tanks

  a. The two 400,000-gallon water storage tanks are nearly 75 years old. Both tanks will have new coating systems by the end of next year and will be ready for the next maintenance cycle. Both tanks will likely require replacement within 15 years. This type of elevated storage tank is outdated and can likely be replaced in the future with a standpipe, or modern elevated tank. We recommend establishing a capital reserve account in the amount of $57,000 per year per tank to create a sufficient fund to rehabilitate the tanks in 15 years.

  b. The active storage volume in the two storage tanks is about 800,000 gallons. From a fire suppression perspective, the storage tanks have adequate volume and elevation to meet the needs at JBCC.

- Water Distribution System

  a. The water distribution system is comprised of 49 miles of water mains. The system consists primarily of small diameter 6, 8 and 10-inch mains were constructed in the 1940s and 1950s. The mains are primarily cast iron and asbestos cement pipelines. Most mains date back to the early inception of the

system; records are poor and leaks have become more common in recent years. A pipe renewal program is needed to begin modernizing the distribution system.

b. We recommend establishing an annual replacement program of 2,600 feet of new main a year will result in complete replacement of the distribution system in 100 years. Although recent evidence suggests that some older cast iron mains can remain serviceable for more than 100 years, the system must catch up from lack of maintenance. The estimated cost to replace mains at this rate is $351,000 per year.

c. We recommended conducting a leak detection survey of the entire distribution system in order to establish priority for main renewals in the JBCC water system.

- Service Metering
  a. Presently, service connections to all buildings and structures are unmetered. Water use is estimated using a demand algorithm developed by JBCC utility managers.
  b. We recommend that service meters be installed at each structure, including a new meter, meter horn to mount the meter and a touchpad meter reading service mounted on the outside of each building. Radio read technology is the state of the art approach in water metering but would be more costly than the basic system proposed herein. The estimated cost for a basic meter installation for the estimated 380 service connections in the JBCC system is $1,140,000 (based on a $3,000 allocation per service connection).

- Budgeting for Recommended Reserve Accounts
  a. We recommend the establishment of several reserve accounts (i.e., for storage tanks, service meters and main replacement/rehabilitation) in order preserve and maintain the water system assets. Funding these reserve accounts would result in a significant increase in the annual budget requirements for the water system. The existing water system budget is approximately $252,000 per year. If all of these

reserve accounts were funded to the suggested levels, the annual budget would increase to approximately $534,000.

b. This would increase the cost of service from $3.79/Mgal to $11.79/Mgal. Based on 120 hundred cubic feet (HCF) of consumption, this would equate to an annual bill ranging from $340 to $1,060, respectively. By way of comparison, the average water bill in the Commonwealth of Massachusetts for 120 HCF of consumption is about $498/year.

- Opinion of Water System Valuation
    a. Given the condition of the existing water system and the upcoming asset management needs, MassDevelopment should not pay for the water system assets.
    b. Further, the water system should not be acquired without the wastewater system as the wastewater system has a larger user base and has a greater ability to gather revenue from regional partners to help supplement reserve accounts and maintain stable rates.
    c. If the water system assets were to be transferred to MassDevelopment at no cost, the operating costs plus the recommended investments would require revenue for water sales to be increased. This would require rate increases to existing military and non-military users.
    d. Selling surplus water outside JBCCs boundaries could present an opportunity to raise revenue to offset costs or reduce the need for a subsidy. Transferring ownership of the J-Well and appurtenances to the UCRWSC in exchange for a higher water allowance and a lower "wholesale" rate may also provide a similar benefit.
    e. While sale of wastewater capacity will produce revenue sufficient to fund *wastewater reserve accounts*, it will not produce revenue sufficient to also fund *water reserve accounts*. The "optimized best case" sewer user rates (refer to Section 4) provide the most net surplus revenue.

- Opinion of Water System Valuation
    a. We recommend conducting a more detailed evaluation to develop an appropriate rate schedule and allocate cost based on various cost categories such as minimum quarterly charges, use of consumption costs, meter installation charges and other techniques to distribute and allocate cost. In customary water utility rate making, revenue projections are used to develop a graduated rate scale or cost blocks for various user classes. Typically, an increasing block structure is preferred to incentivize water conservation.

6.3 IMPLEMENTATION STEPS

6.3.1. Wastewater System

As MassDevelopment considers assuming ownership and responsibility for the JBCC wastewater system, we recommend the following key implementation steps for Scenario 1D:

1. Meet with JBCC to provide an informal status update on the project.
2. Develop a negotiating strategy and initial proposal.
3. Meet with the USAF and ANG to discuss an initial draft proposal.
    a. Define military protocols and timeframes for review and approval of a subsequent formal proposal.
    b. Request preliminary review and comments from the military on the form of the proposal and preliminary indication of the willingness of the USAF to enter formal negotiations for the transfer of the system under the terms of the proposal.
4. Determine eligibility for state SRF loans and develop financing plan
5. Meet with interested towns, DEP and Cape Cod Commission to define issues, implementation processes, and timeframe for connecting to the JBCC system. Request a letter of interest or commitment from selected neighboring municipalities.
6. Draft, modify and execute a joint Memorandum of Understanding (MOU) among appropriate parties (including the military) that defines the interests, process, roles, responsibilities, assumptions and funding framework for jointly investigating beneficial options for the JBCC wastewater system.

7. Coordinate and/or conduct additional targeted studies on wastewater system components for the purpose of mitigating risk (i.e., by refining cost estimates or by confirming revenue sources). Specific studies should be considered include field inspections of select portions of the collection system, field inspections of select portions of the effluent forcemain, operational reviews at the WWTF, "re-rating" analysis for the RIBs, determination of the appropriate effluent limits to be met by new "effluent disposal users" as well as follow-on rate work to refine the business case model. Funding for the studies would be as defined in the MOU.
8. Update the initial proposal based on findings of additional studies and enter negotiations with the USAF and ANG.
9. Evaluate the benefits of using a design-build-operate (D/B/O) contract for project implementation. Solicit or otherwise develop more detailed preliminary "bids" or estimates for contract operations of the systems under various investment and operating scenarios.
10. Refine the business plan to reflect actual needs and interests as defined by the towns, including revised flows, loads, capital and operating costs, connection fees, user fees, governance structure, financing methods and other factors that provide a firm basis for town decisions based on the particular wastewater services being provided to each town through the plan.
11. Apply for interim and permanent financing for the upgrades under the authority of the agreed-upon governing entity.
12. Draft and enact legislation to authorize use D/B/O procurement and implementation for the project improvements and operations.
13. Refine the risk management plan for MassDevelopment based on studies, discussions and other information.
14. Enter final negotiations with the USAF for transfer of the system. Confirm terms, conditions, agreements and assumptions. Finalize and execute agreement between MassDevelopment and the USAF for transfer of facilities. Conduct transfer of the assets and permits.

15. Initiate procurement for a contract operator or D/B/O contractor for the JBCC wastewater system. D/B/O Contractor will develop and attain regulatory approval of Sewer Use Ordinance and Industrial Pre-Treatment Program documents. Issue draft industrial user permits to applicable existing users.

For Scenario 2D, we recommend an additional step prior to committing to capital project(s) in order to increase capacity. Specifically, securing verification in the revised business plan of the viability and benefit of one or more joint wastewater arrangements (e.g. wastewater district, IMAs), draft, negotiate and execute agreements, enact legislation and complete other legal and administrative actions necessary to bind parties to their responsibilities under the plan. This step would include the necessary town meeting(s) and other approvals necessary to commit funding.

6.3.2. Water System

As MassDevelopment considers assuming ownership and responsibility for the JBCC water system, we recommend the following key implementation steps:

1. If the wastewater system transfer appears likely:
   a) Expand the wastewater business case model to include the water system costs and revenues;
   b) Meet with the UCRWSC, DEP and the Cape Cod Commission to discuss the potential to transfer ownership of the J-well to the UCRWSC and increase of the JBCC water allocation. Potentially meet with neighboring municipalities to assess their needs for supplemental water supply under MassDevelopment ownership. Request a letter of interest or commitment from the relevant entities.
2. Develop a negotiating strategy and initial proposal for the water system.
3. Meet with the USAF and ANG to discuss an initial proposal.
4. If MassDevelopment, USAF and ANG are in general agreement with the initial draft proposal, align the water system acquisition tasks with the wastewater system acquisition tasks as described in Section 1.6.1.

6.3.3. Implementation Timeline

A preliminary implementation timeline is presented in **Table 6-1**. The timeline shows a range of dates for each major action item. In terms of the range of dates, Scenario 1D has less uncertainty than Scenario 2D primarily because it does not rely on appropriations from a municipal entity.

TABLE 6-1
IMPLEMENTATION TIMELINE

Implementation Task	Timeline
Develop a negotiating strategy and initial proposal for the wastewater system. Meet with USAF/ANG to discuss initial proposal. Develop a preliminary agreement.	2015
Meet with neighboring municipalities, CCC and DEP to define a framework for regional use of the wastewater system. Request a letter of interest or commitment from the relevant entities.	2015
Meet with the Upper Cape Regional Water Supply Cooperative, CCC and DEP to discuss potential transfer of ownership of the J-well to the UCRWSC. Request a letter of interest or commitment.	2015
Determine SRF loan eligibility for the wastewater system.	2015
Develop Memorandum of Understanding among all interested parties for the wastewater and water systems.	2015
Complete Engineering Studies (wastewater and water)	2015 to 2016
Gather financial commitments from applicable potential users	2015 to 2020 (1)
Evaluate D/B/O procurement method. Draft and enact legislation as appropriate. Procure contractor operator.	2015 to 2016
Complete legal transfer of ownership	2016 to 2017
Design, construct and commission upgrades	2016 to 2020 (1)
Collect Connection Fees from New Users	2016 to 2020 (1)
Begin Loan Repayment on New Debt	2018 to 2021 (1)
Receive Flow from New Users	2018 to 2021 (1)

Notes:1) Financial commitments from municipalities are subject to Town Meeting appropriation which may take several years.

7 REFERENCES

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Sagamore Lens Sustainable Management of water Resources Plan, Upper Cape Regional Water Supply Cooperative, Tata and Howard In., April 2014

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APPENDIX A
GROUNDWATER DISCHARGE PERMIT
WWTF BASIC DESIGN CRITERIA

Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

One Winter Street Boston, MA 02108 • 617-292-5500

DEVAL L. PATRICK
Governor

TIMOTHY P. MURRAY
Lieutenant Governor

RICHARD K. SULLIVAN JR.
Secretary

KENNETH L. KIMMELL
Commissioner

October 31, 2012

Emily Rose Ware
Massachusetts Air National Guard
197 Granville Avenue, Box 46
Otis ANG Base, MA 02542

Dear Groundwater Discharge Permittee:

I am writing to inform you of recent legislative developments and how they affect your Groundwater Discharge Permit renewal timeline.

In August 2010, Governor Patrick signed Chapter 240 of the Acts of 2010 into law. Section 173 of this Act is known as the Permit Extension Act ("PEA" or "the Act"). In August 2012, Governor Patrick signed Chapter 238 of the Acts of 2012, which included two sections amending the PEA. As amended, the Act automatically extends (with limited exceptions), for four years beyond its otherwise applicable expiration date, any permit or approval for the use or development of property that was "in effect or existence" during the qualifying period beginning on August 15, 2008, and extending through August 15, 2012.

The Permit Extension Act's provisions have extended the term of your Groundwater Discharge Permit, # 41-3 issued to Otis AFB in Sandwich, as it was in effect during the specified time period. This permit will now expire on 4/23/2018. **Please do not submit a permit renewal application at this time. Your renewal application for this permit will now be due on 10/25/2017, six months prior to the new expiration date.** We apologize for any time that you may have spent preparing your permit renewal application and suggest you hold on to those materials developed to date in anticipation of your future filing. Until then your existing permit continues in effect.

Please contact Marybeth Chubb at (617) 556-1029 or Linda Barba at (617) 556-1150 if you have any questions regarding your permit's status or the effect of the Permit Extension Act.

Sincerely,

David R Ferris

David Ferris, Program Director
Wastewater Management Program

cc: DEP/SERO

This information is available in alternate format. Call Michelle Waters-Ekanem, Diversity Director, at 617-292-5751. TDD# 1-866-539-7622 or 1-617-574-6868
MassDEP Website: www.mass.gov/dep
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COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY & ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION
SOUTHEAST REGIONAL OFFICE
20 RIVERSIDE DRIVE, LAKEVILLE, MA 02347 508-946-2700

DEVAL L. PATRICK
Governor

TIMOTHY P. MURRAY
Lieutenant Governor

IAN A. BOWLES
Secretary

LAURIE BURT
Commissioner

April 23, 2009

Emily R. Ware
102nd Intelligence Wing
197 Granville Avenue, Box 46
Otis Air National Guard Base, MA 02542

RE: BRPWP12, Otis ANG Base Wastewater Treatment Facility
Permit No.: 41-3
Transmittal No. W227706

Dear Ms. Ware:

The Department has completed its review of your request for a change to the existing permit to discharge treated wastewater from the facility located at the Otis ANG Base Wastewater Treatment Facility to the ground and after due public notice, hereby issues the enclosed final permit.

The Department, during the public comment period, received no comments objecting to the issuance or terms of this permit. Therefore, in accordance with 314 CMR 2.08, the permit becomes effective upon issuance.

Parties aggrieved by the issuance of this permit are hereby advised of their right to request an Adjudicatory Hearing under the provision of Chapter 30A of the Massachusetts General Laws and 314 CMR 1.00: Rules for the Conduct of Adjudicatory Proceeding. Unless the person requesting the adjudicatory hearing requests and is granted a stay of the terms and conditions of the permit, the permit shall remain fully effective.

Should you have any questions regarding this matter, please contact Christos Dimisioris at (508) 946-2736.

Very truly yours,

for Brian A. Dudley
Bureau of Resource Protection

This information is available in alternate format. Call Donald M. Gomes, ADA Coordinator at 617-556-1057. TDD Service - 1-800-298-2207.

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COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY & ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION

GROUNDWATER DISCHARGE PERMIT

Name and Address of Applicant: ***102nd Intelligence Wing, 197 Granville Avenue, Box 46, Otis Air National Guard, MA 02542.***

Date of Application:	***July 10, 2008***
Application/Permit No.	***41-3***
Date of Issuance:	***April 23, 2009***
Date of Expiration:	***April 23, 2014***
Effective Date:	***April 23, 2009***

AUTHORITY FOR ISSUANCE

Pursuant to authority granted by Chapter 21, Sections 26-53 of the Massachusetts General Laws, as amended, 314 CMR 2.00, and 314 CMR 5.00, the Massachusetts Department of Environmental Protection (the Department) hereby issues the following permit to: 102nd Intelligence Wing (hereinafter called "the permittee") authorizing discharges from the on-site wastewater treatment facility to the ground located at 971 South Outer Road, Otis Air National Guard Base, MA 02542, such authorization being expressly conditional on compliance by the permittee with all terms and conditions of the permit hereinafter set forth.

for Brian A. Dudley
Bureau of Resource Protection

4/23/09
Date

This information is available in alternate format. Call Donald M. Gomes, ADA Coordinator at 617-556-1057. TDD Service - 1-800-298-2207.

DEP on the World Wide Web: http://www.mass.gov/dep

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I. SPECIAL CONDITIONS

A. Effluent Limits

The permittee is authorized to discharge into the ground from the wastewater treatment facilities for which this permit is issued a treated effluent whose characteristics shall not exceed the following values:

Effluent Characteristics	Discharge Limitations
12 month moving average flow	360,000 GPD
Maximum day flow	840,000 GPD
Oil and grease	15 mg/l
Total Suspended Solids (TSS)	30 mg/l
Total Nitrogen (NO_2 + NO_3 + TKN)	10 mg/l
Nitrate-Nitrogen	10 mg/l
Biochemical Oxygen Demand, 5-day @20°C (BOD_5)	30 mg/l
Fecal Coliform	200 colonies / 100 ml

a) The pH of the effluent shall not be less than 6.5 nor greater than 8.5 at any time.

b) The discharge of the effluent shall not result in any demonstrable adverse effect on the groundwater or violate any water quality standards that have been promulgated.

c) The monthly average concentration of BOD and TSS in the discharge shall not exceed 15 percent of the monthly average concentrations of BOD and TSS in the influent into the permittee's wastewater treatment facility.

d) When the average annual flow exceeds 80 percent of the permitted flow limitations, the permittee shall submit a report to the Department describing what steps the permittee will take in order to remain in compliance with the permit limitations and conditions, inclusive of the flow limitations established in this permit.

B. Monitoring and Reporting

1) INFLUENT:

The permittee shall monitor and record the quality of the **influent** waste stream to the facility according to the following schedule and other provisions:

Parameter	Minimum Frequency of Analysis	Sample Type
BOD_5	Monthly	24-Hour Composite
Total Suspended Solids	Monthly	24-Hour Composite
Total Solids	Monthly	24-Hour Composite
Ammonia Nitrogen	Monthly	24-Hour Composite

EFFLUENT:

The permittee shall monitor and record the quality and quantity of **effluent** at the effluent pump chamber to the leaching area according to the following schedule and other provisions:

Parameter	Minimum Frequency of Analysis	Sample Type
Flow	Daily	Meter reading
pH	Daily	Grab
Total Suspended Solids	Monthly	24-Hour Composite
Total Solids	Monthly	24-Hour Composite
Oil & Grease	Monthly	Grab
BOD_5	Monthly	24-Hour Composite
Nitrate Nitrogen	Monthly	24-Hour Composite
Total Nitrogen (NO_2 + NO_3 + TKN)	Monthly	24-Hour Composite
Fecal Coliform	Monthly	Grab

Total Phosphorus (as P) [2]	Monthly	Grab
Orthophosphate (as P) [2]	Monthly	Grab
Volatile Organic Compounds[1]	Monthly	Grab

[1]USEPA Method #624
[2]After one full year of monitoring the Total Phosphorus and Orthophosphate results, the Department may determine, upon the request of the permittee, that the frequency of monitoring may be reduced if, in the judgement of the Department, the results of the sampling indicate that existing phosphorus levels will not adversely impact downgradient receptors.

2) The permittee shall sample the upgradient monitoring well: MW16 and the downgradient monitoring wells MW13, MW14 and MW15 as shown on a plan titled "Otis Air National Guard Effluent Force Main and Infiltration Basins" sheet 4 of 55, dated August 12, 1993. Labels identifying each monitoring well's identification in accordance with the above-referenced approved plan shall be affixed to the steel protective casing of each monitoring well.

The permittee shall monitor, record and report the quality of water in the monitoring wells according to the following schedule and other provisions:

Parameter	**Frequency of Analysis**
Static Water Level[1]	Monthly
Specific Conductance	Monthly
pH	Monthly
Total Nitrogen (NO_2+NO_3+TKN)	Quarterly
Nitrate-Nitrogen	Quarterly
Total Phosphorus (as P) [2]	Quarterly
Orthophosphate (as P) [2]	Quarterly
Volatile Organic Compounds[3]	Annually

[1]Static Water Level shall be expressed as an elevation and shall be referenced to the surveyed datum established for the site. It shall be calculated by subtracting the depth to the water table from the surveyed elevation of the top of the monitoring well's PVC well casing/riser.

[2]After one full year of monitoring the Total Phosphorus and Orthophosphate results, the Department may determine, upon the request of the permittee, that the frequency of monitoring may be reduced if, in the judgement of the Department, the results of the sampling indicate that existing phosphorus levels will not adversely impact downgradient receptors.
[3]USEPA Method #624

3) Any grab sample or composite sample required to be taken less frequently than daily shall be taken during the period of Monday through Friday inclusive. All composite samples shall be taken over the operating day.

The permittee shall submit all monitoring reports within 30 days of the last day of the reporting month. Reports shall be on an acceptable form, properly filled and signed and shall be sent to:

Department of Environmental Protection
Southeast Regional Office
20 Riverside Drive
Lakeville, MA 02347

Director of Watershed Permitting
Department of Environmental Protection
Watershed Permitting Group
One Winter Street
Boston, MA 02108

Bourne Board of Health
24 Perry Avenue
Buzzards Bay, Bourne, MA 02532

Mashpee Health Department
16 Great Neck Road North
Mashpee, Massachusetts 02649

Sandwich Board of Health
16 Jan Sebastian Drive
Sandwich, Massachusetts 02563

Submission of monitoring reports in electronic format is available through eDEP and serves as data submission to both the Regional and Boston offices. To register for electronic submission go to: *http://www.mass.gov/dep/service/compliance/edeponlf.htm*

C. Supplemental Conditions

1. The permittee shall notify the Department at least thirty (30) days in advance of the proposed transfer of ownership of the treatment works for which this permit is written. Said notification shall include a written agreement between the existing and new permittees containing a specific date for transfer of permit, responsibility, coverage and liability between them.
2. A staffing plan for the treatment works shall be submitted to the Department once every two years and whenever there are staffing changes. The staffing plan shall include the following components:
   a) The operator(s)'s name(s), operator grade(s) and operator license number(s);
   b) The number of operational days per week;
   c) The number of operational shifts per week;
   d) The number of shifts per day;
   e) The required personnel per shift;
   f) Saturday, Sunday and holiday staff coverage;
   g) Emergency operating personnel
3. The permittee is responsible for the operation and maintenance of all sewers, pump stations, and treatment units for the permitted facility, which shall be operated and maintained under the direction of a properly certified wastewater operator.
4. The permittee shall contract to have any and all solids and sludges generated by the treatment works for which this permit is issued removed off site by a properly licensed waste hauler for disposal at an EPA/DEP approved facility. The name and license number of the hauler along with the quantity of wastes removed and the date(s) of removal shall be reported by the permittee in writing to the Department.
5. Operation and maintenance of the proposed facility must be in accordance with 314 CMR 12.00, "Operation and Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Discharges", and, 257 CMR 2.00, "Rules and Regulations for Certification of Operators of Wastewater Treatment Facilities.
   a. The facility has been rated (in accordance with 257 CMR 2.00), to be a Grade 5 facility. Therefore, the permittee shall provide for oversight by a Massachusetts Certified Wastewater Treatment plant operator (Chief Operator) Grade 5 or higher. The permittee will also provide for a backup operator who shall possess at least a valid Grade 5 license.
   b. The date and time of the operator's inspection along with the operator's name and certification shall be recorded on the required monthly monitoring reports.
6. If the operation and maintenance of the facility is contracted to a private concern, the permittee shall submit a copy of the contract, consistent with what is required by the approved Operation & Maintenance manual and signed only by the contractor, to the appropriate MassDEP Regional Office within thirty days of permit issuance. Along with the contract, a detailed listing of all contract operation obligations of the proposed contractor at other facilities shall also be submitted.
7. Any additional connections to the sewer system, beyond the facility as described on the approved plans shall be approved by MassDEP and the local Board of Health prior to the connection.

8. All tests or analytical determinations to determine compliance with permit standards and requirements shall be done using tests and procedures found in the most recent version of *Standard Methods for the Examination of Water and Wastewater* and shall be performed by a Massachusetts certified laboratory.
9. The permittee shall notify the Department, in writing, within thirty (30) days of the following events:
   a. Any interruption of the treatment system operation, other than routine maintenance.
   b. Final shutdown of the treatment system.
10. Simultaneously with the permit renewal application at year fifteen (2014) following the initiation of plant operations, the permittee shall submit two reports to the Department for its review and approval:
   a. an engineering report, prepared by a registered professional engineer, that outlines in sufficient detail what modifications (if any) to the facility or other changes are required to insure that the facility can remain in compliance with its GWDP and other applicable requirements through the next 5 year permit term (year 2019) and beyond; and
   b. a financial plan that contains the cost estimates for implementing the facility modifications or other changes identified in the engineering report, and describes and demonstrates, how and when the permittee will finance the needed facility modifications or other changes.
11. In the event that effluent limits are not met, or the groundwater quality in the down-gradient monitoring wells does not meet the groundwater quality standards for Class I groundwaters, the permittee may be obligated to modify, supplement or replace the permitted treatment process so as to ensure compliance with the groundwater quality standards.

D. Appeal Rights

This Permit is an action of the Department. Any person aggrieved by this action may request an Adjudicatory Hearing. A request for a hearing must be made in writing and postmarked within thirty (30) days of the Permit issuance date. Under 310 CMR 1.01(6)(b), the request must state clearly and concisely the facts, which are the grounds for the request, and the relief sought.

The Hearing request along with a valid check payable to the Commonwealth of Massachusetts in the amount of one hundred dollars ($100.00) must be mailed to:

Commonwealth of Massachusetts
Department of Environmental Protection
P.O. Box 4062
Boston, MA 02211

The request will be dismissed if the filing fee is not paid, unless the appellant is exempt or granted a waiver as described below. The filing fee is not required if the appellant is a city or town (or municipal agency), county, or district of the Commonwealth of Massachusetts, or a municipal housing authority. The Department may waive the adjudicatory hearing filing fee for a

person who shows that paying the fee will create an undue financial hardship. A person seeking a waiver must file, together with the hearing request as provided above, an affidavit setting forth the facts believed to support the claim of undue financial hardship

II. GENERAL PERMIT CONDITIONS

The following conditions apply to all permits:

1. No discharge authorized in the permit shall result in a violation of the Massachusetts Surface Water Quality Standards (314 CMR 4.00) or the Massachusetts Ground Water Quality Standards (314 CMR 6.00), or any amendments thereto. Upon promulgation of any amended standard, this permit may be revised or amended in accordance with such standard and 314 CMR 2.10 and 3.12 or 5.12. For purposes of determining compliance with ground water quality standards, a violation of the ground water quality standards, and the discharge permit, will be determined to occur when any parameter measured in any downgradient well exceeds the applicable criteria listed in 314 CMR 6.06. In those cases where it is shown that a measured parameter exceeds the applicable criteria listed in 314 CMR 6.06 at the upgradient monitoring well, a violation of the ground water quality standards and the discharge permit will be determined to occur when it is shown that a measured parameter in any downgradient well exceeds the level of that same measured parameter in the upgradient well for the same sampling period. A statistical procedure approved by the Department shall be used in determining when a measured parameter exceeds the allowable level.
2. Duty to comply. The permittee shall comply at all times with the terms and conditions of the permit, 314 CMR, M.G.L. c. 21, §§ 26 through 53 and all other applicable state and federal statutes and regulations.
3. Standards and prohibitions toxic pollutants. The permittee shall comply with effluent standards or prohibitions established under PL 92-500, § 307(a) for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.
4. Proper operation and maintenance. The permittee shall at all times properly operate and maintain all facilities and equipment installed or used to achieve compliance with the terms and conditions of the permit, and in accordance with 314 CMR 12.00.
5. Duty to halt or reduce activity. Upon reduction, loss, or failure of the treatment facility, the permittee shall, to the extent necessary to maintain compliance with its permit, control production or discharges or both until the facility is restored or an alternative method of treatment is provided. It shall not be a defense for a permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of the permit.
6. Power Failure. In order to maintain compliance with the effluent limitations and prohibitions of this permit, the permittee shall either:
   a. provide an alternative power source sufficient to operate the wastewater control facilities; or

b. halt, reduce or otherwise control production and/or all discharges upon the reduction, loss, or failure of the primary source of power to the wastewater control facilities.

7. Duty to mitigate. The permittee shall take all reasonable steps to minimize or prevent any adverse impact on human health or the environment resulting from non-compliance with the permit.

8. Duty to provide information. The permittee shall furnish to the Department within a reasonable time any information which the Department may request to determine whether cause exists for modifying, revoking and reissuing, or terminating the permit, or to determine whether the permittee is complying with the terms and conditions of the permit.

9. Inspection and entry. The permittee shall allow the Department or its authorized representatives to:
   a. Enter upon the permittee's premises where a regulated facility or activity is located or conducted, or where records required by the permit are kept;
   b. Have access to and copy, at reasonable times, any records that must be kept under the conditions of the permit;
   c. Inspect at reasonable times any facilities, equipment, practices, or operations regulated or required under the permit; and
   d. Sample or monitor at reasonable times for the purpose of determining compliance with the terms and conditions of the permit.

10. Monitoring. Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity. Monitoring must be conducted according to test procedures approved under 40 CFR Part 136 unless other test procedures are specified in the permit.

11. Record keeping. The permittee shall retain records of all monitoring information including all calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by the permit, and all records of all data used to complete the application for the permit, for a period of at least three years from the date of the sample, measurement, report or application. This period may be extended by request of the Department at any time.
    Records of monitoring information shall include:
    a. The date, exact place, and time of sampling or measurements;
    b. The individual(s) who performed the sampling or measurement;
    c. The date(s) analyses were performed;
    d. The individual(s) who performed the analyses;
    e. The analytical techniques or methods used; and
    f. The results of such analyses.

12. Prohibition of bypassing. Except as provided in 314 CMR 5.19(13), bypassing is prohibited, and the Department may take enforcement action against a permittee for bypassing, unless the discharge is to a surface water and:
    a. The bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;
    b. There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if the permittee

could have installed adequate backup equipment to prevent a bypass which occurred during normal periods of equipment downtime or preventive maintenance; and

c. The permittee submitted notice of the bypass to the Department:
   i. In the event of an anticipated bypass at least ten days in advance, if possible; or
   ii. In the event of an unanticipated bypass as soon as the permittee has knowledge of the bypass and no later than 24 hours after its first occurrence.

13. Bypass not exceeding limitations. The permittee may allow a bypass to occur which does not cause effluent limitations to be exceeded, but only if necessary for the performance of essential maintenance or to assure efficient operation of treatment facilities.

14. Permit actions. The permit may be modified, suspended, or revoked for cause. The filing of a request by the permittee for a permit modification, reissuance, or termination, or a notification of planned changes or anticipated non-compliance does not stay any permit condition.

15. Duty to reapply. If the permittee wishes to continue an activity regulated by the permit after the expiration date of the permit, the permittee must apply for and obtain a new permit. The permittee shall submit a new application at least 180 days before the expiration date of the existing permit, unless permission for a later date has been granted by the Department.

16. Property rights. The permit does not convey any property rights of any sort or any exclusive privilege.

17. Other laws. The issuance of a permit does not authorize any injury to persons or property or invasion of other private rights, nor does it relieve the permittee of its obligation to comply with any other applicable Federal, State, and local laws and regulations.

18. Oil and hazardous substance liability. Nothing in the permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties to which the permittee is or may be subject under PL 92-500, § 311, and M.G.L. c. 21E.

19. Removed substances. Solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters shall be disposed in a manner consistent with applicable Federal and State laws and regulations including, but not limited to, the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26 through 53 and the Clean Water Act, P.L. 92-500, as amended by P.L. 95-217 and P.L. 95-576, 33 U.S.C. 1251 *et seq*, the Massachusetts Hazardous Waste Management Act, M.G.L. c. 21C, and the federal Resource Conservation and Recovery Act, 42 U.S.C. § 6901, *et seq.*, 310 CMR 19.00 and 30.000, and other applicable regulations.

20. Reporting requirements.
   a. Monitoring reports. Monitoring results shall be reported on a Discharge Monitoring Report (DMR) at the intervals specified elsewhere in the permit. If the permittee monitors any pollutant more frequently than required by the permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the DMR.
   b. Compliance schedules. Reports of compliance or non-compliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of the permit shall be submitted no later than 14 days following each schedule date.

c. Planned changes. The permittee shall give notice to the Department as soon as possible of any planned physical alterations or additions to the permitted facility or activity which could significantly change the nature or increase the quantity of pollutants discharged. Unless and until the permit is modified, any new or increased discharge in excess of permit limits or not specifically authorized by the permit constitutes a violation.

d. Anticipated non-compliance. The permittee shall give advance notice to the Department of any planned changes in the permitted facility or activity which may result in non-compliance with permit requirements.

e. 24 hour reporting. The permittee shall report any non-compliance which may endanger health or the environment. Any information shall be provided orally within 24 hours from the time the permittee becomes aware of the circumstances. A written submission shall also be provided within five days of the time the permittee becomes aware of the circumstances. The written submission shall contain a description of the non-compliance, including exact dates and times, and if the non-compliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the non-compliance.

The following shall be included as information which must be reported within 24 hours:

i. Any unanticipated bypass which exceeds any effluent limitation in the permit.

ii. Violation of a maximum daily discharge limitation for any of the pollutants listed by the Department in the permit to be reported within 24 hours.

f. Other non-compliance. The permittee shall report all instances of non-compliance not reported under 314 CMR 5.19(20)(a), (b), or (e) at the time monitoring reports are submitted. The reports shall contain the information listed in 314 CMR 5.19(20)(e).

g. Toxics. All manufacturing, commercial, mining, or silvicultural dischargers must notify the Department as soon as they know or have reason to believe:

i. That any activity has occurred or will occur which would result in the discharge of any toxic pollutant listed in 314 CMR 3.16 which is not limited in the permit, if that discharge will exceed the highest of the following notification levels:

(1) 100 micrograms per liter (100 µg /l);

(2) 200 micrograms per liter (200 µg /l) for acrolein and acrylonitrile; 500 micrograms per liter (500 µg /l) for 2,4-dinitrophenol and for 2-methyl-4,6-dinitrophenol; and one milligram per liter (1 mg/l) for antimony;

(3) Five times the maximum concentration value reported for that pollutant in the permit application; or

ii. That they have begun or expect to begin to use or manufacture as an intermediate or final product or byproduct any toxic pollutant which was not reported in the permit application.

h. Indirect dischargers. All Publicly Owned Treatment Works shall provide adequate notice to the Department of the following:

i. Any new introduction of pollutants into the POTW from an indirect discharger which would be subject to PL 92-500, § 301 or 306 if it were directly discharging those pollutants; and

ii. Any substantial change in the volume or character of pollutants being introduced into the POTW by a source introducing pollutants into the POTW at the time of issuance of the permit.

iii. For purposes of 314 CMR 5.19, adequate notice shall include information on the quality and quantity of effluent introduced into the POTW, and any anticipated impact of the change on the quantity or quality of effluent to be discharged from the POTW.

i. Information. Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application or in any report to the Department, it shall promptly submit such facts or information.

21. Signatory requirement. All applications, reports, or information submitted to the Department shall be signed and certified in accordance with 314 CMR 3.14 and 5.14.

22. Severability. The provisions of the permit are severable, and if any provision of the permit, or the application of any provision of the permit to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of the permit, shall not be affected thereby.

23. Reopener clause. The Department reserves the right to make appropriate revisions to the permit in order to establish any appropriate effluent limitations, schedules of compliance, or other provisions which may be authorized under the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26 through 53 or the Clean Water Act, P.L. 92-500, as amended by P.L. 95-217 and P.L. 95-576, 33 U.S.C. 1251 *et seq* in order to bring all discharges into compliance with said statutes.

24. Approval of plans and specifications for treatment works. All discharges and associated treatment works authorized herein shall be consistent with the terms and conditions of this permit and the approved plans and specifications. Any modification to the approved treatment works shall require written approval of the Department.

25. Transfer of Permits.

a. RCRA facilities. Any permit which authorizes the operation of a RCRA facility which is subject to the requirements of 314 CMR 8.07 shall be valid only for the person to whom it is issued and may not be transferred.

b. Transfers by modification. Except as provided in 314 CMR 5.19(24)(a) and (c), a permit may be transferred by the permittee to a new owner or operator only if the permit has been modified or revoked and reissued or a minor modification made to identify the new permittee.

c. Automatic transfers. As an alternative to transfers under 314 CMR 5.19(24)(b), any permit may be automatically transferred to a new permittee if:

i. The current permittee notifies the Department at least 30 days in advance of the proposed transfer date in 314 CMR 5.19(2);

ii. The notice includes a written agreement between the existing and new permittees containing a specific date for transfer of permit responsibility, coverage, and liability between them; and

iii. The Department does not notify the existing permittee and the proposed new permittee of the Department's intent to modify or revoke and reissue the permit. A modification under 314 CMR 5.19(24)(c) may also be a minor modification. If this notice is not received, the transfer is effective on the date specified in the agreement mentioned in 314 CMR 5.19(24)(c)2.

26. Permit Fees. Any permittee, other than a public entity, required to obtain a surface water or ground water discharge permit pursuant to M.G.L. c. 21, § 43 and 314 CMR 3.00 and 5.00, shall be required annually to obtain an inspection certificate from the Department, and submit the information and fee associated therewith in accordance with 314 CMR 2.12.

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Table 1-1
Otis Air National Guard Base
Wastewater Treatment Plant Design Criteria

	Initial Year	Design Year
Flow (mgd)		
Average	0.21	0.30
Maximum month	0.30	0.43
Maximum day	0.58	0.80
Peak hour	1.00	1.38
BOD (lb/day)		
Average	480	690
Maximum month	690	990
Maximum 7-day	1,330	1,840
TSS (lb/day)		
Average	390	550
Maximum month	550	790
Maximum 7-day	1,070	1,470
TKN (lb/day)		
Average	90	125
Maximum month	125	180
Maximum 7-day	245	335
Ammonia (lb/day)		
Average	60	90
Maximum month	90	125
Maximum 7-day	170	235
Effluent Limits		
BOD (mg/l)	30	
TSS (mg/l)	30	
Total nitrogen (mg/l)	10	
Preliminary Treatment		
Grit Channel		
Number	2	2
Size		
Length (ft)	27	27
Width (ft)	2	2
Velocity (fps)	1	1
Rotary Screen		
Bar Spacing (in)	1/4	1/4
Motor HP	2	2

Table 1-1
(continued)

	Initial Year	Design Year
Bar Rack size		
Spacing (in)	1-3/4	1-3/4
Width (in)	18	18
Anoxic Tanks		
Number	1	2
Size per Tank		
Length (ft)	34	34
Width (ft)	34	34
Depth (ft)	11.11	11.11
Tank Volume (gal)	96,067	192,134
Detention Time per Tank (hr)		
@ ADF	10.98	7.69
@ Maximum month	7.69	5.36
@ Maximum day	3.98	2.88
@ Peak hour	2.31	1.67
Mixers		
Number per tank	1	1
Motor HP	7.5	7.5
HP/1000 cf	0.58	0.58
Dissolve Oxygen (mg/l)	<0.5	<0.5
Aeration Tanks		
Number	1	2
Size per Tank		
Length (ft)	105	105
Width (ft)	38	38
Depth (ft)	9.75	9.75
Tank Volume (gal)	270,000	540,000
Detention Time		
@ ADF	30.86	43.20
@ Maximum month	21.60	30.14
@ Maximum day	11.17	16.20
@ Peak hour	6.48	9.39
Aeration Equipment		
Type	Surface mechanical aerator	
Number per tank	1	1
Capacity, each (lb Oxy/HP-hr)	3.5	3.5
Motor HP, each	30	30

Table 1-1
(continued)

	Initial Year	Design Year
Basin Sizing Criteria		
Volatile Fraction	0.8	0.8
MLSS (mg/l)	3,000	3,000
MLVSS (mg/l)	2,400	2,400
F/M ratio		
@ ADF	0.09	0.06
@ Maximum month	0.13	0.09
SRT (days)		
@ ADF	16.4	16.4
Effluent Soluble BOD (mg/l)	5	5
Effluent Ammonia (mg/l)	1	1
RAS Concentration (mg/l)	6,000	6,000
Q Recycle (mgd)		
@ ADF	0.21	0.30
@ Maximum month	0.30	0.43
lb Oxy/lb BOD removed	1.2	1.2
lb Oxy/lb NH_3 removed	4.6	4.6
O_2 Required (lb/day)		
@ ADF	840	1,200
@ Maximum day	2,240	3,200
Loading Rate (lb BOD/1000 cf)		
@ ADF	13.30	9.56
@ Maximum month	19.12	13.71
Secondary Clarifiers		
Number	1	2
Size		
Diameter (ft)	35	35
SWD (ft)	12	12
Total Surface Area	962	1,923
Overflow Rate (gpd/sf)		
@ ADF	218	312
@ Maximum month	312	447
@ Peak hour	603	832
Solids Loading (lb/d/sf)		
@ ADF	10.93	15.61
@ Maximum month	15.61	22.38
@ Peak hour	22.90	32.00
RAS Pumping		
Type	Centrifugal, Non-Clog	
Number Operating (w/1 standby)	2	3
RAS Flow (gpm)	125 to 300	200 to 450
Recycle Rate (% flow)	100 to 150	100 to 150

Table 1-1
(continued)

	Initial Year	Design Year
RAS Solids (%)	0.60	0.60
Motor HP	2	2
WAS Pumping		
Type	Centrifugal, Non Clog	
Number Operating	1	2
WAS Production (lb/day)		
@ ADF	260	390
@ Maximum month	406	590
WAS Flow (gpm)	150	150
WAS Solids (%)	0.60	0.60
Hours of Operation (hr/wk)		
@ ADF	4.04	6.06
@ Maximum month	6.31	9.17
Motor HP	2	2
Disinfection		
Agent	Sodium Hypochlorite	
System Capacity (gpd)		
@ 25 mg/l @ ADF	63	90
Maximum Pumping Capacity (gpm)	2.5	3.58
Number of Pumps (including 1 standby)		
Nominal Dosage (mg/l)	2 to 5	2 to 5
Storage Tank Volume (gal)	1,000	1,000
Days of Storage @ 5 mg/l		
@ ADF	119	83
@ Maximum month	83	58
Effluent Pumping		
Type	Single-Stage Split Case Centrifugal	
Number (including 1 standby)	3	3
Pumping Capacity (gpm)		
with 1 pump	700	700
with 2 pumps	975	975
Motor HP	75	75
Effluent Force Main		
Total Length (miles)	10.38	10.38
Pumping Length (miles)	5.85	5.85
Size (in)	12	12
Static El. Difference (ft)	200	200

Table 1-1
(continued)

	Initial Year	Design Year
Detention Time (hr)		
@ ADF	38.88	27.22
@ Maximum month	27.22	18.99
@ Maximum day	14.08	10.21
Infiltration Basins (to be added)		
Number	4	4
Basin Size (sf)		
#1	62,390	62,390
#2	67,000	67,000
#3	65,745	65,745
#4	64,025	64,025
Total Surface Area (sf)	259,160	259,160
Loading Rates (gpd/sf)		
@ ADF	0.81	1.15
@ Maximum month	1.16	1.66
@ Maximum day	2.23	3.08
Sludge Storage Tanks		
Number	3	3
Size, each		
Length (ft)	16	16
Width (ft)	9	9
Depth (ft)	6.5	6.5
Volume per Tank (gal)	7,001	7,001
Total Detention Time (days)		
% Solids	1	1
@ ADF	3.67	2.57
@ Maximum month	2.56	1.79
Total Detention Time (days)		
% Solids	1.5	1.5
@ ADF	5.51	3.86
@ Maximum month	3.84	2.69
Aeration Equipment		
Type	Coarse Bubble Diffused Air	
Total Number of Diffusers	14	14
Flow per Diffuser	20	20

Table 1-1
(continued)

	Initial Year	Design Year
Blowers		
Type	Positive Displacement	
Number	2	2
Capacity (cfm)	140	140
Pressure (psi)	7	7
Dewatering		
Belt Filter Press		
Size (meter)	1	1
% Feed Solids	1.5	1.5
Hydraulic Loading Rate, gpm/m	80	80
Solids Loading Rate		
lb/hr/m @ 1.5%	600	600
lb/hr/m @ 2.0%	801	801
Cake Solids, %	16 to 18	16 to 18
Capture (%)	90	90
Sludge Cake (ld/day)		
@ ADF	318	454
@ Maximum month	456	651
Beltwash Water		
Flow (gpm)	50	50
Pressure (psi)	85	85
Sludge Feed Pumps		
Type	Progressive Cavity	
Number	2	2
Capacity per Pump (gpm)	80	80
Motor HP	7.5	7.5
Composting		
Type	Static Pile	
Sludge Volume (cy/wk)		
@ ADF	7.63	10.90
@ Maximum month	10.94	15.63
Woodchip Mix Ratio	3 to 1	3 to 1
Woodchip Requirements (cy/week)		
@ ADF	22.89	32.70
@ Maximum month	32.82	46.88
Sludge & Woodchip Mix		
@ ADF	24.41	34.88
@ Maximum month	35.01	50.01

Table 1-1
(continued)

	Initial Year	Design Year
Pile (by week)		
Width (ft)	6.66	6.66
Height (ft)	6.5	6.5
@ ADF	17.1	16.7
@ Maximum month	23.3	25.5
Woodchip Base (cy/wk)		
@ ADF	4.2	4.1
@ Maximum month	5.7	6.3
Cover (cy/wk)		
@ ADF	3.5	3.5
@ Maximum month	4.3	4.5
Total Volume (cy/wk)		
@ ADF	32.1	42.4
@ Maximum month	45.0	60.8
Make-up Woodchips (cy/wk)		
@ ADF	9.5	12.9
@ Maximum month	13.5	18.6
Cured Compost (cy/wk)		
@ ADF	11.0	15.1
@ Maximum month	15.7	21.7
Compost Blowers		
Type		Centrifugal
Number	6	6
Capacity (cfm)		
@ Maximum month	300	300
Aeration Rate (cfh/ton)	11,286	7,900

SO# 24899

CARROUSEL SYSTEM JOB SUMMARY

WWTP NAME: Otis Air National Guard Base

WWTP LOCATION: Cape Cod, Massachusetts

CONSULTING ENGINEER: Camp, Dresser & McKee

AGENT: Dave Sullivan

Engineer's Data

INFLUENT	EFFLUENT	
FLOW, MGD 0.43	BOD, mg/l 10 20	NUMBER OF TRAINS two
BOD, mg/l 275	TSS, mg/l 15 30	AERATORS PER TRAIN one
TSS, mg/l 250	NH_3, mg/l 1.0	HP PER AERATOR 30
TKN, mg/l 50	NO_3, mg/l 8 10	SPEED (1,2 OR 5) VFD
		ADJUST WEIR (Y OR N) —

CARROUSEL VOLUME, MG 0.27MG each

CHANNEL WIDTH, FEET 19'0"

CHANNEL DEPTH, FEET 9'9"

AERATION ZONE DEPTH, FEET 9'9"

SRT, DAYS 19

MLSS, mg/l 3,000

MINIMUM, T°C 10

MAXIMUM, T°C 25

PREANOXIC TANK

SRT, days (NITRIFICATION) _____

SRT, days (OVERALL) _____

PREANOXIC VOLUME, MG 0.08/train x 3 basins

NUMBER OF MIXERS one

HP PER MIXER 5

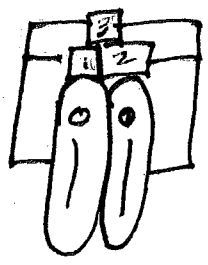
INTERNAL RECYCLE, MGD 6Q/train

DENITE WALL OR PUMPS _____

84,310 gallons 3 anoxic basins

OTHER NOTES:

2.3m VFD



IR can go 1, 2, or 3

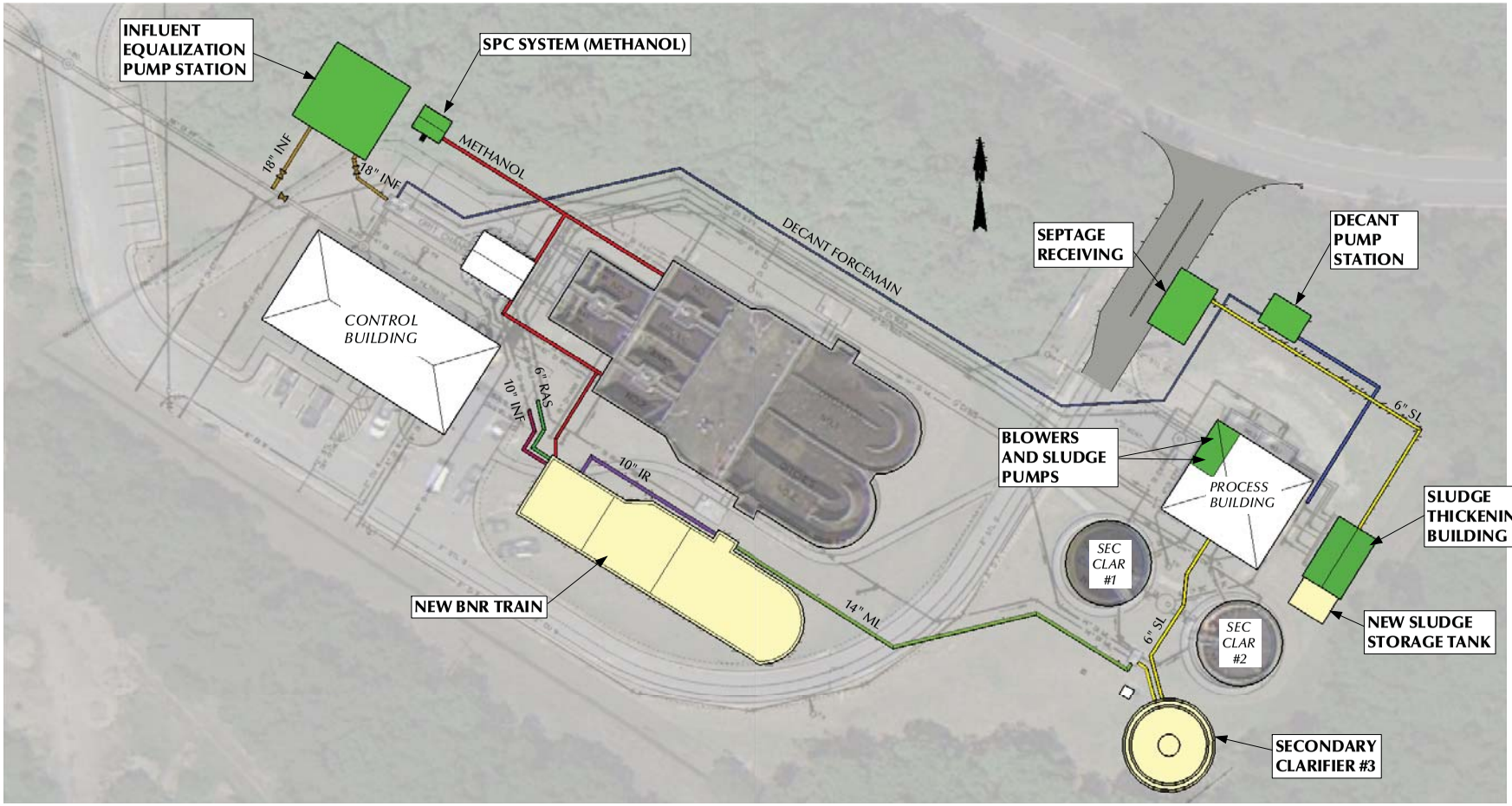
APPENDIX B
MATERIALS SUPPORTING WASTEWATER SYSTEM ANALYSIS

Massachusetts Military Reservation Population	AD Mil	Federal	State	AGR	Mil Tech	NAF	Contr's	Trad	Other
as of 24 Jan 2012	Title	Civ	Civ	Title	Title	Civ		Gdsmen/	
	10	FT/PT	FT/PT	32	32	FT/PT		Res	
Army National Guard									
Environmental & Readiness Center			10						
HQ, Camp Edwards Training Site			20	7	31	2	2	139	
Unit Training Equipment Site (UTES)					37			9	
Field Maintenance Shop (FMS #9)									
HQ 101st Regiment (Regional Training Institute) (note 1&3)				6	3		1	87	
1st Field Artillery Training Battalion									
2nd General Studies Battalion									
387th Ordnance Company (Explosive Ordnance Disposal)				2				23	
181st Engineer Company (Vertical)				3				159	
180th Engineering Detachment (Firefighting)				1				8	
179th Engineering Detachment (Firefighting)				1				8	
Det-1 Recruiting & Retention (RSP)							1	102	
Army Aviation Support Facility #1 (AASF#1)		1		2	37		2		
Detachment 12, Operational Support Airlift Command				4	1			3	
3rd Battalion, 126th Aviation									
Hdqs & Hdqs Co.				1	10			72	
Company A 3rd Battalion 126th Aviation					2			34	
Company D 3rd Battalion 126th Aviation					3			66	
Company E 3rd Battalion 126th Aviation					3			76	
Company F 3rd Battalion 126th Aviation (ATS)					3			37	

	AD Mil	Federal	State	AGR	Mil Tech	NAF	Contr's	Trad	Other
	Title	Civ	Civ	Title	Title	Civ		Gdsmen/	
	10	FT/PT	FT/PT	32	32	FT/PT		Res	
Air National Guard									
102nd Intelligence Wing (note 2)		88	51	145	178		2	708	
253rd Combat Communications Group									
267th Combat Communications Squadron									
202nd Weather Flight				1				14	
Air Force									
6th Space Warning Squadron (PAVE PAWS) (note 3)	70	6		4			47		3*
Coast Guard									
Air Station Cape Cod	267	75				65			
Port Security Unit 301	6							166	
Northeast Regional Fisheries Training Center (NRFTC)	15								
Communication Station, Boston	21								
Electronic Systems Support Detachment Cape Cod	19						1		
Marine Safety Detachment Cape Cod	7							1	
Atlantic Area Armory	4								
Morale Welfare/PX/Commissary						28			
Tenants									
ARNG, Impact Area Groundwater Study Program (NGB)			4/2	1					
AFCEE, Installation Restoration Program (USAF)		4							
Environmental Management Commission (MA)			1						
Federal Aviation Administration, Cape Approach (DOT)		32							
Volpe NTC, Weather Test Facility (DOT)							1		

	AD Mil	Federal	State	AGR	Mil Tech	NAF	Contr's	Trad	Other
	Title	Civ	Civ	Title	Title	Civ		Gdsmen/	
	10	FT/PT	FT/PT	32	32	FT/PT		Res	
US Army Corps of Engineers, New England District (USA)		2					20		
Pest Survey, Detection, and Exclusion Laboratory (USDA)		40/1					1		
Massachusetts National Cemetery (DOVA)		28							
Upper Cape Trash Transfer Station									3
MMR Fire Department			39/1						
Barnstable County Sheriff's Department			308/21						
Tenants without permanent onsite personnel									
US Coast Guard Auxiliary									5
US Air Force Auxiliary (Civil Air Patrol)									
National Oceanic and Atmospheric Administration (DOC)		3							
Barnstable County Health Dept./Buzzards Bay Project									
U.S. Geological Survey (DOI)									
Red Cross									
Senior Environment Corps (Senior Corps)									
Notes:									
1. Roll-up of both Battalions									
2. Roll-up of all ARNG units									
3. Data as of 2008									
* Members of Royal Canadian Air Force									
TOTAL	409	276/1	433/24	178	308	95	78	1733	11

3521/25



PLAN

SCALE: 1"= 50'

ALTERNATIVES 1A, 1B, 1C

ALTERNATIVES 2A, 2B, 2C

JBCC WASTERWATER SYSTEM EVALUATION, WWTF ALTERNATIVES ANALYSIS

PROJ NO:	DATE:	FIGURE:
10912S	NOV 2014	B-1

WRIGHT-PIERCE
Engineering a Better Environment

JBCC WASTEWATER SYSTEM EVALUATION
CONSTRUCTION AND CAPITAL COST ESTIMATES FOR VARIOUS ALTERNATIVES
ENR CCI 9870 (OCTOBER 2014)
Wright-Pierce, 24 Oct 2014

OPINION OF PROBABLE COSTS	CONSTRUCTION COSTS									40%
	Influent Flow EQ Pump Station	Supplemental Carbon	Sludge Thickening	Sludge Feed Pumps	Septage Receiving & Decant PS	3rd BNR Train	4th Sludge Storage Tank	Effluent Transmission Force Main Upgrades & Re-Rate RIBs	Construction Total (Rounded)	Project Cost Total (Rounded)
EXISTING DESIGN CAPACITY (0.30 mgd 'capacity')										
ALT 1A - Baseline (Sewage)	$ 728,000	$ 114,000	$ 766,000	$ 97,000	N/A	N/A	N/A	$ 646,000	**$ 2,350,000**	**$ 3,290,000**
ALT 1B - Baseline (Sewage-Septage)	$ 728,000	N/A	$ 766,000	$ 97,000	$ 1,199,000	N/A	N/A	N/A	**$ 2,790,000**	**$ 3,910,000**
ALT 1C - Baseline (Sewage-Bourne)	$ 728,000	$ 114,000	$ 766,000	$ 97,000	N/A	N/A	N/A	$ 646,000	**$ 2,350,000**	**$ 3,290,000**
ALT 1D - Baseline (Septage-Bourne)	$ 728,000	N/A	$ 766,000	$ 97,000	$ 1,199,000	N/A	N/A	N/A	**$ 2,790,000**	**$ 3,910,000**
INCREASE TREATMENT CAPACITY (0.45 mgd 'capacity')										
ALT 2A - Expansion (Sewage)	$ 728,000	$ 114,000	$ 766,000	$ 97,000	N/A	$ 3,323,000	$ 207,000	$ 1,271,000	**$ 6,510,000**	**$ 9,110,000**
ALT 2B - Expansion (Sewage-Septage)	$ 728,000	N/A	$ 766,000	$ 97,000	$ 1,199,000	$ 3,323,000	$ 207,000	$ 1,271,000	**$ 7,590,000**	**$ 10,630,000**
ALT 2C - Expansion (Sewage-Bourne)	$ 728,000	$ 114,000	$ 766,000	$ 97,000	N/A	$ 3,323,000	$ 207,000	$ 1,271,000	**$ 6,510,000**	**$ 9,110,000**
ALT 2D - Expansion (Sewage-Septage-Bourne)	$ 728,000	N/A	$ 766,000	$ 97,000	$ 1,199,000	$ 3,323,000	$ 207,000	$ 1,271,000	**$ 7,590,000**	**$ 10,630,000**

Construction Costs include 15% GC OH&P, 2% Bonds/Insurance, 15% Design Contingency, and multiplier of 6% to account for inflation.

JBCC WASTEWATER SYSTEM EVALUATION
ANNUAL O&M ESTIMATES FOR VARIOUS ALTERNATIVES
Wright-Pierce, 24 Oct 2014

BUDGET LINE ITEMS		SCENARIO 0-BASELINE			SCENARIO 1A			SCENARIO 1B		
	EXISTING	Change	Change	$$	Change	Change	$$	Change	Change	$$
		As %%	Plus Add $$		As %%	Plus Add $$		As %%	Plus Add $$	
CHEMICALS	$22,904	0%	-	$22,904	129%		$52,536	32%		$30,170
ENZYMS	$571	0%	-	$571	129%	-	$1,309	32%	-	$752
BIOSOLIDS	$22,000	-25%	-	$16,500	65%	-	$36,231	65%	-	$36,231
COLLECTION SYS (DEGREASERS)	$0	0%	-	$0	129%	-	$0	0%	-	$0
LAB TESTING SUPPLIES	$1,301	0%	-	$1,301	129%	-	$2,985	129%	-	$2,985
SUPPLIES AND SHOP STOCK	$55,597	-80%	-	$11,119	-50%	-	$27,799	-30%	-	$38,918
PARTS & EQUIPMENT	$26,393	-	-	$10,000	-	-	$10,000	-	-	$10,000
SERVICE CONTRACTS	$32,769	-	-	$20,000	-	-	$20,000	-	-	$20,000
PROJECTS - SRM	$39,655	-	-	$10,000	-	-	$10,000	-	-	$10,000
GAS	$7,611	0%		$7,611	0%		$7,611	0%		$7,611
ELECTRICITY	$99,087	0%		$99,087	129%		$227,275	129%	$5,454	$232,730
LABOR	$210,000	-	$0	$210,000	-	$70,000	$280,000	-	$70,000	$280,000
TOTAL ANNUAL COSTS:	$517,888			$409,094			$675,746			$669,396
			DELTA	-$108,795		DELTA	$157,858		DELTA	$151,508
			DELTA, SAY	-$110,000		DELTA, SAY	$160,000		DELTA, SAY	$150,000
Existing Flow	47.68		47.68	MG/YR		47.68	MG/YR		47.68	MG/YR
New Flow	0.00		0	MG/YR		61.69	MG/YR		15.1	MG/YR
Total Flow	47.68	Total Flow	47.68	MG/YR	Total Flow	109.37	MG/YR	Total Flow	62.81	MG/YR
Total Flow	131,000	Total Flow	131,000	gpd	Total Flow	300,000	gpd	Total Flow	172,000	gpd
	$0.0086	Unit Cost	$0.0086	$/gal	Unit Cost	$0.0062	$/gal	Unit Cost	$0.0107	$/gal

Note: The existing budget line items for Parts & Equipment, Service Contracts and Projects have been reduced "After MassDev Take-Over" because those line items are funded through

Construction Cost			$0			$2,350,000			$2,790,000	
Capital Cost			$0			$3,290,000			$3,910,000	
Debt Service on Capital			$0			$201,000			$239,000	
Annual O&M			$410,000			$680,000			$670,000	
Incremental O&M per New Flow (Excl. Debt)			-	per kgal		$2.6	per kgal		$9.9	per kgal
Total O&M per Total Flow			-	per kgal		$6.2	per kgal		$10.7	per kgal
Total O&M and Debt per Total Flow			-	per kgal		$8.1	per kgal		$14.5	per kgal

Note: Debt service on capital is calculated using 2% interest rate for a 20 yr term.

New Staff	-		0	new		1	new		1	new

JBCC WASTEWATER SYSTEM EVALUATION
ANNUAL O&M ESTIMATES FOR VARIOUS ALTERNATI
Wright-Pierce, 24 Oct 2014

BUDGET LINE ITEMS		SCENARIO 1C			SCENARIO 1D			SCENARIO 2A			SCENARIO 2D		
	EXISTING	Change	Change	$$	Change	Change	$$	Change	Change	$$	Change	Change	$$
		As %%	Plus Add $$		As %%	Plus Add $$		As %%	Plus Add $$		As %%	Plus Add $$	
CHEMICALS	$22,904	129%		$52,536	32%		$30,170	244%		$78,836	244%		$78,836
ENZYMS	$571	129%	-	$1,309	32%	-	$752	244%	-	$1,964	244%	-	$1,964
BIOSOLIDS	$22,000	65%	-	$36,231	65%	-	$36,231	147%	-	$54,234	147%	-	$54,234
COLLECTION SYS (DEGREASERS)	$0	129%	-	$0	0%	-	$0	0%	-	$0	0%	-	$0
LAB TESTING SUPPLIES	$1,301	129%	-	$2,985	129%	-	$2,985	244%	-	$4,480	244%	-	$4,480
SUPPLIES AND SHOP STOCK	$55,597	-50%	-	$27,799	-30%	-	$38,918	-10.0%	-	$50,037	-10.0%	-	$50,037
PARTS & EQUIPMENT	$26,393	-	-	$10,000	-	-	$10,000	-	-	$10,000	-	-	$10,000
SERVICE CONTRACTS	$32,769	-	-	$20,000	-	-	$20,000	-	-	$20,000	-	-	$20,000
PROJECTS - SRM	$39,655	-	-	$10,000	-	-	$10,000	-	-	$10,000	-	-	$10,000
GAS	$7,611	0%		$7,611	0%		$7,611	0%		$7,611	0%		$7,611
ELECTRICITY	$99,087	139%		$237,184	139%		$237,184	244%		$341,052	254%		$350,961
LABOR	$210,000	-	$70,000	$280,000	-	$70,000	$280,000	-	$140,000	$350,000	-	$140,000	$350,000
TOTAL ANNUAL COSTS:	$517,888			$685,654			$673,850			$928,214			$938,123
			DELTA	$167,766		DELTA	$155,962		DELTA	$410,326		DELTA	$420,235
			DELTA, SAY	$170,000		DELTA, SAY	$160,000		DELTA, SAY	$410,000		DELTA, SAY	$420,000
Existing Flow	47.68		47.68	MG/YR		47.68	MG/YR		47.68	MG/YR		47.68	MG/YR
New Flow	0.00		76.42	MG/YR		29.83	MG/YR		116.44	MG/YR		83.59	MG/YR
Total Flow	47.68	Total Flow	124.10	MG/YR	Total Flow	77.51	MG/YR	Total Flow	164.12	MG/YR	Total Flow	131.27	MG/YR
Total Flow	131,000	Total Flow	340,000	gpd	Total Flow	212,000	gpd	Total Flow	450,000	gpd	Total Flow	360,000	gpd
	$0.0086	Unit Cost	$0.0055	$/gal	Unit Cost	$0.0087	$/gal	Unit Cost	$0.0057	$/gal	Unit Cost	$0.0071	$/gal

Note: The existing budget line items for Parts & Equi dedicated accounts in the new budgets.

Construction Cost			$2,350,000			$2,790,000			$6,510,000			$7,590,000	
Capital Cost			$3,290,000			$3,910,000			$9,110,000			$10,630,000	
Debt Service on Capital			$201,000			$239,000			$557,000			$650,000	
Annual O&M			$690,000			$670,000			$930,000			$940,000	
Incremental O&M per New Flow (Excl. Debt)			$2.2	per kgal		$5.4	per kgal		$3.5	per kgal		$5.0	per kgal
Total O&M per Total Flow			$5.6	per kgal		$8.6	per kgal		$5.7	per kgal		$7.2	per kgal
Total O&M and Debt per Total Flow			$7.2	per kgal		$11.7	per kgal		$9.1	per kgal		$12.1	per kgal

Note: Debt service on capital is calculated using 2% i

New Staff	-		1	new		1	new		2	new		2	new

Appendix A
MMR Wastewater Facilities Inventory

MMR Wastewater System Inventory

Updated: July 2012

Item	Size	Quantity	Unit	Approximate Year of Construction
MAIN BASE				
Collection system				
Asbestos cement pipe	4-in.	2,000	lf	1964
Asbestos cement pipe	6-in.	9,500	lf	1964
Asbestos cement pipe	8-in.	7,000	lf	1964
Asbestos cement pipe	10-in.	6,000	lf	1964
Asbestos cement pipe	12-in.	4,200	lf	1964
Vitrified clay pipe	4-in.	4,500	lf	1952
Vitrified clay pipe	6-in.	15,000	lf	1952
Vitrified clay pipe	8-in.	46,000	lf	1952
Vitrified clay pipe	10-in.	13,600	lf	1952
Vitrified clay pipe	12-in.	10,700	lf	1952
Vitrified clay pipe	15-in.	16,000	lf	1952
Vitrified clay pipe	18-in.	6,020	lf	1952
Vitrified clay pipe	24-in.	2,420	lf	1952
Iron pipe	6-in.	500	lf	1996
Iron pipe	8-in.	1,000	lf	1996
Iron pipe	10-in.	200	lf	1996
Iron pipe	12-in.	1,500	lf	1996
Iron pipe	16-in.	4,700	lf	1996
Poly Vinyl Chloride pipe	4-in.	2,000	lf	1993
Poly Vinyl Chloride pipe	6-in.	4,000	lf	1993
Poly Vinyl Chloride pipe	8-in.	884	lf	1993
Poly Vinyl Chloride pipe	12-in.	1200	lf	1993
Poly Vinyl Chloride pipe	15-in.	2,000	lf	1993
Standard sanitary sewer manhole		100	ea	1952
Standard sanitary sewer manhole		415	ea	1964
Standard sanitary sewer manhole		8	ea	1993

Item	Size	Quantity	Unit	Approximate Year of Construction
Wastewater treatment facility				
Building	0.36 (mgd)	1	ea	1996
Structures	0.36 (mgd)	1	ea	1996
Process equipment	0.36 (mgd)	1	ea	1996
Backup generator	50 kW	1	ea	1996
Diesel storage tank, dual walled, above-ground	500 gal.	1	ea	1996
SCADA System - Treatment Plant				
Engineer Work Station - Computer System 4		2	ea	2001
RTU - Remote Terminal Unit 4		2	ea	2001
Coax cable		1,000	lf	2001
PLC Programming Terminal - Computer System 3		1	ea	2001
Flow sensor		2	ea	2001
Level sensor		2	ea	2001
SCADA System - Lift Stations				
RTU - Remote Terminal Unit 1		5	ea	2001
Level switch		15	ea	2001
Flow sensor		5	ea	2001
Lift/pump stations				
Sewage Lift Station - Beacon - Facility 7307				
Buildings	18'x12'x8' Concrete	1	ea	1996
Wet well	18'x12'x20'	1	ea	1996
Dry well	14'x10'x20'	1	ea	1996
Pumps	2- 20 hp, 680 gpm pumps in dry well	2	ea	1996
Pump controls	Yes	2	ea	1996
Backup generator	50 KW	1	ea	1996
Diesel storage tank, dual walled, above-ground	500 gal.	1	ea	1996
Sewage Lift Station - Central Heating - Facility 7161				
Buildings	18'x12'x8' Concrete	1	ea	1996

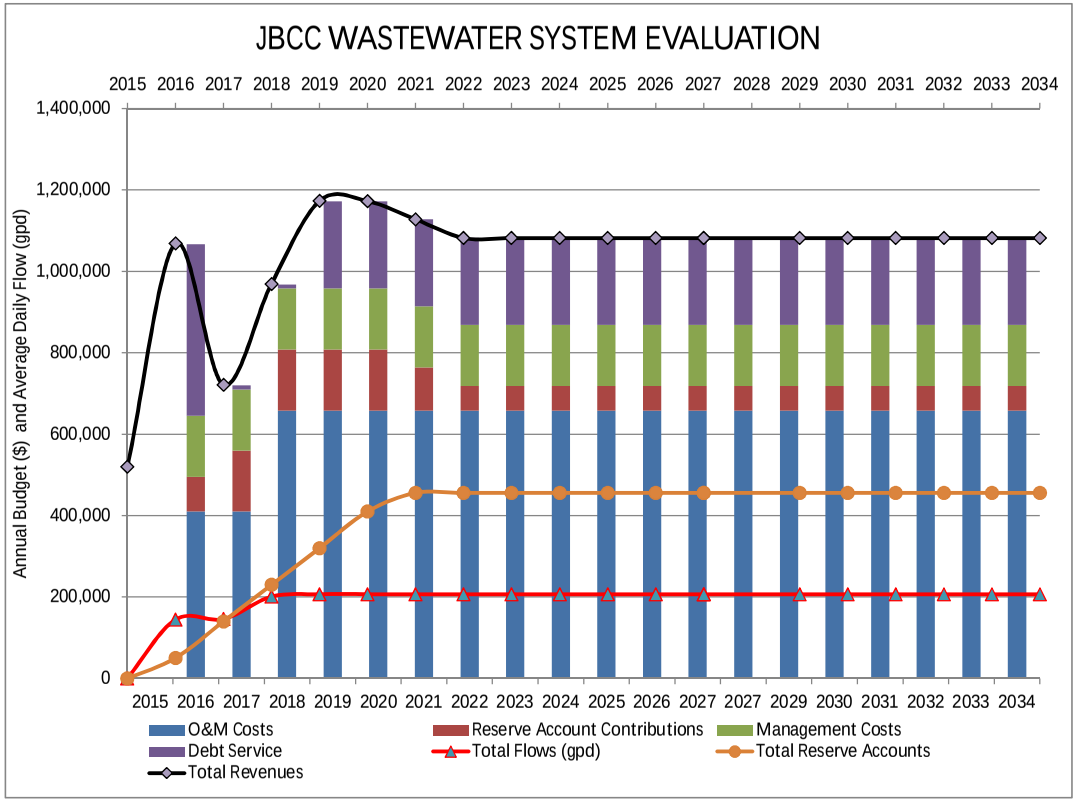
Item	Size	Quantity	Unit	Approximate Year of Construction
Wet well	18'x12'x20'	1	ea	1996
Dry well	14'x10'x20'	1	ea	1996
Pumps	2- 7.5 hp, 350 gpm pumps in dry well	2	ea	1996
Pump controls	Yes	2	ea	1996
Backup generator	50 KW	1	ea	1996
Sewage Lift Station – Rocket Storage - Facility 7120				
Buildings	7'x4'x4' (lxwxh) Plywood shed over the pump motor	28	sf	1982
Wet well	4' diameter x 6' deep	1	ea	1952
Dry well	8'x8'x6'	1	ea	1952
Pumps	2-1.5 hp	2	ea	1952
Pump controls	Yes	2	ea	1952
Sewage Lift Station - Munitions Storage - Facility 7181				
Wet well	8'x8'x12'	1	ea	1952
Pumps	1-3 hp submersible	1	ea	1982
Pump controls	Yes	1	ea	1982
Sewage Lift Station - Alert Hangar - Facility 7175				
Buildings	4'x4'x7' Plywood shed over the pump motor	16	sf	1982
Well	8'x8'x6'	1	ea	1952
Pumps	2-3.0 hp	2	ea	1952
Pump controls	Yes	2	ea	1952
Sewage Lift Station - Bomarc Facility				
Wet well	8'x8'x12'	1	ea	1952
Pumps	1-3 hp submersible	1	ea	1982
Pump controls	Yes	1	ea	1982
Sewage Lift Station - Coast Guard - Facility 3171				
Wet well	8'x8'x12'	1	ea	1952
Pumps	1-3 hp submersible	1	ea	1982

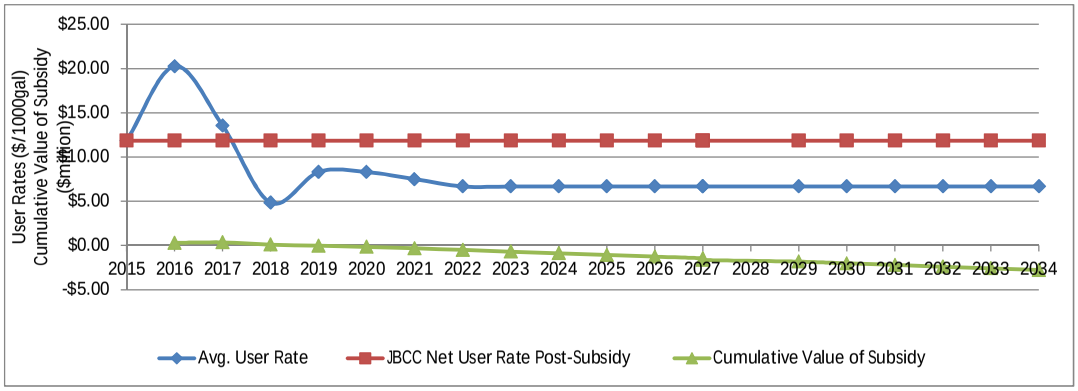
Item	Size	Quantity	Unit	Approximate Year of Construction
Pump controls	Yes	1	ea	1982
Sewage Lift Station - Chiefs Club - Facility 5214				
Wet well	8'x8'x12'	1	ea	1952
Pumps	1-3 hp submersible	1	ea	1982
Pump controls	Yes	1	ea	1982
Sewage Lift Station - Golf Course - Facility 3352				
Wet well	8'x8'x12'	1	ea	1952
Pumps	1-3 hp submersible	1	ea	1982
Pump controls		1	ea	1982
Sewage Lift Station - Air Station - Facility 5202				
Wet well	8'x8'x12'	1	ea	1952
Pumps	1-3 hp submersible	1	ea	1982
Pump controls	Yes	1	ea	1982
Effluent conveyance and discharge				
Ductile iron pipe	12-in.	55,280	lf	1996
Disposal beds – 4-cells covering 6 acres				
Excavation (assume 3 foot depth)		29,000	cy	1996
Coarse sand cover layer, 1 foot thick		29,000	sy	1996
Effluent distribution ductile iron pipe in disposal beds	8 "	1,870	lf	1996
Concrete splitter box	10' x 10' x 12'	1	ea	1996
Gate valve	10-in.	4	ea	1996
Monitoring wells		7	ea	1990
Manholes effluent distribution pipeline (standard sizes)		17	ea	1996
Air relief valves		17	ea	1996
Gate valves in pipeline		12	ea	1996
ANGB – Coast Guard Facilities				
Piping				
Vitrified clay pipe	6-in.	4,000	lf	1964
Standard sanitary sewer manhole	48-in.	20	ea	1964

Item	Size	Quantity	Unit	Approximate Year of Construction
ANGB – Coast Guard Housing				
Piping				
Vitrified clay pipe	6-in.	19,230	lf	1960
Vitrified clay pipe	8-in.	5,985	lf	1960
Vitrified clay pipe	10-in.	6,165	lf	1960
Vitrified clay pipe	12-in.	2,900	lf	1960
Standard sanitary sewer manhole	48-in.	160	ea	1960
Sewage Lift Station - Family Housing – Facility 7310				
Buildings	18x12x8 Concrete	1	ea	1996
Pumps	2- 7.5 hp, 250 gpm pumps in dry well	2	ea	1996
Pump controls	yes	2	ea	1996
Backup generator	50 KW	1	ea	1996
Diesel storage tank, dual walled, above-ground	500 gal.	1	ea	1996
Compost area				
Pavement (conc.-asphalt, 6")		2,810	sy	1993
Pavement subgrade		2,810	sy	1993
Concrete block wall	5' high	500	lf	1993
Compost Shed				
Concrete block wall	12.5' high	125	lf	1993
Aeration System				
Blower		1	ea	1993
4" corrugated pipe, non-perforated	4-in.	100	lf	1993
6" corrugated pipe, perforated	6-in.	400	lf	1993
8" Poly Vinyl Chloride sewer pipe	8-in.	155	lf	1993
Catch basin/manhole		2	ea	1993
Sheet metal roof		1,856	sf	1993
I-Beam supports	4 ea 20'	80	lf	1993
I-Beam supports	4 ea 8'	32	lf	1993
Equipment Shed				
Sheet metal roof		1,610	sf	1993
I-Beam supports	8 ea 20'	160	lf	1993
Mixer		1	ea	1993

Item	Size	Quantity	Unit	Approximate Year of Construction
Mixer/conveyor		1	ea	1993
Control building, cinder block, including controls	15'x20'x10'	1	ea	1993
Roadway	23'x220'	560	sy	1993

NOTES:
sf = square feet
sy = square yards,
lf = linear feet
ea = each
hp = horse power
' = feet
" = inches
gal = gallon
KW = kilowatt





Date: 3-Nov-2014
Scenario: 1D

Input Data	
Owner	MassDev
Operations	ConOps
WWTF Design Flow (gpd)	300,000
Flow from Septage (gpd)	15,000
Flows for Effluent Disposal only (gpd)	40,000
Flow from New Regional Partners (gpd)	0
WWTF Upgrade Scenario	0
Unaccounted for Flow (gpd)	6204
Interest Rate (for reserve accts):	0.50%
Inflation Rate for Capital R&R:	0.00%
CPI-U (Boston):	0.00%
CWSRF Interest Rate:	2.00%
CWSRF Repayment Period:	20
CWSRF Interim Loan Rate:	2.00%
Transaction Cost Percent:	N/A
Bridge Loan Interest Rate:	N/A
Septage Receiving (days/year)	365
Septage Disposal Cost ($/gal)	$0.040
Septage Disposal Fee ($/gal)	$0.110
Effluent Received (days/year)	365
Effluent Disposal Cost ($/gal)	$0.002
Effluent Disposal Fee ($/gal)	$0.0075
O&M Cost for @ Base Flow ($/yr)	$410,000
O&M Cost for Flow above Base Flow ($/gal)	$0.0040
Pump Station Asset Management ($/yr)	$20,000
Collection System Asset Management (&/yr)	$30,000
I/I Investigation & Repair Fund ($/yr)	$25,000
IPP/SUO Management Cost ($/yr)	$25,000
Annual Subsidy for JBCC Military Users	See below
Inflation Rate for JBCC Subsidy	0.00%
2013 JBCC O&M (W-P Estimate; JBCC Ownership) ($/gal)	$0.01139
MassDevelopment-Military Subsidy, 1st 5 years	$ 171,531
MassDevelopment- Military Subsidy, 20-yr Annual Average	$ (74,841)
MassDevelopment-Non-Military Subsidy, 1st 5 years	$ 8,710
MassDevelopment- Non-Military Subsidy, 20-yr Annual Average	$ (50,621)
Net Present Value, 1st 5 Years - MassDevelopment	$ (197,527)
Net Present Value, 1st 10 Years - MassDevelopment	$ 632,055
Net Present Value, 20 year - MassDevelopment	$ 1,997,214
MilitaryProjected Rate/1st 10 years	$ 10.00
Military Current Projected Rate/No Subsidy/10 Years	$ 11.85
MilitaryProjected Rate/1st 10 years/Excess Revenue to Military Ra	$ 8.66
Non-Military Projected Rate/1st 10 years	$ 11.00

Sheet I

Joint Base Cape Cod Business Model
Wastewater Flow Summary

November 3, 2014

RUN SCENARIO:	**1D**	
Ownership:	**MassDev**	
Operations:	**ConOps**	
WWTF Design Flow:	**300,000**	gpd
Flows for Septage Receiving:	**15,000**	gpd
Flows for Effluent Disposal Only:	**40,000**	gpd
Flows from New Regional Partners:	**0**	gpd

Notes:

1 Flows from 2012 CH2M Valuation Study. See tenants with zero recorded flows

2 Per capita flows from 310 CMR 15.203 (Title 5) - Not used in this assessment

3 Unaccounted for Flow = **6,204** gpd

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Capital Cost Allocation by Reserved Capacity for WWTF

	Phase I			Phase II		
	Res. Cap.	**%**	**Cap. Share**	**Res. Cap.**	**%**	**Cap. Share**
JBCC	**100,000**	65.8%	$2,301,447	**0**		$0
MassDev	**5,000**	3.3%	$115,072	**0**		$0
Non-Milit.	**47,000**	30.9%	$1,081,680	**0**		$0
Town #1	**0**	0.0%	$0	**0**		$0
Total	**152,000**	**100.00%**	**$3,498,200**	**0**	**0.00%**	**$0**

Predicted Average Daily Wastewater Flow by Calendar Year (gpd) ----->

Average Daily Flow by User (1)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2027**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Military Flow																				
Army National Guard		11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669
Air National Guard		8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875
Coast Guard		72,245	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697
253D COMBAT COMM (102IW/ANG)		297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297
Installation Restoration Program (AF CEE)		236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236
Flying Eagles Nest (102IW/ANG)		359	359	359	359	359	359	359	359	359	359	359	359	359	359	359	359	359	359	359
Army Corps		237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237
Accounted for Flow	**0**	**93,918**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**
Unaccounted for flow - allocation	0	4,215	4,235	4,235	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058	4,058
Total Flows	**0**	**98,132**	**99,605**	**99,605**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**	**99,428**
MassDevelopment Flow																				
Warehousing/Storage Facility		360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
CCCC Extension Facility		525	525	525	525	525	525	525	525	525	525	525	525	525	525	525	525	525	525	525
Future Flow Allowance		4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115
Accounted for Flow	**0**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**
Unaccounted for flow - allocation	0	224	222	222	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213
Total Flows	**0**	**5,224**	**5,222**	**5,222**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**	**5,213**
Non-Military Customer Flows																				
Barnstable County Sheriff's Office/Correctional Facility		37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715
USDA		216	216	216	216	216	216	216	216	216	216	216	216	216	216	216	216	216	216	216
FAA Cape Approach		675	675	675	675	675	675	675	675	675	675	675	675	675	675	675	675	675	675	675
Bourne Schools		725	725	725	725	725	725	725	725	725	725	725	725	725	725	725	725	725	725	725
Other New Flows					6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096
Accounted for Flow	**0**	**39,331**	**39,331**	**39,331**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**
Unaccounted for flow - allocation	0	1,765	1,747	1,747	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933
Total Flows	**0**	**41,096**	**41,077**	**41,077**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**	**47,360**
New Regional Partners Flows																				
Town #1					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Accounted for Flow	**0**				**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Unaccounted for flow - allocation	0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Flows	**0**				**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total Unaccounted Flows (I/I, etc.) (3)	0	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204
Total Wastewater Flows	**0**	**144,452**	**145,904**	**145,904**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**
Septage Flow (gpd)	**0**	**0**	**0**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**
Effluent Disposal Flows																				
Town of Bourne Landfill Leachate	**0**	**0**	0	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000
Total Flow for Effluent Discharge Only (gpd)	**0**	**0**	**0**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**

Sheet II

JBCC WASTEWATER SYSTEM - Capital Costs - Initial Improvements

November 3, 2014

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Phase I			***Phase II*** (No Phase II facilities assumed in this project)		
Project	**Estimate**	**Costs Incurred/Comments**	**Project**	**Estimate**	**Costs Incurred/Comments**
Wastewter System Purchase Price	**$ -**	TBD			
Planning, Permitting, Legal, Admin.			**Planning, Permitting, Legal, Admin.**		
Facilities Planning & PEF	**$180,000**		Facilities Planning	$0	
Permitting & Permit Negotiation	**$70,000**		Permitting & Permit Negotiation	$0	
MassDevelopment Administration	**$50,000**		MassDevelopment Administration	$0	
PM & Conops Procurement	**$150,000**		Program Management	$0	
Legal Fees	**$30,000**		Legal Fees	$0	
Financial Consulting & Fees	**$5,000**		Financial Consulting & Fees	$0	
Planning Subtotal:	**$485,000**	Assume CY 2016	**Planning Subtotal:**	**$0**	
Design (SRF Ineligible)			**Design**		
Engineering Design	$471,800	Assume 12% of construction cost	Engineering Design	$0	
Land and other Non-eligible Costs:	$0		Land and other Non-eligible Costs:	$0	
Design Subtotal:	**$411,800**	Assume CY 2017	**Design Subtotal:**	**$0**	
Construction			**Construction**		
Construction Cost	$2,790,000	See estimate below	Construction Cost	$0	
Engineering, Inspection & Testing	$223,200	Assume 8% of construction cost	Engineering, Inspection & Testing	$0	
Construction Subtotal:	**$3,013,200**	Assume CY 2018 Begin; 2019 Complete	**Construction Subtotal:**	**$0**	
Collection System Repairs (SRF Ineligible)			**Collection System Repairs**		
Pump station repairs	$0	Cover in Asset Management line items	Pump Station & sewer systems repairs	$0	
Sewer systems repairs	$0	Cover in Asset Management line items	Effluent force main repairs	$0	
Other system repairs	$0	Cover in Asset Management line items	Other system repairs	$0	
Collection System Subtotal:	**$0**	Assume CY 2018	**Collection System Subtotal:**	**$0**	
Total Phase I JBCC/MD Capital Cost	**$3,910,000**		**Total Phase II JBCC/MD Capital Cost**	**$0**	
Total SRF Phase I JBCC/MD Capital Cost	**$3,498,200**	For SRF loan funding	**Total SRF Phase II JBCC/MD Capital Cost**	**$0**	
Regional Facilities			**Regional Facilities**		
WWTF Expansion	$0	Not applicable	WWTF base price	$0	
Connecting sewers & force mains	$0	Not applicable	Force main rehabilitation	$0	
Other facilities	$0	Not applicable	Septage facility	$0	
Total Phase I Regional Cost:	**$0**		**Total Phase II Regional Cost:**	**$0**	
Phase I Construction Estimate			**Phase II Construction Cost Estimate**		
Influent Flow EQ Pump Station	**$728,000**	WP	Base price	$0	
Sludge Feed Pumps	**$97,000**	WP	Other costs	$0	
Sludge Thickening	**$766,000**	WP	Contingency	$0	
Septage Receiving & Decant	**$1,199,000**	WP	**Total Phase II Construction Cost:**	**$0**	
3rd BNR Train	**$0**	WP			
4th Sludge Storage Tank	**$0**	WP			
Effluent Transmission & Force Main	**$0**				
Bourne Leachate Force main Connection	**$0**				
Other/Miscellaneous	**$0**				
Total Phase I Construction Cost:	**$2,790,000**				

Sheet III

DEBT SERVICE PLAN

November 3, 2014

Ownership:	MassDev
Operations:	ConOps
WWTF Design Flow:	300,000
Flows for Septage Receiving:	15,000
Flows for Effluent Disposal Only:	40,000
Flows from New Regional Partners:	0

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Loan History	Amount	Loan Date	
SRF #1 (Phase 1)	$485,000	1/1/2016	Project Planning, Legal, Admin, etc. Loan
SRF #2 (Phase 1)	$0		Not used
SRF #3 (Phase 1)	$3,013,200	1/1/2020	WWTF JBCC Construction Loan
Phase 1 Facilities:	$3,498,200		
Town #1 Connection:	$0		N/A
Total Phase 1 Costs:	$3,498,200		
	0.00%		Regional Facilities Proportion of Total Loan

Assumptions:

Int. Rate (for res. accts):	0.50%
Inflation for Capital R&R:	0.00%
CPI-U (Boston):	0.00%
SRF Interest Rate:	2.00%
Repayment Period (yrs):	20
SRF Interim Loan Rate:	2.00%
Transaction Cost Percent:	N/A
Bridge Loan Interest Rate:	N/A

Notes:

(1) (2) Not used

(3) Based on percentages of regional facilities capacities & lengths:

User	Res. Capacity	Length	Factor	Percentage
JBCC	1	1	1	33.3%
MassDevel.	1	1	1	33.3%
Non-Military	1	1	1	33.3%
Town #1	0	0	0	0.0%
	3	3	3	100%

(4) WCR = 0.0% of Debt Service Reserve requirement

(5) 100% of interim loans for facilities planning & permitting

(6) Assume 115% of Annual Debt Service Amount

(7) Operating Reserve Requirement = Two months operating cost

Account	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Purchase Price		$ -																		
Design Cost		$ 411,800	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Interim Loan Interest (SRF #1&3)		$ 9,700	$ 9,700	$ 9,700		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Loan Repayment - Phase I (SRF #1&3) (From AMORT Table)		$ -	$ -	$ -	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938
Loan Repayment: - Phase II		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Design Cost, Interim Interest & Loan Repayment:		**$ 421,500**	**$ 9,700**	**$ 9,700**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**	**$ 213,938**
JBCC Share		$ 277,303	$ 6,382	$ 6,382	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749	$ 140,749
MassDevelopment Share		$ 13,865	$ 319	$ 319	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037	$ 7,037
Non-Military Share		$ 130,332	$ 2,999	$ 2,999	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152	$ 66,152
Town #1 Share		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Annual WWTF Debt Service (Check):		$ 421,500	$ 9,700	$ 9,700	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938	$ 213,938

DEBT RETIREMENT PLAN - Regional Facilities

Account		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Interim SRF Loan Interest & Capital Outlays (5)		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Repayment:		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Interceptor Debt Service:		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
JBCC Share of Interceptor		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MassDevelopment Share of Interceptor		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non-Military Share of Interceptor		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Town #1 Share of Interceptor		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Interceptor Debt Service (Check)		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

RESERVE ACCOUNT REQUIREMENTS

Renewal & Replacement Reserve Fund		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
R&R Reserve Requirement:		$25,000	$50,000	$75,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
R&R Reserve Depletion:		$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
R&R Reserve Contribution:		$10,000	**$35,000**	**$30,000**	**$30,000**	**$20,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**
R&R Reserve Balance:		$25,000	$50,000	$70,000	$90,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
Debt Service Reserve Fund																				
Debt Service Reserve Require. (6)		$0	$0	$0	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029
Debt Service Reserve Contribution		**$0**	**$40,000**	**$45,000**	**$45,000**	**$70,300**	**$45,729**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Debt Service Reserve Balance:		$0	$40,000	$85,000	$130,000	$200,300	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029	$246,029
Operating Reserve Fund																				
Operating Reserve Requirement (7)		$68,333	$68,333	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700
Operating Reserve Contribution		**$25,000**	**$25,000**	**$25,000**	**$25,000**	**$9,700**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Operating Reserve Balance		$25,000	$50,000	$75,000	$100,000	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700	$109,700
Working Capital Reserve Requirement (4):		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Working Capital Reserve Contribution:		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Working Capital Reserve Balance:		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Balance of Reserve Accounts		**$50,000**	**$140,000**	**$230,000**	**$320,000**	**$410,000**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**	**$455,729**

Sheet IV

Annual Wastewater O&M Costs & Revenues

November 3, 2014

Septage Received (days/year)	365	Effluent Received (days/year)	365
Septage Treatment Cost ($/gal):	$0.04	Effluent Disposal Cost ($/gal)	$0.002
Septage Treatment Fee ($/gal)	$0.11	Effluent Disposal Fee ($/gal)	$0.008
		Fixed O&M Cost for @ Base Flow	$410,000
		Pump Station Asset Management	$20,000
		Collection System Asset Management	$30,000
		I/I Investigation & Repair Fund	$25,000

RED TEXT IN MANUAL INPUT

Assumptions:

Int. Rate (for res. accts):	0.50%
Inflation for Capital R&R:	0.00%
CPI-U (Boston):	0.00%
SRF Interest Rate:	2.00%
Repayment Period:	20
Transaction Cost Percent:	2.60%
Variable WWTF O&M Fee:	$0.0040

Notes:

(1) Not used
(2) From United Water
(3) Working capital reserve = 0% of debt service (not used)
(4) Debt Service Res. = 115% of Max. Ann. Debt Service Amt.
(5) MassDev. System O&M Cost: $0.00 (FY2019$)
(6) JBCC PS/Coll.System O&M: $0.00 (FY2016$)
(7) FY 2014 cost escalated to FY 2016 start-up at CPI;
(9) Contract Contingency: 15% (Not used)

Fiscal/Contract Year ----->

Estimated Flow (from Sheet 2)	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Total Average Daily Flow (gpd) (Actual/Projected)	**0**	**144,452**	**145,904**	**145,904**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**	**152,000**
Total Average Daily Flow (gpd) (Contract)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ANNUAL O&M COSTS - WASTEWATER SYSTEM																				
Wastewater Flow (million gal/yr) (Contract) (Not used)																				
Wastewater Flow (Actual/Predicted)		52.725	53.255	53.255	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480	55.480
Excess Flow over Base Year (million gal/yr)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Excess Flow Fee ($/gal)		$ 0.004	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400	$ 0.00400
Excess Flow Cost		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Fixed Cost for WWTF O&M @ Base Flow (Esc.)		$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000
Cost for Septage Treatment		$ -	$ -	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000
Cost for Effluent FM, PS & RIB for Disposal Only		$ -	$ -	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200
Total Fixed & Variable Annual O&M Costs		**$ 410,000**	**$ 410,000**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**	**$ 658,200**
Renewal & Replacement Fund - SRF		$ 10,000	$ 35,000	$ 30,000	$ 30,000	$ 20,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Pump Station Asset Management		$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000
Sewer System Asset Management		$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
Debt Service Reserve Fund Contribution:		$ -	$ 40,000	$ 45,000	$ 45,000	$ 70,300	$ 45,729	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operating Reserve Fund Contribution:		$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 9,700	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Working Capital Reserve Fund Contribution: (3)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Annual Engineering Inspection & Audit Fees		$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
Mass Development Management and Administration		$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000
IPP & SUO Management		$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
I/I Investigation & Repair Fund		$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
Total Annual O&M Costs		**$ 645,000**	**$ 710,000**	**$ 958,200**	**$ 958,200**	**$ 950,200**	**$ 913,929**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**	**$ 868,200**
Income - Interest on Reserve Accounts		**$ -**	**$ (250)**	**$ (700)**	**$ (1,150)**	**$ (1,600)**	**$ (2,050)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**	**$ (2,279)**
Annual Septage Volume (MG)		-	-	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48
Septage Rate ($/gal.) (Inflated by year per CPI)		$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11
Income from Septage Receiving		**$ -**	**$ -**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**
Annual Effluent Disposal Volume (MG)		-	-	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60
Annual Unit Cost ($/gal.)		$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075
Income from Treated Wastewater Disposal Only		**$ -**	**$ -**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**
Total Net Annual O&M Costs (7)		**$ 645,000**	**$ 709,750**	**$ 245,750**	**$ 245,300**	**$ 244,850**	**$ 200,129**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**
Unit Cost based on Net Annual O&M ($/1000 gal.)		**$ 12.23**	**$ 13.33**	**$ 4.61**	**$ 4.42**	**$ 4.41**	**$ 3.61**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**	**$ 2.78**

Military ANNUAL SHARE OF COSTS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Percentage of Annual Flow to WWTF		67.9%	68.3%	68.3%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%	65.4%
Military Annual O&M Charge	$ -	**$ 438,174**	**$ 484,527**	**$ 167,767**	**$ 160,458**	**$ 160,163**	**$ 130,910**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**	**$ 100,848**
Percentage of Reserved Capacity (From Flow Summary)		65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%	65.8%
Military Annual Capital Charge - WWTF	$ -	**$ 277,303**	**$ 6,382**	**$ 6,382**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**
Military Annual Capital Charge - Regional Facilities	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Military Capital Charge	**$ -**	**$ 277,303**	**$ 6,382**	**$ 6,382**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**	**$ 140,749**
Total Military Annual Wastewater Charge	**$ -**	**$ 715,477**	**$ 490,908**	**$ 174,148**	**$ 301,207**	**$ 300,912**	**$ 271,659**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**	**$ 241,597**

MASSDEVELOPMENT ANNUAL SHARE OF COSTS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Percentage of Annual Flow to WWTF		3.6%	3.6%	3.6%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%
MassDev. Annual O&M Charge	$ -	**$ 23,328**	**$ 25,403**	**$ 8,796**	**$ 8,412**	**$ 8,397**	**$ 6,863**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**	**$ 5,287**
Percentage of Reserved Capacity (From Flow Summary)		3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%
MassDev. Capital Charge - WWTF	$ -	**$ 13,865**	**$ 319**	**$ 319**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**
MassDev. Capital Charge - Regional Facilities	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total MassDevelopment Capital Charge	$ -	**$ 13,865**	**$ 319**	**$ 319**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**	**$ 7,037**
Total MassDevelopment Annual Wastewater Charge	$ -	**$ 37,193**	**$ 25,722**	**$ 9,115**	**$ 15,450**	**$ 15,434**	**$ 13,901**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**	**$ 12,325**

NON-MILITARY CUSTOMERS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Non-Military Sewer System Metering Cost	$ -	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000
Percentage of Annual Flow to WWTF		28.4%	28.2%	28.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%	31.2%
Non-Military Annual O&M Charge	**$ -**	**$ 183,498**	**$ 199,821**	**$ 69,188**	**$ 76,430**	**$ 76,290**	**$ 62,356**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**	**$ 48,036**
Percentage of Reserved Capacity (From Flow Summary)		30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%	30.9%
Non-Military Capital Charge - WWTF	**$ -**	**$ 130,332**	**$ 2,999**	**$ 2,999**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**
Non-Military Capital Charge - Regional Facilities	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Non-Military Capital Charge	**$ -**	**$ 130,332**	**$ 2,999**	**$ 2,999**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**	**$ 66,152**
Total Non-Military Annual Wastewater Charge	**$ -**	**$ 315,831**	**$ 204,820**	**$ 74,187**	**$ 144,582**	**$ 144,442**	**$ 130,508**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**	**$ 116,188**

TOWN #1 ANNUAL SHARE OF COSTS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Town #1 Sewer System O&M Cost (Metering)						$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Percentage of Annual Flow to WWTF						0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Town #1 Annual O&M Charge						$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Percentage of Reserved Capacity (From Flow Summary)						0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Town #1 Capital Charge - WWTF						$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Town #1 Capital Charge - Regional Facilities						$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Town #1 Capital Charge						$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Town #1 Annual Wastewater Charge						$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Total Net Annual O&M Charges (Check)	**$ -**	**$ 645,000**	**$ 709,750**	**$ 245,750**	**$ 245,300**	**$ 244,850**	**$ 200,129**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**	**$ 154,171**
Total Annual Wastewater Charges (Check)	**$ -**	**$ 1,068,500**	**$ 721,450**	**$ 257,450**	**$ 461,238**	**$ 460,788**	**$ 416,068**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**	**$ 370,110**
Total Annual Flow Percentage	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Percentage: Variable Fee/Total Fee for WWTF	**#DIV/0!**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**

Sheet V
User Rates and Revenues
November 3, 2014

RED TEXT IN MANUAL INPUT

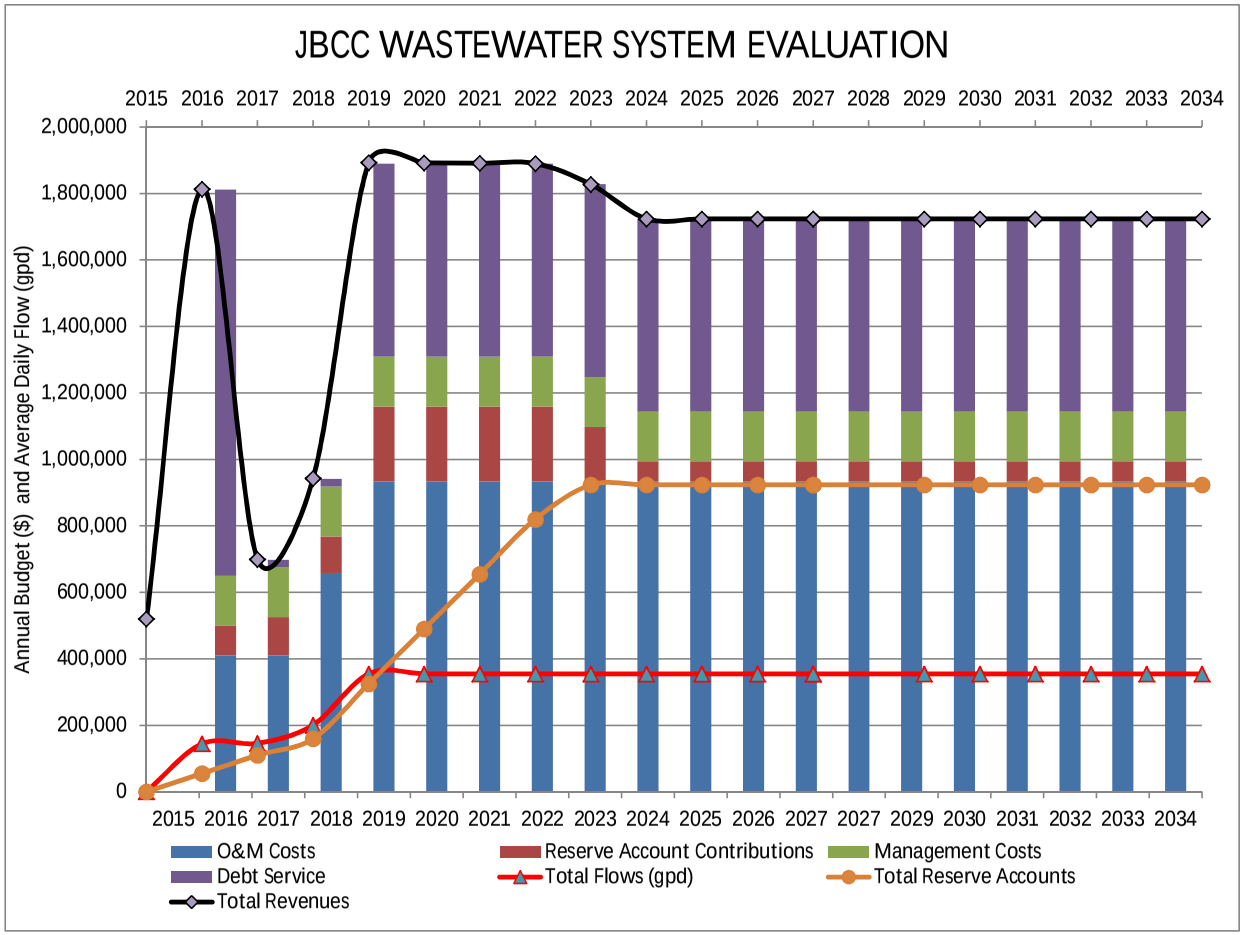
Annual Subsidy for JBCC Military Users: See below
Inflation Rate Applied to JBCC Subsidy: 0.0%

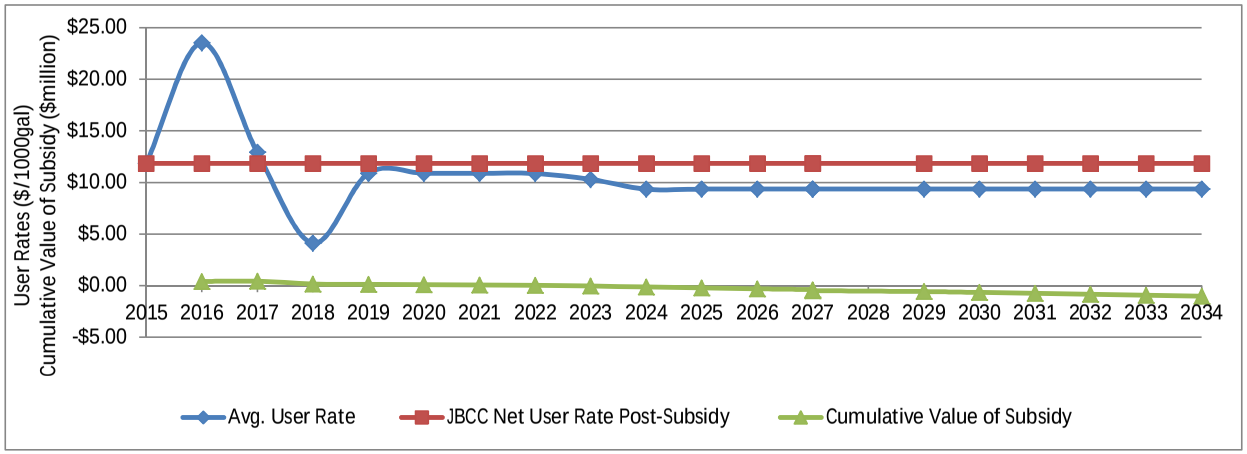
Assumptions:

1. Billing/Collection Percentage: 100.0%
2. Discount Rate: 2.00%
3. Persons per SFR: n/a
4. Gallons per person per day: 65
5. Not used
6. Not used
7. Debt Service Coverage Ratio = Ratio of total revenue to annual outlays of cash to meet annual interest and principal payments on debt, plus sinking fund contributions.

Notes:
(1) From Sheet IV
(2) Composite for three entities
(3) First year cost = 1/2 Full Year ET Proposal

MassDevelopment User Charge	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Projected Daily Flows (1000 gallons/yr.):		1,907	1,906	1,906	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903
Total Wastewater Annual Treatment Charge (1)		$37,193	$25,722	$9,115	$15,450	$15,434	$13,901	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325
Other Annual Costs for Private or Off-Site Facilities	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Wastewater Annual Cost:		$37,193	$25,722	$9,115	$15,450	$15,434	$13,901	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325	$12,325
Required User Rate ($/1000 gal.):		$19.50	$13.49	$4.78	$8.12	$8.11	$7.31	$6.48	$6.48	$6.48	$6.48	$6.48	$6.48	$6.48	$6.48	$6.48	$6.48	$6.48	$6.48	$6.48
User Rate ($/1000 gal.):		**$19.50**	**$13.49**	**$4.78**	**$8.12**	**$8.11**	**$7.31**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**	**$6.48**
MassDevelopmnt User Rate ($/kgal)	$11.00	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**
Revenue from MassDevelopment		**$20,976**	**$20,967**	**$20,967**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**	**$20,929**
Cost of MassDevelopment Flows		**$37,193**	**$25,722**	**$9,115**	**$15,450**	**$15,434**	**$13,901**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**	**$12,325**
Net Annual MassDevelopment Cost		**$16,217**	**$4,755**	**-$11,852**	**-$5,479**	**-$5,495**	**-$7,028**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**	**-$8,605**
Cumulative MassDevelopment Cost		**$16,217**	**$20,972**	**$9,120**	**$3,641**	**-$1,854**	**-$8,883**	**-$17,487**	**-$26,092**	**-$34,696**	**-$43,301**	**-$51,905**	**-$60,510**	**-$69,115**	**-$77,719**	**-$86,324**	**-$94,928**	**-$103,533**	**-$112,137**	**-$120,742**
Military User Charge																				
Military Wastewater Flow (1000 Gallons per Year):		35,818	36,356	36,356	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291	36,291
Total Military Annual Treatment Charge:		**$715,477**	**$490,908**	**$174,148**	**$301,207**	**$300,912**	**$271,659**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**
Other Annual Costs for Private or Off-Site Facilities	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Military Annual Cost:		**$715,477**	**$490,908**	**$174,148**	**$301,207**	**$300,912**	**$271,659**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**
Military User Rate ($/1000 gal.):		**$19.98**	**$13.50**	**$4.79**	**$8.30**	**$8.29**	**$7.49**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**
Current Military User Rate ($/1000 gal.)	$11.85	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**
Annual MassDevelopment Subsidy:		$291,025	$60,087	-$256,673	-$128,849	-$129,143	-$158,397	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459	-$188,459
Cumulative Subsidy:		$291,025	$351,111	$94,438	-$34,411	-$163,554	-$321,951	-$510,410	-$698,869	-$887,328	-$1,075,786	-$1,264,245	-$1,452,704	-$1,641,163	-$1,829,622	-$2,018,081	-$2,206,540	-$2,394,999	-$2,583,457	-$2,771,916
Net Military Rate w/Subsidy ($/1000 gal.):		**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**
Military User Rate ($/kgal)	$10.00	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**
Revenue from Military Flows		**$358,183**	**$363,558**	**$363,558**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**	**$362,911**
Cost of Military Flows		**$715,477**	**$490,908**	**$174,148**	**$301,207**	**$300,912**	**$271,659**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**	**$241,597**
Annual Military Subsidy from MassDevelopment		**$357,294**	**$127,350**	**-$189,410**	**-$61,705**	**-$61,999**	**-$91,252**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**	**-$121,315**
Cumulative Military Subsidy from MassDevelopment		**$357,294**	**$484,645**	**$295,235**	**$233,530**	**$171,531**	**$80,279**	**-$41,036**	**-$162,350**	**-$283,665**	**-$404,979**	**-$526,294**	**-$647,609**	**-$768,923**	**-$890,238**	**-$1,011,552**	**-$1,132,867**	**-$1,254,182**	**-$1,375,496**	**-$1,496,811**
Adjusted Annual Subsidy from MassDevelopment		**$357,294**	**$127,350**	**-$189,410**	**-$61,705**	**-$61,999**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Military User Rate with Excess Credited to Military		**$10**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**	**$6.66**
Non-Military User Charge																				
Projected Daily Flows (MG):		15,000	14,993	14,993	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286	17,286
Total Non-Military Annual Wastewater Charge:		**$315,831**	**$204,820**	**$74,187**	**$144,582**	**$144,442**	**$130,508**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**
Other Annual Costs for Private or Off-Site Facilities	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Non-Military Annual Cost (1)		**$315,831**	**$204,820**	**$74,187**	**$144,582**	**$144,442**	**$130,508**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**
User Rate ($/1000 gal.):		**$21.06**	**$13.66**	**$4.95**	**$8.36**	**$8.36**	**$7.55**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**
Annual Cost per Single Family Residence: (3)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Non-Military User Rate ($/kgal)	$11.00	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**
Revenue from Non-Military Flows		**$165,000**	**$164,926**	**$164,926**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**	**$190,150**
Cost of Non-Military Flows		**$315,831**	**$204,820**	**$74,187**	**$144,582**	**$144,442**	**$130,508**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**	**$116,188**
Net Annual Non-Military Cost		**$150,831**	**$39,894**	**-$90,739**	**-$45,568**	**-$45,708**	**-$59,642**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**	**-$73,961**
Cumulative Non-Military Cost		**$150,831**	**$190,725**	**$99,986**	**$54,418**	**$8,710**	**-$50,932**	**-$124,893**	**-$198,854**	**-$272,816**	**-$346,777**	**-$420,739**	**-$494,700**	**-$568,661**	**-$642,623**	**-$716,584**	**-$790,546**	**-$864,507**	**-$938,469**	**-$1,012,430**
Adjusted Annual Subsidy from MassDevelopment		**$150,831**	**$39,894**	**-$90,739**	**-$45,568**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Non-Military User Rate with Excess Credited to Non-Military		**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$7.55**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**	**$6.72**
Town #1 User Charge																				
Projected Average Daily Flow (MG/yr):		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Town #1 Annual Wastewater Charge:		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other Annual Costs for Customer Off-Site Facilities	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Town #1 Annual Cost (1)		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
User Rate ($/1000 gal.):		N/A	N/A	N/A	N/A	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Annual Cost per Single Family Residence:		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Town #1 User Rate ($/kgal)	$11.00	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**
Revenue from Town #1 Flows		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Cost of Town#1 Flows		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Net Annual Town #1 Cost		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Cumulative Town #1 Cost		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Debt Service Coverage Ratio (2)		**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2027**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Total System Flow (from Customers)		52,725	53,255	53,255	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480	55,480
Total Revenue		$1,068,500	$721,450	$257,450	$461,238	$460,788	$416,068	$370,110	$370,110	$370,110	$370,110	$370,110	$370,110	$370,110	$370,110	$370,110	$370,110	$370,110	$370,110	$370,110
Total O&M Cost		$410,000	$410,000	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200	$658,200
Total Capital Reserve		$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Total Operating Reserve		$25,000	$25,000	$25,000	$25,000	$9,700	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Annual Debt Service		$9,700	$9,700	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$213,938	$0
Debt Service Coverage Ratio: (Not required by WPAT)		**2.35**	**1.59**	**0.28**	**0.51**	**0.52**	**0.47**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.55**
20 Year Average User Rate ($/1000 gal.)	$7.47	**$20.27**	**$13.55**	**$4.83**	**$8.31**	**$8.31**	**$7.50**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**	**$6.67**
20 Year Average User Rate ($/1000 gal.) Set Rates	$9.82	**$10.32**	**$10.32**	**$10.32**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Net Annual Wastewater Balance - MassDevelopment		**$ (524,342)**	**$ (172,000)**	**$ 292,000**	**$ 112,752**	**$ 113,202**	**$ 157,923**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**	**$ 203,881**
Annual Present Value (2015)		**$ (514,061)**	**$ (165,321)**	**$ 275,158**	**$ 104,165**	**$ 102,530**	**$ 140,231**	**$ 177,490**	**$ 174,010**	**$ 170,598**	**$ 167,253**	**$ 163,974**	**$ 160,758**	**$ 157,606**	**$ 154,516**	**$ 151,486**	**$ 148,516**	**$ 145,604**	**$ 142,749**	**$ 139,950**
Wastewater NPV (20yr, 5yr, 10yr)	$1,997,214					**$ (197,527)**					**$ 632,055**					**$ 1,420,390**				





Date: 3-Nov-2014
Scenario: 2D

Input Data	
Owner	MassDev
Operations	ConOps
WWTF Design Flow (gpd)	450,000
Flow from Septage (gpd)	15,000
Flows for Effluent Disposal only (gpd)	40,000
Flow from New Regional Partners (gpd)	148,000
WWTF Upgrade Scenario	0
Unaccounted for Flow (gpd)	6204
Interest Rate (for reserve accts):	0.50%
Inflation Rate for Capital R&R:	0.00%
CPI-U (Boston):	0.00%
CWSRF Interest Rate:	2.00%
CWSRF Repayment Period:	20
CWSRF Interim Loan Rate:	2.00%
Transaction Cost Percent:	N/A
Bridge Loan Interest Rate:	N/A
Septage Receiving (days/year)	365
Septage Disposal Cost ($/gal)	$0.040
Septage Disposal Fee ($/gal)	$0.110
Effluent Received (days/year)	365
Effluent Disposal Cost ($/gal)	$0.002
Effluent Disposal Fee ($/gal)	$0.0075
O&M Cost for @ Base Flow ($/yr)	$410,000
O&M Cost for Flow above Base Flow ($/gal)	$0.0040
Pump Station Asset Management ($/yr)	$20,000
Collection System Asset Management (&/yr)	$30,000
I/I Investigation & Repair Fund ($/yr)	$25,000
IPP/SUO Management Cost ($/yr)	$25,000
Annual Subsidy for JBCC Military Users	See below
Inflation Rate for JBCC Subsidy	0.00%
2013 JBCC O&M (W-P Estimate; JBCC Ownership) ($/gal)	$0.01139
MassDevelopment-Military Subsidy, 1st 5 years	$ 422,844
MassDevelopment- Military Subsidy, 20-yr Annual Average	$ 12,038
MassDevelopment-Non-Military Subsidy, 1st 5 years	$ 130,822
MassDevelopment- Non-Military Subsidy, 20-yr Annual Average	$ (9,104)
Net Present Value, 1st 5 Years - MassDevelopment	$ (547,730)
Net Present Value, 1st 10 Years - MassDevelopment	$ (259,892)
Net Present Value, 20 year - MassDevelopment	$ 630,230
MilitaryProjected Rate/1st 10 years	$ 10.00
Military Current Projected Rate/No Subsidy/10 Years	$ 11.85
MilitaryProjected Rate/1st 10 years/Excess Revenue to Military Ra	$ 10.00
Non-Military Projected Rate/1st 10 years	$ 11.00
Town #1 Projected Rate/1st 10 years	$ 11.00

Sheet I

Joint Base Cape Cod Business Model
Wastewater Flow Summary

November 3, 2014

RUN SCENARIO:	**2D**	
Ownership:	**MassDev**	
Operations:	**ConOps**	
WWTF Design Flow:	**450,000**	gpd
Flows for Septage Receiving:	**15,000**	gpd
Flows for Effluent Disposal Only:	**40,000**	gpd
Flows from New Regional Partners:	**148,000**	gpd

Notes:

1 Flows from 2012 CH2M Valuation Study. See tenants with zero recorded flows

2 Per capita flows from 310 CMR 15.203 (Title 5) - Not used in this assessment

3 Unaccounted for Flow = **6,204** gpd

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Capital Cost Allocation by Reserved Capacity for WWTF

	Phase I			Phase II		
	Res. Cap.	**%**	**Cap. Share**	**Res. Cap.**	**%**	**Cap. Share**
Military	**100,000**	33.3%	$3,163,833	**0**		$0
MassDev	**5,000**	1.7%	$158,192	**0**		$0
Non-Milit.	**47,000**	15.7%	$1,487,002	**0**		$0
Town #1	**148,000**	49.3%	$4,682,473	**0**		$0
Total	**300,000**	**100.00%**	**$9,491,500**	**0**	**0.00%**	**$0**

Predicted Average Daily Wastewater Flow by Calendar Year (gpd) ----->

Average Daily Flow by User (1)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2027**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Military Flow																				
Army National Guard		11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669	11,669
Air National Guard		8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875	8,875
Coast Guard		72,245	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697	73,697
253D COMBAT COMM (102IW/ANG)		297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297
Installation Restoration Program (AF CEE)		236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236
Flying Eagles Nest (102IW/ANG)		359	359	359	359	359	359	359	359	359	359	359	359	359	359	359	359	359	359	359
Army Corps		237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237
Accounted for Flow	**0**	**93,918**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**	**95,370**
Unaccounted for flow - allocation	0	4,215	4,235	4,235	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014	2,014
Total Flows	**0**	**98,132**	**99,605**	**99,605**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**	**97,383**
MassDevelopment Flow																				
Warehousing/Storage Facility		360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
CCCC Extension Facility		525	525	525	525	525	525	525	525	525	525	525	525	525	525	525	525	525	525	525
Future Flow Allowance		4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115
Accounted for Flow	**0**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**	**5,000**
Unaccounted for flow - allocation	0	224	222	222	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106
Total Flows	**0**	**5,224**	**5,222**	**5,222**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**	**5,106**
Non-Military Customer Flows																				
Barnstable County Sheriff's Office/Correctional Facility		37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715	37,715
USDA		216	216	216	216	216	216	216	216	216	216	216	216	216	216	216	216	216	216	216
FAA Cape Approach		675	675	675	675	675	675	675	675	675	675	675	675	675	675	675	675	675	675	675
Bourne Schools		725	725	725	725	725	725	725	725	725	725	725	725	725	725	725	725	725	725	725
Other New Flows					6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096	6,096
Accounted for Flow	**0**	**39,331**	**39,331**	**39,331**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**	**45,427**
Unaccounted for flow - allocation	0	1,765	1,747	1,747	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959
Total Flows	**0**	**41,096**	**41,077**	**41,077**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**	**46,386**
New Regional Partners Flows																				
Town #1					148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000	148,000
Accounted for Flow	**0**				**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**	**148,000**
Unaccounted for flow - allocation	0				3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125	3,125
Total Flows	**0**				**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**	**151,125**
Total Unaccounted Flows (I/I, etc.) (3)	0	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204	6,204
Total Wastewater Flows	**0**	**144,452**	**145,904**	**145,904**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**
Septage Flow (gpd)	**0**	**0**	**0**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**	**15,000**
Effluent Disposal Flows																				
Town of Bourne Landfill Leachate	**0**	**0**	0	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000
Total Flow for Effluent Discharge Only (gpd)	**0**	**0**	**0**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**

Sheet II

JBCC WASTEWATER SYSTEM - Capital Costs - Initial Improvements

November 3, 2014

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Phase I			***Phase II*** (No Phase II facilities assumed in this project)		
Project	**Estimate**	**Costs Incurred/Comments**	**Project**	**Estimate**	**Costs Incurred/Comments**
Wastewter System Purchase Price	**$ -**	TBD			
Planning, Permitting, Legal, Admin.			**Planning, Permitting, Legal, Admin.**		
Facilities Planning & PEF	**$455,400**		Facilities Planning	$0	
Permitting & Permit Negotiation	**$227,700**		Permitting & Permit Negotiation	$0	
MassDevelopment Administration	**$120,000**		MassDevelopment Administration	$0	
PM & Conops Procurement	**$234,400**		Program Management	$0	
Legal Fees	**$80,000**		Legal Fees	$0	
Financial Consulting & Fees	**$25,000**		Financial Consulting & Fees	$0	
Planning Subtotal:	**$1,142,500**	Assume CY 2016	**Planning Subtotal:**	**$0**	
Design (SRF Ineligible)			**Design**		
Engineering Design	$1,138,500	Assume 15% of construction cost	Engineering Design	$0	
Land and other Non-eligible Costs:	$0		Land and other Non-eligible Costs:	$0	
Design Subtotal:	**$1,138,500**	Assume CY 2017	**Design Subtotal:**	**$0**	
Construction			**Construction**		
Construction Cost	$7,590,000	See estimate below	Construction Cost	$0	
Engineering, Inspection & Testing	$759,000	Assume 10% of construction cost	Engineering, Inspection & Testing	$0	
Construction Subtotal:	**$8,349,000**	Assume CY 2018 Begin; 2019 Complete	**Construction Subtotal:**	**$0**	
Collection System Repairs (SRF Ineligible)			**Collection System Repairs**		
Pump station repairs	$0	Cover in Asset Management line items	Pump Station & sewer systems repairs	$0	
Sewer systems repairs	$0	Cover in Asset Management line items	Effluent force main repairs	$0	
Other system repairs	$0	Cover in Asset Management line items	Other system repairs	$0	
Collection System Subtotal:	**$0**	Assume CY 2018	**Collection System Subtotal:**	**$0**	
Total Phase I JBCC/MD Capital Cost	**$10,630,000**		**Total Phase II JBCC/MD Capital Cost**	**$0**	
Total SRF Phase I JBCC/MD Capital Cost	**$9,491,500**	For SRF loan funding	**Total SRF Phase II JBCC/MD Capital Cost**	**$0**	
Regional Facilities			**Regional Facilities**		
WWTF Expansion	$0	Not applicable	WWTF base price	$0	
Connecting sewers & force mains	$0	Not applicable	Force main rehabilitation	$0	
Other facilities	$0	Not applicable	Septage facility	$0	
Total Phase I Regional Cost:	**$0**		**Total Phase II Regional Cost:**	**$0**	
Phase I Construction Estimate			**Phase II Construction Cost Estimate**		
Influent Flow EQ Pump Station	**$728,000**	WP	Base price	$0	
Sludge Feed Pumps	**$97,000**	WP	Other costs	$0	
Sludge Thickening	**$766,000**	WP	Contingency	$0	
Septage Receiving & Decant	**$1,199,000**	WP	**Total Phase II Construction Cost:**	**$0**	
3rd BNR Train	**$3,323,000**	WP			
4th Sludge Storage Tank	**$206,000**	WP			
Effluent Transmission & Force Main	**$1,271,000**				
Bourne Leachate Force main Connection	**$0**				
Other/Miscellaneous	**$0**				
Total Phase I Construction Cost:	**$7,590,000**				

Sheet III

DEBT SERVICE PLAN

November 3, 2014

Ownership:	MassDev
Operations:	ConOps
WWTF Design Flow:	450,000
Flows for Septage Receiving:	15,000
Flows for Effluent Disposal Only:	40,000
Flows from New Regional Partners:	148,000

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Loan History	**Amount**	**Loan Date**	
SRF #1 (Phase 1)	$1,142,500	1/1/2016	Project Planning, Legal, Admin, etc. Loan
SRF #2 (Phase 1)	$0		Not used
SRF #3 (Phase 1)	$8,349,000	1/1/2020	WWTF JBCC Construction Loan
Phase 1 Facilities:	$9,491,500		
Town #1 Connection:	$0		N/A
Total Phase 1 Costs:	$9,491,500		
	0.00%		Regional Facilities Proportion of Total Loan

Assumptions:

Int. Rate (for res. accts):	0.50%
Inflation for Capital R&R:	0.00%
CPI-U (Boston):	0.00%
SRF Interest Rate:	2.00%
Repayment Period (yrs):	20
SRF Interim Loan Rate:	2.00%
Transaction Cost Percent:	N/A
Bridge Loan Interest Rate:	N/A

Notes:

(1) (2) Not used

(3) Based on percentages of regional facilities capacities & lengths:

User	Res. Capacity	Length	Factor	Percentage
JBCC	1	1	1	33.3%
MassDevel.	1	1	1	33.3%
Non-Military	1	1	1	33.3%
Town #1	0	0	0	0.0%
	3	3	3	100%

(4) WCR = 0.0% of Debt Service Reserve requirement

(5) 100% of interim loans for facilities planning & permitting

(6) Assume 115% of Annual Debt Service Amount

(7) Operating Reserve Requirement = Two months operating cost

Account	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Purchase Price		$ -																		
Design Cost		$ 1,138,500	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Interim Loan Interest (SRF #1&3)		$ 22,850	$ 22,850	$ 22,850		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Loan Repayment - Phase I (SRF #1&3) (From Amort Table)		$ -	$ -	$ -	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469
Loan Repayment: - Phase II		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Design Cost, Interim Interest & Loan Repayment:		**$ 1,161,350**	**$ 22,850**	**$ 22,850**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**	**$ 580,469**
JBCC Share		$ 387,117	$ 7,617	$ 7,617	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490	$ 193,490
MassDevelopment Share		$ 19,356	$ 381	$ 381	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674	$ 9,674
Non-Military Share		$ 181,945	$ 3,580	$ 3,580	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940	$ 90,940
Town #1 Share		$ 572,933	$ 11,273	$ 11,273	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365	$ 286,365
Annual WWTF Debt Service (Check):		$ 1,161,350	$ 22,850	$ 22,850	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469	$ 580,469

DEBT RETIREMENT PLAN - Regional Facilities

Account	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Interim SRF Loan Interest & Capital Outlays (5)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Repayment:	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Interceptor Debt Service:	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
JBCC Share of Interceptor	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MassDevelopment Share of Interceptor	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non-Military Share of Interceptor	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Town #1 Share of Interceptor	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Interceptor Debt Service (Check)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

RESERVE ACCOUNT REQUIREMENTS

Renewal & Replacement Reserve Fund	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
R&R Reserve Requirement:	$25,000	$50,000	$75,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
R&R Reserve Depletion:	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
R&R Reserve Contribution:	$10,000	**$35,000**	**$30,000**	**$30,000**	**$20,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**	**$10,000**
R&R Reserve Balance:	$25,000	$50,000	$70,000	$90,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000
Debt Service Reserve Fund																			
Debt Service Reserve Require. (6)	$0	$0	$0	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539
Debt Service Reserve Contribution	**$0**	**$0**	**$0**	**$120,000**	**$130,000**	**$149,333**	**$165,000**	**$103,206**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Debt Service Reserve Balance:	$0	$0	$0	$120,000	$250,000	$399,333	$564,333	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539	$667,539
Operating Reserve Fund																			
Operating Reserve Requirement (7)	$68,333	$68,333	$109,700	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667
Operating Reserve Contribution	**$30,000**	**$30,000**	**$30,000**	**$25,000**	**$25,000**	**$15,667**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Operating Reserve Balance	$30,000	$60,000	$90,000	$115,000	$140,000	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667	$155,667
Working Capital Reserve Requirement (4):	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Working Capital Reserve Contribution:	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Working Capital Reserve Balance:	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Balance of Reserve Accounts	**$55,000**	**$110,000**	**$160,000**	**$325,000**	**$490,000**	**$655,000**	**$820,000**	**$923,207**	**$923,207**	**$923,207**	**$923,207**	**$923,207**	**$923,207**	**$923,207**	**$923,207**	**$923,207**	**$923,207**	**$923,207**	**$923,207**

Sheet IV

Annual Wastewater O&M Costs & Revenues

November 3, 2014

Septage Received (days/year)	365	Effluent Received (days/year)	365
Septage Treatment Cost ($/gal):	$0.04	Effluent Disposal Cost ($/gal)	$0.002
Septage Treatment Fee ($/gal)	$0.11	Effluent Disposal Fee ($/gal)	$0.008
		Fixed O&M Cost for @ Base Flow	$410,000
		Pump Station Asset Management	$20,000
		Collection System Asset Management	$30,000
		I/I Investigation & Repair Fund	$25,000

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Assumptions:	
Int. Rate (for res. accts):	0.50%
Inflation for Capital R&R:	0.00%
CPI-U (Boston):	0.00%
SRF Interest Rate:	2.00%
Repayment Period:	20
Transaction Cost Percent:	2.60%
Variable WWTF O&M Fee:	$0.0050

Notes:

(1) Not used
(2) From United Water
(3) Working capital reserve = 0% of debt service (not used)
(4) Debt Service Res. = 115% of Max. Ann. Debt Service Amt.
(5) Mass Dev. System O&M Cost: $0.00 (FY2019$)
(6) JBCC PS/Coll.System O&M: $0.00 (FY2016$)
(7) FY 2014 cost escalated to FY 2016 start-up at CPI;
(9) Contract Contingency: 15% (Not used)

Fiscal/Contract Year ---->

Estimated Flow (from Sheet 2)	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Total Average Daily Flow (gpd) (Actual/Projected)		**144,452**	**145,904**	**145,904**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**	**300,000**
Total Average Daily Flow (gpd) (Contract)		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ANNUAL O&M COSTS - WASTEWATER SYSTEM																				
Wastewater Flow (million gal/yr) (Contract) (Not used)																				
Wastewater Flow (Actual/Predicted)		52.725	53.255	53.255	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500	109.500
Excess Flow over Base Year (million gal/yr)		0	0	0	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125	151,125
Excess Flow Fee ($/gal)		$ 0.005	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500	$ 0.00500
Excess Flow Cost		$ -	$ -	$ -	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804	$ 275,804
Fixed Cost for WWTF O&M @ Base Flow (Esc.)		$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000	$ 410,000
Cost for Septage Treatment		$ -	$ -	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000	$ 219,000
Cost for Effluent FM, PS & RIB for Disposal Only		$ -	$ -	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200	$ 29,200
Total Fixed & Variable Annual O&M Costs		**$ 410,000**	**$ 410,000**	**$ 658,200**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**	**$ 934,004**
Renewal & Replacement Fund - SRF		$ 10,000	$ 35,000	$ 30,000	$ 30,000	$ 20,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Pump Station Asset Management		$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000
Sewer System Asset Management		$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
Debt Service Reserve Fund Contribution:		$ -	$ -	$ -	$ 120,000	$ 130,000	$ 149,333	$ 165,000	$ 103,206	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operating Reserve Fund Contribution:		$ 30,000	$ 30,000	$ 30,000	$ 25,000	$ 25,000	$ 15,667	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Working Capital Reserve Fund Contribution: (3)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Annual Engineering Inspection & Audit Fees		$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
Mass Development Management and Administration		$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000
IPP & SUO Management		$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
I/I Investigation & Repair Fund		$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
Total Annual O&M Costs		**$ 650,000**	**$ 675,000**	**$ 918,200**	**$ 1,309,004**	**$ 1,309,004**	**$ 1,309,004**	**$ 1,309,004**	**$ 1,247,210**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**	**$ 1,144,004**
Income - Interest on Reserve Accounts		**$ -**	**$ (275)**	**$ (550)**	**$ (800)**	**$ (1,625)**	**$ (2,450)**	**$ (3,275)**	**$ (4,100)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**	**$ (4,616)**
Annual Septage Volume (MG)		-	-	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48
Septage Rate ($/gal.) (Inflated by year per CPI)		$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11	$ 0.11
Income from Septage Receiving		**$ -**	**$ -**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**	**$ (602,250)**
Annual Effluent Disposal Volume (MG)		-	-	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60	14.60
Annual Unit Cost ($/gal.)		$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075	$ 0.0075
Income from Treated Wastewater Disposal Only		**$ -**	**$ -**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**	**$ (109,500)**
Total Net Annual O&M Costs (7)		**$ 650,000**	**$ 674,725**	**$ 205,900**	**$ 596,454**	**$ 595,629**	**$ 594,804**	**$ 593,979**	**$ 531,360**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**
Unit Cost based on Net Annual O&M ($/1000 gal.)		**$ 12.33**	**$ 12.67**	**$ 3.87**	**$ 5.45**	**$ 5.44**	**$ 5.43**	**$ 5.42**	**$ 4.85**	**$ 3.91**	**$ 3.91**	**$ 3.91**	**$ 3.91**	**$ 3.91**	**$ 3.91**	**$ 3.91**	**$ 3.91**	**$ 3.91**	**$ 3.91**	**$ 3.91**

Military ANNUAL SHARE OF COSTS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Percentage of Annual Flow to WWTF		67.9%	68.3%	68.3%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%	32.5%
Military Annual O&M Charge		**$ 441,571**	**$ 460,616**	**$ 140,562**	**$ 193,615**	**$ 193,348**	**$ 193,080**	**$ 192,812**	**$ 172,485**	**$ 138,816**	**$ 138,816**	**$ 138,816**	**$ 138,816**	**$ 138,816**	**$ 138,816**	**$ 138,816**	**$ 138,816**	**$ 138,816**	**$ 138,816**	**$ 138,816**
Percentage of Reserved Capacity (From Flow Summary)		33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%	33.3%
Military Annual Capital Charge - WWTF		**$ 387,117**	**$ 7,617**	**$ 7,617**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**
Military Annual Capital Charge - Regional Facilities		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Military Capital Charge		**$ 387,117**	**$ 7,617**	**$ 7,617**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**	**$ 193,490**
Total Military Annual Wastewater Charge		**$ 828,687**	**$ 468,233**	**$ 148,179**	**$ 387,105**	**$ 386,837**	**$ 386,570**	**$ 386,302**	**$ 365,975**	**$ 332,306**	**$ 332,306**	**$ 332,306**	**$ 332,306**	**$ 332,306**	**$ 332,306**	**$ 332,306**	**$ 332,306**	**$ 332,306**	**$ 332,306**	**$ 332,306**

MASSDEVELOPMENT ANNUAL SHARE OF COSTS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Percentage of Annual Flow to WWTF		3.6%	3.6%	3.6%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%
MassDev. Annual O&M Charge		**$ 23,508**	**$ 24,149**	**$ 7,369**	**$ 10,151**	**$ 10,137**	**$ 10,123**	**$ 10,109**	**$ 9,043**	**$ 7,278**	**$ 7,278**	**$ 7,278**	**$ 7,278**	**$ 7,278**	**$ 7,278**	**$ 7,278**	**$ 7,278**	**$ 7,278**	**$ 7,278**	**$ 7,278**
Percentage of Reserved Capacity (From Flow Summary)		1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%
MassDev. Capital Charge - WWTF		**$ 19,356**	**$ 381**	**$ 381**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**
MassDev. Capital Charge - Regional Facilities		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total MassDevelopment Capital Charge		**$ 19,356**	**$ 381**	**$ 381**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**	**$ 9,674**
Total MassDevelopment Annual Wastewater Charge		**$ 42,864**	**$ 24,530**	**$ 7,750**	**$ 19,825**	**$ 19,811**	**$ 19,797**	**$ 19,783**	**$ 18,717**	**$ 16,952**	**$ 16,952**	**$ 16,952**	**$ 16,952**	**$ 16,952**	**$ 16,952**	**$ 16,952**	**$ 16,952**	**$ 16,952**	**$ 16,952**	**$ 16,952**

NON-MILITARY CUSTOMERS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Non-Military Sewer System Metering Cost		$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000
Percentage of Annual Flow to WWTF		28.4%	28.2%	28.2%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%
Non-Military Annual O&M Charge		**$ 184,921**	**$ 189,960**	**$ 57,968**	**$ 92,224**	**$ 92,096**	**$ 91,969**	**$ 91,841**	**$ 82,159**	**$ 66,121**	**$ 66,121**	**$ 66,121**	**$ 66,121**	**$ 66,121**	**$ 66,121**	**$ 66,121**	**$ 66,121**	**$ 66,121**	**$ 66,121**	**$ 66,121**
Percentage of Reserved Capacity (From Flow Summary)		15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%
Non-Military Capital Charge - WWTF		**$ 181,945**	**$ 3,580**	**$ 3,580**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**
Non-Military Capital Charge - Regional Facilities		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Non-Military Capital Charge		**$ 181,945**	**$ 3,580**	**$ 3,580**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**	**$ 90,940**
Total Non-Military Annual Wastewater Charge		**$ 368,866**	**$ 195,540**	**$ 63,548**	**$ 185,164**	**$ 185,036**	**$ 184,909**	**$ 184,781**	**$ 175,099**	**$ 159,061**	**$ 159,061**	**$ 159,061**	**$ 159,061**	**$ 159,061**	**$ 159,061**	**$ 159,061**	**$ 159,061**	**$ 159,061**	**$ 159,061**	**$ 159,061**

TOWN #1 ANNUAL SHARE OF COSTS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2027	2029	2030	2031	2032	2033	2034
Town #1 Sewer System O&M Cost (Metering)		**$ -**	**$ -**	**$ -**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**	**$ 2,000**
Percentage of Annual Flow to WWTF		0.0%	0.0%	0.0%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%	50.4%
Town #1 Annual O&M Charge		**$ -**	**$ -**	**$ -**	**$ 300,464**	**$ 300,048**	**$ 299,633**	**$ 299,217**	**$ 267,673**	**$ 215,423**	**$ 215,423**	**$ 215,423**	**$ 215,423**	**$ 215,423**	**$ 215,423**	**$ 215,423**	**$ 215,423**	**$ 215,423**	**$ 215,423**	**$ 215,423**
Percentage of Reserved Capacity (From Flow Summary)		49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%	49.3%
Town #1 Capital Charge - WWTF		**$ 572,933**	**$ 11,273**	**$ 11,273**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**
Town #1 Capital Charge - Regional Facilities		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Town #1 Capital Charge		**$ 572,933**	**$ 11,273**	**$ 11,273**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**	**$ 286,365**
Total Town #1 Annual Wastewater Charge		**$ 572,933**	**$ 11,273**	**$ 11,273**	**$ 588,828**	**$ 588,413**	**$ 587,997**	**$ 587,582**	**$ 556,037**	**$ 503,787**	**$ 503,787**	**$ 503,787**	**$ 503,787**	**$ 503,787**	**$ 503,787**	**$ 503,787**	**$ 503,787**	**$ 503,787**	**$ 503,787**	**$ 503,787**

Total Net Annual O&M Charges (Check)		**$ 650,000**	**$ 674,725**	**$ 205,900**	**$ 596,454**	**$ 595,629**	**$ 594,804**	**$ 593,979**	**$ 531,360**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**	**$ 427,638**
Total Annual Wastewater Charges (Check)		**$ 1,813,350**	**$ 699,575**	**$ 230,750**	**$ 1,180,923**	**$ 1,180,098**	**$ 1,179,273**	**$ 1,178,448**	**$ 1,115,829**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**	**$ 1,012,107**
Total Annual Flow Percentage		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Percentage: Variable Fee/Total Fee for WWTF		**0.00%**	**0.00%**	**0.00%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**	**29.53%**

Sheet V
User Rates and Revenues
November 3, 2014

RED TEXT IN MANUAL INPUT

Annual Subsidy for JBCC Military Users: See below
Inflation Rate Applied to JBCC Subsidy: 0.0%

Assumptions:

1. Billing/Collection Percentage: 100.0%
2. Discount Rate: 2.00%
3. Persons per SFR: n/a
4. Gallons per person per day: 65
5. Not used
6. Not used
7. Debt Service Coverage Ratio = Ratio of total revenue to annual outlays of cash to meet annual interest and principal payments on debt, plus sinking fund contributions.

Notes:
(1) From Sheet IV
(2) Composite for three entities
(3) First year cost = 1/2 Full Year ET Proposal

MassDevelopment User Charge	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2027**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Projected Daily Flows (1000 gallons/yr.):		1,907	1,906	1,906	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864	1,864
Total Wastewater Annual Treatment Charge (1)		**$42,864**	**$24,530**	**$7,750**	**$19,825**	**$19,811**	**$19,797**	**$19,783**	**$18,717**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**
Other Annual Costs for Private or Off-Site Facilities	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Wastewater Annual Cost:		**$42,864**	**$24,530**	**$7,750**	**$19,825**	**$19,811**	**$19,797**	**$19,783**	**$18,717**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**
Required User Rate ($/1000 gal.):		$22.48	$12.87	$4.07	$10.64	$10.63	$10.62	$10.62	$10.04	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10
User Rate ($/1000 gal.):		**$22.48**	**$12.87**	**$4.07**	**$10.64**	**$10.63**	**$10.62**	**$10.62**	**$10.04**	**$9.10**	**$9.10**	**$9.10**	**$9.10**	**$9.10**	**$9.10**	**$9.10**	**$9.10**	**$9.10**	**$9.10**	**$9.10**
MassDevelopment User Rate ($/kgal)	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**
Revenue from MassDevelopment		**$20,976**	**$20,967**	**$20,967**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**	**$20,499**
Cost of MassDevelopment Flows		**$42,864**	**$24,530**	**$7,750**	**$19,825**	**$19,811**	**$19,797**	**$19,783**	**$18,717**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**	**$16,952**
Net Annual MassDevelopment Cost		**$21,888**	**$3,563**	**-$13,216**	**-$674**	**-$688**	**-$702**	**-$716**	**-$1,781**	**-$3,547**	**-$3,547**	**-$3,547**	**-$3,547**	**-$3,547**	**-$3,547**	**-$3,547**	**-$3,547**	**-$3,547**	**-$3,547**	**-$3,547**
Cumulative MassDevelopment Cost		**$21,888**	**$25,452**	**$12,235**	**$11,562**	**$10,874**	**$10,172**	**$9,457**	**$7,675**	**$4,128**	**$582**	**-$2,965**	**-$6,511**	**-$10,058**	**-$13,605**	**-$17,151**	**-$20,698**	**-$24,245**	**-$27,791**	**-$31,338**
Military User Charge																				
Military Wastewater Flow (1000 Gallons per Year):		35,818	36,356	36,356	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545	35,545
Total Military Annual Treatment Charge:		**$828,687**	**$468,233**	**$148,179**	**$387,105**	**$386,837**	**$386,570**	**$386,302**	**$365,975**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**
Other Annual Costs for Private or Off-Site Facilities	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Military Annual Cost:		**$828,687**	**$468,233**	**$148,179**	**$387,105**	**$386,837**	**$386,570**	**$386,302**	**$365,975**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**
Military User Rate ($/1000 gal.):		**$23.14**	**$12.88**	**$4.08**	**$10.89**	**$10.88**	**$10.88**	**$10.87**	**$10.30**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**
Current Military User Rate ($/1000 gal.)	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**
Annual MassDevelopment Subsidy:		$404,235	$37,411	-$282,643	-$34,108	-$34,376	-$34,644	-$34,912	-$55,238	-$88,908	-$88,908	-$88,908	-$88,908	-$88,908	-$88,908	-$88,908	-$88,908	-$88,908	-$88,908	-$88,908
Cumulative Subsidy:		$404,235	$441,647	$159,004	$124,896	$90,519	$55,876	$20,964	-$34,274	-$123,182	-$212,090	-$300,998	-$389,905	-$478,813	-$567,721	-$656,629	-$745,537	-$834,444	-$923,352	-$1,012,260
Net Military Rate w/Subsidy ($/1000 gal.):		**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**	**$11.85**
Military User Rate ($/kgal)	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**
Revenue from Military Flows		**$358,183**	**$363,558**	**$363,558**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**	**$355,450**
Cost of Military Flows		**$828,687**	**$468,233**	**$148,179**	**$387,105**	**$386,837**	**$386,570**	**$386,302**	**$365,975**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**	**$332,306**
Annual Military Subsidy from MassDevelopment		**$470,505**	**$104,675**	**-$215,379**	**$31,655**	**$31,388**	**$31,120**	**$30,852**	**$10,525**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**
Cumulative Military Subsidy from MassDevelopment		**$470,505**	**$575,180**	**$359,801**	**$391,456**	**$422,844**	**$453,964**	**$484,816**	**$495,341**	**$472,197**	**$449,053**	**$425,909**	**$402,765**	**$379,621**	**$356,477**	**$333,333**	**$310,189**	**$287,045**	**$263,901**	**$240,757**
Adjusted Annual Subsidy from MassDevelopment		**$470,505**	**$104,675**	**-$215,379**	**$31,655**	**$31,388**	**$31,120**	**$30,852**	**$10,525**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**	**-$23,144**
Military User Rate with Excess Credited to Military		**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**
Non-Military User Charge																				
Projected Daily Flows (MG):		15,000	14,993	14,993	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931	16,931
Total Non-Military Annual Wastewater Charge:		**$368,866**	**$195,540**	**$63,548**	**$185,164**	**$185,036**	**$184,909**	**$184,781**	**$175,099**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**
Other Annual Costs for Private or Off-Site Facilities	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Non-Military Annual Cost (1)		**$368,866**	**$195,540**	**$63,548**	**$185,164**	**$185,036**	**$184,909**	**$184,781**	**$175,099**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**
User Rate ($/1000 gal.):		**$24.59**	**$13.04**	**$4.24**	**$10.94**	**$10.93**	**$10.92**	**$10.91**	**$10.34**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**
Annual Cost per Single Family Residence: (3)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Non-Military User Rate ($/kgal)	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**
Revenue from Non-Military Flows		**$165,000**	**$164,926**	**$164,926**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**	**$186,240**
Cost of Non-Military Flows		**$368,866**	**$195,540**	**$63,548**	**$185,164**	**$185,036**	**$184,909**	**$184,781**	**$175,099**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**	**$159,061**
Net Annual Non-Military Cost		**$203,866**	**$30,614**	**-$101,378**	**-$1,076**	**-$1,204**	**-$1,331**	**-$1,459**	**-$11,141**	**-$27,179**	**-$27,179**	**-$27,179**	**-$27,179**	**-$27,179**	**-$27,179**	**-$27,179**	**-$27,179**	**-$27,179**	**-$27,179**	**-$27,179**
Cumulative Non-Military Cost		**$203,866**	**$234,480**	**$133,102**	**$132,026**	**$130,822**	**$129,491**	**$128,032**	**$116,891**	**$89,712**	**$62,534**	**$35,355**	**$8,177**	**-$19,002**	**-$46,180**	**-$73,359**	**-$100,537**	**-$127,716**	**-$154,895**	**-$182,073**
Adjusted Annual Subsidy from MassDevelopment		**$203,866**	**$30,614**	**-$101,378**	**-$1,076**	**-$1,204**	**-$1,331**	**-$1,459**	**-$11,141**	**-$27,179**	**-$27,179**	**-$27,179**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Non-Military User Rate with Excess Credited to Non-Military		**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**	**$9.39**
Town #1 User Charge																				
Projected Average Daily Flow (MG/yr):		0	0	0	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161	55,161
Total Town #1 Annual Wastewater Charge:		**$572,933**	**$11,273**	**$11,273**	**$588,828**	**$588,413**	**$587,997**	**$587,582**	**$556,037**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**
Other Annual Costs for Customer Off-Site Facilities	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Town #1 Annual Cost (1)		**$572,933**	**$11,273**	**$11,273**	**$588,828**	**$588,413**	**$587,997**	**$587,582**	**$556,037**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**
User Rate ($/1000 gal.):		**N/A**	**N/A**	**N/A**	**N/A**	**$10.67**	**$10.66**	**$10.65**	**$10.08**	**$9.13**	**$9.13**	**$9.13**	**$9.13**	**$9.13**	**$9.13**	**$9.13**	**$9.13**	**$9.13**	**$9.13**	**$9.13**
Annual Cost per Single Family Residence:		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Town #1 User Rate ($/kgal)	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**	**$11.00**
Revenue from Town #1 Flows		**$0**	**$0**	**$0**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**	**$606,768**
Cost of Town#1 Flows		**$572,933**	**$11,273**	**$11,273**	**$588,828**	**$588,413**	**$587,997**	**$587,582**	**$556,037**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**	**$503,787**
Net Annual Town #1 Cost		**$572,933**	**$11,273**	**$11,273**	**-$17,940**	**-$18,355**	**-$18,771**	**-$19,186**	**-$50,731**	**-$102,981**	**-$102,981**	**-$102,981**	**-$102,981**	**-$102,981**	**-$102,981**	**-$102,981**	**-$102,981**	**-$102,981**	**-$102,981**	**-$102,981**
Cumulative Town #1 Cost		**$572,933**	**$584,205**	**$595,478**	**$577,538**	**$559,183**	**$540,413**	**$521,226**	**$470,496**	**$367,515**	**$264,534**	**$161,554**	**$58,573**	**-$44,408**	**-$147,389**	**-$250,369**	**-$353,350**	**-$456,331**	**-$559,311**	**-$662,292**
Debt Service Coverage Ratio (2)		**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2027**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Total System Flow (from Customers)		52,725	53,255	53,255	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500	109,500
Total Revenue		$1,813,350	$699,575	$230,750	$1,180,923	$1,180,098	$1,179,273	$1,178,448	$1,115,829	$1,012,107	$1,012,107	$1,012,107	$1,012,107	$1,012,107	$1,012,107	$1,012,107	$1,012,107	$1,012,107	$1,012,107	$1,012,107
Total O&M Cost		$410,000	$410,000	$658,200	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004	$934,004
Total Capital Reserve		$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Total Operating Reserve		$30,000	$30,000	$30,000	$25,000	$25,000	$15,667	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Annual Debt Service		$22,850	$22,850	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$580,469	$0
Debt Service Coverage Ratio: (Not required by WPAT)		**3.83**	**1.48**	**0.18**	**0.76**	**0.76**	**0.77**	**0.77**	**0.73**	**0.66**	**0.66**	**0.66**	**0.66**	**0.66**	**0.66**	**0.66**	**0.66**	**0.66**	**0.66**	**1.07**
20 Year Average User Rate ($/1000 gal.)	**$9.87**	**$23.53**	**$12.92**	**$4.12**	**$10.90**	**$10.89**	**$10.88**	**$10.87**	**$10.30**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**	**$9.35**
20 Year Average User Rate ($/1000 gal.) Set Rates	**$9.82**	**$10.32**	**$10.32**	**$10.32**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**	**$10.35**
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Net Annual Wastewater Balance - MassDevelopment		**$ (696,259)**	**$ (150,125)**	**$ 318,700**	**$ (11,966)**	**$ (11,141)**	**$ (10,316)**	**$ (9,491)**	**$ 53,128**	**$ 156,850**	**$ 156,850**	**$ 156,850**	**$ 156,850**	**$ 129,671**	**$ 129,671**	**$ 129,671**	**$ 129,671**	**$ 129,671**	**$ 129,671**	**$ 129,671**
Annual Present Value (2015)		**$ (682,607)**	**$ (144,295)**	**$ 300,318**	**$ (11,055)**	**$ (10,091)**	**$ (9,161)**	**$ (8,263)**	**$ 45,344**	**$ 131,245**	**$ 128,672**	**$ 126,149**	**$ 102,245**	**$ 100,240**	**$ 98,275**	**$ 96,348**	**$ 94,459**	**$ 92,606**	**$ 90,791**	**$ 89,010**
Wastewater NPV (20yr, 5yr, 10yr)	**$630,230**					**$ (147,730)**					**$ (259,892)**					**$ 263,364**				

Table 4.2 - Sensitivity Analysis (Water Resources Associates)

MassDevelopment JBCC Business Evaluation

Scenario Modification	NPV 5 years	NPV 10 years	MassDevelopment Military Subsidy 5 years	MassDevelopment Annual Military Subsidy 20 year average	MassDevelopment Non-Military Subsidy 5 years	MassDevelopment Annual Non-Military Subsidy 20 year average	Military Rate 10 yr avg	Non-Military Rate 10 yr avg
Baseline: No inflation, Initial User Rates	$ (197,500)	$ 632,000	$ 171,500	$ (74,800)	$ 8,710	$ (50,621)	$ 10.00	$ 11.00
Military Rate at **Current Full Rate** ($11.85/1000 gal.)	$ 256,800	$ 1,510,000	$ (163,500)	$ (138,600)	$ (138,500)	$ (80,367)	$ 11.85	$ 12.85
Military Rate - **Breakeven Subsidy**	$ 35,200	$ 1,081,000	$ -	$ (107,500)	$ (66,700)	$ (65,900)	$ 10.95	$ 11.95
Baseline: No inflation, Initial User Rates	$ (197,500)	$ 632,000	$ 171,500	$ (74,800)	$ 8,710	$ (50,621)	$ 10.00	$ 11.00
Baseline: Initial User Rates **2% annual inflation on all costs and revenues**	$ (87,500)	$ 1,019,000	$ 96,400	$ (128,100)	$ (30,000)	$ (79,200)	$ 11.17	$ 12.29
Baseline: Initial User Rates **3% annual inflation on all costs and revenues**	$ (30,300)	$ 1,229,000	$ 57,300	$ (160,000)	$ (50,100)	$ (96,200)	$ 11.81	$ 12.99
Baseline: No inflation, Initial User Rates **Septage Tipping Fee** = $0.11/gal.	$ (197,500)	$ 632,000	$ 171,500	$ (74,800)	$ 8,710	$ (50,621)	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Septage Tipping Fee** = $0.13/gal.	$ 106,000	$ 1,403,000	$ (46,500)	$ (135,900)	$ (90,400)	$ (79,500)	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Septage Tipping Fee** = $0.10/gal.	$ (349,300)	$ 246,500	$ 280,500	$ (44,300)	$ 58,200	$ (36,200)	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Effluent Disposal Fee** = $0.0075/1000 gal.	$ (197,500)	$ 632,000	$ 171,500	$ (74,800)	$ 8,710	$ (50,621)	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Effluent Disposal Fee** = $0.010/1000 gal.	$ (96,353)	$ 889,053	$ 98,800	$ (95,200)	$ (24,311)	$ (60,233)	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates **Effluent Disposal Fee** = $0.006/1000 gal.	$ (258,200)	$ 477,900	$ 215,100	$ (62,600)	$ 28,523	$ (44,900)	$ 10.00	$ 11.00
Baseline: No inflation, Initial User Rates	$ (197,500)	$ 632,000	$ 171,500	$ (74,800)	$ 8,710	$ (50,621)	$ 10.00	$ 11.00
Baseline: Optimized Best Case (2% Inflation) Military Rate: Current Full Rate = $11.85/1000 gal. Septage Rate = $0.12/gal. Effluent Disposal Fee = $0.0085/1000 gal.	$ 598,700	$ 2,540,000	$ (405,900)	$ (253,500)	$ (253,100)	$ (138,200)	$ 11.85	$ 12.85

APPENDIX C
EXCERPTS FROM THE CCC DRAFT 208 PLAN

DRAFT

208

CAPE COD AREA WIDE WATER QUALITY MANAGEMENT PLAN UPDATE

as needed, compared with a larger number of smaller facilities.

With funding from Barnstable County, the Town of Orleans supplemented its Comprehensive Wastewater Management Plan with a focused study of the options available to share wastewater facilities with the towns of Eastham and Brewster. The details of this evaluation are presented in the December 2009 Wastewater Regionalization Study (Orleans-Brewster-Eastham) (Wright-Pierce 2009). Compared with each town building its own separate wastewater facilities, two-town and three-town regional solutions may offer 6% to 9% capital cost savings and 18% to 25% O&M cost savings. Potential capital cost savings by town are:

- Brewster - $3.0 to $8.4 million
- Eastham - $2.5 to $6.9 million
- Orleans - $1.9 to $10.5 million

Two identified options involve the installation of public sewers in Brewster and Eastham, and the associated pipelines to transport the collected wastewater to the regional treatment facility. It is also possible for Orleans to remove Brewster and Eastham's shares of watershed nitrogen loads by expanding the proposed Orleans sewer system. In essence, Orleans could eliminate more Orleans septic systems to offset Brewster and Eastham nitrogen loads and have those two towns pay for that expansion. In this way, regionalization could occur without the construction of public wastewater facilities in either Brewster or Eastham.

Given the lack of required collection systems for the non-traditional technologies and approaches discussed in Chapter 3 and utilized in the watershed scenarios, traditional approaches are more likely to benefit from optimizing the factors described above. However, some non-traditional technologies, such as waste reduction toilets, may benefit from regional management arrangements for O&M. For example, a regional effort for managing urine and compost removal and/or reuse, as opposed to a town-by-town or even homeowner-by-homeowner arrangement, may present a cost savings.

Taking advantage of existing intermunicipal arrangements for water and/or wastewater is another potential cost savings method. For example, the Upper Cape Water Supply Cooperative is a regional agreement to supply water to the four Upper Cape towns of Bourne, Falmouth, Mashpee and Sandwich. Management of the Cooperative is by a Board that represents the four public water supply systems – the Town of Falmouth, Bourne Water District, Mashpee Water District and Sandwich Water District. The wells for the Cooperative are located toward the north end of Joint Base Cape Cod (JBCC), in the town of Sandwich. JBCC is also the site of a federally-owned wastewater treatment facility with the potential to support regional wastewater management needs of the Upper Cape. Potential benefits could be realized in this area given the existing intermunicipal arrangement for water supply and the existing infrastructure at JBCC. More information on the JBCC infrastructure can be found in Chapter 6.

RECCOMENDATION S4.2: Cape Cod Commission will create and assign Watershed Teams to provide technical assistance at the local level.

proportion to each town's contribution to the total nitrogen load is one of the simplest approaches.

To determine nitrogen load, the Massachusetts Estuaries Project (MEP) uses a water use approach that is applied on a parcel-by-parcel basis within a watershed. Annual water meter data is linked to parcel information and the parcel specific data is converted to septic system nitrogen discharges to the receiving watershed by adjusting for consumptive use (typically 90%) and applying a wastewater nitrogen concentration. The Commission's WatershedMVP tool is available to provide updated information on parcel specific water use to assist towns and WMAs seeking to allocate responsibility.

Not all nitrogen loads to coastal watersheds impact coastal water quality. A considerable amount of nitrogen is lost to the atmosphere and other sinks as nitrogen loads discharge to fresh surface waters before being transported to coastal waters. For example, towns that are up-gradient of ponds and streams will see that their nitrogen loads to coastal waters are significantly diminished relative to the load entering the watershed. This is referred to as natural attenuation.

Towns or waste management agencies have the option to use unattenuated nitrogen loads, which are the actual loads discharged to the ground, or attenuated nitrogen loads, which reflect the load that reaches the estuary or embayment once it's made its way through the watershed.

The stakeholder process associated with this §208 Plan Update identified a number of other factors, in addition to water use and natural attenuation, that might be considered when allocating responsibility. Stakeholders generally agreed that year round population and seasonality, as well as local growth management and land protection and acquisition plans, should be available for consideration when multiple towns are working to come to agreement on shared responsibility.

In many shared watersheds there are towns that contribute very little to the estuary or embayment. For example, Waquoit Bay is shared by Falmouth, Mashpee, and Sandwich. The attenuated nitrogen load contributions are as follows:

- Falmouth – 54%
- Mashpee – 42%
- Sandwich – 4%

The bulk of the responsibility for nitrogen management in this watershed, after attenuation, lies with Falmouth and Mashpee; however, Sandwich has a small share. In addition, part of the watershed is controlled by Joint Base Cape Cod (JBCC). See Chapter 6 for more information on JBCC, its wastewater treatment facility, and the towns within which it has land holdings.

In areas where land is controlled by a government agency that is not local the appropriate agencies need to be included in the discussion around allocating responsibility.

Towns, WMAs, or other government entities should have the option to address their portion of the responsibility by remediating nitrogen within their political boundaries or by paying for the implementation of strategies elsewhere in the watershed or receiving water body. This may be most practical for watersheds in which one of the towns has a small share of the responsibility, but could be applicable in a number of circumstances.

Another example of where this may be appropriate is in the Pleasant Bay Watershed, which is shared by the towns of Brewster, Chatham, Harwich, and Orleans. Brewster's land area is in the upper portion of the watershed and the town has little to no frontage on the estuary itself. Brewster should have the opportunity to contribute to a remediation strategy within the embayment, outside of its town boundaries, or within Pleasant Bay itself.

One option for allowing this type of cost sharing is through the use of a nutrient credit exchange program. Suggestions for this type of program are discussed further below.

Agreements allocating responsibility should include a provision relative to future amendments or changes to the TMDL approved by MassDEP and US EPA.

Towns and WMAs are encouraged to immediately begin discussions in shared watersheds to allocate responsibility for nitrogen remediation. The Commission is available to initiate and/or assist in these multi-party discussions.

The Commission will require binding agreements allocating nitrogen remediation responsibility between towns and WMAs, as appropriate, as a condition prior to issuing regulatory approvals for water quality plans and projects. This 208 Plan Update recommends that MassDEP require the same.

with conditions to develop an adaptive management plan.

Spring 2014 Town Meeting subsequently approved $50 million to construct a targeted watershed approach for a Little Pond watershed collection system and implement the pilot projects over the next five years, concluding in 2020.

A more detailed chronology of water quality planning efforts in Falmouth is available in Appendix 6G.

HARWICH

The Town of Harwich established a water quality management task force to coordinate both fresh and marine water sampling. The task force is responsible for wastewater planning, which consists of developing a CWMP and participating in the Pleasant Bay Alliance. The Harwich efforts were on hiatus while waiting for the Massachusetts Estuaries Project (MEP) to complete the technical reports for Herring River and several of the south-side embayments. These reports were received by the town in 2010–2012.

The town has since submitted an expanded ENF and anticipates participating in joint MEPA/DRI review with the Cape Cod Commission.

The CWMP includes options for regional infrastructure with the Town of Chatham for the East Harwich economic development area of town (part of the shared Pleasant Bay watershed). The town recently signed an agreement with the Town of Chatham to evaluate this option.

Harwich is also the lead town in a shared effort to improve circulation in Muddy Creek with a culvert-widening project that will likely reduce nitrogen removal requirements. Design of the culvert is close to complete and construction was scheduled to begin in May 2014. The project received two federal grants - $3.4 million of Hurricane Sandy Mitigation and Resiliency funding and a $1 million National Coastal Wetlands Conservation grant - and spring 2014 Town Meeting approved the appropriation of an additional $1.75 million.

A more detailed chronology of water quality planning efforts in Harwich is available in Appendix 6H.

MASHPEE

The Mashpee CWMP was scoped through a joint MEPA/DRI review as an ENF in 2001. In 2007, the town submitted its Needs Assessment Report entitled, “Town of Mashpee, Popponesset Bay and Waquoit Bay-East Watersheds Needs Assessment Report.” The report documents the significant level of effort that has gone into determining the nitrogen TMDLs for the two subject embayments over the course of six years. Also in 2007, the town completed a technology screening report, which was followed shortly by its draft alternative scenarios and site evaluation report in March 2008.

Mashpee has been engaged in numerous county, state, and federally funded projects, including the 2009 MassDEP Pilot Project and the 2009 Cape Cod Commission TMDL Implementation Project, which were both funded by US EPA. Through these projects, the town ran a number of scenarios through the MEP linked water quality model to evaluate TMDL compliance strategies, including an assessment of cranberry bogs and streams for potential additional natural attenuation. These projects also allowed Mashpee, together with representatives of Barnstable and Sandwich, to participate in the determination of nitrogen allocation for Popponesset Bay for each town and prepare a draft intermunicipal agreement. Mashpee received wastewater grant funds from Barnstable County to model sewer collection systems in the Popponesset watershed and technical assistance from the USGS and Commission staff to use the Sagamore Lens groundwater model to evaluate potential wastewater disposal sites.

The Needs Assessment contains a characterization of the nine operating private sewage treatment facilities, including treatment efficiency and excess capacity. This work allowed the town to focus on three potential wastewater scenarios that were developed in 2012. These options are being reviewed and will be the basis for development of their preferred alternative. The wastewater scenarios include use of the existing private plants at their planned capacity and either three or four subregional plants with consideration of shared town responsibility. Off-site disposal of effluent outside of the impaired watersheds is an important consideration for the plan’s approach. The alternatives analysis included consideration of private effluent disposal sites at New Seabury, Willowbend, and others, in addition to the town’s transfer facility site.

The town has an appointed seven-member Sewer Commission and an in-house coordinator for wastewater projects as the town proceeds with selecting a preferred alternative. Special legislation filed by the town to convert the Mashpee Water District to the Mashpee Water and Sewer District was signed by the Governor on April 18, 2014 and is pending approval by Mashpee voters. In addition to the needs and alternatives identified, the town is considering the use of the JBCC treatment facility and disposal site as long-term regional solutions.

In April 2014, the Sewer Commission met with Cape Cod Commission staff to begin the discussion around filing its

Management Plan and components of the Cape-wide Section 208 Water Quality Management Plan.

A more detailed chronology of water quality planning efforts in Orleans is available in Appendix 6J.

PROVINCETOWN

Provincetown completed a Wastewater Facility Plan in 2001. The plan dealt with the public health issues of failing septic systems and inadequate infrastructure for its commercial downtown area. The comprehensive plan was approved by state agencies through MEPA and by the Cape Cod Commission through DRI review in 2001. The wastewater facility and phase 1 and 2 areas were subsequently built and are performing well. The plan included a number of innovative aspects, including a lot-by-lot assessment of Title 5 systems, use of the Route 6 median and right-of-way for effluent disposal, combination of force mains, conventional gravity and vacuum sewers, and "checkerboard" sewer areas. The plan included three phases. The town is presently expanding sewers into the Phase 3 area and is upgrading the facility to its planned capacity. During this implementation, the town was able to use measured wastewater flow to compare to the design capacity and to negotiate the use of that excess capacity for new wastewater flow.

A more detailed chronology of water quality planning efforts in Provincetown is available in Appendix 6K.

SANDWICH

The Town of Sandwich has established a water quality committee to oversee water quality and wastewater planning efforts. The committee developed a scope of work for a Comprehensive Wastewater Management Plan and submitted the scope under the Sagamore Lens Natural Resource Damages Assessment, related to past groundwater contamination at the Textron facility at the JBCC. The town received an award of $400,000 t0 conduct its water/wastewater plan and completed a comprehensive needs assessment, as well as an interim wastewater solutions plan to accommodate economic development in the South Sandwich Village Center (often referred to as the Golden Triangle area).

The town spent several years working with a private developer on a development project that included a public-private wastewater component involving the construction of a facility that would accommodate the private project and a certain amount of general public wastewater need. That project will not be completed, but the town is again seeking a private partner to create new economic growth and to potentially participate in infrastructure development.

The town is participating in discussions at JBCC about the potential use of its existing wastewater infrastructure as a regional option for the Upper Cape towns.

A more detailed chronology of water quality planning efforts in Sandwich is available in Appendix 6L.

TRURO

The Town of Truro approved funds for a CWMP, acknowledging that protection of private-well drinking water is of paramount importance, and established a water resources oversight committee. The CWMP kicked off in 2012 with a focus on septic systems and stormwater-runoff and their impact on drinking water and embayment water quality. The planning process seeks to assemble existing data, and develop a GIS program to evaluate land and water data, historic septic-system management information and key areas for further analysis and characterization. The committee is in the process of reviewing the phase I of the draft water management plan.

A more detailed chronology of water quality planning efforts in Truro is available in Appendix 6M.

WELLFLEET

The town of Wellfleet has an established Comprehensive Wastewater Management Planning Committee that is charged with providing a comprehensive strategy for addressing wastewater treatment and disposal issues for the next 40 years and for the foreseeable build out conditions in town. Along with their consultant, they completed a draft of its CMWP Needs Assessment and Alternatives Analysis reports in June 2012. The objectives of the CWMP are to protect and enhance the Wellfleet Harbor ecosystem, promote aquaculture-based water quality management solutions, identify low-cost and sustainable remedies, develop least-cost alternatives and, only as a final resort, engage in structured solutions.

The CWMP process allowed Wellfleet to pursue and implement pilot scale ecotoilet and oyster restoration solutions. Spring 2013 Town Meeting appropriated funds to build a bathhouse at Bakers Field Beach that uses composting toilet technology to reduce the nitrogen load to Wellfleet Harbor. The oyster restoration project is a 2-acre site in Wellfleet Harbor and has a well-structured monitoring component. Water quality monitoring was conducted at the site in 2012 and 2013 and provided necessary data for the town to make informed decisions moving forward.

A more detailed chronology of water quality planning efforts in Wellfleet is available in Appendix 6N.

restriction of 0.8 MGD. The permit limits flows to the WWTF to 0.23 MGD inside the West Falmouth Harbor watershed and 0.57 MGD outside the West Falmouth Harbor watershed. On January 10, 2014 the Town received a Certificate of Adequacy from the Secretary Of Energy and Environmental Affairs to sewer the Little Pond Service Area and discharge up to 260,000 GPD at a new disposal site is being pursued ("Site 7"), north of the existing beds and outside the West Falmouth Harbor watershed. The Town is moving forward with a new effluent measuring system and optimization and improvement to the existing treatment system including the sludge thickening process at the facility.

PROVINCETOWN

The Provincetown WWTF is an advanced secondary treatment plant that is capable of treating a maximum daily flow (MDF) of 650,000 GPD, with discharge to four subsurface disposal beds at six locations along Route 6. Additional upgrades may be required to increase the capacity to allow a MDF of 750,000 in the future, and will occur when required.

AECOM is currently under a 20-year design-build-operate (DBO) agreement with the Town of Provincetown (Town) to design, permit, construct and operate its wastewater collection, treatment, and disposal systems.

The current sludge management plan includes periodic removal from the SBRs, storage for aeration and mixing, and hauling by a contractor for disposal at a facility in Cranston, RI.

JOINT BASE CAPE COD

There is also an existing WWTF at Joint Base Cape Cod. It is discussed in further detail below.

Planning Partnerships

Cape Cod is greater than the sum of its 15 towns. Because Wastewater Management Agencies will need physical domain over the lands and nutrient contributions they seek to manage, we must work with our federal and state partners to achieve water quality goals. Joint Base Cape Cod and the Cape Cod National Seashore are the largest of these state and federal land holdings, and they provide important open space and significantly reduced residential density and related wastewater discharges within their borders.

The Massachusetts Department of Transportation (MassDOT) state roadway system impacts coastal and freshwater bodies through stormwater runoff and tidal restrictions caused by state roadway bridge abutments and there is an opportunity to work cooperatively to address these issues. Federal, state and municipal governments and local land trusts also play an important role through past and future open space acquisitions that prevent new development and protect water resources. Naturally forested open space also provides a valuable nitrogen "sink" as natural systems attenuate nitrogen contributions from atmospheric deposition. Various federal and state programs are also available to assist the region as we implement water quality restoration measures.

JOINT BASE CAPE COD

RELATIONSHIP TO SURROUNDING TOWNS

At approximately 22,000 acres, Joint Base Cape Cod (JBCC), formerly known as the Massachusetts Military Reservation (MMR), is one of the largest contiguous properties in state or federal ownership on Cape Cod. JBCC is a full service military base and is home to the Massachusetts Air National Guard's (MAANG) Otis Air National Guard (ANG) Base, the U.S. Coast Guard's (USCG) Air Station Cape Cod, the Veterans Administration Cemetery, the U.S. Air Force's Cape Cod Air Force Station, and the Massachusetts Army National Guard's (MAARNG) Camp Edwards.

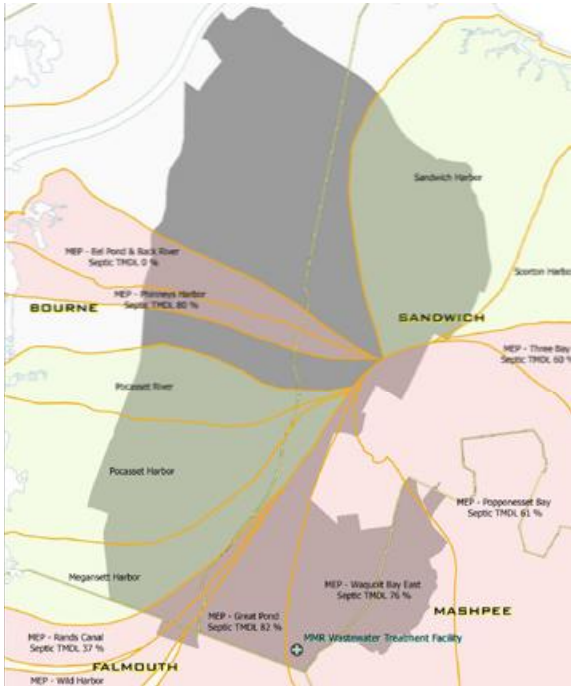
Camp Edwards, principally used for Army National Guard training, is comprised of approximately 15,000 acres in the northern portion of the base. The cantonment area, which is substantially more developed with structures, roads and other infrastructure, is comprised of approximately 7,000 acres in the southern portion of the base. JBCC includes parts of the towns of Bourne, Mashpee, and Sandwich, and abuts the town of Falmouth in Barnstable County, Massachusetts. The northern 15,000 acres of the base, also called the Upper Cape Water Supply Reserve, where the majority of the Army National Guard training occurs, was protected through a Memorandum of Agreement (MOA) and an Executive Order in 2001. The MOA was codified into law in 2002. Activities in the Reserve are subject to Environmental Performance Standards that were enacted to ensure the permanent protection of the Cape's drinking water supply and wildlife habitat in that area (Harshbarger 1998). The Environmental Management Commission ("EMC") of the JBCC consists of three members: The Commissioner of the Department of Fish and Game, the Commissioner of

the Department of Conservation and Recreation, and the Commissioner of the Department of Environmental Protection. The EMC's responsibility is to ensure the permanent protection of the drinking water supply and wildlife habitat of the Reserve and to ensure all military and other activities in those 15,000 acres are consistent with the Environmental Performance Standards. The northern 15,000 acres contains four public water supply wells as part of the Upper Cape Regional Water Supply Cooperative discussed above. The EMC is assisted by the Community Advisory Council ("CAC"), which consists of the following members: one each from Falmouth, Bourne, Sandwich and Mashpee; one family member resident of the JBCC; two representatives from the military; one from the Cape Cod Commission; one from the Wampanoag Tribe; and five other members. All members are appointed by the Governor.

STATUS OF JBCC WASTEWATER TREATMENT FACILITY

The 102nd Intelligence Wing (IW) is the host for utilities at JBCC, including the wastewater treatment plant. Massachusetts DEP issued the 102nd IW a new discharge permit early in 2004 that authorizes an average 360,000-gallon per day discharge from the Wastewater Treatment Plant (WWTP) to enable the WWTP to accept a maximum 60,000-gallon per day sewage discharge from the new Barnstable County Jail and House of Corrections just north of Connery Avenue. The location of the treatment facility is shown in Figure 6-1. The MAARNG operates two facilities in the Reserve (Camp Edwards) with individual septic systems: Range Control and the Ammunition Supply Point (ASP).

The status of the 102nd's wastewater treatment facility is based in part on information contained in Appraisal Consulting



Joint Base Cape Cod, surrounding towns, and the location of the wastewater treatment facility

Figure 6-1

Services for the Wastewater Treatment System at the MMR (Appraisal) completed in December 2012 by CH2MHill for MassDevelopment, a quasi-public state financing and development agency for the Commonwealth. Additional information was obtained from CWMPs either completed or currently in process by the four Upper Cape towns.

The JBCC wastewater system components are identified below in Table 6-1.

The wastewater management system at JBCC was designed to provide wastewater collection, onsite treatment, and onsite disposal of treated wastewater from installation facilities. As shown in Figure 6-2, wastewater is collected and conveyed by gravity and force mains to the WWTP located at the southern boundary of the base. Treated wastewater from the onsite WWTP is pumped through a 10.5 mile long effluent force main and used to recharge groundwater through rapid infiltration beds (RIBs), which are located on the northern boundary of the installation. The effluent force main and the disposal beds were constructed in 1996. The system was originally designed to allow biosolids from the WWTP to be composted and disposed of onsite as a soil amendment. Currently, wet biosolids are trucked offsite for disposal.

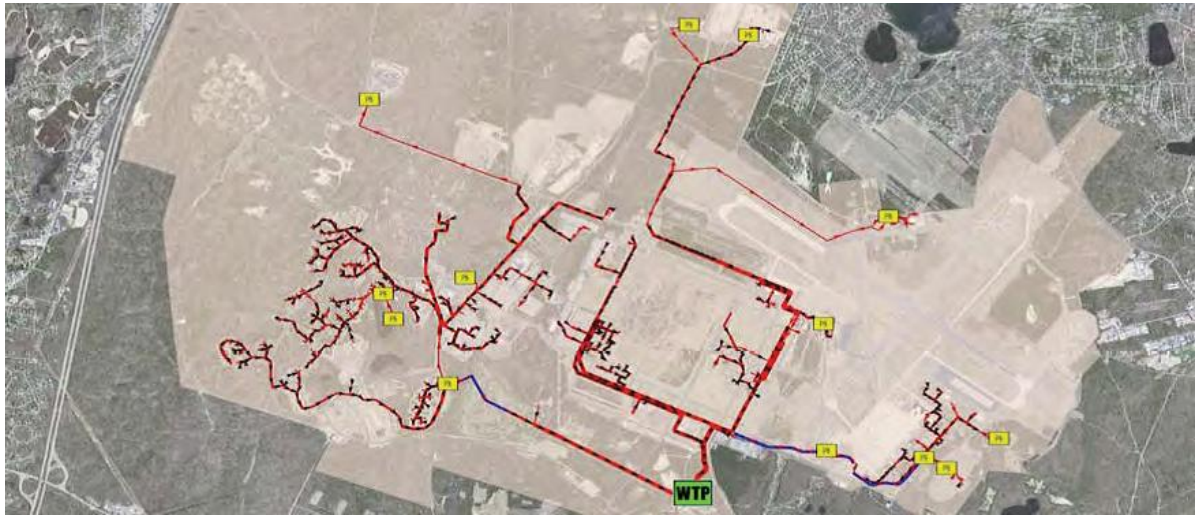
The general condition of the wastewater treatment plant was found by the CH2MHill report to be "fair" since it was upgraded in 1996 with a number of part replacements in 2002. The report also noted the condition of the collection system

COMPONENTS OF THE JBCC WASTEWATER SYSTEM

Facility Component	Size/Quantity
Collection & Conveyance Conduits:	161,000 linear feet (lf)
Manholes:	595
Pump Stations:	11
Wastewater Treatment Plant:	360,000 gpd permitted capacity
12" Treated Effluent Force Main:	55,280 lf
Rapid Infiltration Disposal Beds:	4 cells; 6 acres
Monitoring Wells:	7

Components of the JBCC Wastewater System

Table 6-1



Joint Base Cape Cod wastewater collection system (Source: CH2MHill 2012)

Figure 6-2

SUMMARY OF WASTEWATER TREATMENT AND DISPOSAL NEEDS

Entity	Near-Term Needs (gpd)	20-Year Needs (gpd)	Requirements
JBCC Users	140,040	147,300	Treatment and Disposal
Town of Falmouth	200,000	200,000	Disposal only
Bourne Landfill	40,000	80,000	Disposal only
Town of Bourne	0	1,836,000	Treatment and Disposal
Town of Sandwich	156,000	630,000	Treatment and Disposal
Town of Mashpee	158,000	658,600	Treatment and Disposal
Total: Treatment and Disposal	454,040	3,271,900	
Total: Disposal Only	240,000	280,000	

Summary of Wastewater Treatment and Disposal Needs

Table 6-2

was "cautious" since the collection system is over 50+ years old and no formal assessments have been completed. A 2001 inflow and infiltration study (I/I) indicated that I/I was a significant portion of the flow captured by the system.

The study reported that the replacement cost was $44 million, but that the replacement cost less depreciation was $16 million. The near-term and 20-year needs for JBCC users were reported as 140,000 and 147,000 gpd respectively.

The study attempted to gauge the wastewater needs of the surrounding communities. This effort made use of the best available information from the towns to reflect existing and potential wastewater needs. The total short-term and future needs were 694,000 and 3,551,900 gpd respectively for treatment and total disposal as indicated in Table 6-2 (excerpted from the study).

STATUS OF DISPOSAL SITE

Final treated effluent is pumped through a 10.5-mile ductile iron force main to four sand-lined RIBs, as shown in Figure 6-3, located on the northern boundary of the JBCC south of Route 6 (Sandwich Road).

The effluent disposal system consists of the following components:

- Piping to distribute effluent to RIBs.
- Four sand lined RIBs that cover approximately 6 acres.
- Seven groundwater monitoring wells (three pairs downgradient, one upgradient).

The soil characteristics and design parameters for the treated wastewater disposal system are described in the Hydrogeo-

logic Investigation and Design Effluent Infiltration Basins technical memorandum (CDM Smith 1993). Review of the hydrologic analysis indicates that the design capacity of the RIBs, according to Massachusetts Department of Environmental Protection (MassDEP) criteria, is substantially higher than the permitted flow to the WWTP. Based on the size of each infiltration basin and an assumed hydraulic conductivity that is typical of the Cape, the total capacity of the four RIBs is approximately 907,000 gpd. With one RIB as reserve capacity, the disposal capacity is about 672,000 gpd.

JBCC JOINT LAND USE STUDY

The Cape Cod Commission completed an update to a 2005 JBCC Joint Land Use Study (JLUS) in October, 2013. Factors prompting the Army's re-nomination of JBCC for a JLUS were changes to missions on the installation due to the 2005 Base Realignment and Closure (BRAC) round; an increase in the training population using JBCC's ranges; and concern about the compatibility of future civilian land uses surrounding JBCC.

As demonstrated in the Appraisal discussed above, the WWTP and RIBs have sufficient capacity for existing and future (20-years) JBCC military wastewater needs. Those facilities also have excess capacity to treat and dispose of wastewater generated by non-military entities. Through the JLUS process, and based on the Appraisal, the JLUS identified the potential for a military/municipal partnership and shared services through municipal use of the excess capacity of the JBCC WWTP and RIBs for wastewater and landfill leachate disposal. The JLUS states:

Given the wastewater nutrient management needs of the region to achieve TMDL [total maximum daily load] compliance and limited wastewater infrastructure on Cape Cod, existing capacity at the JBCC WWTP should be reserved for military and community needs.



Joint Base Cape Cod rapid infiltration beds (Source: CH2MHill 2012)

Figure 6-3

The Commission is developing a grant application for submission to the Office of Economic Adjustment, U.S. Department of Defense, for funds to conduct a feasibility study of the potential scenarios under which the JBCC WWTP and RIBs may be shared with the Upper Cape towns. The results of that study are anticipated in the Fall of 2014.

JBCC MILITARY AND NON-MILITARY NITROGEN CONTRIBUTIONS

As stated above, there is sufficient wastewater treatment and disposal capacity for existing and future (20-years) military needs. The JBCC controls land within 13 watersheds that are shared with the towns of Bourne, Sandwich, Falmouth and Mashpee, as shown in Figure 6-1 above. The individual municipalities are responsible for planning and implementation to prevent violations

RECOMMENDATION S6.1: Discussion and coordination with JBCC, MassDevelopment and the CCC regarding a no-net nitrogen land use policy for the base.

of the Clean Water Act. Because the JBCC controls land within watersheds that are shared with the towns, increases in the contribution of nitrogen from the JBCC within those watersheds will raise the bar for towns striving to meet TMDLs, and potentially increase the burden on municipal taxpayers.

While there is adequate treatment and disposal capacity for military uses, an unknown level of nitrogen contribution could result from non-military uses on the base. MassDevelopment has expressed an interest in promoting new development on the base with uses that do not compete with municipal economic development opportunities, and which are military-compatible. With these two caveats, this Plan supports the creation of new non-military uses that have proper wastewater treatment and disposal to ensure no net nitrogen impacts in nitrogen sensitive embayments. First, non-military uses indeed should not compete with municipal economic development, and second, that new growth facilitated by MassDevelopment should not appropriate excess capacity at the WWTP and the RIBs that would otherwise be available to serve the surrounding towns.

It is in the best interest of the military and the towns to prioritize allocation of the excess capacity of the JBCC for the needs of the neighboring towns and the military in a way that reduces the military's overhead to ensure that the base remains a strong and viable presence in our region. In the event that excess capacity is allocated to municipal uses, MassDevelopment's interest in attracting new development to JBCC can be accommodated through WWTP and RIB upgrades and possible expansion.

To ensure equity and parity between the base and the surrounding towns, this Plan proposes further discussion and coordination between JBCC leadership, MassDevelopment, and the Commission to establish a no-net-nitrogen policy for land uses within nitrogen sensitive watersheds that emanate from the base (**Recommendation S6.1**). Future agreements could also establish a protocol for allocating excess capacity at the WWTP and RIBs for municipal purposes, and establish a new, proactive communications policy between the JBCC, MassDevelopment, the Commission, and the surrounding towns.

PAST PLANS AND STUDIES REGARDING JBCC

The Commission has a webpage that provides comprehensive information on current and past plans and studies completed by the Commission regarding the JBCC, including the 2005 Joint Land Use Study and its 2013 update, as well as the MMR Master Plan Final Report, which includes background information on past environmental issues that led to subsequent planning processes. For more information, visit www.capecodcommission.org/index.php?id=306&maincatid=4.

ROLE OF THE MASSACHUSETTS DEPARTMENT OF TRANSPORTATION (MASSDOT) IN STORMWATER MANAGEMENT

79% of the Cape's land mass is in a watershed to a coastal embayment. It is therefore not surprising that miles of state roadway run through nutrient impaired watersheds on Cape Cod. To varying degree, stormwater runoff from these roadways contributes to the nutrient problems experienced on the Cape.

Through the MassDOT Impaired Waters Program (IWP), MassDOT has instituted a program to address roadway stormwater runoff draining to impaired water bodies. The program is part of the agency's compliance with its NPDES Phase II Small MS4 General Permit and commitments in an EPA enforcement

Regulatory Reform

The existing regulatory framework for wastewater is better suited for permitting traditional facilities and needs to evolve to meet the challenges of diffuse, non-point source nutrient pollution. Changes are necessary to make it easier for communities and to better respond to the problem.

Process improvements recommended in this update create a streamlined Special Review Procedure for the review of Targeted Watershed Plans jointly by MEPA and the Cape Cod Commission. **SRP (R5.5)** In shared watersheds, Targeted Nutrient Management Plans should be required; CWMPs that address only a portion of a shared watershed should no longer be permissible. Minimum performance standards and guidance will be drafted and issued pursuant to this update within 90 days of its approval. **Targeted Nutrient Management Plan (R4.4)** The MEPA process is generally the first hurdle encountered by communities planning wastewater programs requiring SRF funds.

The Cape Cod Commission Development of Regional Impact review that follows the issuance of a MEPA certificate of adequacy from the Secretary of Energy and Environmental Affairs will be reformed. A simpler and more supportive process to review Capital Developments of Regional Impacts will be developed. **CDRI (R5.4)** Local water quality management plans, and material changes to existing plans will be reviewed to ensure consistency with this update. **Consistency Review (R4.2)**

Additionally the collective responsibility of localities for nutrient loading should be updated and corresponding enforcement actions clarified. This update recommends the Massachusetts Department of Environmental Protection develop regulations outlining the process for Watershed permits for nutrient loads. **Watershed Permitting (R5.3)** This will allow communities more flexibility in designing efforts to comply with nutrient load limitations defined in the permit.

The DEP should designate those Cape Cod watersheds contributing to degraded marine estuaries and embayments as Nitrogen Sensitive Watersheds. **Designation of Nitrogen Sensitive Watersheds (R5.2)** This action brings with it certain burdens to homeowners regarding septic system upgrade requirements. These regulatory burdens should be stayed for a period of 12 months. In this timeframe, as part of the 208 update implementation process, the Cape Cod Commission, as the designated 208 regional planning entity, will convene a WMA task force to evaluate waste management agencies for watersheds in the planning area for designation by June 30, 2015. **Designation of WMA (R5.6)** MassDEP should mandate the formation of a water pollution abatement district(s) in any planning area watershed without a designated waste management agency(ies) as of June 30, 2015. **WPAD (R5.7)**

Given the importance of the federal Clean Water Act and the long-term commitment necessary to implement solutions to nutrient pollution on Cape Cod, the commonwealth should consider seeking delegated authority for the NPDES program. **NPDES delegated authority to the State (R5.1)**

Support

More direct support of local wastewater planning is warranted. This update recommends that local planning efforts consult with the Commission early in the process. The Commission will provide technical assistance by providing watershed teams to support community planning efforts. **Watershed Teams (S4.2)** These teams will assist in advising on the development of watershed scenarios with nutrient management plans consistent with this 208 update. **Hybrid Watershed Planning Approach (S4.3)** These plans will result in adaptive management implementation plans **Adaptive Management (R4.1)** qualifying for the Watershed Permit Program.

The watershed plans developed as part of the 208 Plan Update will also identify Pilot Projects and assist in identifying financial resources and direct support through the Regional Monitoring Program. **Pilot Projects (S4.1)**

Additionally, this report recognizes the importance of third-party facilitation of intra and intermunicipal disagreements and recommends the allocation of federal, state and regional resources for this purpose. **Managing Disagreement (S1.1)**

The report also suggest continued cooperation with planning partners including MassDOT **(MassDOT S6.1)** in part to develop methodologies to assess stormwater contributions from state roadways, identify opportunities to improve tidal flushing in coastal areas and use rights-of-way for water quality improvement projects. This Plan proposes further discussion and coordination with **JBCC (JBCC S6.2)** to establish a policy for land uses within nitrogen sensitive watersheds that emanate from the base.

APPENDIX D
MATERIALS SUPPORTING WATER SYSTEM ANALYSIS

Print

Acts 2000 CHAPTER 352 AN ACT ESTABLISHING THE UPPER CAPE REGIONAL WATER SUPPLY COOPERATIVE.

Be it enacted by the Senate and House of Representatives in General Court assembled, and by the authority of the same, as follows:

SECTION 1. It is hereby declared essential for the benefit of the people of the towns of Falmouth, Bourne, Sandwich and Mashpee, in order to sustain and protect their welfare, prosperity and their living conditions, that the towns establish a supplementary water supply system, that accurate, appropriate, and self-sustaining fees, rates and charges for said supplementary water supply be established; that said supplementary systems for said municipalities be operated in a modern, efficient and financially self-sustaining manner to further their sound financial, environmental and physical condition; that conservation of water sources be encouraged; that water supplies be protected and improved; and that the towns be provided a means to insure the continued availability of water; all to the public benefit and good, and to the extent and in the manner provided herein.

SECTION 2. For the purposes specified in section 1, the Bourne water district, the town of Falmouth, the Mashpee water district and the Sandwich water district may create a water supply agency to be known as the Upper Cape Regional Water Supply Cooperative which, as created in accordance with this section, shall be a body politic and corporate and a public instrumentality, hereinafter referred to as the cooperative. The cooperative shall be created when this act has been accepted by at least the town of Falmouth and any other water district enumerated above, or by any two water districts enumerated above. Such acceptance shall be, in the case of the town of Falmouth, by a vote taken in accordance with section 4 of chapter 4 of the General Laws and in the case of the Mashpee water district, the Sandwich water district or the Bourne water district, by a vote of its inhabitants at an annual or special ballot election. Upon creation, the cooperative shall have, any general or special law notwithstanding, as hereinafter provided and in accordance with this act, the power and authority to extract groundwater supplies as the board of managers may determine is appropriate, and to locate wells, determine rates of extraction, construct, operate, and maintain a public water supply and appurtenant water distribution works within the geographical area described as follows:

That land located in the towns of Sandwich, Bourne, and Mashpee, Falmouth, owned by the commonwealth and known as the Massachusetts Military Reservation; provided, however, that the cooperative shall take no action which will interfere with the lawful operations of: (*i*) the Department of the Army pursuant to a lease between the commonwealth and the United States of America

dated July 1, 1976; (*ii*) the Department of the Air Force pursuant to a lease dated July 1, 1974 between the commonwealth and the United States of America, as superseded by lease contract No. DACA51-5-75-293 between the United States of America and the commonwealth, and as modified by a supplemental agreement between the commonwealth and the United States of America dated July 1, 1976, lease contract No. DACA51-5-75-293, Modification No. 3, and Supplemental Agreement No. 4 dated April 11, 1995; (*iii*) the Department of Transportation, U.S. Coast Guard, pursuant to a lease between the commonwealth and the United States of America dated July 1, 1976; (*iv*) the Massachusetts army national guard, pursuant to a license from the secretary of the Army to the commonwealth dated July 2, 1976; or (*v*) the Massachusetts air national guard pursuant to a license from the secretary of the Air Force to the commonwealth dated November 30, 1983.

If any municipal entity, once having accepted this act in accordance with the provisions of this section, desires to withdraw from the cooperative, it may do so with 24 months prior written notice to the board of managers, and in the same manner provided for acceptance of this act; provided, however, that such withdrawing municipal entity shall be obligated to pay its pro rata share on the municipal entity's obligations for the fiscal year in which it withdraws, together with its pro rata share on all bonds or notes which have been approved prior to the date upon which such municipal entity gives notice of its intention to withdraw from the cooperative. In the event that any municipal entity which has not accepted this act within one year of its effective date, desires thereafter to do so, it may do so in accordance with this section, provided that the board of managers, in consultation with the board of selectmen or water commissioners of such municipal entity, shall first fix and determine an equitable share of capital expenses incurred to that date by the cooperative, which sums shall be payable upon such terms as may be agreed between the board of managers and such municipal entity. In the event that the board of managers and the municipal entity desiring to join the cooperative are unable to agree on such equitable share, the matter shall be submitted to arbitration by a panel consisting of one member of the board of managers, or its designee, one member of the board of selectmen or water commissioners for the municipal entity or their designee, and a third party selected by the first two members of the panel. Said third party shall be a disinterested person without any business interest or residence in any of the municipal entities. Said arbitration panel shall hear the arguments and information submitted by the board of managers and the municipal entity desirous of joining the cooperative. After consideration of the respective positions of the board of managers and the municipal entity desirous of joining the cooperative on what constitutes an equitable share of capital expenses incurred to that date by the cooperative, the arbitration panel shall determine the amount of such equitable share and, if the parties are unable to agree, the terms of payment therefore, and such determination shall be final and conclusive upon the board of managers and the municipal entity desirous of joining the cooperative. The availability of water from the cooperative shall not be considered an alternative to the development of municipal supplies of water by any of the municipal entities for the purposes of section 62B of chapter 30 of the General Laws, irrespective of whether or not the municipal entity seeking approval of such municipal water supplies has joined the cooperative or not, nor shall the

availability of such water form any basis for the decision of an agency of the commonwealth to make a finding pursuant to section 61 of said chapter 30.

SECTION 3. The management and control of all property acquired by, and the exercise of all powers, privileges and duties conferred upon the cooperative pursuant to the provisions of this act shall be vested in and exercised by a board of managers, which shall consist of two members appointed by the board of water commissioners, in the case of any water district which has accepted this act, and by the board of selectmen, in the case of any town which has accepted this act. The cooperative shall be deemed a governmental body pursuant to chapter 30B of the General Laws. Notwithstanding any general or special law to the contrary, the administrators of the cooperative who are procurement officers for said cooperative shall participate in the Massachusetts public purchasing official certification program conducted by the office of the inspector general in order to earn a Massachusetts public purchasing official certificate. Of the two representatives of each town or district which has accepted this act, one member shall serve for a term of two years, and the other shall serve for a term of three years. Members of the board of managers shall be paid $1,000 annually, and the chairman shall be paid $1,500 annually. Members may be removed for cause by their appointing authority. Members of the board of managers, together with its agents, employees, and professional staff shall be indemnified against personal liability by the cooperative. The cooperative shall be deemed a public employer pursuant to chapter 258 of the General Laws. The cooperative acting through its initial board of managers shall promptly adopt by-laws describing by whom and how meetings of the board may be called, notified and conducted; establish rules and regulations for the management of its affairs not inconsistent with this act or any other provision of law; shall appoint for such term as it may determine, a corporate treasurer of the cooperative, and such other officers and employees not specifically provided for in this act as it may deem necessary and proper, and shall fix their compensation. The treasurer shall not be a member of the board of managers, and shall give bond to the cooperative in such an amount as may be approved by said board with a surety company authorized to transact business in the commonwealth as a surety. The cooperative may contract with any of the municipal entities for treasurer services upon terms mutually agreeable to the cooperative and the municipal entity. A majority of appointed managers shall constitute a quorum of the board of managers. Vacancies occurring in the membership of the board of managers from any cause may be filled for the remainder of the unexpired term by the appointing authority. No vacancy occurring in the membership of the board of managers shall disqualify the board of managers from taking any action authorized by this act.

The board of managers shall annually prepare and provide to the board of selectmen of the town of Falmouth and the water commissioners of the towns of Bourne, Mashpee, and Sandwich that have accepted this act, and to each user of water of the cooperative who requests the same, a written report of the condition of the system, the actions of the board of managers, and receipts and expenditures of the cooperative for the preceding fiscal year.

SECTION 4. The cooperative, acting by and through its board of managers, shall have all the rights and powers necessary or convenient to carry out and effectuate the purposes of this act including, but without limiting the generality of the foregoing, the following rights and powers:

(*a*) to adopt the by-laws for the regulation of its affairs and the conduct of its business, to promulgate rules, regulations and procedures in connection with the performance of its functions and duties, and to fix, enforce, and collect penalties for the violations thereof;

(*b*) to adopt an official seal and alter the same at its pleasure;

(*c*) to maintain an office at such place or places as it may determine;

(*d*) to apply for, receive, accept, administer, expend, and comply with the conditions, obligations and requirements respecting any grant, gift, loan, including without limitation any grant, gift or loan from agencies of local, state, and federal governments, donation or appropriation of any property or money in aid of the purposes of the cooperative, and to accept contributions of money, property, labor, or other things of value;

(*e*) to acquire by purchase, lease, lease purchase, sale and lease back, gift, or devise, or to obtain options for the acquisition of, any property, real or personal, easements, water, or water rights, or any interest therein, in the exercise of its powers and the performance of its duties;

(*f*) to sell, lease, mortgage, exchange, transfer or otherwise dispose of, or grant options for any such purposes with respect to, any water, water rights, and any other property, real or personal, tangible or intangible, or any interest therein;

(*g*) to enter onto any land within the geographical boundaries of the cooperative to make surveys, borings, soundings and examinations thereof, provided that the cooperative shall insofar as possible restore the land to the same condition as prior to the making of such surveys, borings, soundings, and examinations;

(*h*) to construct, improve, extend, enlarge, maintain, and repair the water works system located within the geographical jurisdiction of the cooperative;

(*i*) to make contracts of every name and nature, and to execute and deliver all instruments necessary or convenient for carrying out any of its purposes;

(*j*) to fix, revise, charge, collect and abate fees, rates, rents, delinquency charges and other charges for water and other services, facilities and commodities furnished or supplied by it;

(*k*) to sue and be sued and to prosecute and defend actions relating to its properties and affairs, provided that only property of the cooperative other than revenues pledged to the payment of bonds

or notes shall be subject to attachment or levied upon execution or otherwise;

(*l*) to from time to time sell such of the property of the cooperative as shall, in the opinion of its board of managers, be no longer useful in the conduct of the affairs of the cooperative;

(*m*) to employ personnel and to engage architectural, engineering, accounting, management, legal, financial, and environmental consulting and other professional services;

(*n*) to establish specific construction standards and specifications for the water distribution supply system;

(*o*) to charge a systems development charge to customers who are not municipal entities seeking to connect into the water supply system; in such amount as the board of managers may determine; provided, however, that no systems development charge shall be made to Otis air national guard Base, 102FIW/DEEV, Building 971, Otis air national guard Base, MA 02542-5028 any successor registrant for any connection to the water supply system which provides an amount of water equal to or less than the amount of 197.10 MGY Total Annual Volume withdrawal for which the Otis air national guard Base registered with the department of environmental protection pursuant to registration no. 4-22-225.02, dated May 28, 1999, but the said Otis air national guard Base, or any successor registrant may be charged a systems development charge for any supply of water over or above the volume set forth in said registration; and

(*p*) to do all things necessary, convenient or desirable for carrying out the purposes of this act for the purposes expressly granted or necessarily implied in this act.

SECTION 5. Fees, rates, rents, assessments, and other charges for water or other services, facilities, and commodities furnished or supplied by the cooperative shall be fixed and adjusted by the board of managers so as to provide funds at least sufficient in each fiscal year, together with other revenues and funds of the cooperative, if any, available therefore, to pay the full cost of operation of the cooperative for that fiscal year, including all current expenses; all debt service on bonds or notes of the cooperative; all costs of maintenance, repair and replacement, including the establishment of reasonable sinking funds, overlay funds, stabilization funds, replacement reserves, and other similar funds in accordance with generally accepted accounting principles, as determined by the board of managers to be necessary or desirable to be funded as current expenses; and all other amounts which the cooperative may be obligated to pay or provide for by law or by contract. Notwithstanding any general or special law to the contrary, the board of managers may establish rates, including differential rates, rents, assessments, fees and other charges authorized by this act which may vary depending on whether the customer is a municipal entity as referred to in section 2, or is a customer which is not a municipal entity.

SECTION 6. The cooperative, for the purpose of paying expenses of maintenance and operation not covered by charges for water may, any other general or special law notwithstanding, and in

accordance with this section, from time to time assess sums against the municipal entities that have accepted this act in accordance with section 2. If the board of managers of the cooperative desires to make such assessments, the board of managers shall determine what sum, in the aggregate, is necessary to pay for expenses of the cooperative not covered by fees charged in accordance with section 5, and shall apportion such amount in accordance with the proportional annual use by each municipal entity of the total amount of water being supplied by the cooperative. Upon determining such amounts, the board of managers shall certify, to the board of selectmen in the town of Falmouth, and to the board of water commissioners of the Bourne water district, Sandwich water district or Mashpee water district who shall have accepted the provisions of this act in accordance with section 2, that the board of managers have authorized an assessment against such municipal entities, and the amount to be assessed against each municipal entity therefore. The board of selectmen or the board of water commissioners, as the case may be, of each municipal entity, shall cause to be placed on the warrant for the next available special or annual town or district meeting, an article in the form specified by the board of managers, seeking authorization from the town or district meeting to raise and appropriate such amounts, for payment over to the cooperative. Upon approval by the town or district meeting of two-thirds of such municipal entities, notwithstanding any other general or special law to the contrary, all municipal entities that have been assessed by the board of managers in accordance with this section, shall raise and appropriate, and pay over to the cooperative, such sums as have been assessed. Any sums assessed by the cooperative and raised and appropriated by a municipal entity in accordance with this section shall not be subject to sections 20A, 20B and 21C of chapter 59 of the General Laws.

SECTION 7. The cooperative, for the purpose of paying necessary expenses and liabilities incurred under this act, other than expenses of maintenance and operation, may, any other general or special law notwithstanding, and in accordance with this section, from time to time borrow such additional sums as may be necessary, not exceeding, in the aggregate $50,000,000 and issue bonds or notes therefore which shall bear on their face the words Upper Cape Regional Water Supply Cooperative Loan Act of 2000 and such other distinguishing designation as may be determined by the board of managers, and each authorized issue shall constitute a separate loan and such loans shall be payable in not more than 40 years from their dates, notwithstanding any other provision of law. The cooperative may borrow from time to time such funds as may be necessary for the purposes of this act in anticipation of revenue without the necessity of complying with this section. Indebtedness incurred under this act shall, except as otherwise provided herein, be subject to chapter 44 of the General Laws.

Prior to the issuance of such bonds or notes, other than borrowings in anticipation of revenue, the board of managers shall apportion the cost of repayment of each bond or note, which cost shall be apportioned to each municipal entity which has accepted this act pursuant to section 2 in accordance with the proportional annual use by each such municipal entity of the total amount of water supplied by the cooperative. Upon determining such amounts, the board of managers shall

certify, to the board of selectmen in the town of Falmouth, and the board of water commissioners of the Bourne water district, Sandwich water district or Mashpee water district, who shall have accepted this act in accordance with section 2, that the board of managers have authorized the issuance of such bonds or notes, and the amount to be assessed against each municipal agency therefore. The board of selectmen or board of water commissioners, as the case may be, of each municipal entity, shall cause to be placed in the warrant for the next available special or annual town or district meeting, an article in the form specified by the board of managers, seeking authorization from the town or district meeting for the cooperative to issue such bonds or notes, and the amount to be assessed therefore against each municipal agency. Upon approval by the town or district meeting of two-thirds of such municipal entities, the cooperative may issue such bonds or notes as have been approved. Such bonds or notes shall be issued upon the full faith and credit of the cooperative, and of all municipal entities who have accepted this act in accordance with section 2, notwithstanding any other provision of law. If two-thirds of the municipal entities which have accepted this act in accordance with section 2 shall approve the issuance of bonds or notes as set forth herein, all municipal entities which have accepted this act in accordance with section 2 shall, notwithstanding their refusal to approve such bonds or notes at an annual or special district or town meeting, as the case may be, be obligated to pay all sums certified by the cooperative pursuant to this section. The indebtedness on bonds or notes issued by the cooperative and the municipal entities pursuant to this act shall not be subject to section 10 of chapter 44, and sums assessed by the cooperative to repay such bonds or notes shall not be subject to sections 20A, 20B and 21C of chapter 59 of the General Laws.

The fiscal year of the cooperative shall commence July 1 and end June 30, or as otherwise provided in the by-laws of the cooperative.

SECTION 8. Whoever intentionally corrupts, pollutes or diverts any water obtained or supplied under this act, or intentionally injures any reservoir, well, standpipe, aqueduct, pipe or other property owned or used by the cooperative for any of the purposes of this act, or tampers with any metering device owned or utilized by the cooperative, shall forfeit and pay to the cooperative three times the amount of damages assessed therefore, to be recovered in an action of tort, together with reasonable attorney's and engineering costs and expenses incurred by the cooperative in the investigation, assessment, and prosecution of such action. Whoever is convicted of any of the above acts shall be punished by a fine of not more than $10,000 or by imprisonment for not more than one year, or both.

SECTION 9. In the event that the board of managers desires to terminate the cooperative and dispose of its assets, a majority of the board of managers then existing shall first vote to do so, and give notice of such vote, in writing, to the board of selectmen, and board of water commissioners, of any municipal entity which has accepted this act in accordance with section 2. Each municipal entity shall thereafter provide, at its next regular or special election, a ballot vote which shall contain the question "Shall the Upper Cape Regional Water Supply Cooperative be dissolved, and its assets

deposed of in accordance with the vote of its board of managers?". If a majority of municipal entities which have accepted this act vote in the affirmative, the cooperative shall be dissolved, but not otherwise. In the event of such affirmative vote, the board of managers shall be empowered to dispose of the assets of the cooperative in accordance with the General Laws.

SECTION 10. If the cooperative authorized by section 2 is not created in the manner described in said section 2 within ten years from the effective date of this act, then this act shall be without further legal effect.

SECTION 11. This act shall take effect upon its passage.

Approved December 21, 2000.

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY & ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION
ONE WINTER STREET, BOSTON, MA 02108 617-292-5500

DEVAL L. PATRICK
Governor

TIMOTHY P. MURRAY
Lieutenant Governor

IAN A. BOWLES
Secretary

LAURIE BURT
Commissioner

RENEWAL REGISTRATION STATEMENT FOR VERIFIED WATER WITHDRAWAL

The Massachusetts Department of Environmental Protection ("the Department") hereby accepts the Registration Renewal Request filed by the following Registrant pursuant to 310 CMR 36.10 for the water withdrawal described below. The Registrant is hereby authorized to withdraw up to the registered volume of water from the registered withdrawal point(s) until the expiration date, as set forth below, in compliance with M.G.L. c. 21G and 310 CMR 36.00, subject to the Registration Conditions set forth below.

GENERAL INFORMATION

Registration Number: 42222502 River Basin: CAPE COD

Registrant: OTIS ANG BASE
197 GRANVILLE AVE
OTIS ANG BASE, MA 02542

Number of registered withdrawal points: 2
Groundwater: 2 Surface water: 0

SourceID	Type	Source Name
4096001-01G	GW	WELL J
	GW	WELL G

Use: Public Water Supply

Average Volume per Day (MGD): 0.54 Total Annual Volume (MGY): 197.10

Days of Operation: 365

Effective Date: January 1, 2008 Expiration Date: December 31, 2017

can implement the MassDEP Model Conservation Plan for UAW at any time and then be considered to have met the functional equivalent of the performance standard.

The MassDEP Model Conservation Plan has not been completed at this time. The Department is committed to working with interested stakeholders, particularly the Massachusetts Water Works Association, to develop model conservation plan that provides a menu of best management practices for registrants to refer to and to use as they develop their own compliance plan. We anticipate developing a water management toolbox over the next several months that will meet the needs of suppliers and meet the Department's commitment to protect water resources while we balance human and environmental needs.

The Department plans to engage interested parties in discussions on rate structures, the experiences of water suppliers and other utilities incorporating rates into their conservation programs, and the impact of conservation on revenues. The Department anticipates incorporating the findings of our discussions into the water management toolbox. We look forward to your input on these matters.

Seasonal Demand Management

PWSs will be required to develop a Seasonal Demand Management Plan to reduce nonessential outdoor water use from May 1st to September 30th. The Department will be working in the coming months with the Massachusetts Water Works Association and the Water Management Advisory Committee to develop an outline of the minimum elements that will be required in a Seasonal Demand Management Plan. The Department will forward the Seasonal Demand Management Plan outline to registrants by May 1, 2008. Registrants will be required to forward a draft of their proposed Seasonal Demand Management Plan to the Department for its review and approval by August 1, 2008. The Department anticipates that many PWSs will already have developed and implemented seasonal water use restrictions that meet the minimum requirements in this Registration Statement. Suppliers can always implement stricter restrictions than those required by the Department. For more information on the Massachusetts Drought Task Force and drought declarations, please see http://www.mass.gov/dcr/waterSupply/rainfall/drought.htm

In addition, the Department has included more information that was submitted by Registrants in 1988 and updated the documents to include changes that have occurred since 1988, including:

- A detailed list of ground and surface water sources, including the PWS source ID, for all registered withdrawal points. The Department has added this information to reflect the withdrawal points registered in 1988; and
- Replacement wells and/or satellite wells, if applicable.

Finally, the Department has included the following administrative language:

- Enforcement language that reserves the Department's rights in any case where there is an ongoing proceeding, or may be a future proceeding; and
- Appeal language that explains how the registrant can seek review of the Registration Conditions in the Renewal Registration Statement in an adjudicatory proceeding.

Many registered PWSs also hold Water Management Act permits. If the Registrant holds a Water Management Act permit, then the conditions in the permit, including all applicable deadlines, shall supersede the corresponding conditions in this Registration Statement.

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Secretary

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Commissioner

Massachusetts Water Management Act Registration Statement
Content and Conditions for 2008-2017

The enclosed renewed Water Management Act Registration Statement authorizes continued withdrawals from January 1, 2008 through December 31, 2017. This Registration Statement reflects your documented water withdrawals from January 1, 1981 through December 31, 1985, and the source locations from which this water was withdrawn. While the initial Water Management Registration Statements had to be filed with the Massachusetts Department of Environmental Protection (the Department) by January 1, 1988, existing registrants have the opportunity to renew the Statements every ten years thereafter. Earlier this year you requested that your Registration be renewed, and the attached Registration Statement confirms your authorized registered withdrawal volumes and sources.

As noted in the Department's August 2007 Registration Renewal Request, the Department has evaluated including water conservation measures in registrations that are consistent with the State Water Conservation Standards approved by the Water Resources Commission (WRC) in July 2006. To better achieve a balance between competing water withdrawals and uses mandated by the Act, to protect the natural environment, and to provide continued and sustainable economic growth in the Commonwealth, the Department is including water conservation measures in Public Water Supply (PWS) Registration Statements pursuant to M.G.L. c. 21G, §§(5) and (6), that include:

- a requirement that PWSs meet the WRC's performance standards of 65 residential gallons per capita day water use (RGPCD) and 10% unaccounted for water loss (UAW) by December 31, 2017
  - because of the difficulty accurately calculating the RGPCD value in seasonal communities, PWSs on the Cape and Islands are not required to meet the 65 RGPCD standard;
- a requirement that those not meeting specific performance milestones must develop and implement a compliance plan in advance of December 31, 2017;
- a prohibition on the use of decreasing block rates in establishing service charges (M.G.L. c.40, § 39L);
- a requirement that PWSs begin implementing by May 1, 2009 a Seasonal Demand Management Plan that, at a minimum, restricts nonessential outdoor water use between May 1st and September 30th when the Massachusetts Drought Management Task Force declares a drought level of "Advisory", "Watch", "Warning" or "Emergency" for the region in which the PWSs withdrawals are located. Restrictions on outdoor water use shall remain in force until the drought level is declared to be "Normal" by the Drought Management Task Force.

<u>UAW Performance Standard</u>
The Registration Statements include steps that PWSs will need to take if they are having difficulty meeting the performance standard. The Registration Statement outlines a timetable for PWSs to develop and implement their own plan for bringing their system into compliance with the performance standard. Alternatively, a PWS

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Secretary

LAURIE BURT
Commissioner

December 31, 2007

OTIS ANG BASE -
196 GRANVILLE AVE
BOX 46
OTIS ANG BASE, MA 02542

Dear Registrant:

Please find the attached documents:

- A description of the Massachusetts Water Management Act Registration Statement Contents and Conditions for 2008-2017; and
- The Water Management Act Registrant Statement #**42222502** for 2008-2017.

If you have any questions regarding the Registration Statement, please contact Duane LeVangie at (617) 292-5706 or Beth McCann at (617) 292-5901.

Sincerely,

Glenn Haas
Acting Assistant Commissioner
Bureau of Resource Protection

Enclosures
Cc: Duane LeVangie, MassDEP-WMA Program, Boston

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This information is available in alternate format. Call Donald M. Gomes, ADA Coordinator at 617-556-1057. TDD Service - 1-800-298-2207.
MassDEP on the World Wide Web: http://www.mass.gov/dep
Printed on Recycled Paper

REGISTRATION CONDITIONS

The Registrant shall comply at all times with M.G.L. c. 21G, 310 CMR 36.00 and all other applicable state and federal statutes and regulations.[1] In addition, the Registrant shall comply with the following conditions, provided, however, that if the Registrant holds a currently valid Water Management Act permit, then the conditions in the permit, including all applicable deadlines, shall supersede the corresponding conditions in this Renewal Registration Statement.

Metering:
The Registrant shall install and maintain source meter(s) for each withdrawal point(s).
The Registrant shall calibrate all source meter(s) annually.

Records:
The Registrant shall maintain withdrawal records in sufficient detail to timely provide the information necessary to accurately complete each Annual Statistical Report (ASR) it files with the Department.

Performance Standard for Unaccounted-for Water:
The Registrant shall comply with the 10 % Unaccounted-for Water (UAW) performance standard included in the Massachusetts Water Resources Commission's State Water Conservation Standards (July 2006) as soon as feasible but no later than **December 31, 2017.** The Registrant shall annually document its actual UAW in the ASRs it files with the Department, commencing with its ASR for calendar year 2008. The Registrant's ASRs shall document that it is making demonstrable progress towards meeting the UAW performance standard. Commencing with its ASR for calendar year 2017, and for each year thereafter, the Registrant shall document that it is in full compliance with the performance standard for UAW.

If the Registrant's ASR for calendar year 2009 indicates that the Registrant is exceeding 15% UAW, then the Registrant shall develop and implement an annual compliance plan designed to meet the 10% UAW performance standard by December 31, 2017. The Department will make the MassDEP Model Conservation Plan, including a menu of best management practices (BMPs), available to the Registrant for adoption or consideration in developing its own compliance plan. The Registrant shall submit a copy of its first compliance plan to the Department by December 31, 2010, and begin implementation upon submittal.

If the Registrant's ASR for calendar year 2012 indicates that the Registrant is exceeding 10% UAW, then the Registrant shall develop and implement an annual compliance plan designed to meet the 10% UAW performance standard by December 31, 2017, unless it has done so already. The Registrant shall submit a copy of its first compliance plan to the Department by December 31, 2013, and begin implementation upon submittal.

The Department reserves the right to commence enforcement against the Registrant if it is not making demonstrable progress towards meeting the performance standard, or if it has not developed and implemented an annual compliance plan that is reasonably designed to meet the 10% UAW performance standard by December 31, 2017. In exercising its enforcement discretion, the Department will consider the Registrant's past efforts to come into compliance with the requirement.

Note: Those registrants with UAW above 10% may choose to adopt the MassDEP Model Conservation Plan at any time before December 31, 2017. Those registrants that have adopted the MassDEP Model

[1] Regulations may change from time-to-time. The Registrant is responsible for complying with the most current version of the applicable regulations, unless the regulations expressly provide otherwise.

Conservation Plan, and have made appropriate arrangements to finance, implement and enforce its provisions, will not be subject to enforcement for exceeding the 10% UAW performance standard provided that they are continuing to make reasonable efforts to implement and enforce their compliance plan. Those registrants that have not adopted the MassDEP Model Conservation Plan prior to December 31, 2017, and/or that are not making reasonable efforts to finance, implement and enforce their compliance plan provisions, may be subject to enforcement for exceeding the 10% UAW performance standard and may be required to adopt the MassDEP Model Conservation Plan, if they have already not done so.

Seasonal Demand Management – May 1 through September 30:
The Registrant shall submit a Seasonal Demand Management Plan by August 1, 2008 for the Department's review and approval. The Plan must begin by May 1, 2009, and must restrict at a minimum, nonessential outdoor water use from May 1 through September 30th when the Massachusetts Drought Management Task Force declares a Drought Advisory, Drought Watch, Drought Warning or Drought Emergency for the region where the Registrant's withdrawals are located. Restrictions on outdoor water use shall remain in place until the drought level is returned to "Normal."

> Nonessential Water Use: As used herein, "nonessential outdoor water use" means uses that are not required: (a) for health or safety reasons; (b) by regulation; (c) for the production of food and fiber; (d) for the maintenance of livestock; or (e) to meet the core functions of a business.
>
> Examples of nonessential outdoor water uses include: the irrigation of lawns or landscaping, except by means of a hand-held hose outside the hours of 9:00 a.m. to 5:00 p.m.; washing vehicles other than by means of a commercial car wash or except as necessary for operator safety; and washing of exterior building surfaces, parking lots, driveways and/or sidewalks, except as necessary to apply paint, preservatives, stucco, pavement, cement, or the like.
>
> Examples of acceptable outdoor water uses outside the hours of 9:00 a.m. to 5:00 p.m. include: irrigation to establish a new lawn during the months of May and September; irrigation for the production of food and fiber or the maintenance of livestock; irrigation by plant nurseries as necessary to maintain stock; irrigation by golf courses as necessary to maintain greens and tees, and limited fairway watering; and irrigation of public parks and recreational fields.

Nothing in this Registration Statement shall be construed to prohibit or prevent the Registrant from implementing any water use restrictions stricter than those contained herein.

Note: 310 CMR 22.15(8) requires that all public water systems establishing mandatory restrictions on water use notify the Department in writing within 14 days of the effective date of such restrictions. Notice must include a description of the regulations, bylaws or ordinances imposing the restriction. Registrants may also be required to document implementation and enforcement of the restrictions in their ASRs.

For the most up-to-date information on the drought status in your region, the Registrant should monitor the Department's website at www.mass.gov/dep and MassDCR's website at http://www.mass.gov/dcr/waterSupply/rainfall/drought.htm.

SERVICE CHARGES
The Registrant shall not charge for water services on a descending unit rate basis (i.e. decreasing block rates). Descending unit rate basis that charge lower unit prices as water use increases during the billing period are prohibited by M.G.L. c. 40, § 39L.

REPORTING

The Registrant shall file an annual statement of withdrawal, as required by 310 CMR 36.11, for each year that this registration is in force, on forms provided and by the deadline specified by the Department. At the request of the Department, the Registrant may be required to report withdrawal volumes monthly or daily in accordance with 310 CMR 36.08.

EFFECT ON ANY PENDING AND FUTURE ACTIONS

The withdrawal registration program is intended to provide a procedure and deadline for persons making existing withdrawals above the threshold quantity to file a registration statement with the Department for their existing withdrawals to enable the Department to document baseline water use to manage the surface and groundwater of the Commonwealth. Except as expressly provided herein, this Renewal Registration Statement shall not be construed or operate as barring, diminishing, adjudicating or in any way affecting any legal or equitable right of the Department with respect to any pending administrative or judicial action, or any such future action, including without limitation any pending enforcement action or permit appeal, or any legal or equitable right of the Department to pursue any claim, action, suit, cause of action, or demand that the Department may have with respect to any matter covered by this Renewal Registration Statement.

REGISTRATION RENEWAL

This Registration Statement expires on January 1, 2018, unless the Registrant files a registration renewal request with the Department prior to that date in accordance with 310 CMR 36.10. Failure to file a registration renewal request by the expiration date shall result in the loss of the Registrant's right to withdraw the water volumes authorized by this Renewal Registration Statement until a permit for such withdrawal has been obtained from the Department.

REGISTRATION TRANSFER

The transfer of Registration Statements is governed by 310 CMR 36.09. Except as provided in 310 CMR 36.09(2), this Renewal Registration Statement may be transferred, in whole or in part, by the Registrant to another person if (1) the Department is notified of the proposed transfer at least 30 days in advance of the proposed transfer date, (2) the notice includes a written agreement between the parties to the transfer, (3) the notice provides the date that the proposed transfer is to take place, and (4) the notice describes the registration to be transferred. A transfer request must be accompanied by the applicable fee established in 310 CMR 4.00. This Renewal Registration Statement shall be surrendered to the Department upon transfer of any withdrawal authorized by this document.

APPEALS

The Registrant may request an adjudicatory hearing on this Renewal Registration Statement by timely filing a Notice of Claim for an Adjudicatory Appeal ("Notice of Claim") in accordance with M.G.L. c. 30A, § 10 and 310 C.M.R. 1.00 within twenty-one (21) days of its receipt of this Renewal Registration Statement. The Notice of Claim shall state specifically, clearly and concisely the facts that are grounds for the appeal, the relief sought, and any additional information required by applicable law or regulation. A copy of this Renewal Registration Statement shall be included with a Notice of Claim. The Notice of Claim and supporting documentation must be sent to:

Case Administrator
Office of Appeals and Dispute Resolution
Department of Environmental Protection
One Winter Street, Second Floor
Boston, MA 02108

In addition, a valid check made payable to the Commonwealth of Massachusetts in the amount of $100 for the appeal filing fee, if required, must be mailed to:

Commonwealth of Massachusetts Lock Box
Department of Environmental Protection
P.O. Box 4062
Boston, MA 02211

The Notice of Claim may be dismissed if the filing fee is not paid, unless the appellant is exempt or granted a waiver. The filing fee is not required if the appellant is a city, town (or municipal agency), county, district of the Commonwealth of Massachusetts, or a municipal housing authority. The Department may waive the adjudicatory filing fee for a person who shows that paying the fee will create an undue financial hardship. A person seeking a waiver must file, along with the hearing request, an affidavit setting forth the facts believed to support the claim of undue financial hardship.



Glenn Haas, Acting Assistant Commissioner
Bureau of Resource Protection

12/31/07
Date

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In association with Water Resources Associates

Appendix LL

JBCC Shared Wastewater Management Study, 2017

Shared Wastewater Management Study

Towns of Bourne, Falmouth, Mashpee, Sandwich and Joint Base Cape Cod

November 2017

Prepared for the

Town of Falmouth

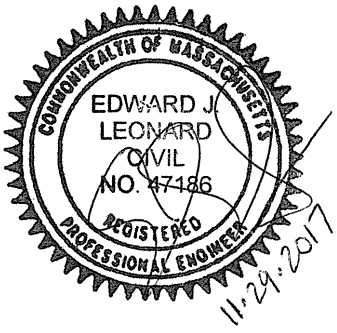
by

WRIGHT-PIERCE

Engineering a Better Environment

Shared Wastewater Management Study
Towns of Bourne, Falmouth, Mashpee, Sandwich and Joint Base Cape Cod

November 2017



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SHARED WASTEWATER MANAGEMENT STUDY

TOWNS OF BOURNE, FALMOUTH, MASHPEE, SANDWICH AND JOINT BASE CAPE COD

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SECTION 1

PRELIMINARY STRATEGY

1.1 INTRODUCTION

The Towns of Bourne, Falmouth, Mashpee and Sandwich were awarded a Community Compact Cabinet's Efficiency and Regionalization Grant for a Shared Wastewater Management Study. The purpose of the study is to prepare an engineering assessment for a potential partnership for shared wastewater management options among the four towns utilizing the Joint Base Cape Cod (JBCC) treatment, collection and discharge system. A list of commonly used acronyms and abbreviations is included in Table 1-1.

1.2 JOINT STATEMENT AND PROJECT PREMISE

The four towns have a long and proud history of active cooperation and collaboration with their neighbors at JBCC, including such items as solid waste management (Upper Cape Regional Transfer Station) planning/contracting, groundwater contamination clean-up, Upper Cape Regional Water Supply Cooperative management, Upper Cape Water Supply Reserve Community Advisory Council, and the Cape Cod Commission's Joint Land Use Study planning. The four towns are each in various stages of wastewater management planning and implementation; however, the four towns and JBCC are interested in actively and collaboratively exploring a shared wastewater solution utilizing the JBCC wastewater facilities. This is evidenced by the joint application for the Efficiency and Regionalization Grant. The four towns, JBCC and MassDevelopment have jointly developed the following project premise to guide the preparation and review of this document:

> *The potential transfer of the JBCC wastewater facilities from the federal government to a local entity represents a significant opportunity for regional use by the surrounding towns; however, there are legal, political and financial issues to work through. The existing wastewater facilities will require short-term upgrades and will likely require significant expansion to serve the anticipated mid-term to long-term Upper Cape needs. MassDevelopment is performing a comprehensive due diligence to study the potential ownership of the facilities as the "initial management entity", anticipating transferring the facilities to a "successor management entity" in the future. The purpose of this study is to develop a framework for regionalization based on a phased implementation approach with both short-term and long-term goals in mind.*

TABLE 1-1
LIST OF COMMONLY USED ACRONYMS AND ABBREVIATIONS

ACEC	Area of Critical Environmental Concern
ANG	Air National Guard, Massachusetts (102nd Intelligence Wing)
BOD_5	Biochemical Oxygen Demand
CCC	Cape Cod Commission
Current	Representing present conditions as applied to population, wastewater flow or nitrogen load
CWMP/CWRMP	Comprehensive Wastewater Management Plan
CWNMP	Comprehensive Watershed Nitrogen Management Plan
CWRMP	Comprehensive Water Resources Management Plan
D/B/O	Design/Build/Operate contract delivery method
DEIR	Draft Environmental Impact Report
DEP	Department of Environmental Protection
DRI	Developments of Regional Impact
EIR	Environmental Impact Report
EENF	Expanded Environmental Notification Form
EOEEA	Executive Office of Energy and Environmental Affairs
ESA	Environmentally Sensitive Area
FEIR/SEIR	Final Environmental Impact Report/ Single Environmental Impact Report
Future	Referring to population, wastewater flows or nitrogen loads, expected in the future
GIS	Geographic Information System
gpd	Gallons Per Day
gpd/sf	Gallons Per Day Per Square Foot
I/I	Infiltration and Inflow
IMA	Inter-Municipal Agreement
hp	Horsepower
JBCC	Joint Base Cape Cod (aka Massachusetts Military Reservations)
kg/day	Kilograms Per Day
lb/yr	Pounds Per Year
MEP	Massachusetts Estuaries Project
MCL	Maximum Contaminant Level
MEPA	Massachusetts Environmental Policy Act
Mgal	Million gallons
Mgal/yr	Million gallons per year
mgd	Million gallons per day
mg/l	Milligrams per liter
MOU	Memorandum of Understanding
NHESP	Natural Heritage and Endangered Species Program
NPV	Net Present Value
O&M	Operations and Maintenance
RIB	Rapid Infiltration Basin
SCADA	Supervisory Control and Data Acquisition system (computer control system)
SMAST	School of Marine Science and Technology, University of Massachusetts at Dartmouth
SRF	State Revolving Fund (administered by Massachusetts Department of Environmental Protection)
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TSS	Total Suspended Solids
TWMP	Targeted Watershed Management Plan
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
USGS	United States Geologic Survey
VOC	Volatile Organic Compound
WWTF	Wastewater Treatment Facility

1.3 SUMMARY OF PREVIOUS WASTEWATER PLANNING EFFORTS

The towns and JBCC/MassDevelopment have been engaged in wastewater management planning over the past decade. This section summarizes the relevant components of the previous wastewater planning efforts undertaken by each town.

1.3.1 Bourne

Bourne completed its initial town-wide Comprehensive Wastewater Management Plan in 2007. The 2007 plan estimated current and future wastewater flows and septage volumes town-wide, but focused on alternatives and solutions for the most pressing wastewater management needs on the north side of the Cape Cod Canal, including on-going discussions and negotiations with Wareham regarding its wastewater treatment inter-municipal agreement (IMA) as well as siting of supplemental treatment and disposal facilities on the north side of the Canal. Bourne has also been focused on addressing landfill leachate needs on the south side of the Canal. In the future, it is expected that Bourne will need to address nutrient-related wastewater management drivers (based on the Massachusetts Estuaries Project work) and density-of-development-related wastewater management drivers on the north and south sides of the Canal. Bourne has indicated that it is considering the long-term opportunity to transport treated effluent north of the canal to the disposal beds via a force main attached to the possible future third Cape Cod Canal bridge.

1.3.2 Falmouth

Falmouth most recently completed its Targeted Watershed Management Plan (TWMP) for Little Pond, Great Pond, Green Pond, Bournes Pond, Eel Pond and Waquoit Bay Watersheds in 2013. The TWMP proposes a sewer extension to serve Little Pond, upgrades to the Blacksmith Shop Road WWTF, an additional effluent disposal site (outside of the West Falmouth Harbor watershed), a number of demonstration projects (including aquaculture, inlet widening at Bournes Pond, eco-toilets, permeable reactive barriers, and stormwater management), and an adaptive management plan. This project received its EOEEA Certificate in 2014 and is currently being implemented.

1.3.3 Mashpee

Mashpee completed a town-wide Comprehensive Watershed Nitrogen Management Plan (CWNMP) in 2015. The CWNMP identifies a regional approach with a proposed aquaculture program, a proposed connection to the JBCC wastewater facilities, two or three proposed small decentralized WWTFs located in Mashpee, expansion/upgrades to several small existing public and private WWTFs in Mashpee, and a preliminary agreement to review nitrogen trading with Sandwich, Barnstable and potentially Falmouth. The 2015 CWNMP Final Environmental Impact Report received a MEPA Certificate from the Secretary of Energy and Environmental Affairs dated July 31, 2015. The 2015 CWNMP is under DRI review by the Cape Cod Commission. Town-wide wastewater flows were identified in the Needs Assessment Report (2007) and are summarized in the 2015 WNMP.

1.3.4 Sandwich

Sandwich is currently in the final phase of completing its town-wide Comprehensive Water Resources Management Plan (CWRMP). The CWRMP identifies a regional approach with two proposed small decentralized WWTFs located in Sandwich, a proposed connection to the JBCC wastewater facilities, and a proposed nitrogen trading program with Mashpee, Barnstable and potentially Falmouth. The draft June 2017 CWRMP will be presented for public comment over the upcoming months.

1.3.5 MassDevelopment/ JBCC

MassDevelopment, on behalf of JBCC, has completed several wastewater planning efforts – one in 2012 (CH2M-Hill) and another in 2014 (Wright-Pierce). Both planning efforts were performed looking at a potential transfer of ownership of the wastewater facilities from JBCC to MassDevelopment or another local management entity. These studies concluded that the JBCC military needs a fairly small capacity allowance for the planning period and that excess capacity could be made available to municipalities.

1.3.6 Cape Cod Commission

The Cape Cod Commission completed a Joint Land Use Study (JLUS) for JBCC in 2005 and completed the JLUS Update in 2013. The JLUS Update affirmed the potential for a military/municipal partnership through shared facilities and recommended that the excess capacity at the JBCC wastewater facilities be used for military and municipal needs.

The JLUS Update identified a potential Upper Cape wastewater and effluent capacity need of 454,000 gpd to 3,270,000 gpd within a 20-year planning period (Executive Summary, Table 5). This table cites the 2012 CH2M-Hill study which was prepared for MassDevelopment, as described above.

The Cape Cod Commission completed its 208 Plan Update (Cape Cod Area Wide Water Quality Management Plan Update) in 2015. One general outcome of the 208 Plan Update is that it provides a technical framework for municipalities to incorporate non-traditional nitrogen control methods into wastewater management planning. Each of the four towns is exploring non-traditional nitrogen control methods to varying degrees in accordance with the framework provided by the 208 Plan Update which, if successful, may postpone or eliminate the need for traditional wastewater infrastructure in certain portions of the respective towns. This will likely result in a longer planning period to reach the upper limit flow projections previously identified in the 2012 CH2M-Hill study and JLUS Update study (say 40 to 50 years, rather than the 20 years used in the 2012 report).

Lastly, the 208 Plan Update has two specific recommendations regarding the JBCC wastewater facilities (Section 7):

- Recommendation S7.1 – "The Cape Cod Commission shall continue discussion and coordination with JBCC and MassDevelopment regarding wastewater allocation policy for the base."
- Recommendation S7.1 – "The Military should ensure that future development within the cantonment area be connected to the JBCC wastewater treatment plant wherever feasible."

The Cape Cod Commission completed an analysis of septage disposal need in 2016. The study estimated the volume of septage generated on Cape Cod (i.e., 52.8 Mgal/year) as well as the septage treatment capacity on Cape Cod (i.e., 53.3 Mgal/year, which excludes the recently closed Tri-Town Septage Treatment Plant). This analysis did not identify the volume of septage generated by each town on Cape Cod. [CCC/AECOM Task Order #12D Technical Memorandum on Barnstable County Septage Analysis, Table 2-2 and 3-1 (Rev Sept 30, 2016)]

1.3.7 Summary of Key Data for Wastewater Planning

The following definitions are applicable to the information in this table:

- Current Wastewater Flow is the estimated or known wastewater for pre-2017 conditions, based on town documentation or input. These flows are intended to represent the general population, level of commercial activity and wastewater generation rates that exist today.
- Theoretical Build-Out is the population, commercial activity, and wastewater flow associated with the ultimate development in each town, to the fullest extent possible under current zoning and other regulation, regardless of economic issues.
- Practical Build-Out is the population, commercial activity and wastewater flow associated with more realistic assumptions on the extent of build-out, factoring in such concerns as economic realities, other limitations on growth (such as infrastructure capacity), land protection efforts, and retention of estate properties.
- Planning Horizon is the population, commercial activity, and wastewater flow that will serve as the basis for this planning effort. The planning horizon for this study is 20 years.
- Future Wastewater Flow is the estimated wastewater flow at the "planning-horizon" identified in town documentation.

A summary of key data for each town is presented in Table 1-2, including "current wastewater flow" and "future wastewater flow".

TABLE 1-2: KEY DATA FOR PARTICIPATING TOWNS AND JBCC

	Bourne	Falmouth	Mashpee	Sandwich	JBCC
Population (2010)	19,754	31,531	14,006	20,675	~3,500
Area of Land and Water (TW)	52.9 sq mi.	48.8 sq mi.	27.2 sq mi.	44.2 sq mi.	~22,000 ac
Current Wastewater Flow (TW,AA)	2,200,000 gpd	4,000,000 gpd	1,136,000 gpd	1,667,000 gpd	140,000 gpd
Current Wastewater Flow to WWTFs (TW,AA)	110,000 gpd (Wareham)	440,000 gpd (Falmouth)	180,000 gpd	0 gpd	140,000 gpd (JBCC)
Current Septage Volume (TW,AA)	4.1 Mgal/yr	8.0 Mgal/yr	2.7 Mgal/yr	3.9 Mgal/yr	0 Mgal/yr
Future Wastewater Flow (TW,AA)	3,751,000 gpd	4,000,000 gpd	2,007,000 gpd	2,164,000 gpd	152,000 gpd
Future Wastewater Flow to WWTFs (TW,AA)	1,061,000 to 1,782,000 gpd	750,000 to 2,200,000 gpd	1,076,000 to 1,776,000 gpd	540,000 to 900,000 gpd	152,000 gpd
Future Septage Volume (TW,AA)	6.2 Mgal/yr	9.5 Mgal/yr	1.5 Mgal/yr	5.1 Mgal/yr	0 Mgal/yr
Town-Wide Wastewater Planning Year Completed, Firm	2007 Tighe&Bond	2013 GHD	2015 GHD	2017 Wright-Pierce	2012 CH2M-Hill 2014 Wright-Pierce

Notes:
1.) See report text on previous page for definitions.
2.) 2010 Population – 2010 US Census (municipalities) and 2009 JBCC Base population survey.
3.) Area of land and water based on Wikipedia.
4.) TW = “all town-wide whether to an on-site system or a WWTF”; AA = annual average basis
5.) Falmouth’s Little Pond Sewer Service Area flow will increase the existing annual average flow to 710,000 gpd when completed.

1.4 DESCRIPTION OF EXISTING JBCC WASTEWATER FACILITIES

This section of the report describes the existing JBCC wastewater system, the current wastewater flows and loadings, and the overall facility condition assessment for the JBCC wastewater system.

1.4.1 Overall System

The existing JBCC wastewater system provides service for on-base facilities. It is currently owned by the United States Air Force (USAF) and is currently operated and maintained by the Massachusetts Air National Guard 102nd Intelligence Wing (ANG). The existing JBCC wastewater system is shown on Figure 1-1. The major components of the existing wastewater treatment system are summarized in Table 1-3.

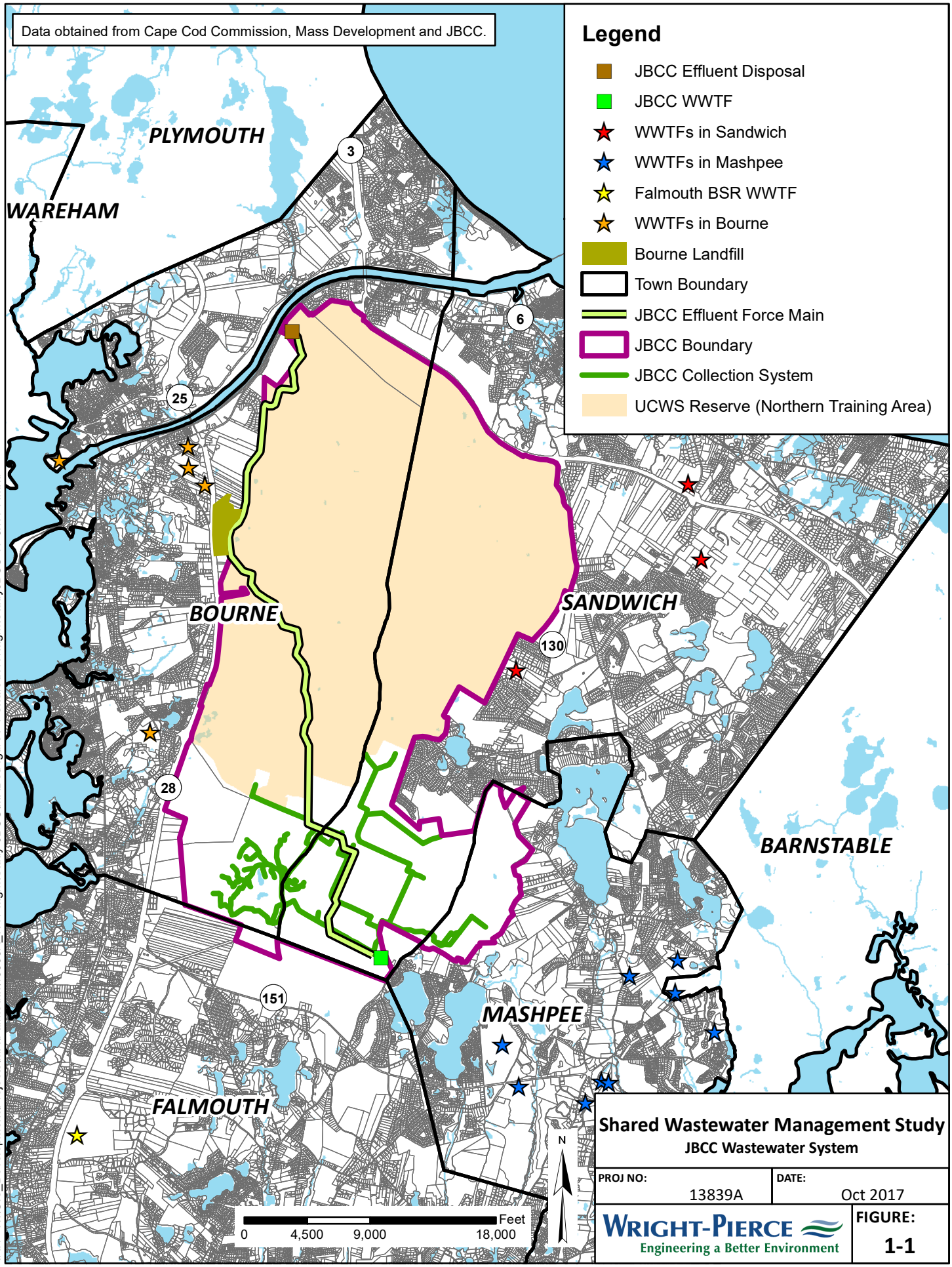
The WWTF and all of the collection system are located within the Cantonment Area, which comprises approximately 25% of JBCC. Most of the effluent force main and the entire effluent disposal system are located in the Upper Cape Water Supply Reserve, which comprises the northerly 75% of JBCC.

1.4.2 Wastewater Flows and Loads

The wastewater flows and loads for the period 2008 to 2012 and for the period 2012 to 2014 are summarized in Table 1-4. Based on this information, the WWTF is operating at just under 50% of its design capacity.

1.4.3 Collection System

The collection system was built when the population served was approximately 70,000; whereas, there is currently a population served of approximately 3,500 (JBCC Base Population Survey, 2009). The collection system includes 11 pumping stations and approximately 30.5 miles of sewers ranging in size from 6-inch to 24-inch diameter including several pipe materials. The collection system was constructed between the 1940s and present.



Shared Wastewater Management Study

JBCC Wastewater System

PROJ NO:	DATE:
13839A	Oct 2017

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FIGURE: 1-1

TABLE 1-3
WASTEWATER SYSTEM COMPONENTS

Component	Quantity
Collection & Conveyance	161,000 linear feet sewers, 595 manholes
Pump Stations	11
Wastewater Treatment Facility	360,000 gpd
Effluent Force Main	55,280 linear feet
Rapid Infiltration Disposal Beds (RIBs)	4 cells, 6 acres
Monitoring Wells for RIB Compliance:	4
Composting Facilities (abandoned)	25,290 square feet

TABLE 1-4
CURRENT WWTF FLOWS AND LOADINGS

Parameter	Condition	Design Rating	Permit Value	Current 2008 to 2012	Current 2012 to 2014
Flow (gpd)	Annual Average	300,000	360,000 (1)	143,000	131,000
	Maximum Month	430,000	-	248,500	210,000
	Maximum Day	800,000	840,000	555,600	390,000
	Peak Hourly	1,380,000	-	-	-
BOD Load (lb/day)	Annual Average	690	-	337	-
	Maximum Month	990	-	548	-
	Maximum Week	1840	-	948	-
TSS Load (lb/day)	Annual Average	550	-	272	-
	Maximum Month	790	-	453	-
	Maximum Week	1470	-	884	-
TKN Load (lb/day)	Annual Average	125	-	60	-
	Maximum Month	180	-	104	-
	Maximum Week	335	-	233	-
Ammonia Load (lb/day)	Annual Average	90	-	43	-
	Maximum Month	125	-	76	-
	Maximum Week	235	-	163	-

Notes:
1) 12-month rolling average flow.
2) Data in "Design Rating" and "Current 2008 to 2012" columns are from CH2M-Hill, 2012.

1.4.4 Wastewater Treatment Facility

The WWTF is an extended aeration activated sludge facility (biological nitrogen removal) with disinfection that was constructed in 1995. The WWTF was constructed with a capacity of 300,000 gpd (annual average); however, when the Barnstable County Jail was constructed in the early 2000s, the WWTF was upgraded to a design capacity of 360,000 gpd (annual average). The WWTF design maximum day flow of 840,000 gpd. Major unit processes at the WWTF include:

- Preliminary Treatment (screening and grit removal)
- Advanced secondary treatment (biological nutrient removal)
- Disinfection
- Effluent Pumping
- Sludge Holding and Aeration
- Sludge Decanting
- Biosolids hauling (for off-site processing and disposal)

1.4.5 Effluent Force Main

The existing effluent force main is a 12-inch diameter ductile iron pipe that runs approximately 10.5 miles from the WWTF, through the Reserve, to the Rapid Infiltration Basins (located at the northwest edge of JBCC). There is a short section of 8-inch diameter ductile iron pipe (at 5.5% slope) between Static Head Structure No.1 and the Hydraulic Distribution Structure. The force main is shown on the design drawings entitled "Effluent Force main and Infiltration Basins" (CDM/SAIC, 1993). The force main is hydraulically complex and has approximately 20 air and/or vacuum relief valves. Based on the existing pumping system design, the effluent disposal force main has a design capacity of 1,400,000 gpd on a peak hour basis (i.e., 2.8 feet per second). This capacity could potentially be increased to 1,750,000 gpd on a peak hour basis; however, some modifications to the pumping/surging suppression system would be required. Increases beyond that flow rate would require additional piping in parallel. Additional analysis on this item will be required.

1.4.6 Rapid Infiltration Basins

The existing effluent disposal facility consists of four rapid infiltration basins (RIBs), with a total surface area of 259,160 square feet. The RIBs were constructed on the basis of design drawings

entitled “Effluent Forcemain and Infiltration Basins” (CDM/SAIC, 1993) as well as a *Hydrogeologic Investigation and Design Effluent Infiltration Basins* technical memorandum (CDM/SAIC, 1993). The existing RIBs are in very good condition with the only reported operational challenge being the control of vegetation growth. There are no reports of “effluent breakout” occurring downgradient of the RIBs. DEP has not identified the Cape Cod Canal as nitrogen-sensitive. A preliminary review of the design surficial loading rates and the groundwater mound elevations indicates that the sizing of the RIBs is conservative and that additional capacity can likely be obtained through a re-permitting and re-rating process with DEP. This will need to reviewed closely with DEP.

1.4.7 Groundwater Discharge Permit Requirements

The WWTF effluent quality requirements are contained in a Groundwater Discharge Permit (GWDP) which is issued by the Massachusetts Department of Environmental Protection (DEP). The GWDP (Application/Permit No. 41-3) allows for disposal of suitable quality effluent up to 360,000 gpd on a 12-month rolling average basis and up to a maximum of 840,000 gpd on any given day (so-called “maximum day flow”). The GWDP is included in Appendix A and its requirements for the WWTF effluent are summarized in Table 1-5. The GWDP requirements for groundwater monitoring at the RIB site are summarized in Table 1-6. The current permit expires in April 2018 and a renewal application is due in October 2017. As a part of this impending GWDP renewal process, JBCC should request that the “maximum day flow of 840,000 gpd” be revised to a “maximum flow of 840,000 gpd based on a 3-day rolling average”.

1.4.8 Facility Condition

The JBCC WWTF was operational in 1995 and now just over 20 years old. A comprehensive upgrade for the facility should be expected within the next 10 years. In the interim, the facility will require modest upgrades and investments in order to maintain reliability of treatment performance and permit compliance, to better utilize its existing available capacity and to reduce annual operations and maintenance costs. Several baseline improvements were identified for this purpose in the 2014 JBCC Water and Wastewater System Evaluation, including:

- Provide off-line influent equalization tank and a pump station to aid in peak flow management. Set equalization volume at 100,000 gallons.

TABLE 1-5
GWDP – WWTF EFFLUENT LIMITS AND MONITORING REQUIREMENTS

Parameter	Discharge Limitation	Minimum Frequency
Flow, 12-month moving average	360,000 gpd	Daily
Flow, maximum day	840,000 gpd	Daily
Oil and grease	15 mg/l	Monthly
Total Suspended Solids (TSS)	30 mg/l	Monthly
Total Nitrogen (NO2-N + NO3-N + TKN)	10 mg/l	Monthly
Nitrate-Nitrogen (NO3-N)	10 mg/l	Monthly
Biochemical Oxygen Demand, 5-day at 20°C (BOD_5)	30 mg/l	Monthly
Fecal Coliform	200 colonies/ 100 ml	Monthly
pH	6.5 to 8.5	Daily
Total Solids	Report	Monthly
Total Phosphorus (as P)	Report	Monthly
Orthophosphate (as P)	Report	Monthly
Volatile Organic Compounds	Report	Monthly

TABLE 1-6
GWDP – GROUNDWATER MONITORING REQUIREMENTS

Parameter	Discharge Limitation	Minimum Frequency
Static Water Level	Report	Monthly
Specific Conductance	Report	Monthly
pH	Report	Monthly
Total Nitrogen (NO2-N + NO3-N + TKN)	Report	Quarterly
Nitrate-Nitrogen (NO3-N)	Report	Quarterly
Total Phosphorus (as P)	Report	Quarterly
Orthophosphate (as P)	Report	Quarterly
Volatile Organic Compounds	Report	Quarterly

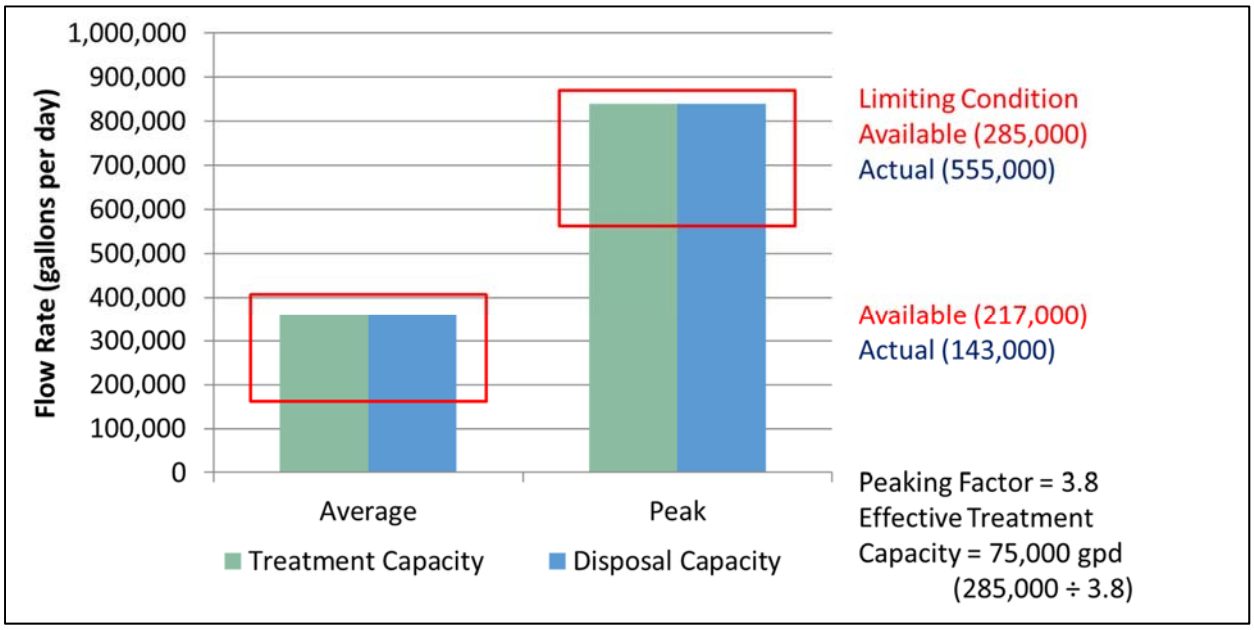
- Install a small supplemental carbon system (i.e., glycerin) including 500-gallon storage tank, one chemical feed pump, instrumentation interface with SCADA and electrical feeds.
- Install a rotary disc or drum thickener over the existing Sludge Storage Tanks and enclose it in a small building. Automate sludge wasting and polymer feed system to pre-thicken waste sludge prior to storage.
- Replace existing sludge feed pumps (progressing cavity) with higher rate sludge feed pumps (rotary lobe) to convey thickened sludge to a tanker truck at high rate (say 200 gpm) to allow for shorter truck fill times. Add new truck fill piping with quick-connect to building exterior.
- Upgrade components of the effluent forcemain. Increase the diameter of 180 feet of pipe from 8-inch to 18-inch between Static Head Structure No. 1 to Hydraulic Distribution Structure at the RIB site (the remainder of the forcemain is 12-inch diameter). Replace all existing air/vacuum release valves and add a surge tank at the Frank Perkins Road Static Head Structure).

1.4.9 Estimate of Existing Available Capacity

Based on the WWTF design capacity and the 2008 to 2012 flows and loads, the WWTF has approximately **157,000 gpd (annual average)** of residual capacity which can be made available to neighboring communities or users on the base.

On an annual average basis, the effluent disposal system also has approximately 157,000 gpd of additional capacity. On a peak day basis (due to the impacts of inflow), the effluent disposal system has approximately 285,000 gpd of additional capacity. Given that the existing peaking factor for peak to average flows is 3.8:1 (again, due primarily to the impacts of inflow), the *effective available capacity* is approximately **75,000 gpd (annual average basis)**. It is important to note this *effective capacity* is less than that available at the WWTF. Without inflow control, available treatment capacity will go unused due to the limitations inherent in the GWDP. The capacity and effective capacity is illustrated on Figure 1-2.

FIGURE 1-2
ESTIMATE OF EXISTING AVAILABLE CAPACITY



This existing available capacity can be made available to neighboring communities or to new users which may be located on JBCC. From a regionalization perspective, it is very important to maximize the available capacity. This available capacity can be maximized by one or more of the following methods:

- Aggressively investigating and removing collection system inflow sources;
- Securing customers with low wastewater flow "peaking factors" (i.e., customers with a peak flow that is similar to the average flow);
- Seeking opportunities for beneficial reuse of effluent;
- Providing influent flow equalization at the WWTF;
- Addressing the effluent force main capacity limitation; and/or
- Increasing the capacity of the disposal system by re-rating the RIBs and revising the GWDP with DEP review and approval.

1.5 REGULATORY FRAMEWORK

1.5.1 Effluent Disposal

The existing GWDP is focused primarily on addressing conventional parameters (BOD, TSS, bacteria) as well as nutrients (nitrogen, phosphorus). Over time, additional parameters or more stringent effluent limits may be imposed.

- Nitrogen – DEP has indicated that there is no intention to revise the effluent nitrogen limits for the JBCC GWDP at this time. DEP has also indicated that there is no Total Maximum Daily Load (TMDL) Study completed or planned because the effluent disposal site is not located in a nitrogen-sensitive watershed. Given that the RIBs are located in a non-nitrogen-sensitive watershed (Canal South), the imposition of a more stringent nitrogen limit is unlikely.
- Phosphorus – DEP has not indicated any intention to add a phosphorus limit at this time. Given the location of the discharge, the imposition of a phosphorus limit is very unlikely.
- Compounds of emerging concern (CECs) – CECs encompass a wide variety of compounds including endocrine disrupting compounds, pharmaceuticals, flame retardants, hormones, industrial solvents and surfactants, metals, pesticides, and personal care products. CECs have been found in wastewater for decades; however, they have recently reached the forefront of regulatory and public concern, and there is currently a great deal of research on CECs. One of the difficulties associated with addressing this topic is the large number and wide array of substances that can be classified as CECs. Given that the location of the discharge is outside water supply recharge areas, the short-term imposition of CEC limits is very unlikely. DEP has developed regulatory limits for Total Organic Carbon (an indicator of CEC's) for groundwater discharges within a Zone II of a public water supply, but there is no indication that limits will be extended to other groundwater categories.

Future effluent limits will be dictated by the disposal location and by potential changes in environmental policy over time. While capital upgrades would be required if the GWDP requirements were made more stringent, this eventuality appears unlikely within a 10- to 20-year timeframe. Refer to Section 2 for additional description of permit considers based on alternative effluent disposal methods.

To the extent that sufficient capacity can be obtained via RIB expansion, DEP will consider this a better environmental solution than a surface water discharge to the Cape Cod Canal and should be achievable at less cost and regulatory complexity. If sufficient capacity cannot be obtained via the existing or expanded RIBs, then alternative methods will need to be considered (e.g., deep well injection, surface outfall to the Cape Cod Canal, etc.).

1.5.2 Total Maximum Daily Loads for Nitrogen

The DEP and the Massachusetts Estuaries Project (MEP) have no plans to study the Cape Cod Canal at this time; however, the DEP and MEP have studied many of the Upper Cape watersheds and have developed Total Maximum Daily Load (TMDL) Studies on many of the studied watersheds. TMDLs may require that towns consider off-site wastewater management at more locations than currently considered or at greater flow rates than currently anticipated in this or previous studies. The elimination of private septic systems will increase the amount of wastewater flow requiring off-site wastewater management at WWTFs.

1.5.3 Municipal Reviews

Each municipality needs to review and approve its participation in a regional solution. The review would occur at a technical level (department heads and review boards) and an executive level (boards of selectmen and town meeting).

1.5.4 Cape Cod Commission

The Cape Cod Commission will need to review and approve any proposed regional project of the nature described in this document for consistency with the 208 Plan Update.

1.5.5 Massachusetts DEP and United States EPA

The DEP will need to review and approve proposed/requested capacity increases for the JBCC wastewater facilities. DEP will also need to address the issue of multiple permittees and effluent sources discharging to a single effluent disposal location (e.g., joint and several responsibilities related to monitoring requirements, maintenance requirements, etc.). EPA involvement is not anticipated unless there is a proposed surface water discharge to the Cape Cod Canal.

1.5.6 Upper Cape Water Supply Reserve/ Northern Training Area

The Upper Cape Water Supply Reserve (the "Reserve", also known as the "Northern Training Area") is located in the northern portion JBCC and is approximately 15,000 acres. The Reserve was created in 2001 to 2002 to protect the drinking water supply and wildlife habitat. The Reserve is governed by the Environmental Management Commission (3 members) and is advised by the Community Advisory Council (15 members). All activities in the Reserve are subject to Environmental Performance Standards and are subject to the approval of the Environmental Management Commission. The effluent force main and the RIBs are both within the Reserve. Also, the proposed effluent pipe connection from Bourne and Falmouth would cross the Reserve.

1.6 PRELIMINARY STRATEGY FOR REGIONAL APPROACH

1.6.1 Project Planning Horizon

The project planning horizon was agreed to be 20 years; however, the conceptual alternatives identified and evaluated in this report will also consider future expansion potential beyond the 20-year time frame.

1.6.2 Potential Opportunities, Challenges and Logistical Issues

There are many opportunities associated with regional wastewater facilities at the JBCC location. There are also a number of legal, political and financial challenges to overcome for the wastewater facilities to be shared. These opportunities and challenges are summarized in **Figure 1-3**.

1.6.3 Potential Phasing Framework

The use of excess capacity at JBCC by adjacent municipalities has been identified as an 'ideal option' for over a decade. If this concept were straight-forward, it would already be underway or completed. Given the complexity of this endeavor, a multi-phase implementation framework is most advantageous. A potential phasing framework is summarized below.

FIGURE 1-3 OPPORTUNITIES AND CHALLENGES FOR SHARED WASTEWATER FACILITIES AT JBCC

Opportunities

- Central location in Upper Cape
- History of collaboration among Bourne, Falmouth, Mashpee, Sandwich and JBCC
- Existing wastewater collection, treatment and disposal facilities
- Disposal in non-nitrogen-sensitive watershed
- Potential regional solution for septage and potential source of operating revenue
- Easement across the UCWSR for effluent connection from Bourne is almost approved
- Rail spur on JBCC, existing contract with SEMASS
- Preservation of military mission
- Preservation/protection of federally designated sole-source aquifer
- Extensive land area, lack of abutters
- Consensus from JBCC, municipalities, DEP and CCC on benefits
- Potential future regional solutions for biosolids and/or source-separated organics digestion
- Potential capital and O&M cost savings due to efficiencies gained by economies of scale

Challenges

- Complicated land ownership/lease arrangements
- Different needs, goals and implementation timelines among towns and JBCC
- Shared military/ civilian facilities
- Capacity limitations of existing wastewater infrastructure
- Identification of mutually agreeable successor management entity to run facilities
- Land use restrictions in the Upper Cape Water Supply Reserve area
- Inconsistent WWTF performance
- Re-permitting of RIBs to receive different types of flow (e.g., municipal sewage vs treated landfill leachate) and flow from different communities
- Development of sustainable cost structure for future operations.
- Future changes in effluent limits or regulatory drivers (e.g., phosphorus, CECs)
- Potential third-party or non-governmental entity influence on the proposed project based on increased effluent flows and loadings to the Cape Cod Canal, Cape Cod Bay and Buzzards Bay.

Phase 1/ Year 0 to Year 5:

- Develop partnership and IMAs/IGAs with matrix of future flows
- Confirm initial management entity
- Transfer facility to initial management entity
- Development of full-build wastewater master plan
- Design and permitting of Phase 2 wastewater improvements
- Develop rate structure, sewer use ordinance, inter-municipal agreements, permit modifications, etc.

Phase 2/ Year 5 to Year 10:

- Complete construction of initial treatment and disposal upgrades for short-term and mid-term needs.
- Begin municipal connections.
- Create successor management entity (to be determined, refer to Section 3).
- Transfer facility to successor management entity.
- Design and permitting of Phase 3 wastewater improvements
- Continue municipal connections.

Phase 3/ Year 10 to Year 20:

- Complete construction of treatment and disposal upgrades for long-term needs.
- Continue municipal connections.

1.6.4 Options for Inter-Governmental Agreements and Management Entity

Inter-Governmental Agreements

The Upper Cape communities have previously developed inter-municipal agreements and it is expected that this will be a viable option for formalizing "next steps" among the towns. JBCC will also need to be a party to an inter-governmental agreement if this partnership were to proceed.

Management Entity

Previous studies have evaluated potential management models to allow for shared use of the wastewater facilities (CH2M-Hill, 2012). The current study presumes that an "initial management entity" will take over ownership of the wastewater facilities and manage the technical and financial aspects of the project until a "successor management entity" is established.

An initial list of potential successor management entities includes: 1) MassDevelopment; 2) one of the towns (Bourne, Falmouth, Mashpee or Sandwich); or 3) an existing or new special purpose district (e.g., the Upper Cape Regional Water Supply Collaborative). These options are evaluated further in Section 2 of this report.

1.6.5 Requested Capacity by Wastewater Type

Each of the towns and JBCC has provided capacity requests by wastewater type to address wastewater management needs including Nitrogen TMDL compliance. For the purposes of this study, the following terms will be used for this study for the wastewater types:

- ***Sewage*** is residential/commercial/light industrial wastewater collected and conveyed to the JBCC WWTF for treatment and disposal.
- ***Effluent*** is treated wastewater. References to "effluent disposal only" mean that the wastewater will be treated elsewhere (e.g., the Integrated Solids Waste Management or "ISWM" WWTF) and the effluent will be conveyed to the JBCC disposal system via the existing forcemain (i.e., not treated at the JBCC WWTF).
- ***Leachate*** is from the Bourne ISWM landfill.
- ***Leachate effluent*** is leachate treated at the proposed Bourne ISWM WWTF.
- ***Septage*** is the liquid/sludge mixture pumped from septic tanks.

At the project kick-off meeting, all towns agreed that including an allocation for receiving and treating septage at the JBCC WWTF is appropriate for this study. Accordingly, the "current condition" septage flows indicated in Table 1-2 will be used in the analysis moving forward as it is anticipated that increase in septage volume from non-sewered growth will offset the reduction in septage volume from current structures being connected to sewer.

Bourne

- Study Basis: The study basis includes the following key assumptions:
    1. Wastewater flow does not cross the Cape Cod Canal.
    2. Leachate effluent from the Bourne "ISWM WWTF" is connected to the JBCC effluent forcemain and disposal system (i.e., 100,000 gpd) in the short-term.
    3. Wastewater flow from Bourne wastewater planning areas 8, 9, 10, 12, 13, and 14 goes to the ISWM WWTF for co-treatment with landfill leachate and the effluent is directed to the JBCC effluent forcemain and disposal system in the mid-term and long-term. The ISWM WWTF would need to be designed for co-treatment under this approach.
    4. Wastewater flow from Bourne wastewater planning areas 15 through 20 goes to the JBCC WWTF location and is treated as sewage in the mid-term and long-term.
    5. Wastewater flow from Bourne wastewater planning area 11 (MacArthur Boulevard/Route 28) is split equally between the ISWM WWTF and the JBCC WWTF.
    6. Wastewater flows connected to sewer are estimated based on the priority assigned to the wastewater planning areas in the 2007 Tighe & Bond study
    7. Septage treatment capacity is provided at the JBCC WWTF.
- Low End: The low end estimate includes the following assumptions:
    1. Leachate effluent from the Bourne "ISWM WWTF" is connected to the JBCC effluent forcemain and disposal system (i.e., 100,000 gpd) in the short-term.
    2. A maximum of 100,000 gpd of wastewater flow from Bourne wastewater planning areas 8, 9, 10, 12, 13, and 14 goes to the ISWM WWTF for co-treatment with landfill leachate and the effluent is directed to the JBCC effluent forcemain and disposal system in the mid-term and long-term.
    3. Septage treatment capacity is provided at the JBCC WWTF.
- High End: Same elements/flows/volumes as the study basis.

Falmouth

- Study Basis: The study basis includes the following key assumptions:
    1. Some/most of the effluent from the existing Blacksmith Shop Road WWTF is directed to the JBCC effluent forcemain and disposal system. Specifically, in the mid-term, the BSR WWTF is assumed to receive and treat 1,200,000 gpd, of which 710,000 gpd of

effluent will go to the existing BSR WWTF RIBs and 490,000 gpd of effluent will go to the JBCC effluent disposal system. In the long-term, the BSR WWTF is assumed to receive and treat 2,200,000 gpd, of which 710,000 gpd of effluent will go to the existing BSR WWTF RIBs and 1,490,000 gpd of effluent will go to the JBCC effluent disposal system.

2. Septage treatment capacity is provided at the JBCC WWTF [Note, this is a conceptual scenario, Falmouth does not have any plans to terminate septage receiving at the BSR WWTF at this time].

- Low End: Same elements; however, less effluent is directed to the JBCC effluent forcemain and disposal system in the mid-term and the long-term.
- High End: The high end assumes that all effluent flow goes to the JBCC effluent disposal system in the mid-term and that the BSR WWTF is eventually abandoned and all Falmouth wastewater flow is directed to the JBCC WWTF in the long-term. Septage also goes to the JBCC WWTF.

Mashpee

- Study Basis: The study basis includes the following key assumptions:
    1. A specified amount of sewage from Mashpee will be directed to the JBCC WWTF
    2. Septage treatment capacity is provided at the JBCC WWTF.
- Low End: Same elements/flows/volumes as the study basis.
- High End: Same elements; however, more sewage is directed to the JBCC WWTF.

Sandwich

- Study Basis: The study basis includes the following key assumptions:
    1. A specified amount of sewage from Sandwich will be directed to the JBCC WWTF. For the study basis, the amount of capacity requested is equivalent to the capacity identified for the JBCC WWTF and the proposed so-called "IWS WWTF" in CWRMP Plan B.
    2. Septage treatment capacity is provided at the JBCC WWTF.
- Low End: Same elements, however, the amount of capacity is reduced to just the amount identified for the JBCC WWTF in CWRMP Plan B.

- High End: Same elements, however, the amount of capacity is reduced to the amount identified in for the JBCC WWTF, the proposed "IWS WWTF" and the proposed "CS WWTF" in CWRMP Plan A (fully traditional backup plan).

JBCC

- Study Basis: Future flow from military and non-military users was estimated to be 7,000 gpd (CH2M-Hill, 2012). This future flow is utilized herein.
- Low End/ High End: Same elements as the study basis.

A summary of the capacity requests is provided in Table 1-7.

TABLE 1-7: REQUESTED CAPACITY BY WASTEWATER TYPE

	Capacity Requested – Annual Average Basis		
	Low End (gpd)	Study Basis (gpd)	High End (gpd)
BOURNE			
Short-term (2017 to 2020)			
Sewage Treatment	0	0	0
Effluent Disposal Only	100,000	100,000	100,000
Septage Treatment	0	0	0
Mid-term (2020 to 2040)			
Sewage Treatment	0	259,000	259,000
Effluent Disposal Only	200,000	444,000	444,000
Septage Treatment	11,000	11,000	11,000
Long-term (2040+)			
Sewage Treatment	0	456,000	456,000
Effluent Disposal Only	200,000	651,000	651,000
Septage Treatment	11,000	11,000	11,000
FALMOUTH			
Short-term (2017 to 2020)			
Sewage Treatment	0	0	0
Effluent Disposal Only	0	0	0
Septage Treatment	0	0	0
Mid-term (2020 to 2040)			
Sewage Treatment	0	0	0
Effluent Disposal Only	300,000	490,000	1,200,000
Septage Treatment	22,000	22,000	22,000
Long-term (2040+)			
Sewage Treatment	0	0	2,200,000
Effluent Disposal Only	490,000	1,490,000	0
Septage Treatment	22,000	22,000	22,000
MASHPEE			
Short-term (2017 to 2020)			
Sewage Treatment	200,000	200,000	200,000
Effluent Disposal Only	0	0	0
Septage Treatment	0	0	0
Mid-term (2020 to 2040)			
Sewage Treatment	200,000	200,000	370,000
Effluent Disposal Only	0	0	0
Septage Treatment	0	3,000	7,000
Long-term (2040+)			
Sewage Treatment	200,000	200,000	850,000
Effluent Disposal Only	0	0	0
Septage Treatment	1,000	3,000	4,000

TABLE 1-7: REQUESTED CAPACITY BY WASTEWATER TYPE (Continued)

	Capacity Requested – Annual Average Basis		
	Low End (gpd)	Study Basis (gpd)	High End (gpd)
SANDWICH			
Short-term (2017 to 2020)			
Sewage Treatment	0	0	300,000
Effluent Disposal Only	0	0	0
Septage Treatment	0	0	0
Mid-term (2020 to 2040)			
Sewage Treatment	0	100,000	340,000
Effluent Disposal Only	0	0	0
Septage Treatment	10,000	10,000	10,000
Long-term (2040+)			
Sewage Treatment	40,000	340,000	900,000
Effluent Disposal Only	0	0	0
Septage Treatment	10,000	10,000	10,000
JBCC			
Short-term (2017 to 2020)			
Sewage Treatment	140,000	140,000	140,000
Effluent Disposal Only	0	0	0
Mid-term (2020 to 2040)			
Sewage Treatment	147,000	147,000	147,000
Effluent Disposal Only	0	0	0
Long-term (2040+)			
Sewage Treatment	147,000	147,000	147,000
Effluent Disposal Only	0	0	0

1.6.6 Capacity Needs at Planning Horizon

Based on our review of the four towns and JBCC wastewater needs, we have developed a summary of the capacity needs by entity of the 20-year planning horizon in Table 1-8. All flows are presented on an annual average flow basis.

- The short-term capacity needs can be met with a 0% increase in treatment capacity and a 28% increase in disposal capacity.
- The mid-term capacity needs will require a 111% increase in treatment capacity and a 372% increase in disposal capacity.
- The long-term capacity needs will require a 233% increase in treatment capacity and a 831% increase in disposal capacity.

TABLE 1-8: SUMMARY OF CAPACITY REQUESTS USED IN ENGINEERING ASSESSMENT

	Capacity Requested - Annual Average Flows (gpd)							
	JBCC	**Bourne**	**Falmouth**	**Mashpee**	**Sandwich**	**Total**	**Capacity Provided**	**% Increase Existing Capacity**
Existing								
Sewage Treatment	140,000	0	0	0	0	140,000	**360,000**	n/a
Septage Treatment	0	0	0	0	0	0		
Effluent Disposal Only	0	0	0	0	0	0		
Effluent Disposal	140,000	0	0	0	0	140,000	**360,000**	n/a
Short-Term (5-year)								
Sewage Treatment	147,000	0	0	200,000	0	347,000	**360,000**	0%
Septage Treatment	0	0	0	0	0	0		
Effluent Disposal Only	0	100,000	0	0	0	100,000		
Effluent Disposal	147,000	100,000	0	200,000	0	447,000	**460,000**	28%
Mid-Term (10 year)								
Sewage Treatment	147,000	259,000	0	200,000	100,000	706,000	**760,000**	111%
Septage Treatment	0	11,000	22,000	3,000	10,000	46,000		
Effluent Disposal Only	0	444,000	490,000	0	0	934,000		
Effluent Disposal	147,000	714,000	512,000	203,000	110,000	1,686,000	**1,700,000**	372%
Long-Term (20 year)								
Sewage Treatment	147,000	456,000	0	200,000	340,000	1,143,000	**1,200,000**	233%
Septage Treatment	0	11,000	22,000	3,000	10,000	46,000		
Effluent Disposal Only	0	651,000	1,490,000	0	0	2,141,000		
Effluent Disposal	147,000	1,118,000	1,512,000	203,000	350,000	3,330,000	**3,350,000**	831%
Notes	1	1	1	1	1		2, 4	3

1) Refer to Table 1-7 for additional information.

2) Existing Capacity based on WP 2014, GWDP and WWTF O&M.

3) Capacity for Short-Term, Mid-Term and Long-Term conditions are increases over the existing capacity.

4) Organic loading treatment capacity will need to account for concentrated nature of septage.

SECTION 2

ENGINEERING ASSESSMENT

2.1 INTRODUCTION

Section 1 of this report summarizes the previous wastewater planning efforts and capacity needs for each of the participating entities. This section of the report identifies and evaluates the technical factors, costs and management considerations associated with potential shared wastewater facilities at JBCC.

2.2 WASTEWATER FLOWS USED IN THE ENGINEERING ASSESSMENT

Different components of a wastewater system are designed based on different process conditions (e.g., minimum day, annual average, maximum month, maximum multi-day, maximum day and peak instantaneous, etc.). In the absence of existing data on short-term peak flows, peaking factors are typically utilized to establish the other conditions. For the purposes of this study:

- Sewage peaking factors were established using the TR-16 Guides for the Design of Wastewater Treatment Works curves entitled "Relation of Extreme Discharges on Maximum and Minimum Days to the Average Daily Discharge of Domestic Sewage" (New England Interstate Water Pollution Control Commission, 2016) and were adjusted upward by 0.2 to account for seasonal population/flow variations on Cape Cod. Septage peaking factors were set assuming that equalization tanks would be provided.
- Effluent-only peaking factors were estimated by assuming that the remote facilities (i.e., BSR WWTF and ISWM WWTF) have, or will have, effluent equalization tanks sized to meet these peaking factor limitations or will utilize existing or new effluent disposal systems local to the ISWM and BSR WWTFs to manage peak flows.

Table 2-1 summarizes the peaking factors which have been used for this project. The peaking factors from Table 2-1 were applied to the annual average flows from Table 1-8 in order to establish the wastewater flows that will be used for this engineering assessment. Table 2-2 summarizes the annual average, maximum 3-day flows and the peak conveyance flows for the existing, short-term, mid-term and long-term conditions. The flows in Table 2-2 have been used for the conceptual sizing and costing of proposed wastewater system components.

TABLE 2-1: PEAKING FACTORS FOR MIMIMUM AND MAXIMUM FLOW CONDITIONS

Ratio to Annual Average	Sewage	Septage	Effluent Only
Minimum Day	0.40	0.50	0.50
Minimum Month	0.75	0.75	0.75
Annual Average	1.00	1.00	1.00
Maximum Month	1.25	1.50	1.25
Maximum 3-Day	2.4 to 2.7	1.75	1.25
Peak Instantaneous	4.0 to 4.6	1.75	1.25

TABLE 2-2: FLOWS USED IN ENGINEERING ASSESSMENT

Flows in gpd	Annual Average	Maximum 3-Day	Peak Conveyance
Existing	140,000	386,000	1,400,000
Short-Term	450,000	1,080,000	1,750,000
Mid-Term	1,690,000	3,030,000	4,240,000
Long-Term	3,350,000	5,520,000	7,350,000

Note: Refer to Appendix A for a breakdown of flows by category. Rounded to nearest 10,000 gpd.

2.3 IDENTIFICATION OF FUTURE WASTEWATER SYSTEM COMPONENTS

This section identifies the components of the future wastewater system to address future wastewater needs at shared facilities. The analysis and costs are presented in these categories.

2.3.1 Conveyance

Each community will have a collection system that transports flow to the location of the regional conveyance facilities. This report addresses the conveyance system costs but will not address the collection system costs.

2.3.2 Treatment

The JBCC WWTF will require upgrade/replacement to serve the regional needs. This report considers the costs for WWTF upgrade/replacement at the current WWTF location or at the former WWTF location (immediately adjacent to the current location). Any potential future WWTF expansions to include more regional flow and/or regional biosolids processing and/or regional source separated organics digestion is beyond the scope of this study.

2.3.3 Transport to Effluent Disposal

WWTF effluent is conveyed to the existing RIBs via the existing 11-mile long, 12-inch diameter forcemain. This report considers the costs for upgrades to this forcemain as well as supplemental forcemain(s) to the supplemental or replacement effluent disposal methods.

2.3.4 Effluent Disposal

The JBCC RIBs will need to be supplemented or replaced in order to serve the regional needs. This report considers the costs for additional RIBs as well as other supplemental/replacement effluent disposal methods.

2.4 CONVEYANCE

This section identifies the options for wastewater conveyance systems required to support shared wastewater management opportunities for Bourne, Falmouth, Mashpee, Sandwich and JBCC. The objectives of the conveyance study include the following:

- Identify alignments for conveyance of sewage from Bourne's southern section, Mashpee and Sandwich to JBCC WWTF for treatment and disposal;
- Identify alignments for conveyance of treated wastewater ("effluent") from the JBCC WWTF, the Bourne ISWM WWTF and the Falmouth BSR WWTF to the JBCC treated effluent conveyance system and disposal areas;
- Identify rehabilitation of sections of the JBCC gravity sewer system where shorter alignments and capital cost savings are available;

- Review conceptual profiles of each force main alignment to evaluate conceptual static and dynamic head on the pumping system;
- Develop preliminary hydraulic calculations to determine conceptual forcemain sizes; and
- Determine conceptual number and size of required pump stations.

2.4.1 Concept Design Criteria

The following key assumptions are used in this analysis:

- Elevation data were obtained from topographic information within Google Earth.
- Conceptual forcemain piping and wastewater lift station sizing are based on the conveyance flows in Table 2-2.
- Raw wastewater concept design criteria:
    - Peaking factor used for pump station flow: 4.0
    - Minimum force main velocity: 3 ft/s
    - Maximum force main design pressure: 275 ft (120 psi)
- Treated effluent concept design criteria:
    - Peaking factor used for pump station flow: 1.25
    - Minimum force main velocity: none
    - Maximum force main design pressure: 275 ft (120 psi)
- Force main materials:
    - Existing effluent force main: ductile iron
    - Proposed force mains: C900/C905 DR 18 PVC (235 psi) or HDPE (200 to 255 psi)
- Medium wastewater/effluent lift stations:
    - Flow: up to 1200 gpm
    - Pumps: wetwell installation, submersible, up to 75 hp
    - Generator and control panel in pump house
    - Conceptual construction cost: $1M each
- Large wastewater/effluent lift stations:

- Flow: 1200gpm or more
- Pumps: drywell installation, greater than 75 hp
- Generator and control panel in pump building over wetpit/drypit installation
- Conceptual construction cost: $2.5M each

- Conveyance routes utilizing existing JBCC gravity conveyance systems assume the rehabilitation of those sections through trenchless methods. Rehabilitation costs are assumed to be $150 per foot.
- Forcemain costs vary depending on the conditions of the route and are shown below in Table 2-3. A route within a public way with heavy traffic volumes or dense development has a higher cost than a route along routes with little traffic or adjacent development.

TABLE 2-3: FORCEMAIN COSTS PER FOOT

Forcemain Diameter	Route Characteristics		
	Public Way or Dense Development	Off Public Way or Less Dense	Within Railroad Right of Way
8-inch	$200	$120	$300
12-inch	$240	$160	$340
18-inch	$280	$200	$380

2.4.2 Summary of Preferred Conveyance Options

Multiple alternatives for each town were evaluated and the details of this evaluation are found in Appendix A. Current preferred conveyance routes are shown on Figure 2-1 and identified as follows:

- Bourne North (effluent) – Proposed lift station at ISWM WWTF connected to existing JBCC effluent forcemain, via a new 8" Bourne forcemain.
- Bourne South (sewage) – Proposed lift station at the intersection of Valley Bars and County Roads to JBCC WWTF via a new 12" Bourne forcemain and rehabilitated gravity sewer (shared with Sandwich).

- Falmouth (effluent) – Proposed lift station at BSR WWTF connected to the JBCC effluent forcemain(s) via a new 18-inch Falmouth forcemain in Routes 28 and 151.
- Mashpee (sewage) – Proposed lift station on Back Road Site 1 (Town lot) to JBCC WWTF via new 8" Mashpee forcemain.
- Sandwich (sewage) – Proposed lift station on portion of Lot-06-236 at 40 Route 130 to JBCC WWTF via Sandwich forcemain, and rehabilitated gravity sewers (shared with Bourne).

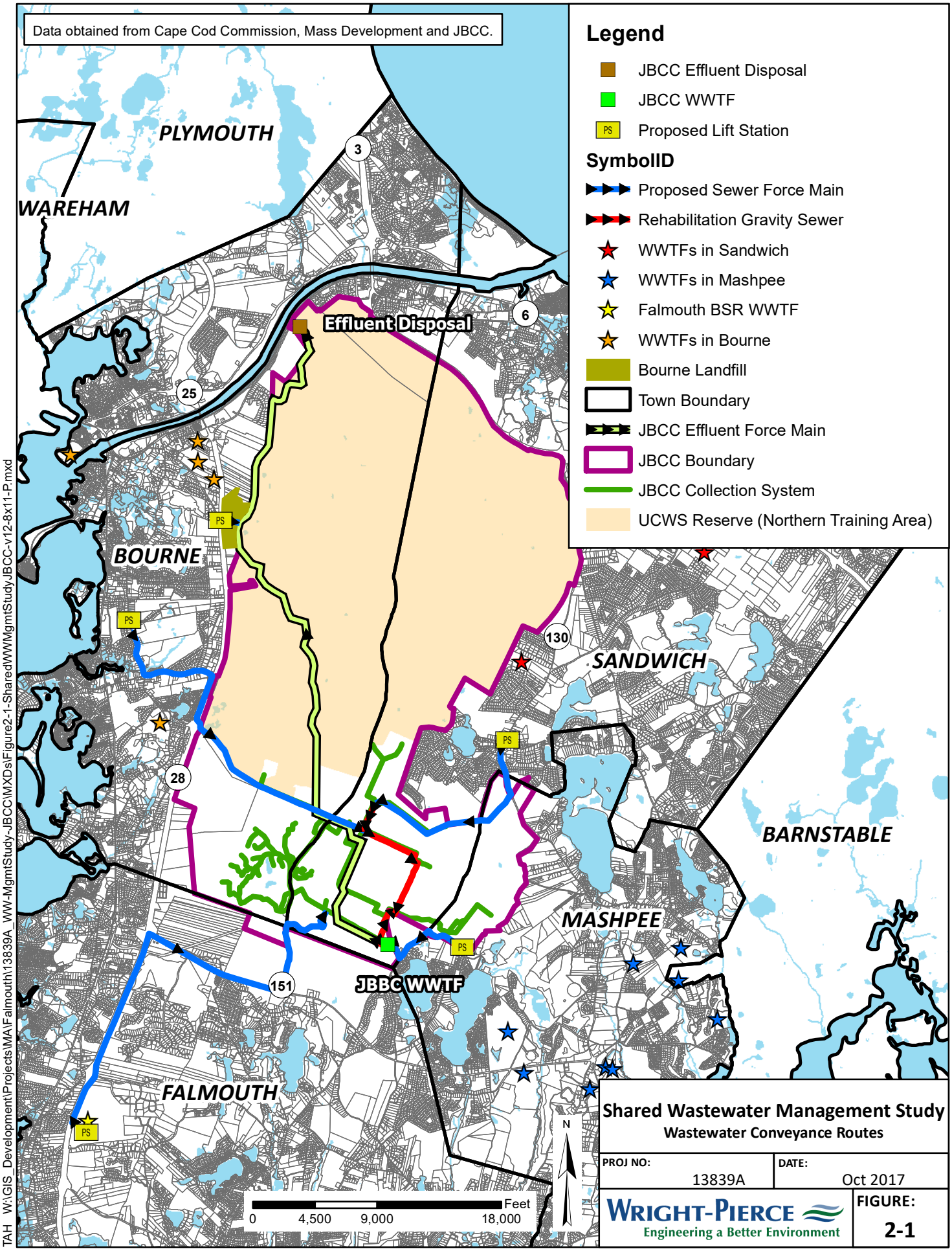
2.4.2.1 Preferred Bourne Alignment Details

One alignment was investigated for Bourne effluent flow from the ISWM WWTF to the JBCC effluent forcemain. We assumed the construction of a medium sized pump station to accommodate long-term conditions.

- 1 medium pump station, 570 gpm, 50 hp, velocity 1.7 fps
- 8" Forcemain, 100 feet

Option 1 was selected, which has the shortest route through the JBCC base, utilizing rehabilitated existing JBCC gravity sewer.

- 1 large pump station, 1250 gpm, 150 hp
- 12" Force main, velocity 3.6 fps, 5.1 miles
- JBCC rehabilitated gravity sewer, 2.3 miles
- Total route length: 7.4 miles
- Advantages - Least expensive (by $4.1M); shortest route by 2.1 miles; least amount in public ways and along dense development.
- Disadvantages - Uncertainty of obtaining construction easements within federal lands for forcemains; and uncertainty of the level of rehabilitation required for JBCC gravity sewers



Shared Wastewater Management Study

Wastewater Conveyance Routes

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FIGURE: 2-1

2.4.2.2 Preferred Falmouth Alignment Details

Option 1 was selected, which has the shortest route in public way.

- 1 Large Pump Station, 1300 gpm, 150 hp
- 18" Falmouth effluent forcemain, velocity 1.7 fps, 6.7 miles
- Total route length, 6.7 miles
- Advantages - Least expensive (by $0.1M).
- Disadvantages – Longer length in public way.
- Note: The route along the JBCC rail spur and right-of-way is approximately 1.4 miles shorter; however, the cost premium associated with constructing within the railroad right-of-way is significant. If Falmouth can negotiate fewer constraints than would typically be required by a railroad owner, then this shorter alignment may become less expensive and more favorable.

2.4.2.3 Preferred Mashpee Alignment Details

Option 1 was selected, which is the shortest route.

- Medium Pump Station, 560 gpm, 75 ft TDH, 20 hp
- 8" Mashpee forcemain, velocity 3.5 fps, 1.4 miles
- Total route length: 1.4 miles
- Advantages – Least expensive ($1.7M); shortest forcemain route by 3.4 miles
- Disadvantages – None identified.

2.4.2.4 Preferred Sandwich Alignment Details

Option 1 was selected, which has a shared rehabilitated gravity main with Bourne

- Large Pump Station, 1050 gpm, 40 hp
- 12" Dedicated Sandwich forcemain, velocity 3.0 fps, 2.9 miles
- JBCC rehabilitated gravity sewer, 0.4 miles (Sandwich) and 2.3 miles (shared with Bourne)
- Total route length: 5.6 miles
- Advantages - Least expensive- by $0.8M; shortest forcemain route by 0.9 miles
- Disadvantages - Uncertainty of obtaining construction easements within federal lands for forcemains; and uncertainty of the level of rehabilitation required for JBCC gravity sewers.

2.5 TREATMENT

This section identifies the treatment components of the future wastewater system, including the preliminary criteria used for sizing components. The primary factors which contribute to the selection of wastewater treatment processes are: wastewater flow and characteristics (domestic, commercial, industrial, septage, etc.); and effluent disposal method. Each of these factors is described below.

2.5.1 Wastewater Flow and Characteristics

The Upper Cape regional sewage treatment needs exceed the available capacity at the existing JBCC WWTF. As noted in Table 1-8, the targeted treatment capacity for sewage and septage flows are (annual average flow basis):

- Existing: 140,000 gpd
- Short-Term: 360,000 gpd
- Mid-Term: 760,000 gpd
- Long-Term: 1,200,000 gpd

The existing collection system serves the Cantonment, which includes domestic, food preparation and light industrial activities for the military population. The future collection system identified in Section 1 includes a higher volume of 'more conventional' sewage flows. The flow values above include 46,000 gpd of septage flow for mid-term and long-term. Septage is very concentrated and, in simplistic terms, has an 'equivalent load' of an additional 500,000 gpd of sewage and will result in higher cost for treatment on a 'per gallon basis'.

Given the order of magnitude increase in design flow, the existing treatment tank sizes and arrangement on the site will not be suitable for the necessary amount of expansion. Accordingly, we have assumed the WWTF will be replaced and will be constructed on the original WWTF site (i.e., adjacent to the current WWTF site). Portions of the existing WWTF will be rehabilitated for continued use, as described later in this section. There are many types of wastewater treatment processes which are applicable to this wastewater flow range (e.g., conventional activated sludge, sequencing batch reactors, oxidation ditches, membrane bioreactors, etc.); however, comparison

of the advantages/disadvantages and costs of the various type of wastewater treatment process is beyond the scope and objectives of this study. For the purposes of this report, sequencing batch reactor and membrane bioreactor activated sludge systems are considered.

2.5.2 Effluent Disposal Methods and WWTF Effluent Limits

The existing JBCC wastewater facilities have a Groundwater Discharge Permit (GWDP No 41-3) which is issued by the Department of Environmental Protection (DEP). The effluent limits imposed by DEP in GWDPs are common and well-established for rapid infiltration basins (RIBs) which do not discharge to watersheds of impaired waters or zones of contribution to drinking water wells (which is the case for the JBCC GWDP). Since the wastewater treatment and disposal needs defined herein are significantly greater than the existing GWDP, additional effluent disposal capacity will be needed. As noted in Table 1-8, the targeted effluent disposal capacity is 3,350,000 gpd (annual average flow basis).

This additional capacity will come in the form of additional land-based discharge (regulated by DEP) and/ or surface water discharge (regulated by EPA with input from DEP). The effluent disposal methods that were identified for consideration in this evaluation consist of: rapid infiltration; wicks; deep well injection; spray irrigation; effluent reuse; and outfall to surface water. The effluent disposal methods that were selected for more detailed evaluation consist of: rapid infiltration; wicks; deep well injection; and outfall to surface water. Each of these methods and the justification for keeping/eliminating methods is described in Section 2.7.

The anticipated WWTF effluent limits for each of the effluent disposal methods are presented in **Table 2-4**. The contents of this table should be reviewed with state and federal regulators at the appropriate time.

TABLE 2-4 ANTICIPATED MONTHLY AVERAGE WWTF EFFLUENT PERMIT LIMITS AND ASSOCIATED TREATMENT PROCESSES

Parameter	Rapid Infiltration	Wicks	Deep Well Injection	Outfall (Class SB)
Current				
BOD_5, mg/l	30	30	10	30
TSS, mg/l	30	30	5	30
Total Nitrogen, mg/l	10	10	5	5 (2)
Nitrate-Nitrogen, mg/l	10	10	5	n/a
Ammonia-Nitrogen, mg/l	n/a	n/a	n/a	n/a(4)
Oil & Grease, mg/l	15	15	n/a	n/a
Fecal Coliform, #/100 ml	200	200	14	88
Enterococci, #/100 ml	n/a	n/a	n/a	104
Total Residual Chorine, mg/l	n/a	n/a (1)	n/a (1)	n/a (3)
Total Recoverable Metals, mg/l	n/a	n/a	n/a	n/a (4)
Total Organic Carbon, mg/l	n/a	n/a	1	n/a
Turbidity, NTU	n/a	n/a	2	n/a
Virus Removal, log removal	n/a	n/a	5	n/a
Potential Future at Planning Horizon				
Total Phosphorus	unlikely	unlikely	unlikely	unlikely
Total Organic Carbon	unlikely	unlikely	applicable	unlikely
Unit Process				
Preliminary (Screening/Grit)	Yes	Yes	Yes	Yes
Primary	Yes	Yes	Yes	Yes
Conventional Nitrogen (TN <8 mg/l)	Yes	Yes	Yes	Yes
Enhanced Nitrogen (TN <5 mg/l)	No	No	Yes	Yes
Sand Filtration	No	Yes	No	No
Reverse Osmosis	No	No	Yes	No
Advanced Oxidation	No	No	Yes	No
Disinfection (Ultraviolet Light)	Yes	Yes	Yes	Yes
Chlorine Residual	No	Yes	Yes	No

Notes:

1.) Recommended for biofouling control. DEP would likely limit the chlorine residual to 4 mg/l.
2.) Presumed based on other surface water discharges in Massachusetts in southeast region.
3.) Use ultraviolet disinfection.
4.) Assume dilution factors of greater than 30:1 can be obtained which would preclude the need for metals or other toxics limits. Ammonia limits not needed since TN limit governs.

2.5.3 Concept Design Criteria

Treatment processes were selected to achieve the WWTF effluent limits associated with each effluent disposal method. These treatment processes are also summarized in Table 2-4. For example, in order to achieve the criteria for wicks, the new WWTF would need to include preliminary, primary, conventional nitrogen removal, sand filtration, disinfection and chlorine residual unit processes.

2.5.3.1 Existing WWTF

The existing WWTF will require some limited upgrades in the short-term in order to maintain reliability. These items were identified in the JBCC Water and Wastewater System Evaluation report (Wright-Pierce, 2014, Alternative 1A) and were summarized in Section 1.4.8 of this report. Once the new WWTF is constructed, the existing WWTF buildings and tankage will be upgraded and repurposed for continued use as administrative facilities, laboratory, shop, garages and septage receiving facilities.

2.5.3.2 Enhanced Nitrogen Removal/Sequencing Batch Reactor

The new WWTF will consist of an enhanced nitrogen removal (ENR) activated sludge treatment system targeting less than 5-mg/l effluent total nitrogen using a sequencing batch reactor (SBR) for the RIB, Wick and Canal Outfall disposal scenarios. The new WWTF will include the following additional items:

- Headworks Building (preliminary treatment).
- Process Building, to include process equipment (e.g., pumps, blowers, etc.), control room, sludge thickening/dewatering activities.
- Exterior primary treatment, SBR, sludge storage, and disinfection tankage.
- Odor control facilities.
- Standby power generator.
- Effluent pump station.

2.5.3.3 Enhanced Nitrogen Removal/ Membrane Bioreactor

The new WWTF will consist of an ENR activated sludge treatment system targeting less than 5-mg/l effluent total nitrogen using a membrane bioreactor (MBR) for the Deep Well Injection disposal scenarios. The new WWTF will include all the same elements as the ENR/SBR facility except that the MBR activated sludge tankage will also be enclosed in a building.

2.5.3.4 Sand Filtration

Conventional sand filtration will be included for the Wick effluent disposal option in order to keep the effluent total suspended solids well below the target criteria. The sand filtration system and appurtenant equipment will be located in a building.

2.5.3.5 Reverse Osmosis/ Advanced Oxidation

As noted in Section 2.7.3, reverse osmosis (RO) treatment will be used as the supplemental treatment method required to achieve the effluent limits specified for Deep Well Injection. It is presumed that Falmouth and Bourne effluent would not meet the necessary effluent limits for DWI without supplemental treatment, the ENR/MBR process will need to be sized for the full effluent disposal flow rate (depending on which composite scenario is applicable). In addition, RO produces reject water at approximately 10% to 20% of forward flow. For the purposes of this report, a reject rate of 15% has been utilized. This reject water has high concentrations of nutrients and organics and may have high concentrations of minerals (e.g., calcium, magnesium, sulfates, chlorides, etc.). This reject water will be recycled through the WWTF; accordingly, the WWTF needs to be upsized in order to treat the reject water. A reject water equalization storage tank, sized at 1 day of reject flow volume, is included in order to minimize any peaks or shock loadings. The reject water will also be treated via advanced oxidation to further breakdown TOC compounds prior to recycling through the WWTF.

An effluent storage tank will also be included for the purpose of storing effluent that does meet the criteria for DWI. This tank will be sized for 1 day effluent flow (3.3Mgal) to allow for the process to be remedied. Any liquid pumped to this tank will be disposed of via the RIBs or will be re-treated through the WWTF.

2.6 TRANSPORT TO EFFLUENT DISPOSAL

The concept design criteria for the effluent disposal piping are the same as was defined in Section 2.4.1 above. The following phased implementation approach was used for the transport to effluent disposal.

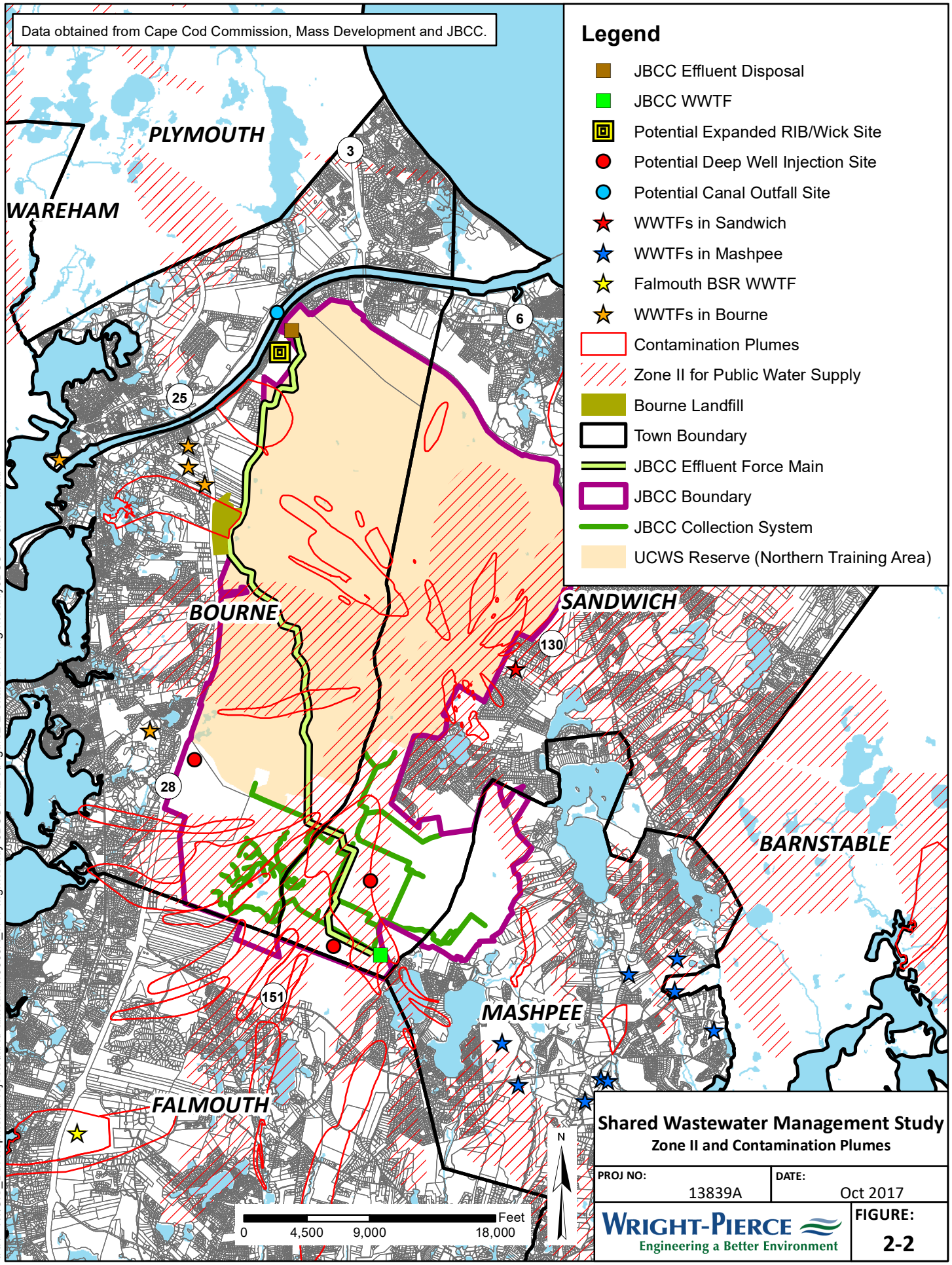
- Short term
    - Connect Bourne ISWM WWTF (effluent) to existing forcemain.
    - Connect Mashpee (sewage) to the JBCC collection system.
    - Continue to operate existing effluent pump station and existing effluent forcemains.
- Mid-term
    - Add additional flow from Bourne ISWM WWTF (effluent) and Mashpee (sewage)
    - Connect Falmouth BSR WWTF (effluent) to the JBCC effluent forcemains.
    - Connect Bourne-South (sewage) and Sandwich (sewage) to the JBCC collection system. Flow addition via septage from all communities as well.
    - Construct new 18-inch force main and valving interconnection with existing 12-inch force main.
    - Operate new effluent pump station and existing/new effluent forcemains.
- Long-term
    - Add additional flow from Bourne ISWM WWTF (effluent), Bourne-South (sewage), Falmouth BSR WWTF (effluent), and Sandwich (sewage).
    - Construct new 18-inch forcemain and valving interconnection with existing 12-inch and existing 18-inch forcemain.

2.7 EFFLUENT DISPOSAL

This section identifies the effluent disposal components of the future wastewater system, including the preliminary criteria used for sizing components. As noted above, the projected annual average effluent flows are 3,350,000-gpd. The needed additional capacity will come in the form of additional land-based discharge (regulated by DEP and in some cases by EPA as well) and/ or surface water discharge (regulated by EPA with input from DEP). The following effluent disposal methods are considered most applicable for this WWTF:

- Rapid infiltration
- Wicks
- Deep well injection
- Spray irrigation
- Effluent reuse
- Outfall to surface water

Subsurface leaching was not considered due to the relatively low application rates and relatively large land area requirement. A brief description of each effluent disposal method is presented below to provide context for the implications on the treatment unit processes required at the WWTF presented in Section 2.5 of this report. The locations of existing Zone II water supply protection areas and current/former contamination plumes are shown on Figure 2-2. The locations of MEP watersheds and TMDL status of each watershed are shown on Figure 2-3.


Data obtained from Cape Cod Commission, Mass Development and JBCC.
Legend
JBCC Effluent Disposal
JBCC WWTF
Potential Expanded RIB/Wick Site
Potential Deep Well Injection Site
Potential Canal Outfall Site
WWTFs in Sandwich
WWTFs in Mashpee
Falmouth BSR WWTF
WWTFs in Bourne
Contamination Plumes
Zone II for Public Water Supply
Bourne Landfill
Town Boundary
JBCC Effluent Force Main
JBCC Boundary
JBCC Collection System
UCWS Reserve (Northern Training Area)
PLYMOUTH
WAREHAM
BOURNE
SANDWICH
BARNSTABLE
MASHPEE
FALMOUTH
3
6
25
28
130
151
0
4,500
9,000
18,000
Feet
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Shared Wastewater Management Study
Zone II and Contamination Plumes
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FIGURE:
2-2
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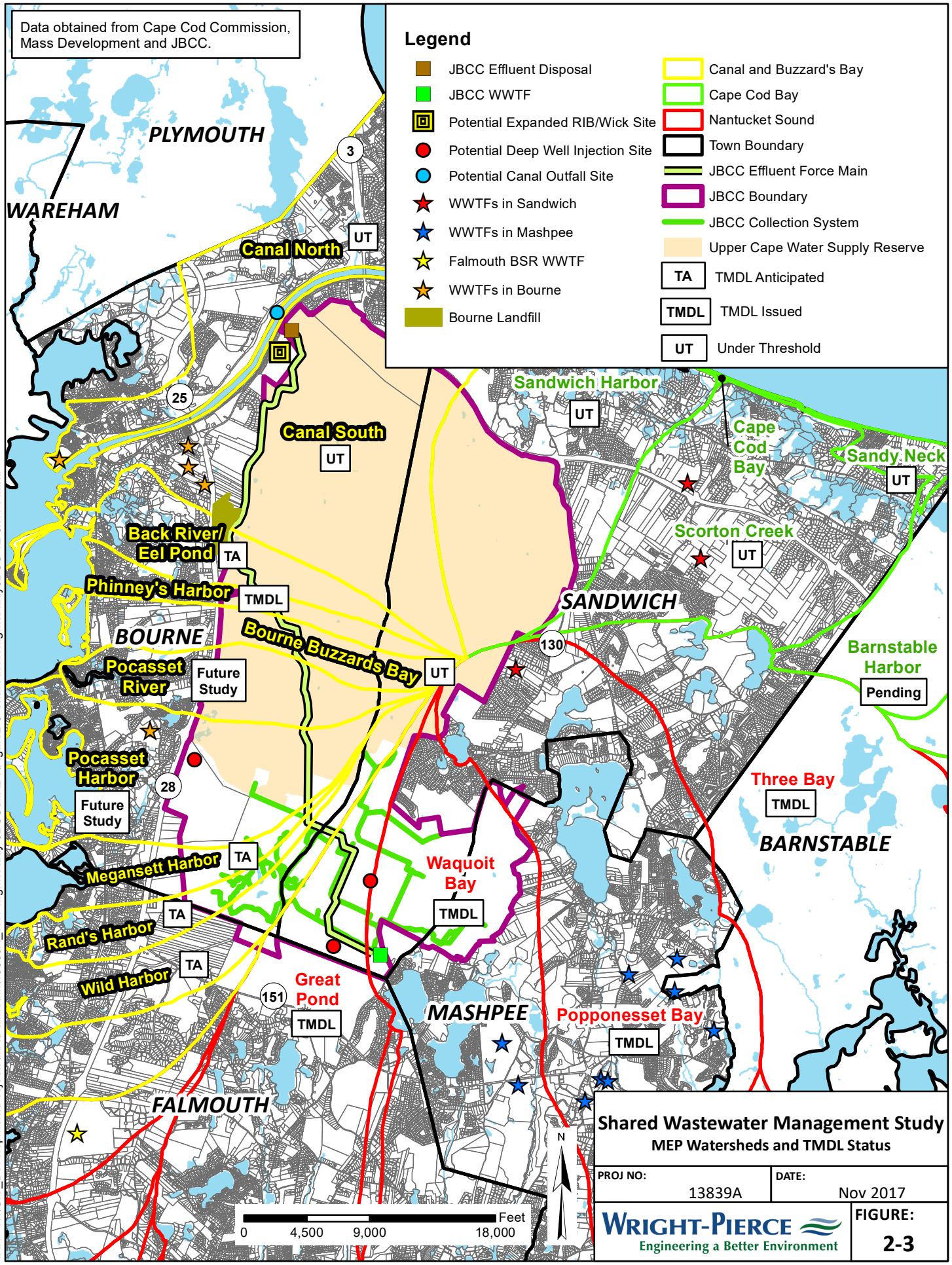
Data obtained from Cape Cod Commission, Mass Development and JBCC.
Legend
JBCC Effluent Disposal
JBCC WWTF
Potential Expanded RIB/Wick Site
Potential Deep Well Injection Site
Potential Canal Outfall Site
WWTFs in Sandwich
WWTFs in Mashpee
Falmouth BSR WWTF
WWTFs in Bourne
Bourne Landfill
Canal and Buzzard's Bay
Cape Cod Bay
Nantucket Sound
Town Boundary
JBCC Effluent Force Main
JBCC Boundary
JBCC Collection System
Upper Cape Water Supply Reserve
TA TMDL Anticipated
TMDL TMDL Issued
UT Under Threshold
PLYMOUTH
WAREHAM
BOURNE
SANDWICH
MASHPEE
BARNSTABLE
FALMOUTH
Canal North
UT
Canal South
UT
Sandwich Harbor
UT
Cape Cod Bay
Sandy Neck
UT
Scorton Creek
UT
Back River/ Eel Pond
TA
Phinney's Harbor
TMDL
Bourne Buzzards Bay
UT
Pocasset River
Future Study
Pocasset Harbor
Future Study
Megansett Harbor
TA
Rand's Harbor
TA
Wild Harbor
TA
Waquoit Bay
TMDL
Great Pond
TMDL
Popponesset Bay
TMDL
Barnstable Harbor
Pending
Three Bay
TMDL
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25
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Shared Wastewater Management Study
MEP Watersheds and TMDL Status
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FIGURE: 2-3
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2.7.1 Rapid Infiltration

Rapid infiltration, also referred to as open sand beds or rapid infiltration basins (RIBs), can operate at high loading rates on sites with good permeability and significant depth to groundwater. Year-round application is routine. The reduced footprint compared with subsurface disposal often outweighs the drawback that the selected site can only be used for effluent disposal and that the effluent must be disinfected. A smaller disposal footprint also broadens the number of parcels that can be used as effluent disposal sites. Rapid infiltration systems require fencing around the perimeter to keep out wildlife and humans. The maintenance of the system includes periodic solids removal from the application surface (scarifying) and infrequent weeding. Rapid infiltration beds are considered less aesthetically pleasing than other alternatives and may not be recommended in densely populated areas.



2.7.1.1 Re-Rating Existing RIBs

In order to maximize the capacity of the existing RIBs, the following upgrades are recommended:

- Changing the GWDP to allow the 840,000 gpd value to represent the "Maximum 3-Day Peak Flow, moving average" instead of the current "Maximum Day";
- Segmenting the RIBs such that the site functions as 8 RIBs vs the existing 4 RIBs (which would allow the reserve area to represent 12% of the total infiltrative surface instead of the existing 25% of the total infiltrative surface); and
- Increasing the permitted loaded rate of the RIBs from 4.37 gpd/sf to a significantly higher rate (assumed to be 7 gpd/sf for this analysis) through large-scale loading tests, coordinated and approved with DEP.

In combination, these re-rating measures are anticipated to increase the permitted capacity from 840,000 gpd to 1,550,000 gpd. These items will need to be closely coordinated with DEP.

2.7.1.2 Sizing of New RIBs

For the purposes of this report, rapid infiltration at or near the existing RIB site will be sized based on 7 gpd/sf and will require a total site footprint based on 2 times the calculated infiltration area (3-day max flow basis) to account for site buffers/setbacks, roadways, etc. We have assumed the subsurface conditions in the immediate vicinity of the existing RIB site will have similar hydrogeologic properties and that the resulting groundwater mounds will be consistent with the existing groundwater mound.

2.7.2 Wicks



A wick is a vertical cylinder of highly permeable material that provides an efficient path for effluent to travel from the surface point of discharge to the soil in the vadose (unsaturated) zone. Effluent from a wick receives soil aquifer treatment (SAT) through the vadose zone. Wicks allow for very high loading rates on a small footprint because they disperse effluent both horizontally and vertically. Another advantage to wicks is the ability to bypass less permeable material. Wicks are not very intrusive. The only above-grade components include an access vault and cover.



This technology is relatively new and therefore DEP has stringent permitting requirements. First, the design must include standby wicks to provide more than 100 percent redundant disposal capacity, so that if a wick were to fail or be overloaded, another wick can be brought on-line immediately. Second, there must be another permitted disposal location that could be developed with a traditional system if the wicks fail prematurely. Extensive hydrogeologic evaluations are required to determine the suitability of the soil for wicks. WWTF effluent must be filtered to maintain a total suspended solids concentration of 5 mg/l or less. The use of chlorine to manage biofouling have the potential to create trihalomethanes (THMs) in groundwater due to elevated background concentrations of chloroform in the groundwater on Cape Cod. This should be considered in permitting/design.

This technology has been permitted at three locations in Massachusetts (i.e., Hingham, Tisbury and West Island in Fairhaven) and is being considered for implementation in at least one other location in Massachusetts (i.e., Orleans). For the purposes of this report, each wick will be sized to handled 100,000 gpd of effluent (3-day max flow basis).

2.7.3 Deep Well Injection



Deep well injection (DWI) involves a special-purpose well designed for the disposal of effluent into the groundwater in the saturated zone. The groundwater in the Upper Cape is designated as a Sole Source Aquifer (Sagamore Lens). DWI would be regulated by the DEP under the Groundwater Discharge regulations (314 CMR 5.00) and by the EPA under the Underground Injection Control (UIC) program and the Sole Source Aquifer (SSA) program. As of the date of this report, "aquifer storage and recovery" (ASR) and indirect potable water reuse have been implemented in water-strained areas of the United States (e.g., California, Florida, Arizona). There are no full-scale DWI applications for effluent disposal in Massachusetts at this time; however, there are numerous groundwater treatment systems on JBCC that use a pump/treat/disposal approach similar to DWI. A DWI pilot test was conducted at the Hyannis WPCF in 2003 (*Pilot Test for Using Injection Wells for Reclaiming Treated Municipal Wastewater, Town of Barnstable, MA*, Stearn & Wheler, 2003). The pilot test report recommended filtration (<10 micron, to prevent fouling), maintaining a chlorine residual (to prevent biofouling), and additional pilot-scale and full-scale testing prior to further consideration of use on Cape Cod. DWI will have similar concerns regarding potential THM formation as wicks. This should be considered in permitting/design.

Based on the requirements outlined in 314 CMR 5.10, the treatment limits summarized below are applicable for discharge within a Zone II, for a discharge within a Zone II and with less than a 2-year travel time to a water supply well, and for any groundwater discharge "without the benefit of treatment in the unsaturated zone".

	Column A Within Zone II (4A-a)	Column B Within Zone II and Less than 2-Year Travel Time (4A-c,d)	Column C Any GW Discharge without Treatment in Unsaturated Zone (5.10.4C)
TSS	<10 mg/l	<5 mg/l	<5 mg/l
Turbidity	<5 NTU	<2 NTU	<2 NTU
TOC	<3 mg/l	<1 mg/l	<1 mg/l
Total Nitrogen and Nitrate-Nitrogen	<10 mg/l	<5 mg/l	<5 mg/l
Fecal Coliform	<200/ 100ml	<14/ 100ml	<14/ 100ml
Viruses	n/a	>5 log removal	>5 log removal

The primary regulatory focus for deep well injection applications is the impact on drinking water (i.e., TOC, fecal coliform and virus removal). As noted in the table above, there is no difference in the effluent limits between Column B and Column C. This means that the regulations provide no relief in treatment standards for the DWI approach even if located remote from water supply wells.

In order to achieve the criteria for discharge within a Zone II and less than a 2-year travel time to a water supply well (Column B) or for any discharge "without the benefit of treatment in the unsaturated zone" (Column C), a reverse osmosis (RO) treatment system will be required primarily related to the TOC limits of <1 mg/l. For the purposes of this report, the approach is to inject highly treated effluent into the Sole Source Aquifer very deep in the aquifer (i.e., between approximately EL -100 to EL -200, or approximately 300 feet below ground surface) and substantially below the lowest elevation of the deepest drinking water supply wells. The typical screened interval in the Bourne and Falmouth water supply wells is EL 5.0 to EL -46.6 (USGS, SIR-2004-5181, Table 1-3). The premise is that water is returned to the local hydrologic cycle by replenishing the water levels in the Sagamore Lens at the bottom of the aquifer. At this depth, it is presumed that all DWI effluent will emerge beyond all nitrogen sensitive embayments/watersheds. The DWI will not include any concentrated reject water. For the purposes of this report, each DWI well is assumed to convey 750,000 gpd effluent flow (3-day max flow basis).

If the criteria for discharge within a Zone II (Column A) were applicable, a granular activated carbon (GAC) filtration system would likely be sufficient primarily based on its presumed ability to achieve <3 mg/l TOC. A GAC filtration system would be much less costly and less complicated to operate than the other treatment options and may be sufficiently conservative for permitting, given the following considerations:

- Much of the water to be disposed of via DWI already recharges the Sagamore Lens in a decentralized manner through individual septic systems.
- The DWI effluent would be treated to a substantially higher level than the existing decentralized treatment levels.
- The proposed DWI volume represents an estimated 1.7% of the annual average precipitation recharge to the Sagamore Lens with an assumed 3.35-mgd DWI recharge and an estimated 190-mgd annual average precipitation recharge (USGS, 2000).
- The DWI effluent would be injected approximately 50 to 100 feet below the bottom of the deepest drinking water well in the Sagamore Lens.

2.7.4 Spray Irrigation



Landscape spray irrigation is an example of technology that can be used at site with a dual use (e.g., effluent can be applied to parks, sports fields, golf courses, or landscaping. All of these activities are associated with human activity and require meeting the effluent reuse guidelines (DEP reclaimed water regulations and US EPA Reclaimed Water Guidelines), which usually adds to the cost of wastewater treatment. Irrigation is certainly restricted to seasonal operation which requires either winter storage or a complementary effluent disposal system. This technique uses moderate application rates.

Based on an assumed application rate of 1.5 inches of wastewater per week and an assumed total site area at 1.5 times the area required for spray fields to account for site buffers/setbacks, roadways, etc. The mid-term site area needs are 55 acres total and the long-term site area needs are 146 acres total. Based on the presumption that this amount of land would likely need to be within in the UCWS Reserve/ Northern Training area and would likely be in or around existing Zone II water supply protection areas and existing contamination plumes, this approach is determined to be not viable.

2.7.5 Effluent Reuse

DEP uses the term "reclaimed water" which it defines as wastewater that has been treated at a wastewater treatment facility to an advanced degree and used again for various applications. The fundamental premise behind effluent reuse is the recognition of the value of water and the nutrients it may carry, tempered by the public health aspects of public contact with wastewater-derived material.

A good way to contrast "effluent disposal" and "use of reclaimed water" is to consider spray irrigation. A spray irrigation site that receives typical treatment plant effluent must include fencing or other means of preventing public access, as well as significant vegetated buffers to control spray drift (i.e., effluent disposal). If a higher level of treatment is provided, DEP allows for spray irrigation on golf courses where the public has access (i.e., reclaimed water).

The artificial recharging of aquifers is only permitted in watershed basins and sub-basins which are stressed water resource areas where it is necessary to replenish stream flow, enhance the productivity and capacity of an aquifer, and/or improve upon or mitigate water quality problems. The water quality criteria for the treated wastewater are extremely rigorous, requiring that reclaimed water be virtually pathogen and contaminant free, and are dependent on which “class” of effluent reuse is proposed. Based on the requirements outlined in 314 CMR 20.17, the treatment limits summarized below are applicable for the various classes of reclaimed water use.

	Class A Reuse	Class B Reuse	Class C Reuse
BOD_5, mg/l	10	30	30
TSS, mg/l	5	10	30
Total Nitrogen, mg/l	-	-	-
Nitrate-Nitrogen, mg/l	10	10	10
Turbidity, NTU Average Maximum	 2 10	 - -	 - -
Fecal Coliform, #/100ml Median Maximum	 0 14	 14 100	 0 200
Potential Uses	<u>Public contact</u> Irrigation Toilet flushing Agriculture Industrial use Car washes Fire protection Recreational Impoundments	<u>No public contact likely</u> Irrigation Concrete mix Aggregate washing Street cleaning	<u>No public contact</u> Irrigation of non-edibles Industrial use

The primary regulatory focus for effluent reuse applications is the impact on human health from incidental contact (i.e., fecal coliform). The effluent limits for effluent reuse are less stringent than for deep well injection with the exception of fecal coliform, which is substantially more stringent.

There are a number of potential effluent reuse applications at JBCC, including golf course irrigation, vehicle washing, toilet flushing and fire protection. Each of these potential uses is intermittent and will not represent a disposal source for all or even a large portion of the effluent flow. Accordingly, this approach is considered viable but only as a supplemental method in the future. This approach has not been incorporated into the cost analysis.

2.7.6 Outfall to Surface Water

A new effluent discharge to surface water in Massachusetts must meet the requirements of Massachusetts Ocean Sanctuaries Act MGL Ch.132A, Sec.16G (OSA). The OSA requires that the following 10 items must be met (*italics indicate text from MGL*):

1) *The new or modified discharge shall be consistent with the intent and purpose of the act. Any discharge shall meet the water quality standards of the receiving water body and the standards of the act to protect the appearance, ecology and marine resources of the waters of the sanctuary.*
2) *The new or modified discharge shall meet the United States Environmental Protection Agency's approved TMDL, if any, on the receiving water body.*
3) *The applicant shall have adopted and implemented a plan approved by the department requiring the pretreatment of all commercial and industrial wastes discharged to the POTW.*
4) *The applicant shall have adopted and implemented a program for water conservation according to the guidelines established by the water resources commission.*
5) *The applicant shall have adopted and implemented a plan, approved by the department, to control and minimize inflow and infiltration.*
6) *The applicant shall have adopted and implemented a plan, approved by the department, to control any combined sewer overflows.*
7) *The new or modified discharge shall not significantly affect the quality or quantity of existing or proposed water supplies by reducing ground or surface water replenishment.*
8) *The new or modified discharge is consistent with the policies and plans of the Massachusetts coastal zone management program.*
9) *The new or modified discharge and treatment plans are consistent with all applicable federal, state and local laws, ordinances, by-laws, rules and regulations protecting the environment, including but not limited to, the requirements of chapters 21, 91, 130 and 131.*
10) *The proposed discharge and outfall structure will not adversely impact marine fisheries or interfere with fishing grounds or the normal operation of fishing vessels.*

If the above can be met, then a surface water discharge could be permitted by DEP and EPA. The JBCC effluent discharge would need to meet standards set forth in state and federal water quality legislation. These standards establish minimum effluent discharge requirements which must be satisfied at all times. In accordance with Section 402 of the Clean Water Act, the WWTF's effluent quality requirements would be stipulated in a National Pollutant Discharge Elimination System (NPDES) permit which would be issued by the EPA. For the purposes of this report, we have presumed that a permit for surface water discharge to the Cape Cod Canal, which is designated as

a Class SB waterway by the Massachusetts DEP (SWQ Standards) and is not designated as an Outstanding Resource Water or an Area of Critical Environmental Concern, can be obtained.



MADEP Implementation Policy for Mixing Zone (January 1993) defines how a mixing zone is established for a surface water outfall. A "mixing zone" is an area or volume of a waterbody in the immediate vicinity of a discharge where the initial dilution of the discharge occurs. Within a mixing zone, excursions from certain water quality criteria may be tolerable, provided this does not interfere with the existing or designated uses of the segment. Water quality criteria apply at the boundary of the mixing zone. The mixing zone is a function of the proposed outfall flow rate versus the minimum flow of the receiving water. In the case where there is tidal flow, there is a significant amount of judgement used by the permit writer in calculating the appropriate dilution factor and sizing the mixing zone. The following physical parameters were used in our evaluation:

- Minimum channel width at the channel bottom of 450 feet.
- Minimum channel width at the water surface of 670 feet.
- Minimum water depth of 32 feet.
- Estimated westward flow of 22,000 Mgal per tide cycle and an estimated eastward flow of 19,000 Mgal per tide cycle, with a net 8,500 Mgal per tide cycle to the west (Sandwich Draft Environmental Impact Statement, 1981).
- Canal water velocity between 3 to 5 fps between high and low tide and a minimum net velocity of 0.1 fps at slack tide.
- Depth of water over diffusers of 30 feet, minimum.
- The use of multi-port diffusers oriented perpendicular to receiving water flow, with a discharge velocity of approximately 10 fps per port, in order to maximize dispersion and mixing of effluent with the receiving water.

In the case of a simple single-directional flow (i.e., river), the dilution factor is calculated by the formula: (River flow + WWTF flow) / WWTF flow. On this basis, the estimated dilution factor

would be 2,500:1 for an effluent flow of 3.50 mgd and a receiving water flow of 8,500 mgd. However, given that this application would be for tidal, dual-directional flow, the simple dilution factor is not applicable. Based on our experience with tidal outfalls, we anticipate that it will be possible to achieve a dilution factor of at least 30:1 with an overall diffuser length of 50 to 60 feet. We recommend a minimum dilution factor of 20:1 in order to avoid the toxics criteria. Given that the Canal is a heavily used commercial shipping channel, heavily used recreational fishing location and has a strong current, construction and maintenance of an outfall will be expensive.

It is important to note the following considerations related to a surface water outfall:

- Site-specific data collection and modelling will be required in order to determine actual dilution factor at this location.
- Long-term water quality monitoring will be needed to establish existing conditions in order for MADEP to make an anti-degradation determination.
- A "parallel to shore diffuser" or a "sidebank outfall" would be preferred based on the existing uses of the Canal and the construction/maintenance aspects of this application
- Numerous other factors go into siting and permitting a surface water outfall, including evaluation of existing water quality, completion of an anti-degredation review, and evaluation of existing uses (including human uses and aquatic life uses).
- The application and review process for a new surface water discharges should be expected to take a minimum of 3 to 5 years and the successful conclusion is not assured.

2.7.7 Summary of Land-Based Effluent Disposal Alternatives

The hydrogeologic aspects of the effluent disposal options have been reviewed by GeoHydroCycle (GHC). GHC's analysis is presented in Appendix B and summarized here.

2.7.7.1 Rapid Infiltration Beds

The existing 4 RIBs, once upgraded and loaded at the projected 1.55-mgd rate, will produce a groundwater mound of approximately 10 to 15 feet above the seasonal high water table. That mound is expected to dissipate in a down-gradient direction sufficiently to prevent any breakout

of effluent-impacted groundwater. All of the effluent-impacted groundwater will emerge in the Cape Cod Canal over several hundred feet of its length, without impacting drinking water wells.

A set of 4 new RIBs located immediately west of the existing RIBs is expected to exhibit similar mound heights when those RIBs are loaded with the medium-term flow of 1.55 mgd. While there may be some superposition of the mounds of the existing and new RIBs, the additional mound is relatively minor compared to the significant unsaturated zone at this location. No break-out or well impacts are expected.

The set of 6 new RIBs needed for the long-term flows (an additional 2.4 mgd) is expected to behave similarly to the existing and medium-term RIBs since they would be loaded at the same surficial rate in a similar geologic setting.

2.7.7.2 Wicks

Wicks are a relatively new disposal technology for Massachusetts. The significant depth to water table and glacial outwash soils at JBCC provide the conditions were wicks can be successful. Wicks would best be located outside of nitrogen-sensitive watersheds and downgradient from water supply wells. The location, design and capacity of wicks can only be determined through large-scale testing.

2.7.7.3 Deep Well Injection

Deep injection wells could be located in an area near the military cemetery at the southwest corner of JBCC and near the existing WWTF at the southeast corner of JBCC. There are no existing contaminant plumes or Zone IIs in either location. With screens located near bedrock, the injection wells would discharge approximately 100 feet to 150 feet below the intake screens at the deepest water supply wells. The near-bedrock discharges would allow the effluent-impacted groundwater to emerge in Buzzards Bay (westerly injection wells) or in Nantucket Sound (easterly injection wells), with little or no expected impact on coastal embayments. The travel time from the injection wells to the point of emergence is expected to be 2 or more decades.

Injection wells are a new technology for Cape Cod and the location, design and capacity of the wells would be determined only through large-scale testing. The ability to bypass coastal embayments would need to be further demonstrated through detailed groundwater modeling.

2.8 IDENTIFICATION OF COMPOSITE ALTERNATIVES

This section identifies and describes the following alternatives for the treatment and disposal aspects of the future wastewater system:

1) New WWTF with RIBs
2) New WWTF with RIBs and Wicks
3) New WWTF with RIBs and Deep Well Injection
4) New WWTF with RIBs and Canal Outfall
5) New WWTF with Deep Well Injection
6) New WWTF with Canal Outfall

As described previously, the above disposal methods were determined to be the most appropriate. Spray irrigation was determined to be not feasible at this scale and effluent reuse is possible but only as a supplemental disposal method. Treatment process schematics for each alternative are shown on Figure 2-4. Each of the alternatives includes limited upgrades to the existing JBCC wastewater facilities in order to maintain permit compliance and capacity in the short-term to mid-term. All flow rates indicated in Section 2.8 reference the 3-day peak flow. Each of the alternatives includes a description of the anticipated phasing requirements. A summary of the upgraded and new facilities for each of the composite alternatives is presented on the following pages. The project phasing and management entity boundaries which are included in the planning-level cost estimates are shown on Figure 2-5.

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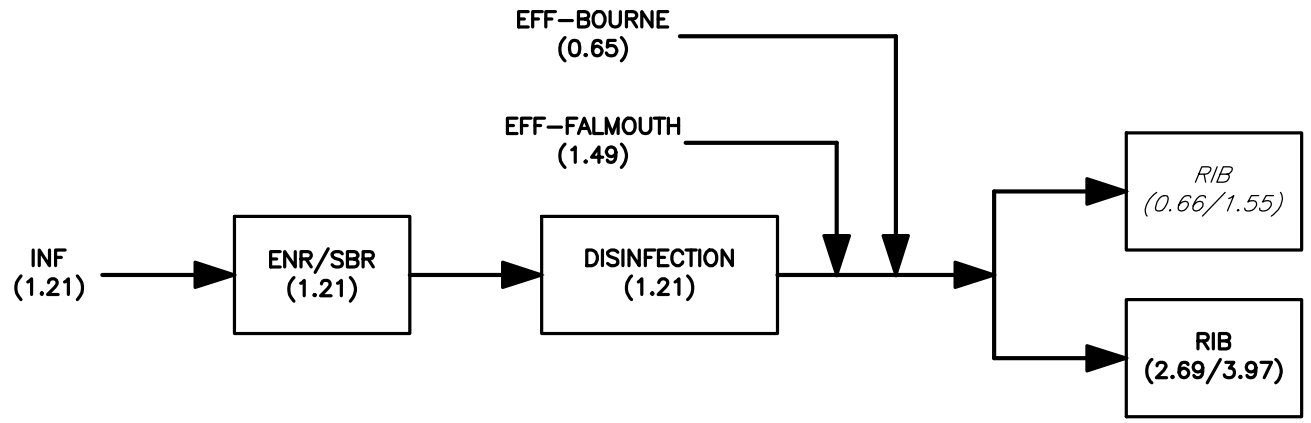
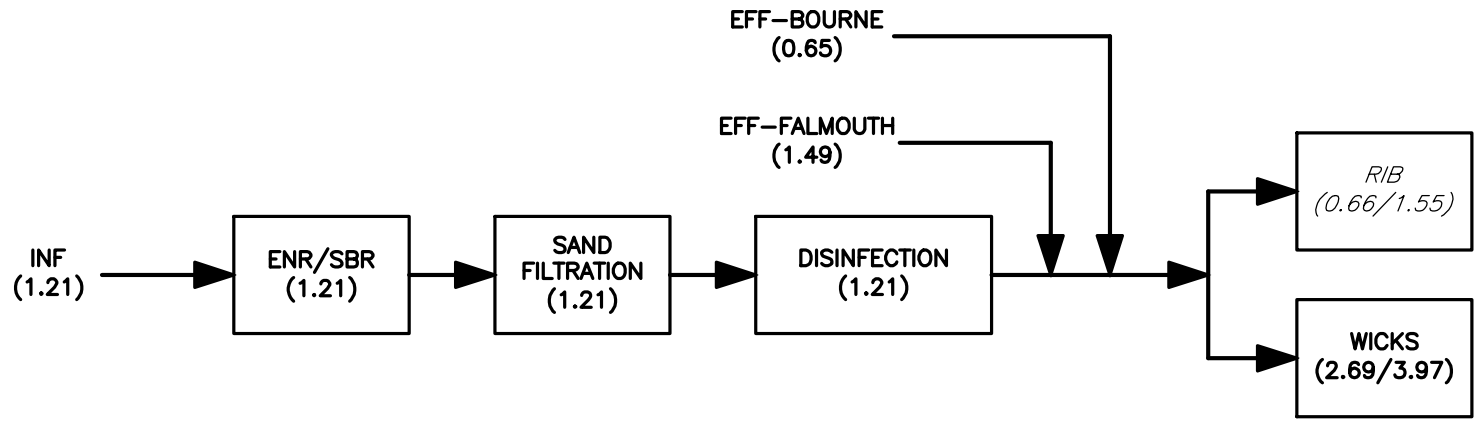
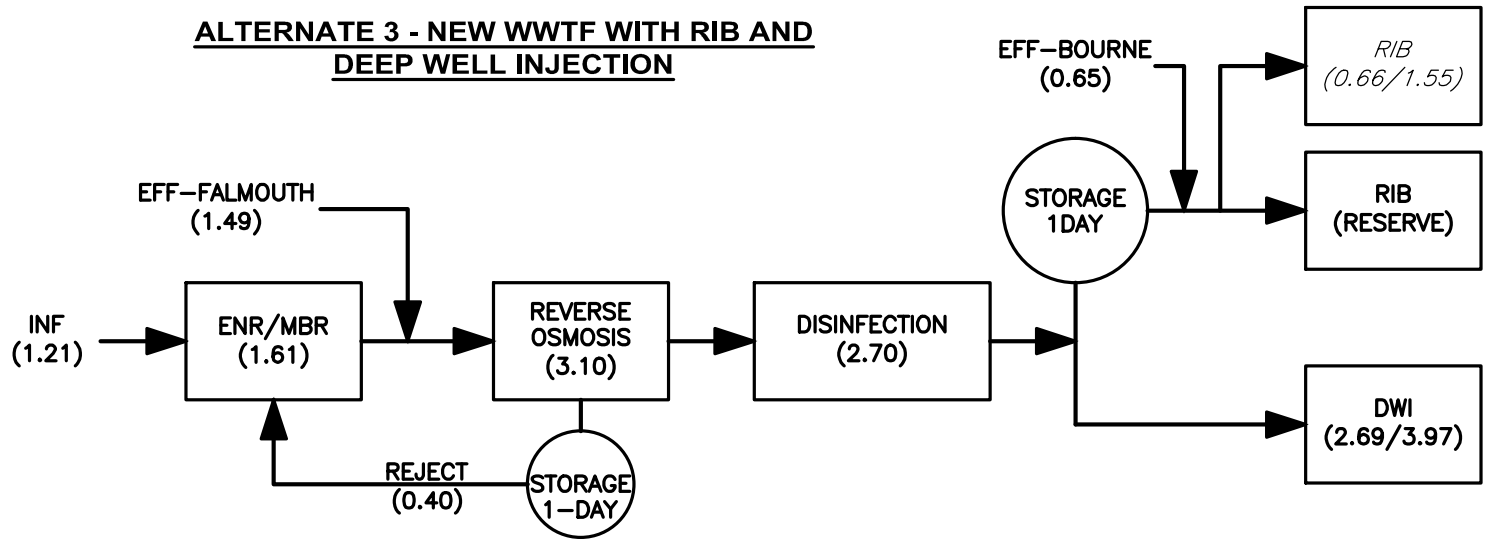
ALTERNATE 1 - NEW WWTF WITH RIB



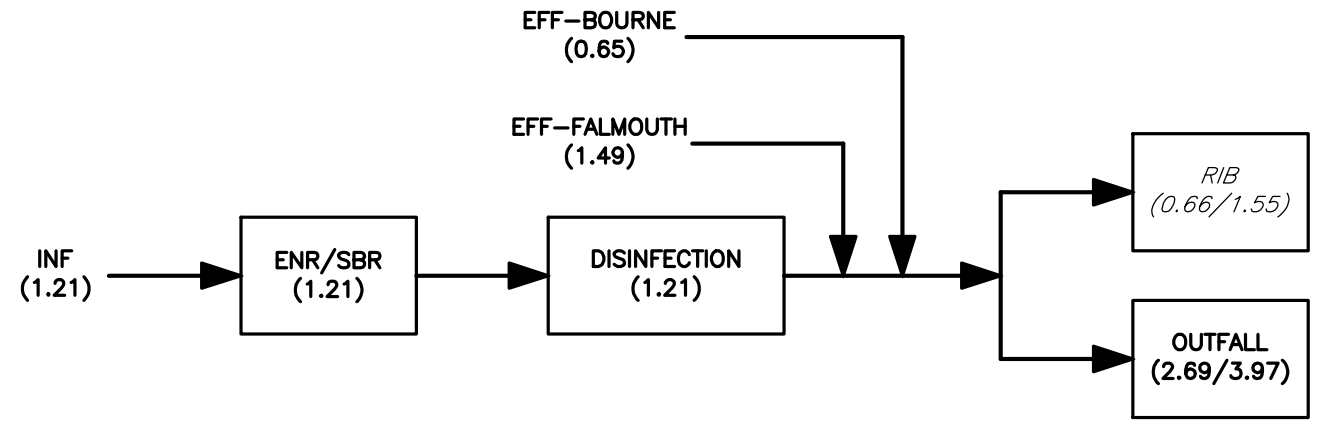
ALTERNATE 2 - NEW WWTF WITH RIB AND WICKS



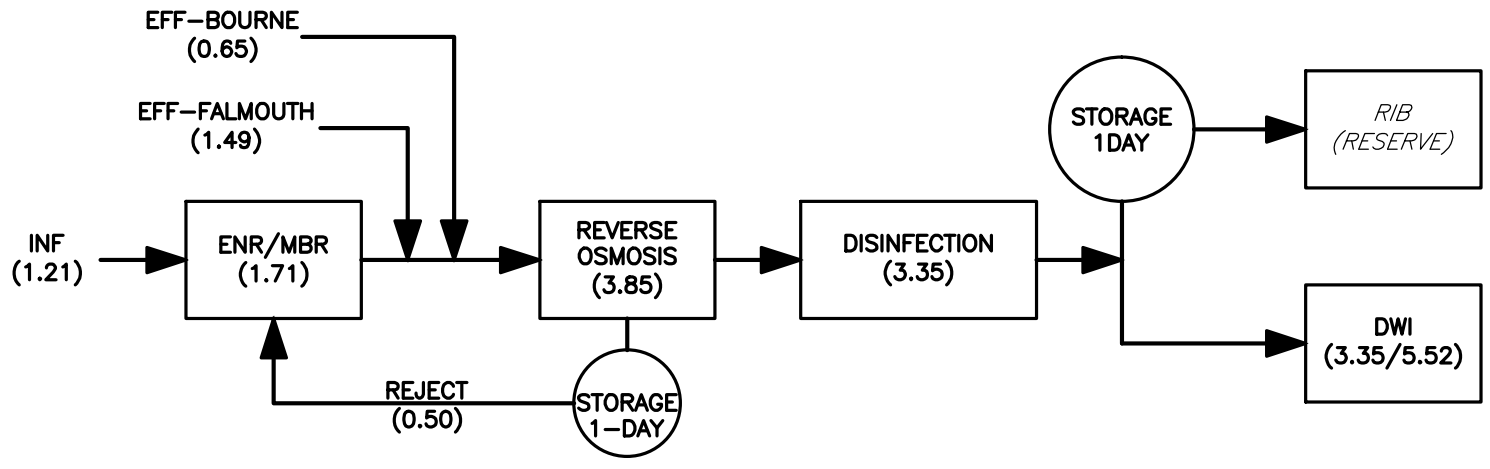
ALTERNATE 3 - NEW WWTF WITH RIB AND DEEP WELL INJECTION



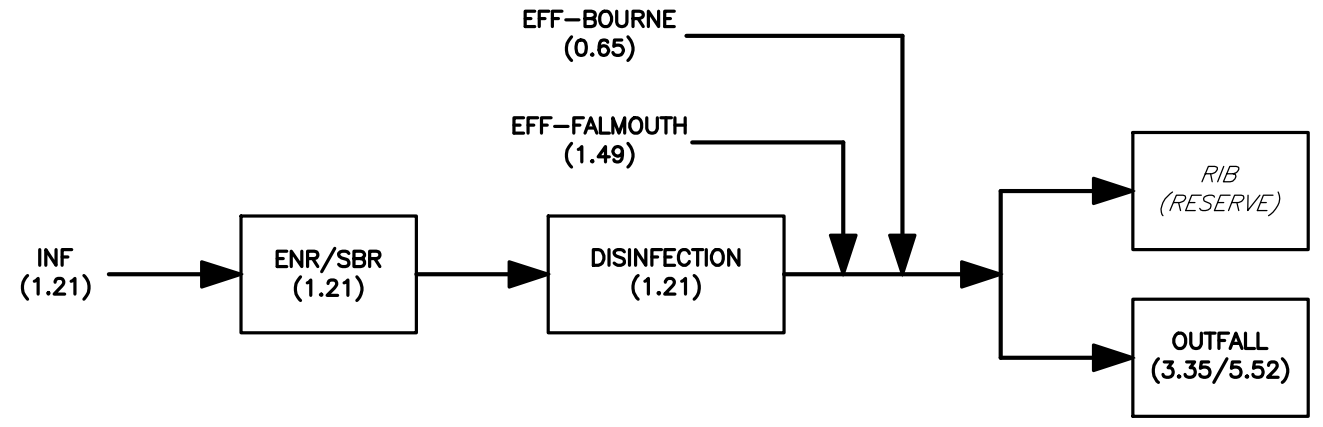
ALTERNATE 4 - NEW WWTF WITH RIB AND CANAL OUTFALL



ALTERNATE 5 - NEW WWTF WITH DEEP WELL INJECTION



ALTERNATE 6 - NEW WWTF WITH CANAL OUTFALL



NOTES:

(#.##/#.##) = LONG–TERM FLOW IN MGD. FIRST NUMBER IS ANNUAL AVERAGE FLOW BASIS. SECOND NUMBER IS 3–DAY MAXIMUM FLOW BASIS.

EXISTING = EXISTING PROCESS

PROPOSED = PROPOSED PROCESS

SHARED WASTEWATER MANAGEMENT STUDY
JBCC WASTEWATER SYSTEM
TREATMENT PROCESS SCHEMATICS

PROJ NO:	DATE:	FIGURE:
13839A	OCTOBER 2017	2-4

WRIGHT-PIERCE
Engineering a Better Environment

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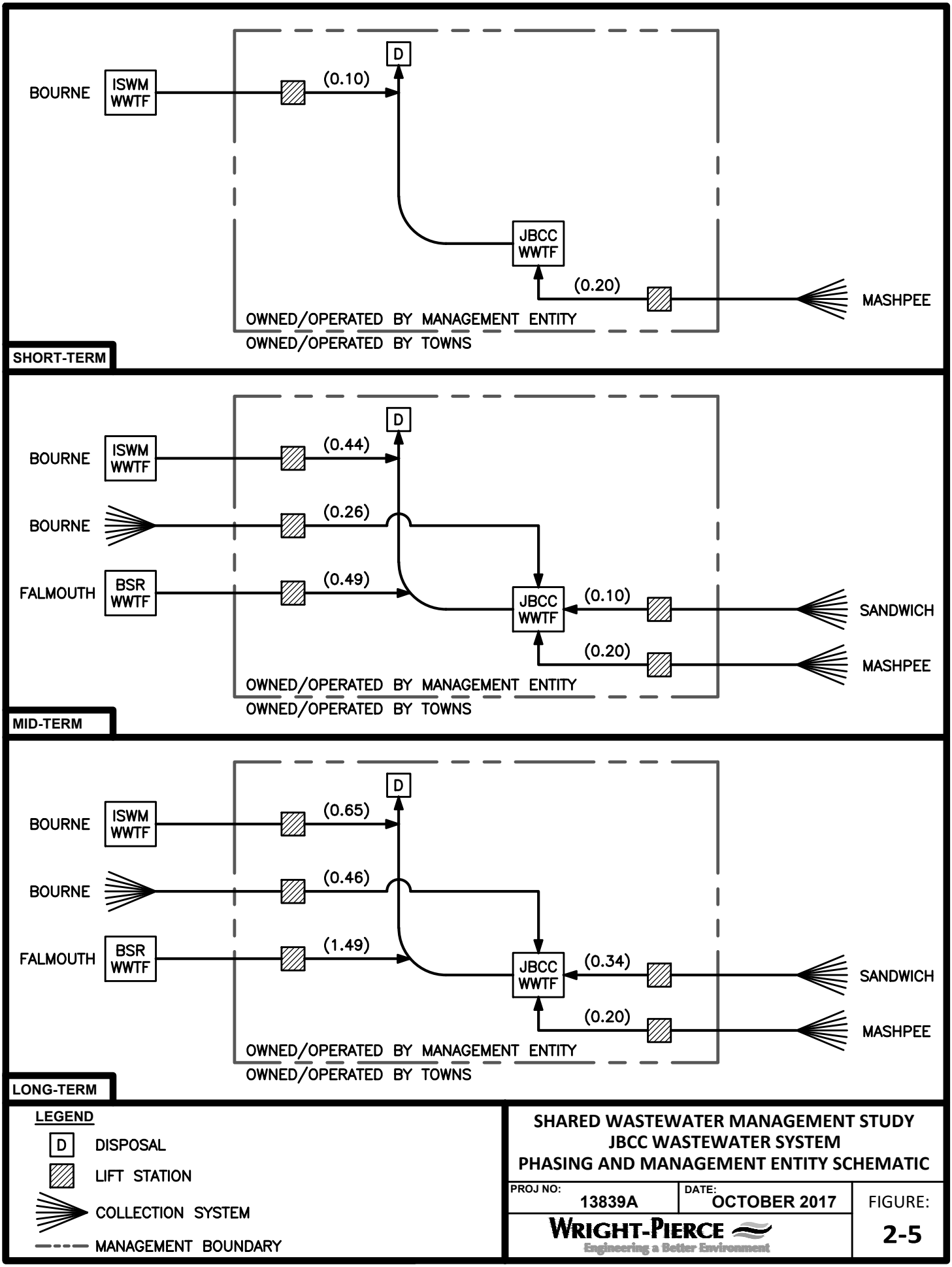


SHARED WASTEWATER MANAGEMENT STUDY
JBCC WASTEWATER SYSTEM
PHASING AND MANAGEMENT ENTITY SCHEMATIC

PROJ NO:	DATE:	FIGURE:
13839A	OCTOBER 2017	2-5

WRIGHT-PIERCE
Engineering a Better Environment

2.8.1 New WWTF with RIBs

Short-Term: • Upgrades to existing JBCC wastewater facilities. • Upgrades to existing RIBs to achieve 1.55-mgd capacity. • Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).
Mid-Term: • New ENR/SBR WWTF plus disinfection. • 4 new RIBs on the adjacent US Government parcel (ACOE) to achieve an additional 1.55-mgd capacity. • 1 new effluent forcemain (11.0 miles) located parallel to existing. • Connect Falmouth BSR WWTF (effluent), Bourne and Sandwich (sewage)
Long-Term: • 6 new RIBs on the adjacent US Government parcel (ACOE) to achieve an additional 2.42-mgd capacity. • 1 new effluent forcemain (11.0 miles) located parallel to existing (3 total forcemains).

2.8.2 New WWTF with RIBs and Wicks

Short-Term: • Upgrades to existing JBCC wastewater facilities. • Upgrades to existing RIBs to achieve 1.55-mgd capacity. • Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).
Mid-Term: • New ENR/SBR WWTF plus sand filtration and disinfection. • Assume that Bourne ISWM WWTF and Falmouth BSR WWTF can meet the effluent TSS and turbidity requirements for wicks (i.e., no cost included herein). • 16 new wicks to achieve an additional 1.55-mgd capacity. • 1 new effluent forcemain (11.0 miles) located parallel to existing. • Connect Falmouth BSR WWTF (effluent), Bourne and Sandwich (sewage)
Long-Term: • 25 new wicks to achieve an additional 2.42-mgd capacity. • 1 new effluent forcemain (11.0 miles) located parallel to existing (3 total forcemains).

2.8.3 New WWTF with RIBs and Deep Well Injection

Short-Term: • Upgrades to existing JBCC wastewater facilities. • Upgrades to existing RIBs to achieve 1.55-mgd capacity. • Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).
Mid-Term: • New ENR/MBR WWTF plus RO/Storage and disinfection. • 3 new DWI wells in the Cantonment to achieve an additional 1.55-mgd capacity. • Add RIBs or wicks to serve as reserve disposal (1.55 mgd) • 1 new effluent forcemain (2.3 miles) located parallel to existing. • Connect Falmouth BSR WWTF (effluent), Bourne and Sandwich (sewage)
Long-Term: • 4 new DWI wells in the Cantonment to achieve an additional 2.42-mgd capacity. • 1 new effluent forcemain (2.3 miles) located parallel to existing (3 total forcemains).

2.8.4 New WWTF with RIBs and Canal Outfall

Short-Term: • Upgrades to existing JBCC wastewater facilities. • Upgrades to existing RIBs to achieve 1.55-mgd capacity. • Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).
Mid-Term: • New ENR/SBR WWTF plus disinfection. • Assume that Falmouth BSR WWTF and Bourne ISWM WWTF can meet the effluent requirements for a Canal outfall (i.e., no cost included herein). • New Canal outfall sized for an additional 3.97-mgd capacity. • New effluent forcemain (11.5 miles) located parallel to existing. • Connect Falmouth BSR WWTF (effluent), Bourne and Sandwich (sewage)
Long-Term: • New effluent forcemain (11.5 miles) located parallel to existing (3 total forcemains).

2.8.5 New WWTF with Deep Well Injection

Short-Term: • Upgrades to existing JBCC wastewater facilities. • Upgrades to existing RIBs to achieve 1.55-mgd capacity. • Maintain existing RIBs to serve as reserve disposal. • Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).
Mid-Term: • New ENR/MBR WWTF plus RO/Storage and disinfection. All Falmouth and Bourne effluent flow brought to JBCC WWTF site. • 6 new DWI wells in the Cantonment to achieve an additional 3.10-mgd capacity. • 1 new effluent forcemain (2.3 miles) located parallel to existing. • Connect Falmouth BSR WWTF (effluent), Bourne and Sandwich (sewage)
Long-Term: • 4 new DWI wells in the Cantonment to achieve an additional 2.42-mgd capacity. • 1 new effluent forcemain (2.3 miles) located parallel to existing (3 total forcemains).

2.8.6 New WWTF with Canal Outfall

Short-Term: • Upgrades to existing JBCC wastewater facilities. • Upgrades to existing RIBs to achieve 1.55-mgd capacity. • Maintain existing RIBs to serve as reserve disposal. • Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).
Mid-Term: • New ENR/SBR WWTF plus UV disinfection. • Assume that Bourne ISWM WWTF and Falmouth BSR WWTF can meet the effluent requirements for a Canal outfall (i.e., no cost included herein). • New Canal outfall sized for an additional 5.52-mgd capacity. • New effluent forcemain (11.5 miles) located parallel to existing. • Connect Falmouth BSR WWTF (effluent), Bourne and Sandwich (sewage)
Long-Term: • New effluent forcemain (11.5 miles) located parallel to existing (3 total forcemains).

2.9 EVALUATION OF COMPOSITE ALTERNATIVES

This section evaluates the composite alternatives for the future wastewater system for cost and non-cost factors. Planning-level cost estimates for the long-term flows are summarized in Table 2-5. Planning-level cost estimates for the mid-term flows are summarized in Table 2-6

2.9.1 Planning-Level Capital Costs

Planning-level capital cost estimates were developed using cost estimating procedures consistent with industry standards utilizing concept layouts, unit cost information, and planning-level cost curves, as necessary. The capital costs include the following key components: wastewater collection, transport-to-treatment, wastewater treatment, transport-to-disposal, effluent disposal, land acquisition, and technical services and contingencies. Key technical data were compiled for all plans, based on conceptual designs. Next, typical "unit costs" were applied (e.g., dollars per foot of pipe, or dollars per pump station) using recent experience from publicly-bid wastewater projects across New England. Unit costs for “baseline” treatment and disposal facilities (i.e., ENR/SBR and disinfection) were taken from the Barnstable County Cost Report (“*Comparison of Costs for Wastewater Management Systems Applicable to Cape Cod*”, April 2010). Once basic construction costs were estimated, allowances were added for contingencies and technical services (40% of construction subtotal) and financing/legal/administration expenses (3% of construction subtotal). Land costs were excluded from this analysis. Backup information and additional assumptions are identified in Appendix A. The cost information presented herein is in current dollars and is based on ENR Index 10800. The planning-level capital costs for the long-term flows are summarized in Table 2-5 and indicate that:

- Option 1 (New WWTF with RIBs) is the alternative with the lowest capital cost
- Option 4 (New WWTF with RIB & Outfall) has the second lowest capital cost
- Option 2 (New WWTF with RIB & Wicks) has the third lowest capital

TABLE 2-5: SUMMARY OF PLANNING-LEVEL COST ESTIMATES AND COST ALLOCATION (BASED ON LONG-TERM CONSTRUCTED AS A SINGLE PROJECT)

Option	1	2	3	4	5	6
Description of Effluent Disposal	**RIB**	**RIB & Wicks**	**RIB & DWI**	**RIB & Outfall**	**DWI**	**Outfall**
Capital Cost						
Construction - Conveyance	$27,030,000	$27,030,000	$27,030,000	$27,030,000	$27,030,000	$27,030,000
Construction - Treatment	$38,900,000	$41,300,000	$66,100,000	$41,300,000	$72,700,000	$41,300,000
Construction - Transport to Disposal	$22,900,000	$22,900,000	$5,160,000	$23,950,000	$6,340,000	$23,950,000
Construction - Disposal	$9,500,000	$8,900,000	$11,700,000	$6,700,000	$12,900,000	$8,400,000
Contingency, Technical, Legal/Admin/Finance	$42,280,000	$43,060,000	$47,300,000	$42,560,000	$51,160,000	$43,290,000
Total Capital Cost	**$140,610,000**	**$143,190,000**	**$157,290,000**	**$141,540,000**	**$170,130,000**	**$143,970,000**
Ratio to Lowest - Total Capital Cost	1.00	1.02	1.12	1.01	1.21	1.02
Ratio to Lowest - Capital Cost, excl. Conveyance	1.00	1.03	1.16	1.01	1.29	1.03
Annual Operation & Maintenance Cost	**$2,110,000**	**$2,210,000**	**$5,230,000**	**$2,310,000**	**$6,490,000**	**$2,310,000**
Ratio to Lowest - Annual O&M	1.00	1.05	2.48	1.09	3.08	1.09
Total Annual Debt Service on Capital Cost	$8,600,000	$8,760,000	$9,620,000	$8,660,000	$10,400,000	$8,800,000
Total Equivalent Annual Cost (Note 3)	**$10,710,000**	**$10,970,000**	**$14,850,000**	**$10,970,000**	**$16,890,000**	**$11,110,000**
Ratio to Lowest - Equivalent Annual Cost	1.00	1.02	1.39	1.02	1.58	1.04
EAC per thousand gallons of disposal capacity	$8.76	$8.97	$12.14	$8.97	$13.81	$9.09

Notes:

1) Costs are presented in current dollars based on Engineering News Record Construction Cost Index 10800 (October 2017).
2) Refer to Appendix A for supporting information.
3) Equivalent Annual Cost equals Annual O&M Cost plus the Annual Debt Service on Capital Cost.
4) Allocation for Conveyance is 100% to each town. Allocation for treatment/transport/disposal is pro-rated based on flow capacity requested.
5) Blue indicates lowest cost option, green indicates second lowest cost option and orange indicates third lowest cost option.

2.9.2 Planning-Level Operation and Maintenance Costs

Annual operation and maintenance (O&M) costs were developed for each plan for the purposes of comparison among the plans. These planning-level O&M costs were developed using the anticipated wastewater flow rates for each plan. Unit O&M costs were taken from the Barnstable County Cost Report (April 2014). These O&M estimated include the following types of expenses: labor, including fringe benefits; electrical energy for powering pumps and treatment equipment; fuel for building heating and vehicular use; chemicals; disposal of dewatered sludge; laboratory testing and other permit compliance costs; administrative costs such as insurance; and equipment maintenance and replacement. The cost information presented herein is in current dollars and is based on ENR Index 10800. Backup information and additional assumptions are identified in Appendix A. The annual O&M costs for the long-term flows are summarized in Table 2-5 and indicate that:

- Option 1 (New WWTF with RIBs) is the alternative with the lowest annual O&M cost
- Option 2 (New WWTF with RIBs & Wicks) has the second lowest annual O&M cost
- Option 4 (New WWTF with RIBs & Outfall) has the third lowest annual O&M cost, tied with Option 6 (New WWTF with Outfall)

2.9.3 Equivalent Annual Cost

The “equivalent annual cost" (EAC) is a standard economic tool that allows for the calculation of a single "cost" to represent the combination of capital costs and annual expenses for O&M. The equivalent annual cost is the sum of the annual O&M cost plus the annualized debt service on the capital costs. For the purposes of this study, the present worth has been computed assuming a 2% interest rate and a 20-year loan based on presumed DEP CWSRF (Clean Water State Revolving Fund) loan financing. The equivalent annual costs for the long-term flows are summarized in Table 2-5 and indicate that:

- Option 1 (New WWTF with RIBs) is the alternative with the lowest equivalent annual cost
- Option 2 (New WWTF with RIBs & Wicks) has the second lowest equivalent annual cost tied with Option 4 (New WWTF with RIB & Outfall)
- Option 6 (New WWTF with Outfall) has the third lowest equivalent annual cost

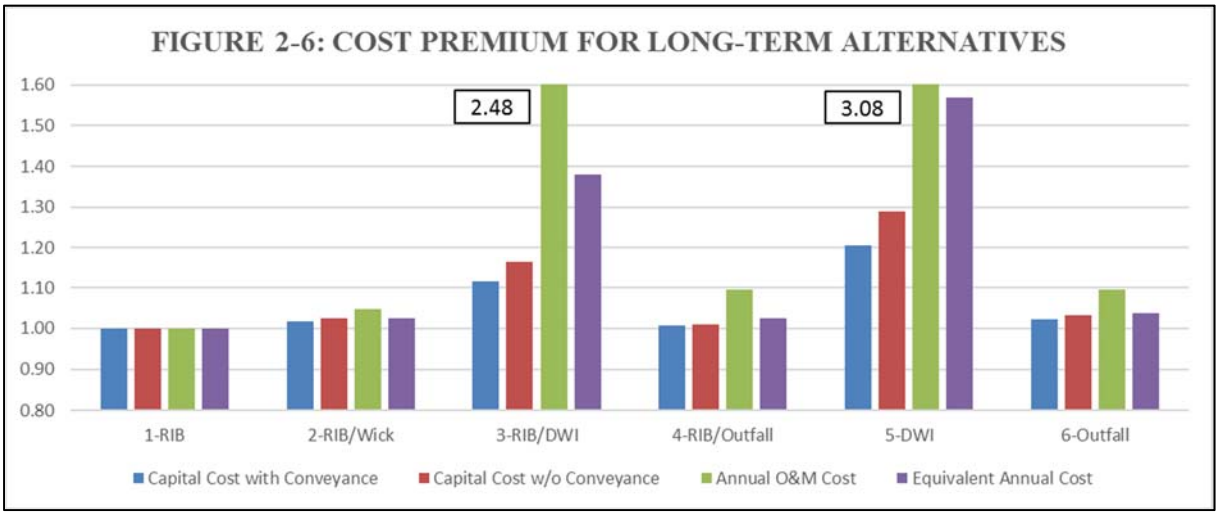
2.9.4 Considerations for Composite Alternatives

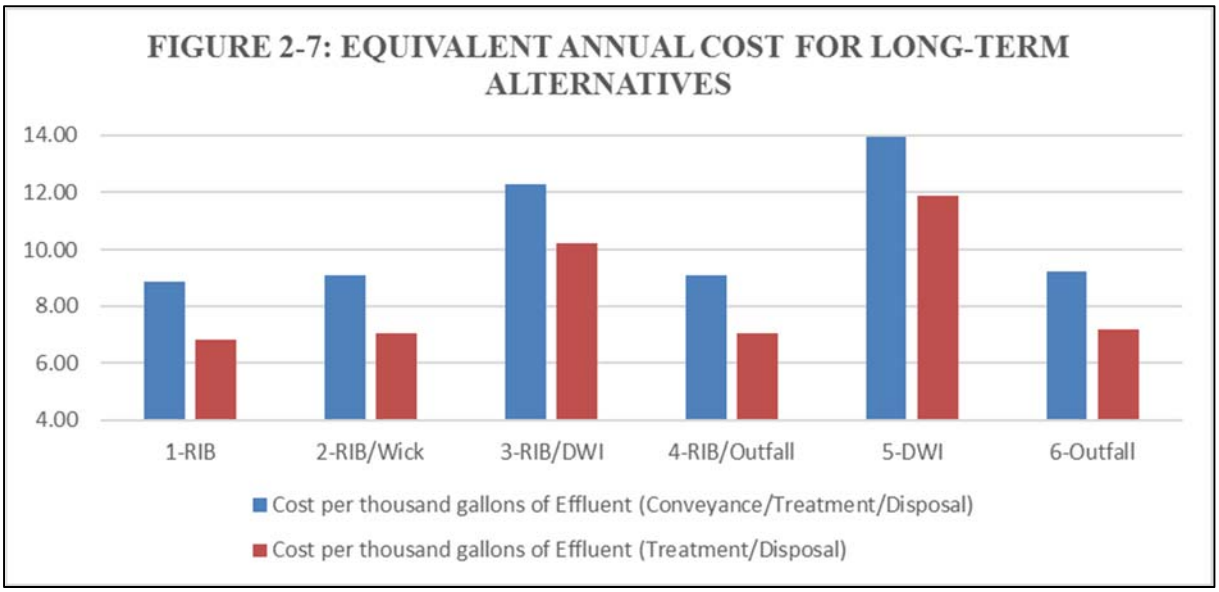
- This analysis represents a complex matrix of alternatives and considerations. There may be other combinations of composite alternatives which are determined to be of interest based on this analysis.
- Each alternative represents a scenario that requires a number of technical, political, permitting and logistical matters to fall into place.
- Laboratory testing should be conducted for a suite of primary and secondary drinking water parameters on the existing WWTF effluent in order to better assess implications to RO treatment throughput and reject water production.
- Pilot testing should be completed on WWTF effluent with potential MBR and RO treatment processes to better assess sizing implications for this project.
- Each alternative includes two new forcemains plus the existing forcemain to the disposal locations (i.e., 3 total forcemains). The reasons for this include increased operational flexibility and redundancy and decreased capital cost for mid-term phasing. This approach could be modified to reduce the long-term capital costs. For example, for Options 1, 2, 4, and 6, a single large effluent forcemain could be installed (i.e., 2 total forcemains) which would save approximately $16M but reduce piping redundancy and would increase the mid-term costs.
- The costs associated with "transport-to-disposal" are significant due to the distance from the WWTF site. Based on a review of Figure 2-2 (Zone II and Contamination Plumes) and Figure 2-3 (MEP Watersheds and TMDL Status), it does not appear that additional RIB sites or wick sites near the existing effluent forcemain would be feasible or recommended until the Canal South watershed is reached, which is approximately 60% of the distance to the existing RIB location and which is within the Reserve/Northern Training Area.
- By selecting disposal sites closer to the WWTF via the use of deep well injection, the transport-to-disposal cost is significantly reduced; however, this savings is more than offset by the additional cost and complexity of the treatment processes required.
- The deep well injection alternatives use RO treatment to achieve the stringent DEP standard related to TOC removal. It may be possible to implement a granular activated carbon (GAC) filtration process but it would likely require changes in the DEP regulations following a

detailed pilot testing protocol. A GAC filtration approach would lower the capital, annual O&M and equivalent annual cost for deep well injection.

- Assuming the towns have relatively few effluent disposal sites which are outside of nitrogen-sensitive MEP watersheds, then the use of the JBCC wastewater facilities will save the towns costs associated with additional sewering required to offset effluent disposal within a nitrogen sensitive area.
- Option 1 (New WWTF with RIBs) is the lowest cost alternative for long-term and mid-term conditions. The cost premium associated with Options 2, 4 and 6 are relatively small (i.e., less than 5%) for the long-term (refer to the "ratio rows" in Table 2-5). For this level of analysis, it is reasonable to consider Options 1, 2, 4, and 6 as equivalent from a cost perspective. Options 3 and 5 are considerably higher cost. The cost premiums are illustrated on Figure 2-6 below.
- A similar analysis was performed for the mid-term costs (refer to Appendix A). The results of the mid-term analysis show a similar ranking of alternatives for capital cost, annual O&M cost and equivalent annual cost. As would be expected, the capital cost, annual O&M cost and equivalent annual cost are lower for the mid-term; but the unit cost (EAC per thousand gallons of disposal capacity) is higher due to diseconomies of scale.
- Costs associated with phased implementation have not been considered. These costs will be considered for the recommended plan.
- It will be important for the participants to agree on whether to make selections and decisions based on the long-term cost or the mid-term.

FIGURE 2-6: COST PREMIUM FOR LONG-TERM ALTERNATIVES





2.9.5 Evaluative Criteria

This section of the report describes the evaluative criteria that were used for this project and resulting ratings. Each alternative was rated as "advantageous", "neutral" or "disadvantageous" for each of the evaluative criteria. Each criterion and the basis for the rating is summarized below.

- Capital cost: This is an objective measure and is the planning-level cost for the project, including technical services and contingency. "Advantageous" is indicated for the lowest cost alternative and any alternatives within 5% of the lowest cost. "Neutral" is indicated for other alternatives that are between 5% and 10% higher than the lowest cost alternative. "Disadvantageous" is indicated for alternatives that are 10% or more higher than the lowest cost alternative.
- Equivalent annual cost: This is an objective measure and is the planning-level equivalent annual cost for the project, including debt service on the capital cost and the annual O&M costs. "Advantageous" is indicated for the lowest cost alternative and any alternatives within 5% of the lowest cost. "Neutral" is indicated for other alternatives that are between 5% and10% higher than the lowest cost alternative. "Disadvantageous" is indicated for alternatives that are 10% or more higher than the lowest cost alternative.

- Technical viability: This is a subjective measure of viability. "Advantageous" is indicated for alternatives approved and in use in Massachusetts.
- Land area required: This is an objective/relative measure and represents total land area needed outside of the Cantonment for treatment and disposal.
- Availability of required land: This is a subjective measure and represents the ease with which land can be obtained. "Advantageous" is indicated for land within the Cantonment or the site currently "owned" by the 102nd ANG. "Neutral" is indicated for land in the Reserve/Northern Training Area. "Disadvantageous" is indicated for land owned by Federal agencies or the public.
- Permitting challenges: This is a subjective measure and represents the effort associated with obtaining the necessary regulatory permits. "Advantageous" is indicated for approaches currently approved in Massachusetts (RIBs and wicks). "Neutral" is indicated for approaches used elsewhere in Massachusetts but with significant technical hurdles at this location. "Disadvantageous" is indicated for approaches not currently approved in Massachusetts.
- Time required for implementation: This is a subjective measure and represents the time necessary to secure land and permits. This is a measure of availability of necessary land (ANL) and permitting challenges (PC). "Advantageous" is indicated only if ANL and PC are both advantageous. "Disadvantageous" is indicated if ANL and PC are both disadvantageous. "Neutral" is indicated for all others.
- Regulatory requirements/short-term: This is a subjective measure and represents the immediate/short-term regulatory framework. "Advantageous" is indicated for groundwater discharges outside of Zone II and with soil aquifer treatment in the unsaturated zone. "Neutral" is indicated for all others.
- Regulatory requirements/long-term: This is a subjective measure and represents the potential for additional effluent treatment parameters in the long-term. "Advantageous" is indicated for groundwater discharges outside of Zone II and with soil aquifer treatment in the unsaturated zone. "Neutral" is indicated for surface water discharges and discharges without soil aquifer treatment in the unsaturated zone.
- Operational flexibility: This is a subjective measure and represents the how much flexibility and redundancy is built into the treatment and disposal processes. All alternatives are intended to provide the same relative flexibility and redundancy.

- Operational complexity: This is an objective measure and represents the complexity of the overall treatment and disposal schematic. "Advantageous" is indicated for alternatives with no additional unit processes/disposal types. "Neutral" is indicated for alternatives with one or two additional unit processes/disposal types. "Disadvantageous" is indicated for alternatives with three or more additional unit processes/disposal types.
- Expandability: This is a subjective/relative measure and represents the ability of the alternative to be expanded in the future. "Disadvantageous" is indicated for RIBs because of the relatively large land footprint required for additional disposal capacity. "Neutral" is indicated for all other alternatives.
- Public perception: This is a subjective measure and represents the perception of the general public on the various alternatives. "Advantageous" is indicated for alternatives that would have no or very limited public profile. "Neutral" is indicated for alternatives that impact surface water. "Disadvantageous" is indicated for alternatives that impact drinking water.
- Non-Governmental Organization (NGO) perception: This is a subjective measure and represents the perception of non-governmental organizations on the various alternatives. "Advantageous" is indicated for no or very limited public profile. "Disadvantageous" is indicated for alternatives that impact surface water or drinking water.
- Sustainability/ groundwater supply: This is an objective measure and represents the whether the alternative recharges the drinking water supply. "Advantageous" is indicated for alternatives that do recharge the Zone II. "Disadvantageous" is indicated for alternatives that do not.
- Sustainability/ chemical use: This is an objective measure and represents whether chemical use will increase. "Advantageous" is indicated for alternatives that do not increase chemical use. "Neutral" is indicated for alternatives that add one chemical process. "Disadvantageous" is indicated for alternatives that add two or more chemical processes.
- Sustainability/ greenhouse gas emissions: This is a subjective/relative measure and represents the increase in energy use. "Advantageous" is indicated for alternatives that are substantially the same energy use. "Neutral" is indicated for alternatives that have a minor increase in energy use. "Disadvantageous" is indicated for alternatives that have a significant increase in energy use.

A summary of the evaluative criteria is presented in Table 2-6 and indicates the following:

- Option 1 – New WWTF with RIBs has the most Advantageous scores (10) and least Neutral scores (3).
- Option 2 – New WWTF with RIB/Wick has the most "Advantageous plus Neutral" scores (16) and the least Disadvantageous scores (1).
- Option 3 – New WWTF with RIB/DWI is tied for the most Disadvantageous scores (8).
- Option 4 – New WWTF with RIB/Outfall has the second highest "Advantageous plus Neutral" scores (14).
- Option 5 – New WWTF with DWI is tied for the most Disadvantageous scores (8).
- Option 6 – New WWTF with Outfall has the third highest "Advantageous plus Neutral" scores (13).

This matrix of alternatives identifies four options with essentially equivalent costs (with the RIB option being the lowest cost) and two options with higher costs (both options being DWI). All of these alternatives each have fairly challenging hurdles related to permitting, public perception, non-governmental organization perception, or all three.

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TABLE 2-6: SUMMARY OF EVALUATIVE CRITERIA

Criteria A = Advantageous; N = Neutral; D = Disadvantageous	**1** **RIB**	**2** **RIB/Wick**	**3** **RIB/DWI**	**4** **RIB/Outfall**	**5** **DWI**	**6** **Outfall**
Capital Cost	A	A	D	A	D	A
Equivalent Annual Cost	A	A	D	A	D	A
Technical Viability	A	N	N	N	N	N
Land Area Required	D	A	A	N	A	N
Availability of Necessary Land	D	N	A	D	A	D
Permitting Challenges	N	N	D	N	D	N
Time Required for Implementation	N	N	N	N	N	N
Regulatory/ Short-Term	A	A	N	N	N	N
Regulatory/ Long-Term	A	A	N	N	N	N
Operational Flexibility	N	N	N	N	N	N
Operational Complexity	A	N	D	N	D	N
Expandability	D	N	N	A	N	A
Public Perception	A	A	D	N	D	D
Non-Governmental Organization Perception	A	A	D	D	D	D
Sustainability/ Groundwater Supply	D	D	A	D	A	D
Sustainability/ Chemical Use	A	N	D	A	D	A
Sustainability/ Greenhouse Gas Emissions	A	N	D	A	D	A
Number of Advantageous Ratings	**10**	**7**	**3**	**5**	**3**	**5**
Number of Neutral Ratings	**3**	**9**	**6**	**9**	**6**	**8**
Number of Disadvantageous Ratings	**4**	**1**	**8**	**3**	**8**	**4**
Number of Advantageous and Neutral Ratings	**13**	**16**	**9**	**14**	**9**	**13**

2.9.6 Cost Breakdown by Phase

The cost breakdown is based on Option 6 (Outfall) because it is the most conservative (i.e., most expensive) of the four composite alternatives that have relatively equivalent cost (i.e., Options 1, 2, 4 and 6). Costs for the phases break down as follows:

- Short-Term Costs – These costs consist of the items identified in Section 1.4 of this report as well as the conveyance costs for Bourne ISWM WWTF and Mashpee sewage.
- Mid-Term Costs – These costs consist of 65% of the ultimate treatment costs, 50% of the ultimate transport to disposal costs and 60% of the ultimate disposal costs as well as all of the conveyance costs for Bourne, Falmouth, Mashpee and Sandwich. These percentages were selected based on engineering judgment for the anticipated scope of work.
- Long-Term Costs – These costs consist of the remainder of the treatment, transport to disposal and disposal costs.

The cost breakdown by phase is presented in Table 2-7. Additional information is provided in Appendix A.

TABLE 2-7: CAPITAL COST BY PHASE (ENR CCI 10800)

	Short-Term	**Mid-Term**	**Long-Term**
Conveyance	$3.6M	$25.4M	$0M
Treatment	$1.9M	$25.6M	$13.8M
Transport	$0.3M	$11.8M	$11.8M
Disposal	$0.4M	$4.6M	$3.4M
Contingency, Technical, Legal, Admin., Finance	$2.7M	$29.1M	$12.5M
Total	$8.9M	$96.5M	$41.5M

2.9.7 Cost Allocation Among Participants

Costs for the various wastewater system components were allocated in the following ways:

- Conveyance – Costs were attributed to the individual towns, except where new or rehabilitated infrastructure is shared and except for baseline inflow removal at JBCC. When shared, the costs are split evenly among the affected individual towns. None of the conveyance costs were attributed to JBCC. Inflow removal costs associated with the existing system are the responsibility of JBCC. As noted earlier in this section, conveyance costs include the cost of the final lift station to convey flow to the JBCC system.
- Transport and Disposal – Costs were attributed to the individual towns and JBCC on a pro-rata flow basis, in accordance with the requested effluent disposal capacity indicated in Section 1.
- Contingency/Technical/Legal/Administration/Finance – Costs were attributed to the individual towns and JBCC pro-rata based on the subtotal of the planning-level construction costs.

The percentage of total effluent flow by phase is presented in Table 2-8. These percentages are used to allocate O&M costs. The basis for allocation of capital costs is presented in Table 2-9. This allocation was used for the mid-term and long-term conditions. The allocations of capital cost, annual O&M, and equivalent cost are presented in Table 2-10, Table 2-11 and Table 2-12, respectively. Additional information is presented in Appendix A.

TABLE 2-8: PERCENTAGE OF TOTAL EFFLUENT FLOW BY PHASE

	Short-Term	Mid-Term	Long-Term
JBCC	33%	9%	4%
Bourne	22%	42%	34%
Falmouth	0%	30%	45%
Mashpee	45%	12%	6%
Sandwich	0%	7%	11%
Total	100%	100%	100%

TABLE 2-9: BASIS FOR CAPITAL COST ALLOCATION (LONG-TERM FLOW)

	Annual Average Flow		% of Total	
	Treatment	Transport/ Disposal	Treatment	Transport/ Disposal
JBCC	147,000	147,000	13%	4%
Bourne	467,000	1,118,000	39%	34%
Falmouth	22,000	1,512,000	2%	45%
Mashpee	203,000	203,000	17%	6%
Sandwich	350,000	350,000	29%	11%
Total	1,189,000	3,330,000	100%	100%

TABLE 2-10: CAPITAL COST ALLOCATION (ENR CCI 10800)

	Short-Term	Mid-Term	Long-Term
JBCC	$1.5M	$5.6M	$3.5M
Bourne	$1.8M	$34.8M	$15.0M
Falmouth	$0M	$28.0M	$10.2M
Mashpee	$5.6M	$7.7M	$4.7M
Sandwich	$0M	$20.4M	$8.1M
Total	$8.9M	$96.5M	$41.5M

TABLE 2-11: ANNUAL O&M ALLOCATION (ENR CCI 10800)

	Short-Term	Mid-Term	Long-Term
JBCC	$0.23M	$0.13M	$0.10M
Bourne	$0.15M	$0.62M	$0.78M
Falmouth	$0M	$0.44M	$1.05M
Mashpee	$0.31M	$0.18M	$0.14M
Sandwich	$0M	$0.09M	$0.24M
Total	$0.69M	$1.46M	$2.31M

TABLE 2-12: EQUIVALENT ANNUAL COST ALLOCATION (ENR CCI 10800)

	Short-Term	Mid-Term	Long-Term
JBCC	$0.32M	$0.47M	$0.31M
Bourne	$0.26M	$2.74M	$1.70M
Falmouth	$0M	$2.16M	$1.67M
Mashpee	$0.65M	$0.65M	$0.43M
Sandwich	$0M	$1.34M	$0.74M
Total	$1.23M	$7.36M	$4.85M

Note:
1) Annual debt services on capital costs is calculated based on a CWSRF at 2% interest for 20 years (CRF 16.35).

It is important to note that cost allocations per entity will change if not all entities ultimately elect to participate or if entities elect to participate at higher or lower flow rates than indicated in Section 1 of this report. Cost allocations will also change if different allocation assumptions are utilized.

2.9.8 Comparison of Costs to Previous Town Planning Documents

This section of the report compares the capital cost allocation to cost estimates prepared as a part of previous planning documents prepared for each entity. This review is described below for each entity. The metric that will be used is "capital cost per thousand gallons of effluent in one year" (i.e., total costs divided by one year of effluent flow). For Alternative 6 (Outfall) in this report, the overall capital cost per thousand gallons of effluent per year is approximately $121 (JBCC SWMS). Additional supporting information is provided in Appendix A and Appendix C.

JBCC

Currently JBCC has a small customer base which results in relatively high unit costs for treatment and debt allocation. Bringing additional customers (i.e., other towns) will significantly reduce this cost burden in the short-term, mid-term and long-term. There is no sewer service expansion for JBCC, so there is no need to calculate or compare the cost metrics. The current operating budget for the JBCC facilities is approximately $0.5M per year, as compared to a project equivalent annual cost of $0.32M to $0.47M as shown on Table 2-12. Given that JBCC's existing operating budget

does not include any debt service (and the projected herein do include debt service), this shows a strong economy of scale for JBCC.

Bourne

Bourne completed wastewater planning for the portion of town north of the Cape Cod Canal in 2007 (as noted in Section 1), but has not completed wastewater planning for the portion of town south of the Cape Cod Canal. Using the Phase 1 wastewater flows and planning-level costs from the Bourne Wastewater Management Study (Tighe & Bond, 2007) and adjusting the costs to current dollars, the Bourne WMS indicates a capital cost per thousand gallons of effluent per year at approximately $162 in current dollars. This is 1.27 times than Bourne's share of the JBCC SWMS which is $127 in current dollars (see Appendix A). This shows a strong economy of scale for Bourne.

Falmouth

As a part of this project, Falmouth's wastewater planning consultant (GHD) was retained to develop a comparison of Falmouth costs under previous planning efforts to the Falmouth costs projected as a part of this evaluation. A technical memorandum from GHD is included in Appendix C. In short, the previous planning efforts indicate a capital cost per thousand gallons of effluent per year at approximately $107 to $170 in current dollars. As presented in Appendix C, Falmouth's projected share of the JBCC SWMS is $104 and $85 for mid-term and long-term, respectively. The JBCC SWMS is projected to cost Falmouth about the same in the mid-term as it planned in the DCWMP. The JBCC SWMS is projected to cost Falmouth less in the long-term than it planned in the DCWMP. Regionalization is expected to be a benefit to Falmouth.

Mashpee

As a part of this project, Mashpee's wastewater planning consultant (GHD) was retained to develop a comparison of Mashpee costs under previous planning efforts to the Mashpee costs projected as a part of this evaluation. A technical memorandum from GHD is included in Appendix C. In short, the previous planning efforts indicate a capital cost per thousand gallons of

effluent per year at approximately $78 for the recommended plan (i.e., connecting to JBCC with a smaller regional approach) and at approximately $207 for the backup plan (i.e., constructing a WWTF in Mashpee to treat and disposal of the same effluent volume), both in current dollars. As presented in Appendix C, Mashpee's projected share of the JBCC SWMS is $27, $130 and $193 for short-term, mid-term and long-term, respectively. These comparative numbers do not include the conveyance costs because they are equal between the WNMP and the JBCC SWMS approaches. The JBCC SWMS is projected to cost Mashpee substantially less in the short-term than was anticipated in the WNMP. The JBCC SWMS is projected to cost Mashpee more in the long-term than was anticipated in the WNMP; however, even at a higher cost, participating in a regional solution at JBCC is projected to cost less than Mashpee providing equivalent facilities on its own (i.e., working separately).

Sandwich

Sandwich completed town-wide wastewater planning in 2017. The Sandwich plan calls for two WWTFs, one near the Cape Cod Canal and one near the Sandwich Industrial Park. Using the wastewater flows and planning-level costs from the Sandwich draft Comprehensive Water Resources Management Plan (Wright-Pierce, 2017) and adjusting the costs to current dollars, the Sandwich CWRMP indicates a capital cost per thousand gallons of effluent per year at approximately $286 in current dollars. This is 1.28 times than Sandwich's share of the JBCC SWMS which is $223 in current dollars (see Appendix A). This shows a strong economy of scale for Sandwich.

Summary

As described on the previous pages, a regional approach appears to be generally favorable for the communities and JBCC and warrants continued consideration. A summary of the cost comparisons described on the previous pages is presented below in the units of "capital cost per thousand gallons of effluent capacity per year".

	JBCC Shared Wastewater Management Study	**Previous Planning Documents**
Bourne (sewage)	$127 (LT)	$162 (LT)
Bourne (leachate)	-	No information received
Falmouth	$85 (LT) to $104 (MT)	$107 to $170 (LT)
Mashpee	$27 (ST) to $193 (LT)	$78 (RP LT) to $207 (BP LT)
Sandwich	$223 (LT)	$286 (LT)

1. Refer to Appendix A for additional details regarding JBCC, Bourne and Sandwich.
2. Refer to Appendix C for additional details regarding Falmouth and Mashpee.
3. Cost metrics are based on October 2017 dollars (ENR CCI 10800). See Appendix A for more information.

It is important to note that these cost estimates are based on numerous key assumptions as described in this report, specifically including: the number of participants identified in Section 1.6; the capacity requests and timing of flows identified in Section 1.6; the phasing approach described in Section 2.8; and the loan financing terms identified in Section 2.9. Changes in these assumptions will result in adjustments to costs and cost allocations and may result in changes in cost comparisons. As more detailed cost information becomes available, these cost allocation comparisons should be refined.

SECTION 3

MANAGEMENT AND POLICY ISSUES

3.1 MANAGEMENT ENTITY

A publicly owned treatment works requires a management entity which must be able to fulfill the following common functions:

- **Planning.** Quantifying wastewater management needs; estimating wastewater flows; determining the necessary level of treatment; evaluating options for collection, treatment and disposal; identifying and evaluating sites; estimating project costs; and obtaining public input.
- **Land Acquisition.** Obtaining fee simple interest or easement rights for land for collection, treatment and disposal functions.
- **Permitting.** Obtaining all the permits and regulatory approvals to allow the proposed wastewater facilities to be built.
- **Design.** Selecting and contracting with design professionals to prepare plans and specifications for the facilities to be built.
- **Construction.** Bidding and issuing contracts for the construction of wastewater facilities, and overseeing the construction.
- **Operation.** Operating and maintaining the wastewater facilities including periodic replacement of failed equipment.
- **Monitoring.** Monitoring the performance of the wastewater facilities, reviewing the performance of the wastewater facilities against the permit requirements and conditions, and taking appropriate action in the event of noncompliance.
- **Funding.** Collecting and/or appropriating funds to pay the capital costs for wastewater facilities and the expenses for ongoing operation and maintenance.

In a successful program, all of the necessary functions will be accomplished without undue cost or complexity.

3.1.1 Initial Management Entity

MassDevelopment has been in discussions with the Air Force and the Air National Guard for several years regarding potentially acquiring ownership of the JBCC water and wastewater systems. MassDevelopment has successfully implemented a similar arrangement in Devens, Massachusetts (formerly Fort Devens). A final decision has not been made by MassDevelopment at the time of publication of this report. Other entities could serve as an initial (and successor) management entity; refer to Section 3.1.2 below.

3.1.2 Potential Successor Management Entities

The following potential successor management entities have been identified:

- **Host Town with Customer Agreements.** It is possible that ownership of the JBCC wastewater system could be transferred to one of the four towns, which in turn could enter into customer agreements with the other towns and the JBCC sewer users. This could make sense if one of the towns had the desire to undertake this significant responsibility. There may also be legal issues to address related to the fact that the WWTF is located in Sandwich and the effluent disposal system is located in Bourne.
- **Creation of a New Special Purpose District.** This approach would require an act of the Legislature to create a new special purpose district. This new district would presumably be established with a governing board representing each of the towns and JBCC. A new special purpose district seems to have significant merit because several towns may benefit from a regional facility, and the JBCC infrastructure is centrally located with respect to Bourne, Falmouth, Mashpee and Sandwich. A new special purpose district would require a number of implementation steps related to establishing a charter, hiring staff, securing office space, developing billing protocols, etc.
- **Modification of an Existing Special Purpose District.** This approach would modify the charter of an existing special purpose to undertake ownership responsibilities for the existing JBCC wastewater systems. A logical example of this approach is the Upper Cape Regional Water Supply Cooperative (UCRWSC) which was established by an act of the Massachusetts Legislature in 2000 and is governed by a Board of Managers with representatives from the

Bourne Water District, Town of Falmouth, Sandwich Water District and Mashpee Water District. This approach may be less logistically and administratively challenging than to create a new special purpose district.

3.1.3 Evaluative Criteria

Each of the management options described above has advantages and disadvantages which can be identified by considering the following evaluative criteria:

- **Ease in implementation**. If a new management structure is difficult to implement, there is less chance of success and higher cost to bring it to fruition.
- **Political acceptability.** The status quo would constitute an impediment to a new entity.
- **First costs to implement.** The ideal option would carry low costs for formation. It would also use existing public employees wherever possible.
- **Potential for long-term cost savings**. The more functions that can be handled regionally, the greater the potential for savings due to economies of scale.
- **Ability to raise money**. The principal means of financing wastewater projects has traditionally been through property taxation and betterment assessments. An effective entity should have access to funds through both means, and others if possible.
- **Loss of local control.** A regional entity will suffer from a real or perceived loss of local control. To the extent that decisions impacting cost, growth and environmental quality are made by someone other than the towns (and town meetings), there could be some opposition.
- **Ability to obtain grants and loans.** A regional entity would need to be carefully established such that the entity would be eligible for grants and loans for environmental infrastructure.

These criteria cover a broad range of issues. Individual towns or interest groups may have other criteria to add to this list, and may place differing emphasis on these criteria.

3.1.4 Summary of Management Entities

Given the options and evaluative criteria described above, a new or modified special purpose district would likely provide the most advantages to the customer communities and entities. The management entity could vary based on the individual wastewater system components. Suggested successor management entities organized by wastewater system component are summarized below. These elements are also schematically on Figure 2-5 by project phase (i.e., short-term, mid-term and long-term).

Wastewater System Component	**Suggested Successor Management Entity**
Collection	Individual towns
Conveyance	Special purpose district (or individual towns)
Treatment	Special purpose district
Transport to Disposal	Special purpose district
Disposal	Special purpose district

Ultimately, the selection of an approach will require input from staff, elected officials and legal counsel for each participating customer community as well as JBCC.

3.2 MULTIPLE PERMITTEES FOR EFFLUENT DISCHARGE PERMIT

This evaluation considers regional treatment at the existing or upgraded JBCC WWTF as well as shared disposal facilities for effluent treated at the JBCC WWTF, the Bourne ISWM WWTF and the Falmouth BSR WWTF. While the use of a single effluent disposal system for multiple WWTFs has been done before, it is far from common and requires that EPA and/or DEP consider the following important permitting factors:

- Sources of wastewater to the individual WWTFs (i.e., residential, commercial, industrial, septage, leachate);
- Treatment processes used at the individual WWTFs;
- Average and peak flow rates, jointly and severally;
- Effluent limits, monitoring requirements and monitoring locations for the individual WWTFs;

- Effluent limits, monitoring requirements and monitoring locations for the common disposal method;
- Legal and financial assurances for meeting effluent limits and groundwater quality standards; and
- Legal and financial assurance for asset management.

The management entity must have the ability to monitor effluent quality from the individual WWTFs and enforce effluent quality standards, or must have the other individual municipalities named as "co-permittees" on the permit. Discussions with DEP regarding the specifics of how the permit will be written should occur as soon as possible.

3.3 ALLOCATION OF AVAILABLE CAPACITY

In the long-term, each participating entity will secure the desired amount of capacity by committing an appropriate amount of the capital cost to the management entity. In the short-term, there is less capacity available than has been requested. It may be necessary to establish a method to allocate the available capacity until such time as the JBCC wastewater system is upgraded in the mid-term. There are numerous potential methods to allocate capacity. A listing of potential methods is provided below.

- Highest bidder
- Highest environmental benefit
- Quickest environmental benefit
- Highest economic benefit to communities
- Equalize economic benefit to communities
- First-come, first-served or "shovel-ready" projects

Each of these methods has some technical, political and financial trade-offs that should be discussed among the participants looking for short-term capacity.

3.4 INTER-MUNICIPAL/ INTER-GOVERNMENTAL AGREEMENTS

This project represents a potential regional approach to address wastewater management needs. It is expected that the remaining planning could take several years and may require one or more iterations to the cost model identified herein. It will be important that each participant clearly indicate its intentions to the other participants in order to converge on an acceptable solution. It is anticipated that one or more inter-municipal/inter-governmental agreements (IMA/IGA) may be necessary in order to implement the project.

- The initial IMA/IGA would commit the towns to collaboratively complete planning phase activities and to confirm conceptual capacity commitments and allocation of capacity in the short-term, mid-term and long-term. The initial IMA/IGA should include all potential participating entities.
- Subsequent IMA(s)/IGA(s) would be required to commit to flow neutral regulations, sewer use regulations, sewer user charges, and capital cost contributions in order to complete design, permitting and construction phase activities. It is envisioned that communities would enter into the subsequent IMAs/IGAs when they prepare to expend capital to connect to the wastewater system.

3.5 PRE-REQUISITES TO CAPITAL IMPROVEMENTS

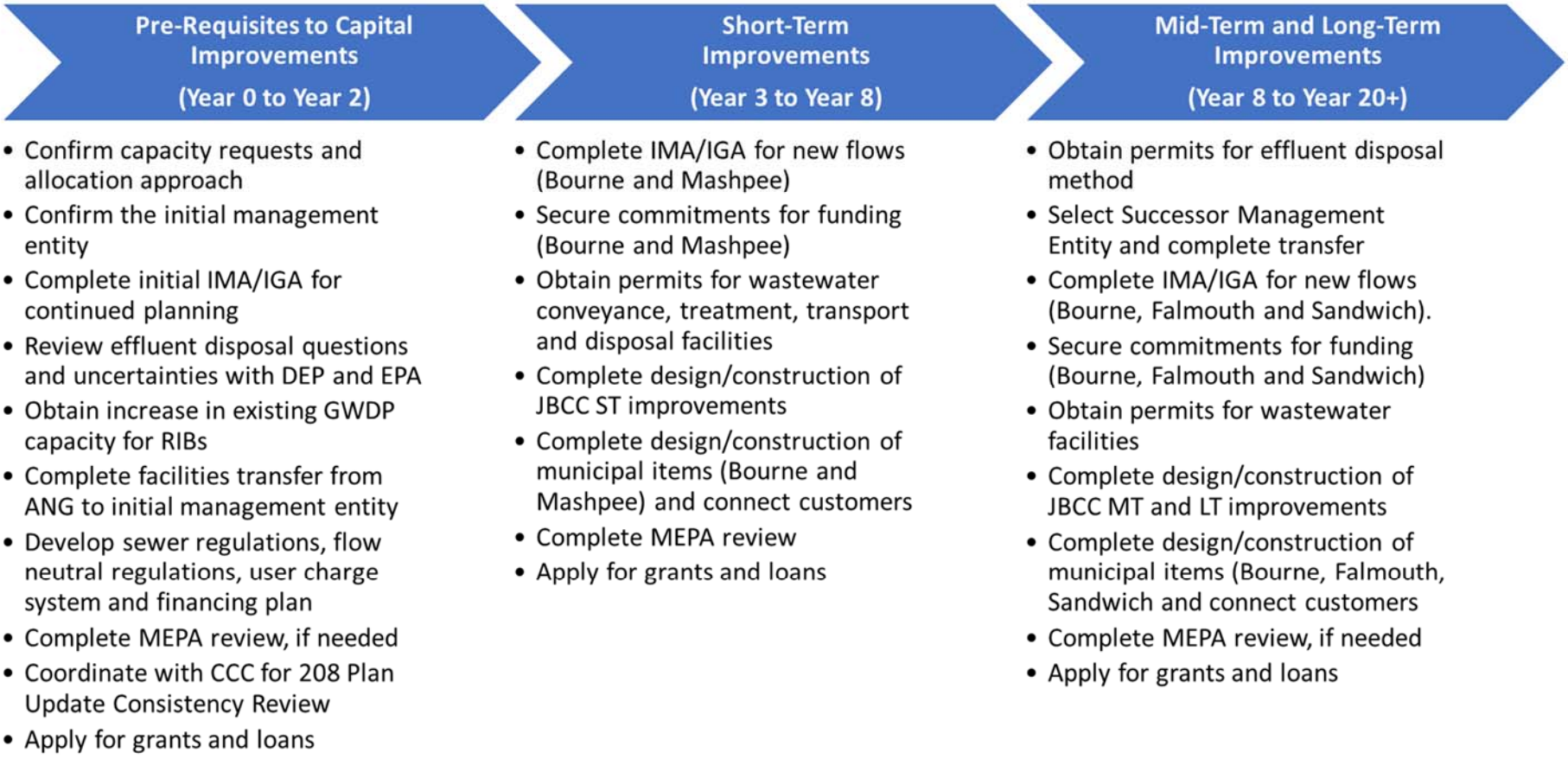
The following is a general list of pre-requisites to implementing any capital improvements related to providing capacity to regional participants beyond the existing system users.

- Complete planning, including confirming conceptual capacity commitments and developing consensus regarding allocation of capacity in the short-term.
- Confirm the initial management entity and complete the initial transfer of ownership
- Develop initial IMA/IGA
- Obtain increase in existing GWDP capacity (prior to short-term improvements)
- Obtain permit approvals from EPA and/or DEP for the selected disposal alternative (prior to mid-term improvements)

- Develop sewer regulations (all) and flow neutral regulations (towns), including coordination with local Boards of Health
- Develop sewer user charge system
- Develop a specific procurement and financing plan
- Secure commitments for the allocated capital costs, including design and permitting, via town meeting authorizations
- Secure commitments for the O&M rate structure
- Enact any special legislation necessary to implement the selected plan
- Acquire land and/or easements for conveyance, treatment, transport and disposal, as required
- Conduct Massachusetts Environmental Policy Act (MEPA) review
- Coordinate with Cape Cod Commission regarding the "208 Plan Update Consistency Review" [Note, the Commission has issued draft "Guidance on Section 208 Plan Update Consistency Review". The initial management entity would need to facilitate this review in coordination and collaboration with the four towns. The majority of the criteria for the consistency review are geared towards municipal planning by the designated Waste Treatment Management Agency (WMA). A proposed regional use of the JBCC wastewater system for the benefits of municipalities which are addressing water quality needs is consistent with the Commission's recommendations contained in Section 7 of the 208 Plan Update.]
- Complete design and obtain permitting for remainder of the project elements from EPA, DEP, local Town boards (Planning, Conservation, Historic District, etc.)
- Apply for grants and loans.

Figure 3-1 presents key pre-requisite activities by project phase.

FIGURE 3-1: DECISION FLOW CHART BY PROJECT PHASE



SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Based on our evaluations, we offer the following conclusions regarding the potential for expanding the JBCC wastewater system to serve as a regional facility:

- There is a regional need on the Upper Cape for facilities to provide wastewater treatment (short-term), septage treatment (mid-term) and effluent disposal (short-term, mid-term and long-term).
- Regionalizing the JBCC wastewater system provides economies of scale and provides apparent cost savings to the potential participating communities (based on capacity requests described herein).
- From a technical perspective, the advantages of regionalizing the JBCC wastewater system exceed the disadvantages. The municipalities will need to evaluate the advantages and disadvantages from political and policy perspectives.
- As described in Section 2, six composite alternatives were identified to provide regional facilities for wastewater treatment of the capacities requested by each municipality and JBCC. The composite alternatives are differentiated primarily by the effluent disposal method that is utilized.
  - Four of the six composite alternatives have essentially equal costs and collectively represent the lowest cost alternatives. These four composite alternatives are Rapid Infiltration Basins (Alternative 1), Rapid Infiltration Basins plus Wicks (Alternative 2), Rapid Infiltration Basins plus a Cape Cod Canal Outfall (Alternative 4) and a Cape Cod Canal Outfall (Alternative 6).
  - In the mid-term and long-term, Rapid Infiltration Basins and Wicks (Alternatives 1 and 2) will require some additional land near the existing disposal site and will require additional hydrogeologic study to obtain permit approvals. In the mid-term and long-term, a Cape Cod Canal Outfall (Alternatives 4 and 6) will require some additional land between the

existing disposal site and the Cape Cod Canal and will require additional study to address the requirements of the Massachusetts Ocean Sanctuaries Act (refer to Section 2.7.6).

- The use of Deep Well Injection in combination with Rapid Infiltration Basins (Alternative 3) has a substantially higher capital cost (1.12 times), annual O&M cost (2.48 times) and equivalent annual cost (1.39 times) than the lowest cost alternatives because Reverse Osmosis treatment processes are required at the WWTF. These differentials are related to the additional capital and operating costs associated with the reverse osmosis treatment process. Alternative 3 could be more cost competitive if there was additional flexibility allowed under Massachusetts regulations or if GAC treatment system could achieve similar requirements under the current regulations. Under either scenario, additional hydrogeologic study as well as pilot testing of Deep Well Injection and WWTF treatment processes would be required. The use of Deep Well Injection only (Alternative 5) should be ruled out at this time due to excessive costs; however, if the Cape Cod Canal were considered nitrogen-sensitive or the Sagamore Lens need additional recharge, then it may be appropriate to consider this alternative in the future.

- Each of the effluent disposal options described herein is allowed under Massachusetts law and regulation; however, each of the disposal options has site-specific challenges related securing permit approvals. These challenges are related to both technical factors and public perception. These challenges should be explored with DEP and EPA as a part of continued planning efforts.
- The cost allocation methodology presented herein is a flow-based allocation model. Other methods of cost allocation could be developed. If some communities choose not to participate, now or later, the capital costs and the cost allocation will change.
- A management entity for the regional facility must be established. Perhaps both as an interim management entity and as longer-term successor management entity. The long-term management entity is recommended to be a new or modified special purpose district.
- As more detailed cost information becomes available, these cost allocation comparisons should be updated and refined.

4.2 RECOMMENDATIONS AND IMPLEMENTATION STEPS

Based on our evaluations, there are sufficient advantages to the participating municipalities and JBCC to warrant continued planning efforts. The following continued planning activities should be a high priority in order to advance this effort:

Activities	**Responsible Party**
Prepare initial letters of support from each participating community.	Towns, JBCC
Secure additional grant funds or local funds from each participating community to continue planning activities identified in Figure 3-1.	Falmouth (as fiscal agent)
Prepare and execute the initial IMA/IGA as described in Section 3.4.	Towns, JBCC
Complete tasks needed to facilitate acceptance of Bourne landfill leachate effluent from the ISWM WWTF.	Bourne
Complete tasks needed to facilitate acceptance of Mashpee sewage.	Mashpee
Coordinate with DEP and EPA regarding DWI, Canal outfall, wicks and RIB permitting issues and uncertainties.	All
Initiate tasks to increase the capacity of the existing RIBs.	All

SECTION 5

REFERENCES

The documents identified below were referenced in the development of this report.

Wastewater Management Study, Bourne, MA, Tighe & Bond, 2007.

Needs Assessment Report, Little Pond, Great Pond, Green Pond, Bournes Pond, Eel Pond, and Waquoit Bay Watersheds, Falmouth, MA, Stearns & Wheler, 2007.

Comprehensive Wastewater Management Plan and Final Environmental Impact report and Targeted Watershed Management Plan, Little Pond, Great Pond, Green Pond, Bournes Pond, Eel Pond, and Waquoit Bay Watersheds, Falmouth, MA, GHD, 2013.

Needs Assessment Report, Popponesset Bay and Waquoit Bay East Watersheds, Mashpee, MA, Stearns & Wheler, 2007

Comprehensive Watershed Nitrogen Management Plan, Final Recommended Plan/ Final Environmental Impact Report, Mashpee, MA, GHD, 2015

Comprehensive Water Resources Management Plan, Draft, Sandwich, MA, Wright-Pierce, 2017

Joint Base Cape Cod, Water and Wastewater System Evaluation, Massachusetts Development Finance Agency, Wright-Pierce, 2014

Appraisal Consulting Services for the Wastewater Treatment System at the Massachusetts Military Reservation, CH2M-Hill, 2012

Groundwater Discharge Permit Application/Permit No. 41-3, Massachusetts DEP, 2009

Contract Drawings for Alteration of Wastewater Treatment Plant, CDM, 1993.

Contract Drawings for Effluent Forcemain and Infiltration Basins, CDM/SAIC Eng., 1993.

Hydrogeologic Investigation & Design Effluent Infiltration Basins, CDM/SAIC Eng., 1993.

314 CMR 5.00: Ground Water Discharge Permit Program

Delineation of Ground-Water Recharge Areas, Western Cape Cod, Massachusetts, Water Resources Investigations Report 00-4000, United States Geological Survey, 2000

Simulated Water Sources and Effects of Pumping on Surface and Ground Water, Sagamore and Monomoy Flow Lenses, Cape Cod, Massachusetts, SIR 2004-5181, United States Geological Survey, 2004

314 CMR 4.00: Massachusetts Surface Water Quality Standards

Implementation Procedures for the Anti-Degredation Provisions of the Massachusetts Surface Water Quality Standards, 314 CMR 4.00, Massachusetts Department of Environmental Protection, October 21, 2009

Massachusetts Surface Water Quality Standards, Implementation Policy for Mixing Zones, January 8, 1993

Environmental Impact Statement - Draft, Wastewater Collection and Treatment Facilities, Sandwich, MA, Environmental Protection Agency, 1981.

314 CMR 20.00: Reclaimed Water Permit Program and Standards

Guidelines for Water Reuse 2012, Environmental Protection Agency, September 2012

Factors to Evaluate When Considering a Reverse Osmosis Concentrate Discharge to a Wastewater Treatment Facility, CH2M-Hill, Boe, Brubaker, 2016

Pilot Test for Using Injection Wells for Reclaiming Treated Municipal Wastewater, Barnstable, MA, Stearns & Wheler, 2003

2013 Joint Land Use Study Update and Community-Military Partnerships Study Final Report, Cape Cod Commission, 2013

208 Cape Cod Area Wide Water Quality Management Plan Update, Cape Cod Commission, 2015

An Act Establishing the Upper Cape Cod Regional Water Supply Cooperative (Act 2000, Chapter 532)

APPENDIX A
Supporting Materials – Wright-Pierce

WRIGHT-PIERCE
Engineering a Better Environment

MEMORANDUM

TO:	File	**DATE:**	8/23/2017, rev 11/27/2017
FROM:	Ed Leonard	**PROJECT NO.:**	13839A
SUBJECT:	JBCC Shared Wastewater Management Study Flow Estimate Backup Materials		

Attached are the following cost estimate backup materials:

1. Basis for Bourne Flows to JBCC Wastewater Facilities
2. Bourne Wastewater Management Study, Figure 2-5
3. Supporting Information for Table 1-8
4. TR-16 Flow Peaking Factor Chart
5. Supporting Information for Table 2-2

Basis for Bourne Flows

The Bourne Wastewater Management Study (Tighe & Bond, 2007) included estimates of existing and future wastewater flow town-wide, as summarized in Table 3-4 of the Bourne WMS, and an assessment of "priority", as shown on Figure 2-5 (attached). The prioritization approach is presented in Section 2.5 of the Bourne WMS and includes consideration of: performance of existing on-site wastewater systems; location relative to 100-year flood plain; location relative to low permeability soils; and location relative to estuaries and coastal embayments.

The Bourne WMS did not assess or estimate off-site wastewater management needs; accordingly, a cursory assessment was conducted in order to support the JBCC SWMS effort. The wastewater flows are summarized on the attached table entitled "Basis for Bourne Flows to JBCC Wastewater Facilities" dated 22 Aug 2017. The following assumptions were utilized in preparing these estimates:

- Wastewater flow identified for off-site treatment and disposal was estimated by the following percentages using the information presented on Bourne WMS Figure 2-5: 25% for low priority (blue, green); 50% for medium priority (yellow, orange); and 75% for high priority (red).

- Wastewater flow does not cross the Cape Cod Canal.
- Wastewater flow from Areas 8 through 14 (except Area 11) goes to the ISWM WWTF location and is connected to the effluent forcemain along with the leachate flow. Area 11 (MacArthur Boulevard/Route 28) is split equally between the ISWM and JBCC WWTFs.
- Wastewater flow from Areas 15 to 20 goes to the JBCC WWTF location and is treated as sewage.
- Septage goes to the JBCC WWTF.

Bourne confirmed via email on 8/15/2017 and 8/23/2017 that the attached flow estimates were suitable for use in this planning effort. Bourne will need to develop a more detailed assessment of off-site wastewater management needs as a part of a town-wide or targeted watershed management planning effort.

WASTEWATER MANAGEMENT STUDY FOR TOWN OF BOURNE, FALMOUTH, MASHPEE, SANDWICH AND JBCC
BASIS FOR BOURNE FLOWS TO JBCC WASTEWATER FACILITIES
Wright-Pierce, 22 Aug 2017
Source of Data: 2007 Bourne Wastewater Management Study, Tighe & Bond

				Flows within WMS Planning Horizon					
				Flow to ISWM WWTF		Flow to JBCC WWTF		Flow to North WWTF	
Study Area	Existing Flows (gpd)	20-Year Future Flows (gpd)	% of Flow Used for JBCC Study	Existing Flows (gpd)	20-Year Future Flows (gpd)	Existing Flows (gpd)	20-Year Future Flows (gpd)	Existing Flows (gpd)	20-Year Future Flows (gpd)
1 Buzzards Bay - Main Street/Hideaway Village	106,000	386,000	75%	n/a	n/a	n/a	n/a	80,000	290,000
2 Buzzards Bay - North of Rt. 28 Bypass	202,000	243,000	50%	n/a	n/a	n/a	n/a	101,000	122,000
3 Buzzards Bay - Head of the Bay Road	1,000	24,000	25%	n/a	n/a	n/a	n/a	0	6,000
4 Scenic Highway	33,000	126,000	25%	n/a	n/a	n/a	n/a	8,000	32,000
5 Bournedale	80,000	115,000	25%	n/a	n/a	n/a	n/a	20,000	29,000
6 North Sagamore - Business Corridor	38,000	80,000	25%	n/a	n/a	n/a	n/a	10,000	20,000
7 Sagamore Highlands/Sagamore Beach/North Sagamore	278,000	352,000	50%	n/a	n/a	n/a	n/a	139,000	176,000
8 Sagamore	108,000	146,000	25%	27,000	37,000	n/a	n/a	n/a	n/a
9 Gray Gables/Mashnee Island	106,000	130,000	50%	53,000	65,000	n/a	n/a	n/a	n/a
10 Sandwich Road/Bourne Village	105,000	143,000	25%	26,000	36,000	n/a	n/a	n/a	n/a
11 MacArthur Boulevard/Route 28A	156,000	608,000	50%	39,000	152,000	39,000	152,000	n/a	n/a
12 Back River/Eel Pond	129,000	185,000	25%	32,000	46,000	n/a	n/a	n/a	n/a
13 Monument Beach	207,000	241,000	50%	104,000	121,000	n/a	n/a	n/a	n/a
14 Northern Pocasset/Tobys Island	125,000	188,000	50%	63,000	94,000	n/a	n/a	n/a	n/a
15 Wings Neck/Scraggy Neck/Bassetts Island	83,000	141,000	50%	n/a	n/a	42,000	71,000	n/a	n/a
16 Tahanto/North Shore/Hen Cove	240,000	274,000	50%	n/a	n/a	120,000	137,000	n/a	n/a
17 Pocasset/Red Brook Harbor	55,000	129,000	25%	n/a	n/a	14,000	32,000	n/a	n/a
18 Flax Pond (Picture Lake)	47,000	58,000	50%	n/a	n/a	24,000	29,000	n/a	n/a
19 Cataumet	72,000	99,000	25%	n/a	n/a	18,000	25,000	n/a	n/a
20 Cataumet Hills/Route 28	9,000	39,000	25%	n/a	n/a	2,000	10,000	n/a	n/a
Septage	12,000	17,000		n/a	n/a	see below	see below	n/a	n/a
Leachate	25,000	27,000		100,000	100,000	n/a	n/a	n/a	n/a
SUBTOTAL	2,217,000	3,751,000		444,000	651,000	259,000	456,000	358,000	675,000

TOTALS CAPACITY BY CATEGORY				Short-Term	Mid-Term	Long-Term
Total - Sewage Capacity				0	259,000	456,000
Total - Septage Capacity				0	11,000	11,000
Total - Effluent Disposal Only				100,000	444,000	651,000
Total - Effluent Disposal				100,000	714,000	1,118,000

NOTES:
1) Estimated flows based on Tighe & Bond Table 3-4 and 3-9. All flows presented as annual average flows.
2) Estimated flows based on Tighe & Bond Figure 2-5 using the following: blue and green = 25%, yellow and orange = 50%, red = 75%.
3) Estimated flows to ISWM WWTF will be for effluent disposal capacity and estimated flow to JBCC WWTF will be for sewage capacity.

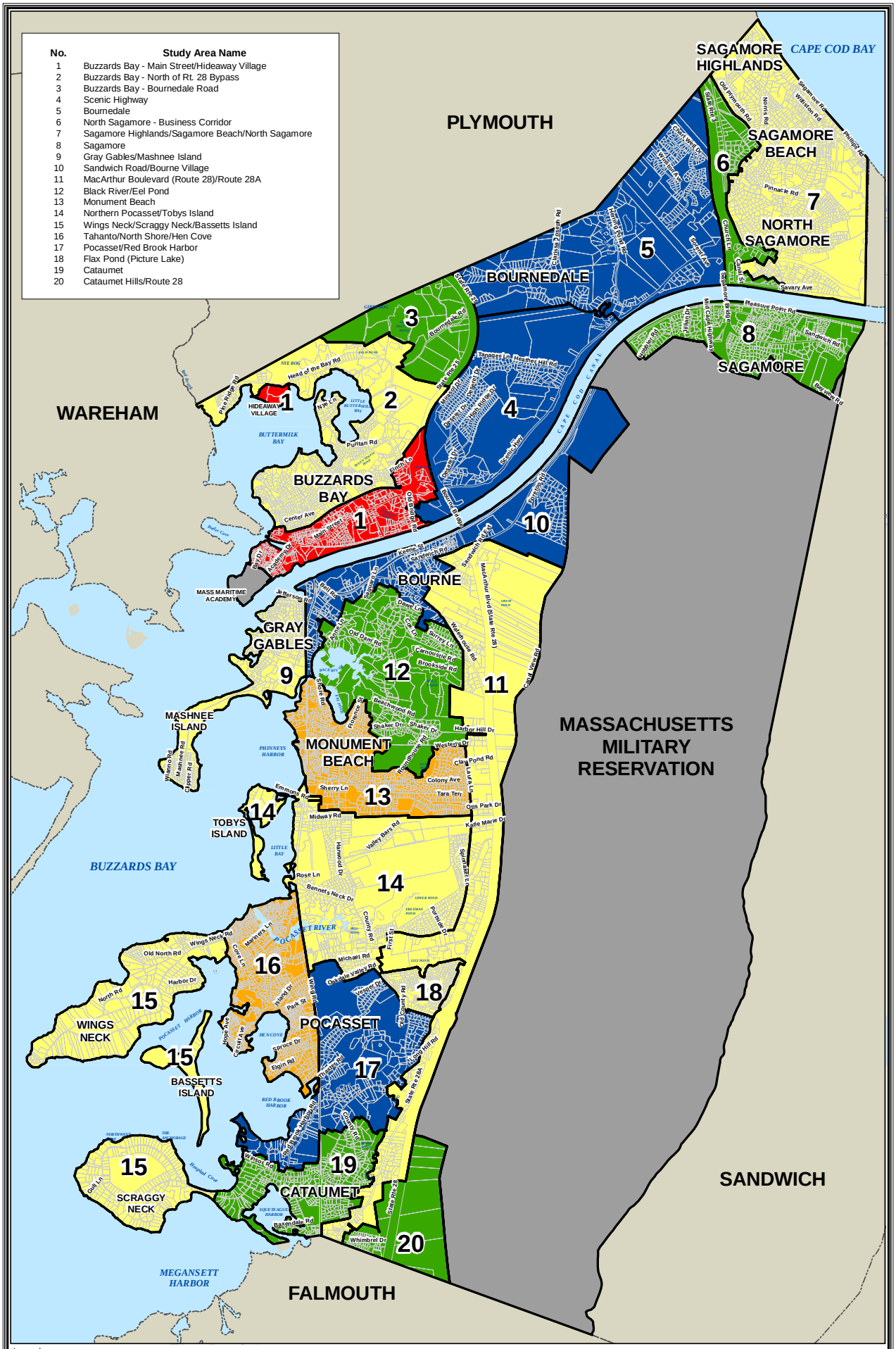


FIGURE 2-5 - STUDY AREA PRIORITIZATION
BASED ON NEED FOR SEWER SERVICE
BOURNE WASTEWATER MANAGEMENT STUDY
BOURNE, MASSACHUSETTS

APRIL 2007

Tighe&Bond

V:\Projects\B\B0403\Mapping\studyarea_prioritization_11x17.mxd

TABLE 1-8: SUMMARY OF CAPACITY REQUESTS TO BE USED IN ENGINEERING ASSESSMENT

Capacity Requested - Annual Average Flows (gpd)								
	JBCC	**Bourne**	**Falmouth**	**Mashpee**	**Sandwich**	**Total**	**Capacity Provided**	**% Increase Existing Capacity**
Existing								
Sewage Treatment	140,000	0	0	0	0	140,000	**360,000**	n/a
Septage Treatment	0	0	0	0	0	0		
Effluent Disposal Only	0	0	0	0	0	0		
Effluent Disposal	140,000	0	0	0	0	140,000	**360,000**	n/a
Short-Term (5-year)								
Sewage Treatment	147,000	0	0	200,000	0	347,000	**360,000**	0%
Septage Treatment	0	0	0	0	0	0		
Effluent Disposal Only	0	100,000	0	0	0	100,000		
Effluent Disposal	147,000	100,000	0	200,000	0	447,000	**460,000**	28%
Mid-Term (10 year)								
Sewage Treatment	147,000	259,000	0	200,000	100,000	706,000	**760,000**	111%
Septage Treatment	0	11,000	22,000	3,000	10,000	46,000		
Effluent Disposal Only	0	444,000	490,000	0	0	934,000		
Effluent Disposal	147,000	714,000	512,000	203,000	110,000	1,686,000	**1,700,000**	372%
Long-Term (20 year)								
Sewage Treatment	147,000	456,000	0	200,000	340,000	1,143,000	**1,200,000**	233%
Septage Treatment	0	11,000	22,000	3,000	10,000	46,000		
Effluent Disposal Only	0	651,000	1,490,000	0	0	2,141,000		
Effluent Disposal	147,000	1,118,000	1,512,000	203,000	350,000	3,330,000	**3,350,000**	831%
Notes	1	1	1	1	1		2, 4	3

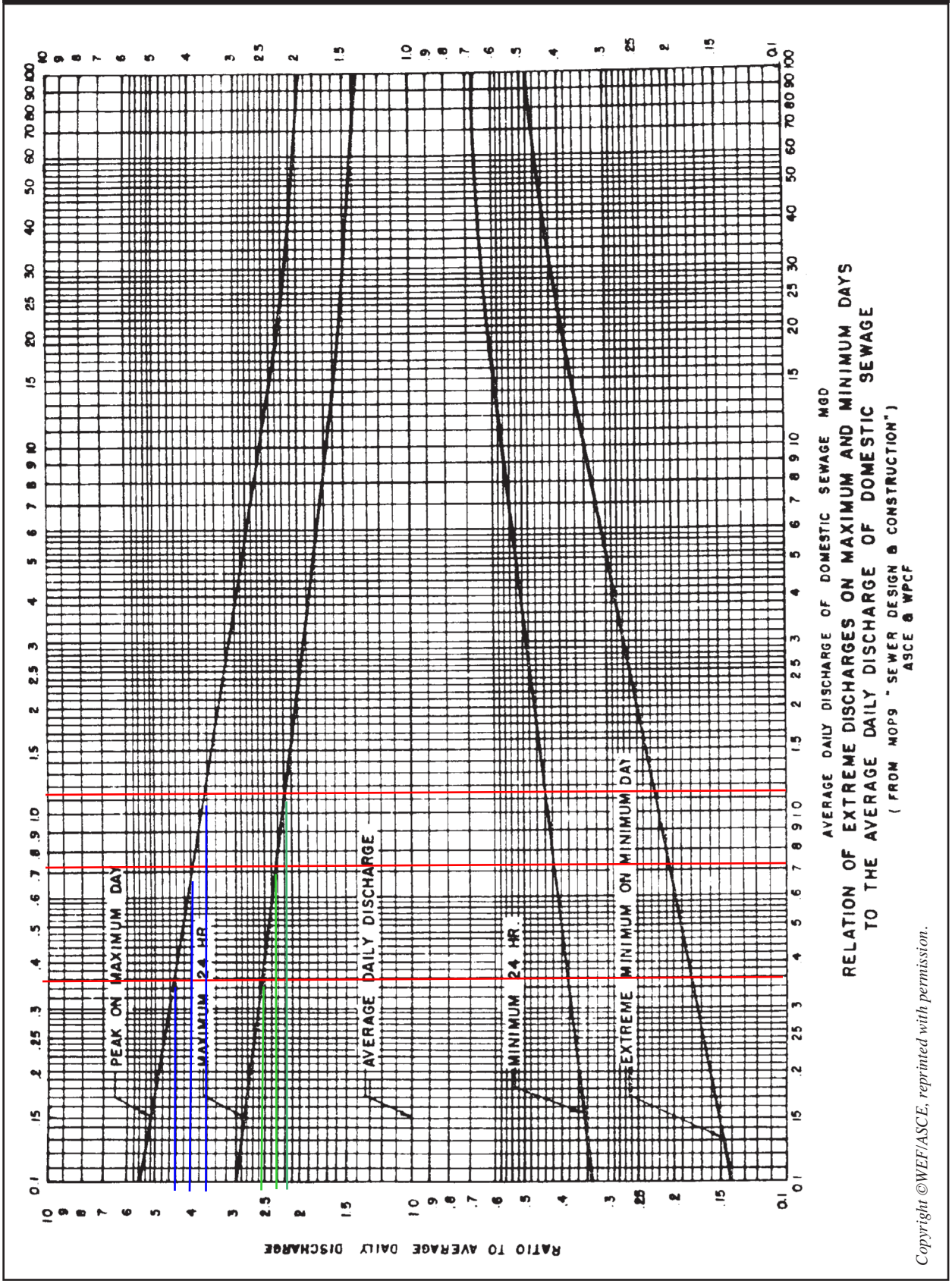
1) Refer to Table 1-7 for additional information.

2) Existing Capacity based on WP 2014, GWDP and WWTF O&M.

3) Capacity for Short-Term, Mid-Term and Long-Term conditions are increases over the existing capacity.

4) Organic loading treatment capacity will need to account for concentrated nature of septage.

Figure 2-1 **Ratio of Extreme Flow to Average Daily Flow**



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BACKUP FOR TABLE 2-2: WASTEWATER FLOWS USED IN ENGINEERING ASSESSMENT

			Capacity - Maximum 3 Day Flow (gpd)			Capacity - Peak Instan. Flow (gpd)		
	Annual Average Flow (gpd)	Treatment Capacity	Peaking Factor (M3D:AA)	Maximum 3 Day Flow	Effluent Disposal Capacity	Peaking Factor (PI:AA)	Peak Instan. Flow	Conveyance Capacity
Existing								
Sewage Treatment	140,000	**360,000**	2.75	386,000		10.0	1,400,000	
Septage Treatment	0		2.0	0		2.0	0	
Effluent Disposal Only	0		1.5	0		1.5	0	
Effluent Disposal	140,000	**360,000**			**386,000**			**1,400,000**
Short-Term (5-year)								
Sewage Treatment	347,000	**360,000**	2.75	955,000		4.7	1,625,000	
Septage Treatment	0		1.75	0		1.75	0	
Effluent Disposal Only	100,000		1.25	125,000		1.25	125,000	
Effluent Disposal	447,000	**460,000**			**1,080,000**			**1,750,000**
Mid-Term (10 year)								
Sewage Treatment	706,000	**760,000**	2.52	1,780,000		4.2	2,990,000	
Septage Treatment	46,000		1.75	80,000		1.75	80,000	
Effluent Disposal Only	934,000		1.25	1,170,000		1.25	1,170,000	
Effluent Disposal	1,686,000	**1,700,000**			**3,030,000**			**4,240,000**
Long-Term (20 year)								
Sewage Treatment	1,143,000	**1,200,000**	2.42	2,760,000		4.0	4,590,000	
Septage Treatment	46,000		1.75	80,000		1.75	80,000	
Effluent Disposal Only	2,141,000		1.25	2,680,000		1.25	2,680,000	
Effluent Disposal	3,330,000	**3,350,000**			**5,520,000**			**7,350,000**

1) Peaking factors for sewage taken from TR-16, New England Interstate Water Pollution Control Commission, 2016. Peaking factors for sewage were adjusted upward by 0.2 to account for Cape Cod seasonality.
2) Peaking factors for septage and "effluent disposal only" are input values and will address via design controls.

WRIGHT-PIERCE
Engineering a Better Environment

MEMORANDUM

TO:	File	**DATE:**	10/26/2017
FROM:	E. Whatley, J. Ducharme	**PROJECT NO.:**	13839A
SUBJECT:	JBCC Shared Wastewater Management Study Evaluation of Conveyance Options		

This memorandum identifies the options for wastewater conveyance systems required to support shared wastewater management opportunities for the towns of Bourne, Falmouth, Mashpee, Sandwich and Joint Base Cape Cod (JBCC). Supplemental information is included in the following attachments:

- Conveyance Option Worksheet with plan and profile figures
- Conveyance Options Costs
- JBCC Conveyance Improvement Worksheet

1.1 OBJECTIVES

The objectives of the conveyance study include the following:

- Identify alignments for conveyance of sewage from Bourne's southern section, Mashpee and Sandwich to JBCC WWTF for treatment and disposal;
- Identify alignments for conveyance of treated wastewater ("effluent") from the JBCC WWTF, the Bourne ISWM WWTF and the Falmouth BSR WWTF to the JBCC treated effluent conveyance system and disposal areas;
- Identify rehabilitation of sections of the JBCC gravity sewer system where shorter alignments and capital cost savings are available;
- Review conceptual profiles of each forcemain alignment to evaluate conceptual static and dynamic head on the pumping system;
- Develop preliminary hydraulic calculations to determine conceptual forcemain sizes; and
- Determine conceptual number and size of required lift stations.

1.1.1 Concept Design Criteria

The following key assumptions are used in this analysis:

- Elevation data was obtained from topographic information within Google Earth.
- Conceptual forcemain piping and wastewater lift station sizing are based on the conveyance flows in Tables 1 and 2.

TABLE 1 RAW WASTEWATER CONVEYANCE FLOWS

(Raw Wastewater Lift Station Peaking Factor: 4)

Flow Source	Existing Flows		Short-Term Flows		Mid-Term Flows		Long-Term Flows	
	Avg.	Peak	Avg.	Peak	Avg.	Peak	Avg.	Peak
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
JBCC	140,000	389	152,000	422	152,000	422	152,000	422
Sandwich	-	-	-	-	100,000	278	340,000	944
Mashpee	-	-	200,000	556	200,000	556	200,000	556
Bourne-S	-	-	-	-	259,000	719	456,000	1,267
Subtotal- Raw WW to WWTF	140,000	389	352,000	978	711,000	1,975	1,148,000	3,189

TABLE 2 EFFLUENT CONVEYANCE FLOWS

(Effluent Lift Station Peaking Factor: 1.25)

Flow Source	Existing Flows		Short-Term Flows		Mid-Term Flows		Long-Term Flows	
	Avg.	Peak	Avg.	Peak	Avg.	Peak	Avg.	Peak
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
JBCC	140,000	122	152,000	132	152,000	132	152,000	132
Bourne Effluent	-	-	100,000	87	444,000	385	651,000	565
Bourne-S	-	-	-	-	270,000	234	467,000	405
Falmouth	-	-	-	-	512,000	444	1,512,000	1,313
Mashpee	-	-	200,000	174	203,000	176	203,000	176
Sandwich	-	-	-	-	110,000	95	350,000	304
Total Effluent Disposal	140,000	122	452,000	392	1,691,000	1,468	3,335,000	2,895

- Raw wastewater concept design criteria:
    - Peaking factor used for lift station flow: 4.0
    - Minimum forcemain velocity: 3 fps
    - Maximum forcemain design pressure: 275 ft (120 psi)
- Effluent concept design criteria:
    - Peaking factor used for lift station flow: 1.25
    - Minimum forcemain velocity: none
    - Maximum forcemain design pressure: 275 ft (120 psi)
- Forcemain materials:
    - Existing effluent forcemain: ductile iron
    - Proposed forcemains: C900/C905 DR 18 PVC (235 psi) or HDPE (200 to 255 psi)
- Pump calculations:
    - Method: Hazen-Williams with friction value of 130
    - Pump Horsepower approximation per Hydraulic Institute method
- Medium-sized wastewater and effluent lift stations:
    - Flow: up to 1200 gpm
    - Pumps: submersible, up to 75 hp
    - Wetwell and valve vault
    - Generator and control panel in pump house
    - Conceptual construction cost: $1M each
- Large-sized wastewater and effluent lift stations:
    - Flow: 1200 gpm or more
    - Pumps: drypit installation, greater than 75 hp
    - Generator and control panel in pump building over wetpit/drypit installation
    - Conceptual construction cost: $2.5M each

- Conveyance routes utilizing existing JBCC gravity conveyance systems assume the rehabilitation of those sections through trenchless methods. Rehabilitation costs are assumed to be $150 per foot.
- Forcemain costs vary depending on the conditions of the route and are shown below in Table 3. A route within a public way with heavy traffic volumes or dense development has a higher cost than a route along routes with little traffic or adjacent development.

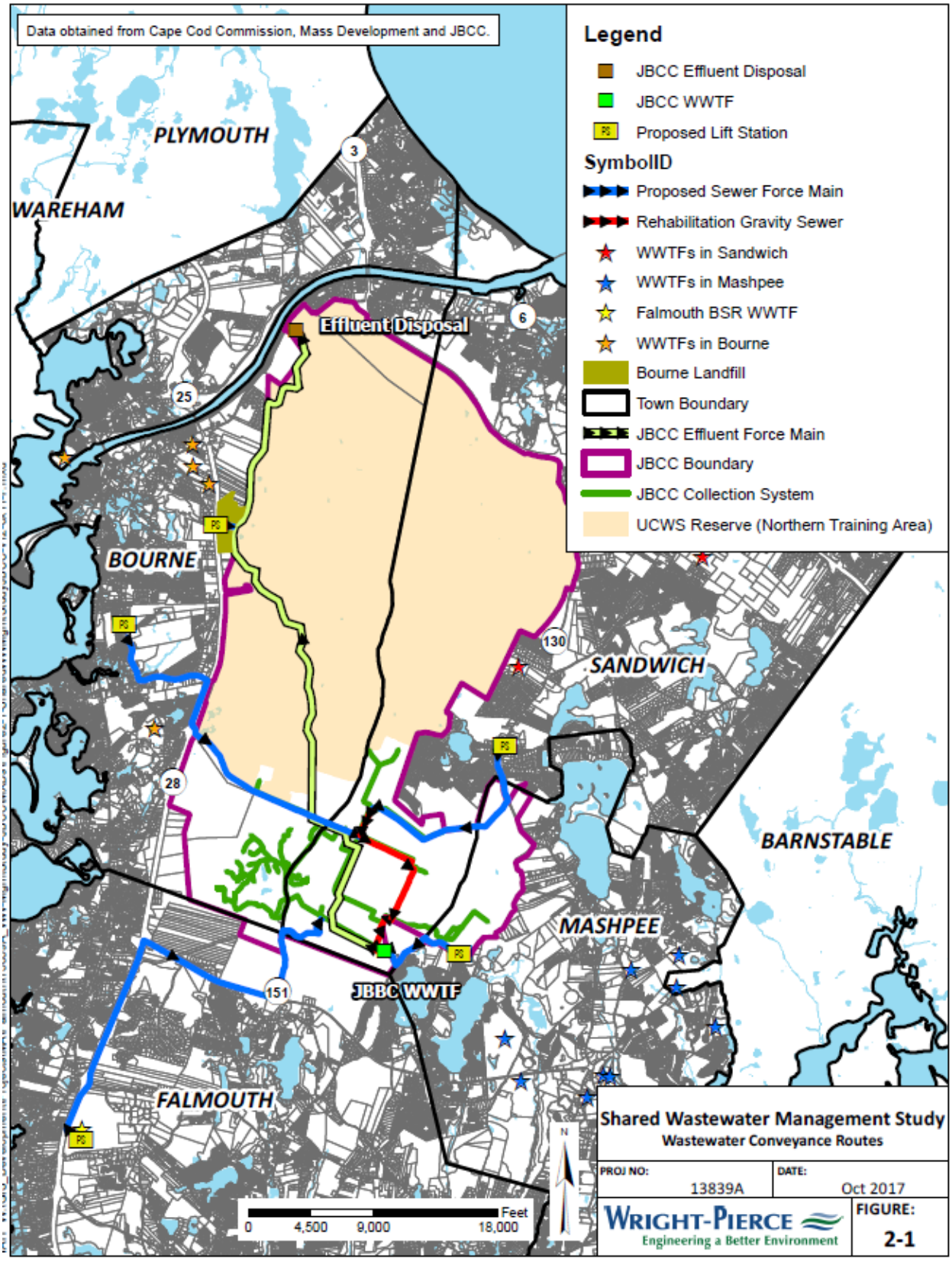
TABLE 3: FORCEMAIN UNIT COSTS

Forcemain Diameter	Route Characteristics		
	Public Way/Dense (Cost/ft)	Off Public Way or Less Dense (cost/ft)	Railroad Right of Way (cost/ft)
8-inch	$200	$120	$300
10-inch	$220	$140	$320
12-inch	$240	$160	$340
14-inch	$260	$180	$360
18-inch	$280	$200	$380

1.2 SUMMARY OF PREFERRED CONVEYANCE OPTIONS

Current preferred conveyance routes are shown on **Figure 2-1** and identified as follows:

- Bourne North (effluent) – Proposed lift station at ISWM WWTF connected to existing JBCC effluent forcemain, via a new 8" Bourne forcemain.
- Bourne South – Proposed lift station at the intersection of Valley Bars and County Roads to JBCC WWTF via a new 12" Bourne forcemain and rehabilitated gravity sewer (shared with Sandwich).
- Falmouth (effluent) – Proposed lift station at BSR WWTF connected to the JBCC effluent forcemain(s) via a new 18" Falmouth forcemain in Routes 28 and 151.
- Mashpee – Proposed lift station on Back Road Site 1 (Town lot) to JBCC WWTF via new 8" Mashpee forcemain.
- Sandwich – Proposed lift station on portion of Lot-06-236 at 40 Route 130 to JBCC WWTF via 12" Sandwich forcemain, and rehabilitated gravity sewers (shared with Bourne).


Data obtained from Cape Cod Commission, Mass Development and JBCC.
Legend
JBCC Effluent Disposal
JBCC WWTF
Proposed Lift Station
SymbolID
Proposed Sewer Force Main
Rehabilitation Gravity Sewer
WWTFs in Sandwich
WWTFs in Mashpee
Falmouth BSR WWTF
WWTFs in Bourne
Bourne Landfill
Town Boundary
JBCC Effluent Force Main
JBCC Boundary
JBCC Collection System
UCWS Reserve (Northern Training Area)
PLYMOUTH
WAREHAM
BOURNE
SANDWICH
BARNSTABLE
MASHPEE
FALMOUTH
Effluent Disposal
JBBC WWTF
3
6
25
28
130
151
PS
N
0
4,500
9,000
18,000
Feet
Shared Wastewater Management Study
Wastewater Conveyance Routes
PROJ NO:
13839A
DATE:
Oct 2017
WRIGHT-PIERCE
Engineering a Better Environment
FIGURE:
2-1

1.3 CONVEYANCE ALIGNMENTS EVALUATED

1.3.1 Bourne Alignments

The following alignments were investigated for Bourne sewage flow from the southern sections of town. This piping is required in the mid-term.

- Option 1. Shortest route through the JBCC base, utilizing existing JBCC gravity sewer
    - 1 large lift station, 1250 gpm, 235 ft TDH, 150 hp
    - 12" forcemain, velocity 3.6 fps, 5.1 miles
    - JBCC rehabilitated gravity sewer, 2.3 miles
    - Total route length: 7.4 miles
    - Advantages
        - Least expensive - by $4.1M
        - Shortest route by 2.1 miles
        - Shortest length within public way / dense route
    - Disadvantages
        - Uncertainty of obtaining construction easements within federal lands for forcemains
        - Uncertainty of the level of rehabilitation required for JBCC gravity sewers
- Option 2A. Route utilizing the Shining Sea bike corridor, 1 lift station
    - 1 large lift station, 1400 gpm, 250 ft TDH, 175 hp
    - 14" forcemain, velocity 3.0 fps, 9.5 miles
    - Total route length, 9.5 miles
- Option 2B. Route utilizing the Shining Sea bike corridor, 2 lift stations
    - 2 large lift stations, 1250 gpm, 175 ft TDH, 100 hp
    - 12" forcemain, velocity 3.6 fps, 9.5 miles
    - Total route length, 9.5 miles
- Option 3A. Route primarily in public way
    - 1 large lift station, 1400 gpm, 250ft TDH, 175 hp

  - 14" forcemain, velocity 3.0 fps, 9.9 miles
  - Total route length, 9.9 miles

- Option 3B. Route primary in public way
  - 2 large lift stations, 1250 gpm, 175 ft TDH, 120 hp
  - 12" forcemain, velocity 3.6 fps, 9.9 miles
  - Total route length, 9.9 miles

Bourne Option 2A, 2B, 3A and 3B appear to be less favorable option based on the following:

- Advantage
  - Avoids having to obtain extensive construction easements within federal lands for forcemains
  - Avoids concern over the level of rehabilitation required for JBCC gravity sewers
- Disadvantage
  - High costs

One alignment was investigated for Bourne effluent flow from the ISWM WWTF to the JBCC effluent forcemain. We assumed the construction of a medium sized lift station to accommodate long-term conditions.

  - 1 medium lift stations, 570 gpm, 180 ft TDH, 50 hp, Velocity 1.7 fps
  - Existing 8" Forcemain, 100 feet

A summary of the Bourne-South Options is shown below.

TABLE 4: BOURNE CONVEYANCE ALTERNATIVES COMPARISON

Conveyance Feature		Option 1	Option 2A	Option 2B	Option 3A	Option 3B
Cost	$M	9.9	14.0	15.5	16.0	17.5
Rehabilitated JBCC sewer (50% Share)	1000 ft	12.3	0.0	0.0	0.0	0.0
Medium PS (Bourne – North)	Each	1	1	1	1	1
Large PS	Each	1	1	2	1	2
Forcemain in public way/dense	1000 ft	12.7	38.5	38.5	17.8	17.8
Forcemain off public way/less dense	1000 ft	14.5	13.5	13.5	32.2	32.2

1.3.2 Falmouth Alignments

The following alignments were investigated for Falmouth effluent flow from the BSR WWTF to the JBCC WWTF effluent forcemain. This piping is required in the mid-term.

- Option 1. Route in public way
    - 1 Large lift station, 1300 gpm, 220 ft TDH, 150 hp
    - 18" Falmouth effluent forcemain, velocity 1.7 fps, 6.7 miles
    - Total route length, 6.7 miles
    - Advantages
        - Least expensive by $100,000
        - Eliminates potentially expensive railroad coordination costs in Option 3
    - Disadvantage
        - Lengthy section of the route is in right of way
- Option 2. Route in public way, with semi-utilization of the Shining Sea bike corridor
    - 1 Large lift station, 1300 gpm, 220 ft TDH, 150 hp
    - 18" Falmouth effluent forcemain, velocity 1.7 fps, 8.1 miles
    - Total route length. 8.1 miles
    - Advantages
        - Shorter section of the route is in right of way
        - Eliminates potentially expensive railroad coordination costs in Option 3
    - Disadvantage
        - More expensive than Option 1 by $1M
- Option 3. Route in public way and rail right of way
    - 1 Large lift station, 1300 gpm, 220 ft TDH, 150 hp
    - 18" Falmouth effluent forcemain, velocity 1.7 fps, 5.3 miles
    - Total route length, 5.3 miles
    - Advantages
        - Shortest route
        - Potential to be less expensive with favorable railroad coordination costs

- Disadvantages
  - Costs associated with railroad safety and flagmen expenses during construction and regular operation
  - Efficient access to the rail corridor during and after construction
  - Potential damage from vibration caused by rail traffic

A summary of the Falmouth Conveyance Options is shown below.

TABLE 5: FALMOUTH CONVEYANCE ALTERNATIVES COMPARISON

Conveyance Feature		Option 1	Option 2	Option 3
Cost	$M	11.7	12.7	11.8
Large PS	Each	1	1	1
Forcemain in public way/dense	1000 ft	25.9	20.1	13.8
Forcemain in railroad right of way	1000 ft	0.0	0.0	14.2
Forcemain off public way/less dense	1000 ft	9.5	22.6	0.0

1.3.3 Mashpee Alignments

The following alignments were investigated for Mashpee sewage flow to the JBCC WWTF. This piping is required in the short-term.

- Option 1. Mashpee forcemain to connect directly to JBCC WWTF
  - Medium lift station, 560 gpm, 75 ft TDH, 20 hp
  - 8” Dedicated Mashpee forcemain, velocity 3.5 fps, 1.4 miles
  - Total route length: 1.4 miles
  - Advantages
    - Least expensive by $1.7M
    - Shortest forcemain route by 3.4 miles
    - Reduced lift station size
    - Smaller diameter force main
  - Disadvantages
    - None

- Option 2. Mashpee forcemain to shared rehabilitated gravity main with Sandwich and Bourne
    - Medium lift station, 1040 gpm, 140 ft TDH, 70 hp
    - 12" Dedicated Mashpee forcemain, velocity 3.0 fps, 4.2 miles
    - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne and Sandwich
    - Total route length: 4.8 miles
    - If the existing 10-inch JBCC forcemain serving JBCC lift stations at Rocket Storage, Central Heating Plant and Hanger was rehabilitated or decommissioned, there could be cost advantages for Mashpee.
    - Advantages
        - Forcemain would be dedicated to Mashpee and maintaining correct operating conditions would be easier for Mashpee.
        - If the existing 10-inch JBCC forcemain serving JBCC lift stations at Rocket Storage, Central Heating Plant and Hanger was rehabilitated or decommissioned, there could be cost advantages for Mashpee.
    - Disadvantages
        - More expensive than Option 1 by $2.4M. (Note: Mashpee Option 3 requires Sandwich to choose Option 2 which is $0.8M more expensive for Sandwich).
- Option 3. Mashpee forcemain to forcemain shared with Sandwich and rehabilitated gravity main shared with Sandwich and Bourne
    - Medium lift station, 1040 gpm, 140 ft TDH, 70 hp
    - 12" Dedicated Mashpee forcemain, velocity 3.0 fps, 2.4 miles
    - 12" S Outer Road forcemain, 0.7 miles, shared with Sandwich
    - 12" Reilly Rd/Grandville Ave forcemain, 1.1 miles, shared with Sandwich
    - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne and Sandwich
    - Total route length: 4.8 miles
    - Advantages

        - If the existing 10-inch JBCC forcemain serving JBCC lift stations at Rocket Storage, Central Heating Plant and Hanger was rehabilitated or decommissioned, there could be additional cost advantages.
    - Disadvantages
        - More expensive than Option 1 by $1.7M.

A summary of the Mashpee options is shown below.

TABLE 6: MASHPEE CONVEYANCE ALTERNATIVES COMPARISON

Conveyance Feature		Option 1	Option 2	Option 3
Cost	$M	2.5	4.9	4.2
Rehabilitated JBCC sewer (33% Share)	1000 ft	0	3.4	3.4
Medium PS	Each	1	1	1
Forcemain in public way/dense	1000 ft	7.5	3.0	3.0
Forcemain off public way/less dense	1000 ft	0	18.9	9.7
Forcemain off public way/less dense - 50% share with Sandwich	1000 ft	0	0.0	9.3

1.3.4 Sandwich Alignments

The following alignments were investigated for Sandwich sewage flow to the JBCC WWTF. The conveyance system is required in the mid-term.

- Option 1. Sandwich forcemain to connect to shared rehabilitated gravity main with Bourne
    - Medium lift station, 1050 gpm, 75 ft TDH, 40 hp
    - 12” Dedicated Sandwich forcemain, velocity 3.0 fps, 2.9 miles
    - JBCC rehabilitated gravity sewer, 0.4 miles
    - JBCC rehabilitated gravity sewer, 1.7 miles, shared with Bourne
    - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne
    - Total route length: 5.7 miles
    - Advantages
        - Least expensive by $0.8M
        - Shortest forcemain route by 0.9 miles
    - Disadvantages

        - Uncertainty of obtaining construction easements within federal lands for forcemains
        - Uncertainty of the level of rehabilitation required for JBCC gravity sewer mains.

- Option 2. Sandwich forcemain to connect shared forcemain with Mashpee (Mashpee Option 2) and shared rehabilitated gravity main with Bourne and Mashpee
    - Medium lift station, 1050 gpm, 140 ft TDH, 60 hp
    - 12" Dedicated Sandwich forcemain, velocity 3.0 fps, 4.2 miles
    - 12" S Outer Road forcemain, 0.7 miles, shared with Mashpee
    - 12" Reilly Rd/Grandville Ave forcemain, 1.1 miles, shared with Mashpee
    - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne and Sandwich
    - Total route length: 6.6 miles
    - Advantages
        - If Mashpee implements Option 2, there would be cost savings with implementation of Sandwich Option 2.
    - Disadvantages
        - More expensive by $0.8M

TABLE 7: SANDWICH CONVEYANCE ALTERNATIVES COMPARISON

Conveyance Feature		Option 1	Option 2
Cost	$M	5.0	5.8
Rehabilitated JBCC sewer (100% Share)	1000 ft	2.2	0.0
Rehabilitated JBCC sewer (50% Share)	1000 ft	12.3	3.4
Medium PS	Each	1	1
Forcemain in public way/dense	1000 ft	3.5	3.5
Forcemain off public way/less dense	1000 ft	11.9	18.3
Forcemain off public way/less dense – share with Mashpee	1000 ft	0.0	9.3

1.3.5 Effluent Conveyance Systems

The effluent conveyance system will require improvements to accommodate anticipated flow increases in each phase.

- Existing Conveyance System Data
    - Existing forcemain
        - 12-inch diameter
        - 10.8 miles
        - Ductile iron
        - Design friction factor, C, 130
        - Distance to high point, 5.8 miles (30,600 feet)
        - Static head: 210 feet
    - Existing system design assumptions
        - Conveyance main operates as a forcemain to the high point and forcemain friction calculations are based on 5.8 miles.
        - From the high point, around 150 feet of head is available to drive flow to the RIB's. A flow of about 1500 gpm uses up the available head.
        - With one pump running at the JBCC WWTF, there is available capacity in the short term for Bourne to discharge treated effluent into the JBCC forcemain at the ISWM.

1.4 SCHEDULE OF IMPROVEMENTS

1.4.1 Short-term improvements:

- JBCC / All Participants
    - Maintain operation of existing lift station and forcemain
    - Accommodate flows from JBCC and Mashpee arriving at the effluent lift station (252,000 gpd / peaked pump flow of 320 gpm)

- Bourne
  - At the ISWM, install a lift station designed to accommodate mid-term and long-term flows
  - Make connection to existing JBCC forcemain
  - Install additional valves and stubs to make a future connection to new effluent forcemains without disrupting service.
- Falmouth – no changes
- Mashpee
  - Construct Mashpee lift station and forcemain conveying flow to the WWTF.
- Sandwich – no changes

1.4.2 Mid-term improvements:

- JBCC / All Participants
  - Maintain operation of existing lift station and forcemain
  - Accommodate effluent from JBCC, Bourne-South, Mashpee and Sandwich in the existing effluent forcemain (peaked pump flow of 640 gpm)
  - Construct new parallel forcemain from Falmouth connection to the RIB's with interconnection valving with existing 12-inch forcemain
- Bourne
  - Connect ISWM forcemain into new 18-inch forcemain (peaked flows increase from 87 to 385 gpm)
  - Construct Bourne Option 1 including lift station, forcemain and JBCC gravity sewer rehabilitation
- Falmouth
  - Construct Falmouth 18-inch forcemain to valving interconnection with existing 12-inch forcemain and new 18-inch forcemain
  - Direct Falmouth flow to new 18-inch forcemain (peaked pump flow of 444 gpm)
- Mashpee – no changes
- Sandwich

- Construct Sandwich lift station, forcemain and JBCC gravity sewer rehabilitation

1.4.3 Long-term improvements

- JBCC / All Participants
  - Construct second 18-inch effluent forcemain and interconnections
- Bourne
  - Connect discharge from ISWM WWTF to second JBCC 18-inch forcemain

ATTACHMENT A

Conveyance Options Worksheets

LIST OF FIGURES

1-1 Bourne -N Effluent Disposal

2-1 Bourne-S Option 1

2-2 Bourne-S Option 2

2-3 Bourne-S Option 3

3-1 Falmouth Option 1

3-2 Falmouth Option 2

3-3 Falmouth Option 3

4-1 Mashpee Option 1

4-2 Mashpee Option 2

4-3 Mashpee Option 3

5-1 Sandwich Option 1

5-2 Sandwich Option 2

6-1 JBCC Effluent Forcemain- Existing Route

6-2 JBCC Effluent Forcemain- Alternate Route

Bourne-N Option 1 **Preferred**

Option 1. Bourne force main to existing JBCC effluent force main

Site Conditions:

Single Pump Station

Length (miles), (ft) - 100 total length Run friction calc only to high point

Average C 130

Low point (ft) 108 (Existing grade at pump station minus 25 feet)

High point(ft) 285 (Existing grade at pump station minus 5 feet)

Static Head(ft) 177

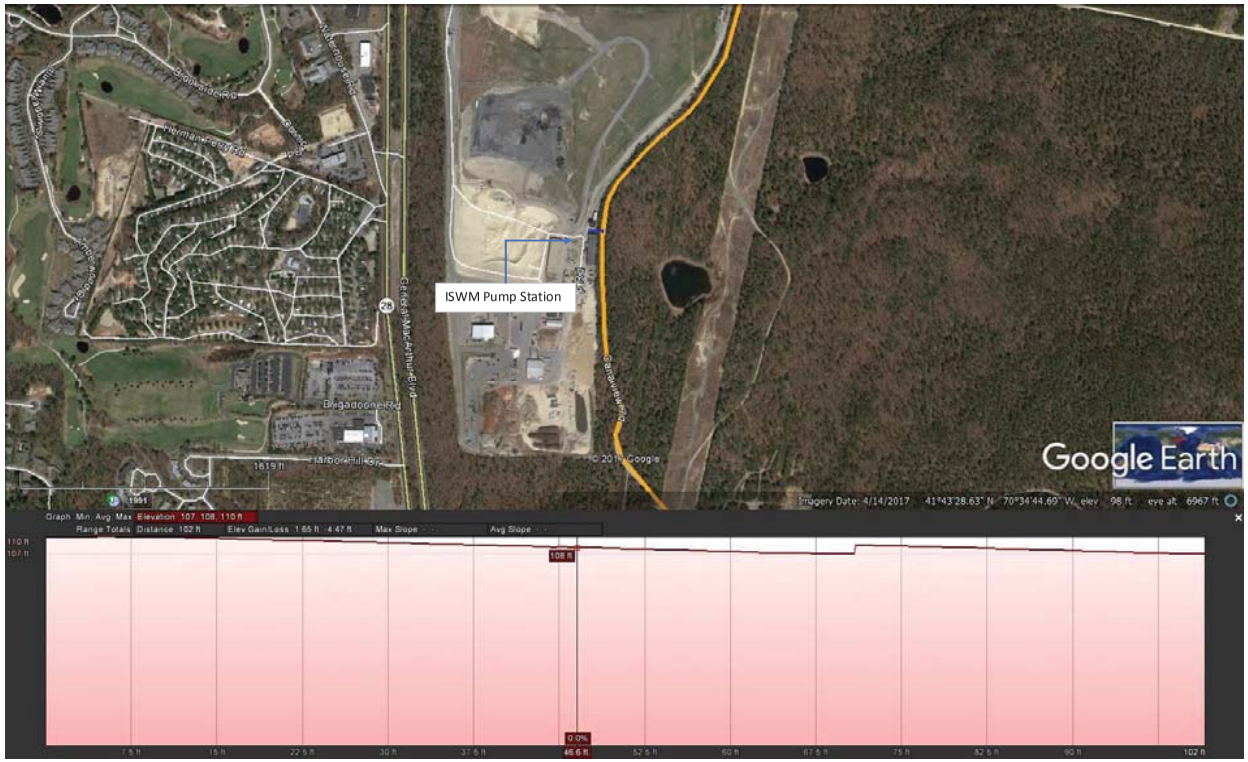
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Bourne-N	-	-	100,000	87	444,000	385	651,000	565
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	100,000	87	444,000	385	651,000	565
Flow(cfs)		0.00		0.19		0.86		1.26

Segment 1 Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
3	0.0	177	3.9	179	17.5	214	25.7	253
4	0.0	177	2.2	178	9.8	186	14.4	196
6	0.0	177	1.0	177	4.4	178	6.4	180
8	0.0	177	0.6	177	2.5	177	3.6	178
10	0.0	177	0.4	177	1.6	177	2.3	177
12	0.0	177	0.2	177	1.1	177	1.6	177

Figure 1-1



Bourne Option 1 **Preferred**

Option 1. Bourne force main to shared rehabilitated gravity main with Sandwich and Mashpee

Site Conditions:

Single Pump Station **Preferred**

Length (miles), (ft)	3.23	17054.4 total length	Run friction calc only to high point
Average C	130		
Low point (ft)	5	(Existing grade at pump station minus 25 feet)	
High point(ft)	175	(Existing grade at pump station minus 5 feet)	
Static Head(ft)	170		

Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Bourne-S	-	-	-	-	259,000	719	456,000	1,267
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	-	-	259,000	719	456,000	1,267
Flow(cfs)		0.00		0.00		1.60		2.82

Single FM Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
6	0.0	170	0.0	170	8.2	861	14.4	2137
8	0.0	170	0.0	170	4.6	340	8.1	655
10	0.0	170	0.0	170	2.9	227	5.2	334
12	0.0	170	0.0	170	2.0	194	3.6	237
14	0.0	170	0.0	170	1.5	181	2.6	202

Figure 2-1



Bourne Option 2

Description: Bourne Raw Wastewater Forcemain-Shining Sea Alternate Path.

Option 2A Single Pump Station Option

Length (miles), (ft)	9.48	50054.4
Average C	130	
Low point (ft)	5	
High Point (ft)	135	
Static Head(ft)	130	

Option 2B Two Pump Station Option

Segment 1	9.48	total length
Length (miles), (ft)	5.1	26928
Average C	130	
Low point (ft)	5	(Existing grade at pump station minus 25 feet)
High point(ft)	75	(Existing grade at pump station minus 5 feet)
Static Head(ft)	70	

$$H.L. = 3.02LD^{(-1.167)}(V/C_h)^{1.85}$$

Segment 2		
Length (miles), (ft)	4.38	23126.4
Average C	130	
Low point (ft)	55	(Existing grade at pump station minus 25 feet)
High point(ft)	135	(Existing grade at pump station minus 5 feet)
Static Head(ft)	80	

Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Bourne-S	-	-	-	-	259,000	719	456,000	1,267
Add'l flow for min v	-	-	-	-	-	-	-	153
Total	-	-	-	-	259,000	719	456,000	1,420
Flow(cfs) - 14" FM		0.00		0.00		1.60		3.16
Flow(cfs) - 12" FM								2.82

Option 2A-Single Pump Station

Single Force Main Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	130	0.0	130	2.0	199	4.0	374
14	0.0	130	0.0	130	1.5	163	3.0	245

Option 2B- Two Pump Stations

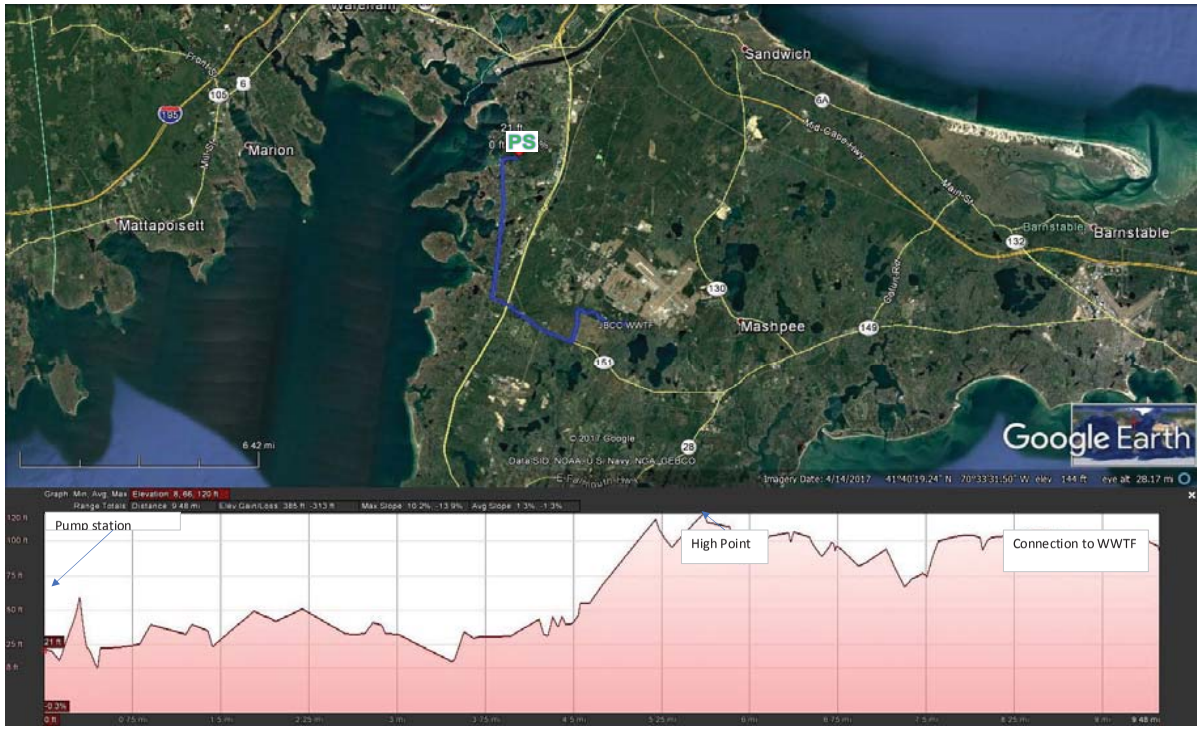
Segment 1: Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	70	0.0	70	2.0	107	3.6	176
14	0.0	70	0.0	70	1.5	88	2.6	120

Segment 2: Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	80	0.0	80	2.0	112	3.6	171
14	0.0	80	0.0	80	1.5	95	2.6	123

Figure 2-2



Bourne Option 3

Description: Force main dedicated to future Bourne Raw Wastewater pump flow.

Site Conditions:

Option 3A - Single Pump Station

Length (miles), (ft)	9.85	52008	5.5
Average C	130		
Low point (ft)	5	(Existing grade at pump station minus 25 feet)	
High point(ft)	135	(Existing grade at pum	100
Static Head(ft)	130		

$$H.L. = 3.02LD^{(-1.167)}(V/C_h)^{1.85}$$

Option 3B- Two Pump Stations

Segment 1 9.85 total length

Length (miles), (ft)	5.5	29040
Average C	130	
Low point (ft)	5	(Existing grade at pump station minus 25 feet)
High point(ft)	100	(Existing grade at pump station minus 5 feet)
Static Head(ft)	95	

$$H.L. = 3.02LD^{(-1.167)}(V/C_h)^{1.85}$$

Segment 2

Length (miles), (ft)	4.35	22968
Average C	130	
Low point (ft)	80	(Existing grade at pump station minus 25 feet)
High point(ft)	135	(Existing grade at pump station minus 5 feet)
Static Head(ft)	55	

Flow Conditions

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Bourne-S	-	-	-	-	259,000	719	456,000	1,267
Add'l flow for min v	-	-	-	-	-	-	-	153
Total	-	-	-	-	259,000	719	456,000	1,420
Flow(cfs)		0.00		0.00		1.60		3.16
Flow(cfs) - 12" FM								2.82

Option 3A -Single FM Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	130	0.0	130	2.0	202	4.0	384
14	0.0	130	0.0	130	1.5	164	3.0	250

Option 3B- Two Pump Stations Option

Segment 1: Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	95	0.0	95	2.0	135	3.6	210
14	0.0	95	0.0	95	1.5	114	2.6	149

Segment 2: Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	55	0.0	55	2.0	87	3.6	146
14	0.0	55	0.0	55	1.5	70	2.6	98

Figure 2-3



Falmouth Option 1 **Preferred**

Description: Force main dedicated to future Falmouth pump flow.

Site Conditions:

Length (miles), (ft)		
Falmouth	6.67	35217.6
JBBC to High Point	5.8	30624
Total Length	12.47	65841.6
Average C	130	
Low point (ft)	110	(Existing grade at pump station minus 10 feet)
High point(ft)	286	(effluent force main Highpoint)
Static Head(ft)	176	

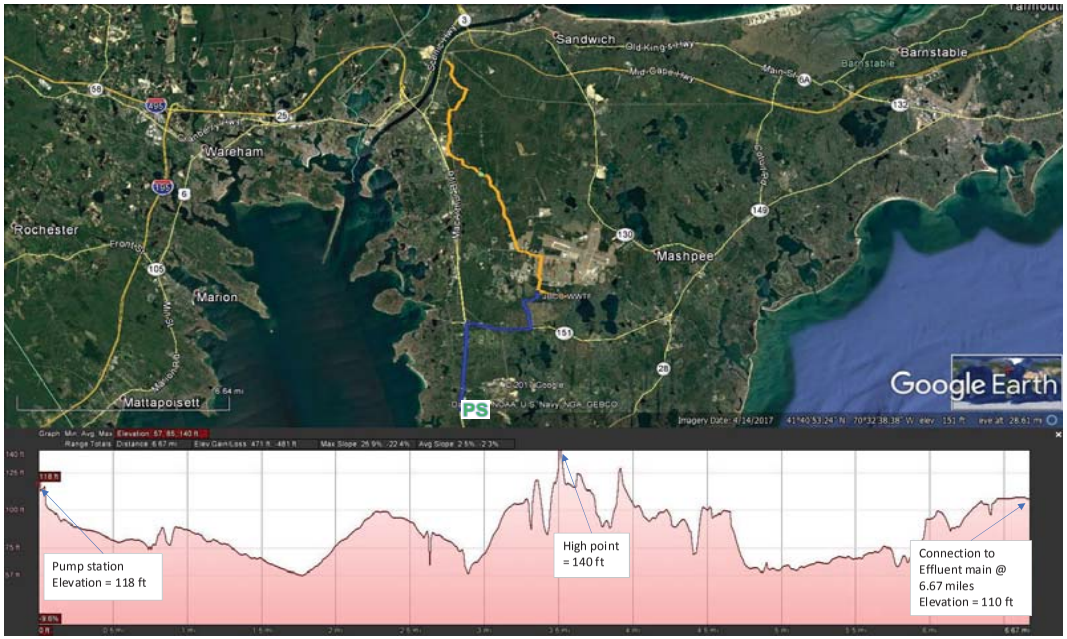
Flow Condtions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Falmouth	-	-	-	-	512,000	444	1,512,000	1,313
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	-	-	512,000	444	1,512,000	1,313
Flow(cfs)		0.00		0.00		0.99		2.92

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	176	0.0	176	2.8	446	8.4	2176
10	0.0	176	0.0	176	1.8	267	5.4	851
12	0.0	176	0.0	176	1.3	213	3.7	454
14	0.0	176	0.0	176	0.9	194	2.7	307
16	0.0	176	0.0	176	0.7	185	2.1	245
18	0.0	176	0.0	176	0.6	181	1.7	215
20	0.0	176	0.0	176	0.5	179	1.3	199
22	0.0	176	0.0	176	0.4	178	1.1	191
24	0.0	176	0.0	176	0.3	177	0.9	186

Figure 3-1



Falmouth Option 2

Description: Force main dedicated to future Falmouth disposal to JBCC using existing shining sea bikeway

Site Conditions:

Length (miles), (ft)		
Falmouth	8.09	42715.2
JBBC to High Point	5.8	30624
Total Length	13.89	73339.2 For TDH Calc
Average C	130	
Low point (ft)	110	(Existing grade at pump station minus 10 feet)
High point(ft)	286	(effluent force main Highpoint)
Static Head(ft)	176	

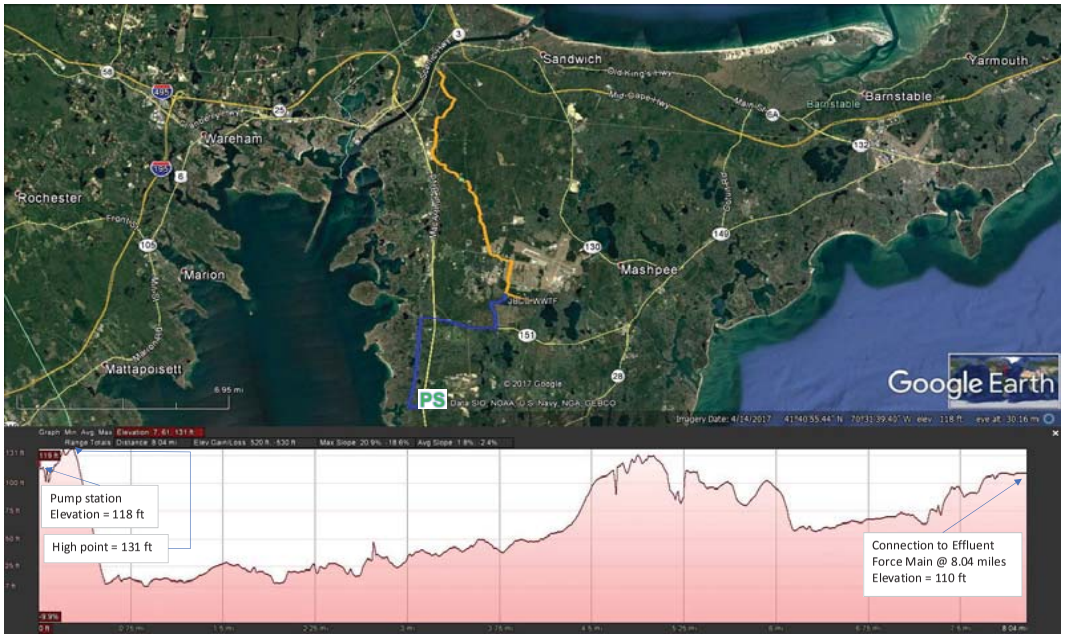
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Falmouth	-	-	-	-	512,000.00	444.44	1,512,000.00	1,312.50
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	-	-	512,000.00	444.44	1,512,000.00	1,312.50
Flow(cfs)		0.00		0.00		0.99		2.92

Pipe Diamter Anaylsis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	176	0.0	176	2.8	476	8.4	2404
10	0.0	176	0.0	176	1.8	277	5.4	928
12	0.0	176	0.0	176	1.3	218	3.7	486
14	0.0	176	0.0	176	0.9	196	2.7	322
16	0.0	176	0.0	176	0.7	186	2.1	252
18	0.0	176	0.0	176	0.6	182	1.7	219
20	0.0	176	0.0	176	0.5	179	1.3	202
22	0.0	176	0.0	176	0.4	178	1.1	192
24	0.0	176	0.0	176	0.3	177	0.9	187

Figure 3-2



Falmouth Option 3

Description: Force main dedicated to future Falmouth disposal to JBCC WWTF, routed along JBCC rail line

Site Conditions:

Length (miles), (ft)		
Falmouth	5.3	27984
JBBC to High Point	5.8	30624
Total Length	11.1	58608 For TDH Calc
Average C	130	
Low point (ft)	110	(Existing grade at pump station minus 10 feet)
High point(ft)	286	(effluent force main Highpoint)
Static Head(ft)	176	

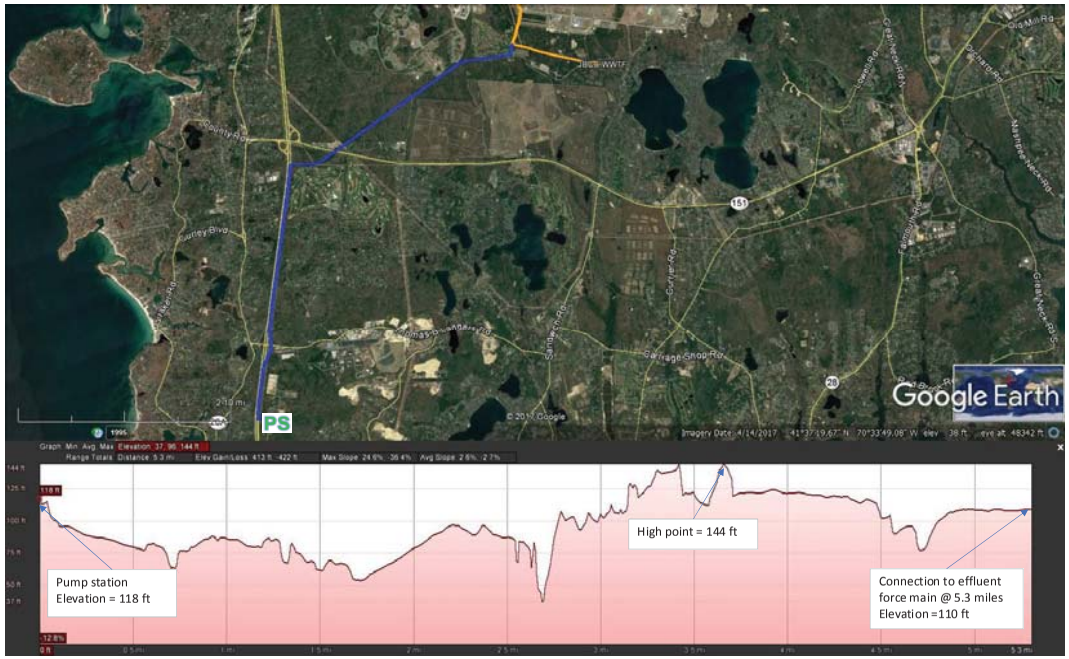
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Falmouth	-	-	-	-	512,000.00	444.44	1,512,000.00	1,312.50
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	-	-	512,000.00	444.44	1,512,000.00	1,312.50
Flow(cfs)		0.00		0.00		0.99		2.92

Pipe Diamter Anaylsis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	176	0.0	176	2.8	416	8.4	1956
10	0.0	176	0.0	176	1.8	257	5.4	777
12	0.0	176	0.0	176	1.3	209	3.7	423
14	0.0	176	0.0	176	0.9	192	2.7	293
16	0.0	176	0.0	176	0.7	184	2.1	237
18	0.0	176	0.0	176	0.6	181	1.7	210
20	0.0	176	0.0	176	0.5	179	1.3	197
22	0.0	176	0.0	176	0.4	178	1.1	189
24	0.0	176	0.0	176	0.3	177	0.9	184

Figure 3-3



Mashpee Option 1 **Preferred**
Mashpee force main to JBCC WWTF

Site Conditions:

Length (miles), (ft)		
Mashpee	1.42	7497.6
Average C	130	
Low point (ft)	72	(Existing grade at pump station minus 25 feet)
High point(ft)	102	
Static Head(ft)	30	

Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Mashpee	-	-	200,000	556	200,000	556	200,000	556
Total	-	-	200,000	556	200,000	556	200,000	556
Flow(cfs)		0.00		1.24		1.24		1.24

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	30	3.5	76	3.5	76	3.5	76
10	0.0	30	2.3	46	2.3	46	2.3	46
12	0.0	30	1.6	36	1.6	36	1.6	36

Figure 4-1



Mashpee Option 2

Mashpee force main to shared force main and rehabilitated gravity main with Sandwich and Bourne

Site Conditions:

Length (miles), (ft)		
Mashpee	2.4	12672
Mashpee-Sandich FM	1.77	9345.6
Total Length	4.17	22017.6
Average C	130	
Low point (ft)	26	(Existing grade at pump station minus 25 feet)
High point(ft)	101	
Static Head(ft)	75	

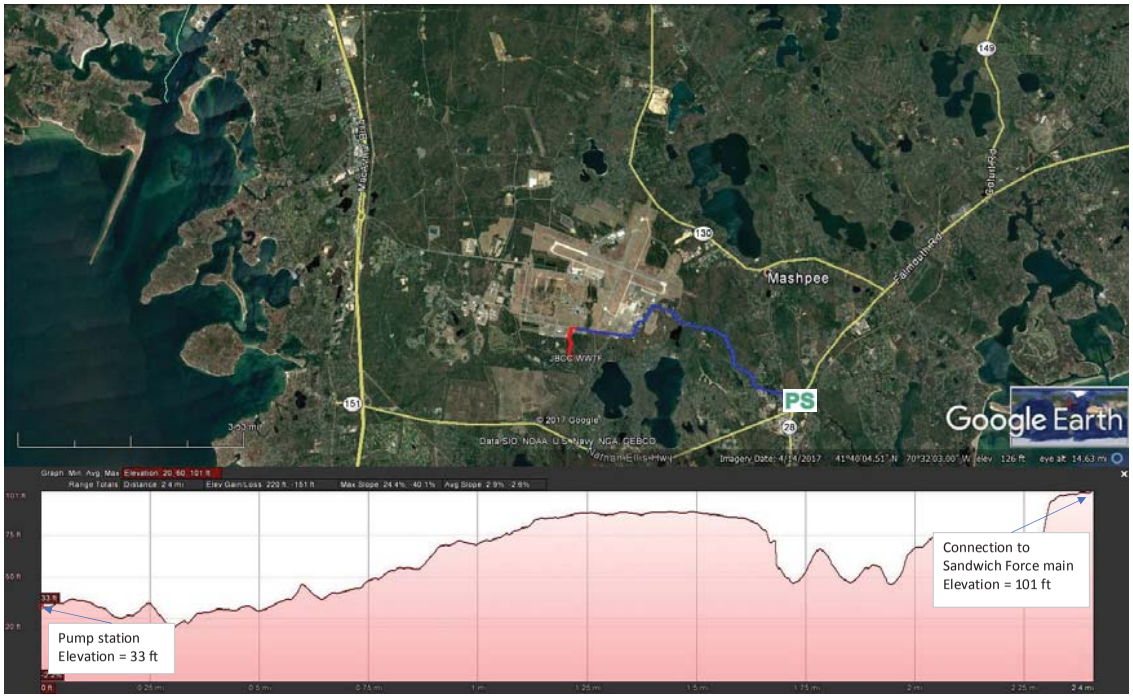
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Mashpee	-	-	200,000	556	200,000	556	200,000	556
Add'l flow for min v	-	-	-	-	-	-	175,000	486
Total	-	-	200,000	556	200,000	556	375,000	1,042
Flow(cfs)		0.00		1.24		1.24		2.32

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
10	0.0	75	2.3	121	2.3	121	4.3	222
12	0.0	75	1.6	94	1.6	94	3.0	136

Figure 4-2



Mashpee Option 3

Mashpee force mains to shared rehabilitated gravity main with Sandwich and Bourne

Site Conditions:

Length (miles), (ft)		
Mashpee	3.4	17952
Mashpee to Gravity	0.74	3907.2
Total Length	4.14	21859.2
Average C	130	
Low point (ft)	26	(Existing grade at pump station minus 25 feet)
High point(ft)	101	
Static Head(ft)	75	

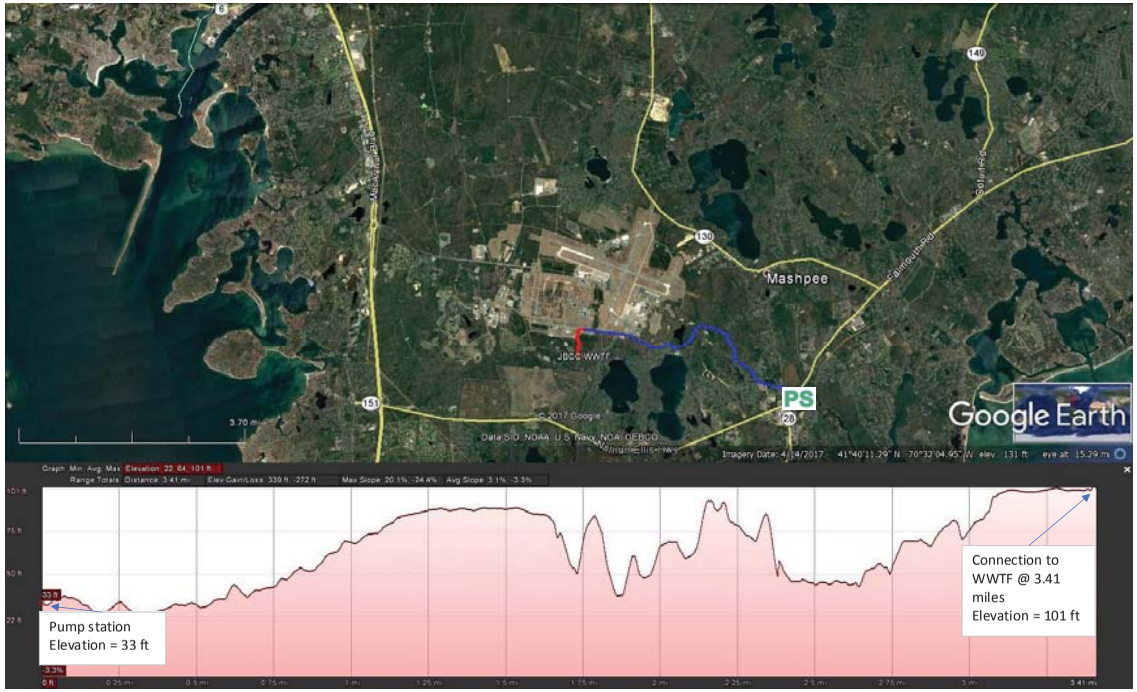
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Mashpee	-	-	200,000	556	200,000	556	200,000	556
Add'l flow for min v	-	-	-	-	-	-	175,000	486
Total	-	-	200,000	556	200,000	556	375,000	1,042
Flow(cfs)		0.00		1.24		1.24		2.32

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
10	0.0	75	2.3	121	2.3	121	4.3	221
12	0.0	75	1.6	94	1.6	94	3.0	135

Figure 4-3



Sandwich Option 1 **Preferred**

Description: Force main for Sandwich raw wastewater connection to existing system

Site Conditions:

Length (miles), (ft)	2.92	15417.6
Average C	130	
Low point (ft)	107	(Existing grade at pump station minus 25 feet)
High point(ft)	140	
Static Head(ft)	33	

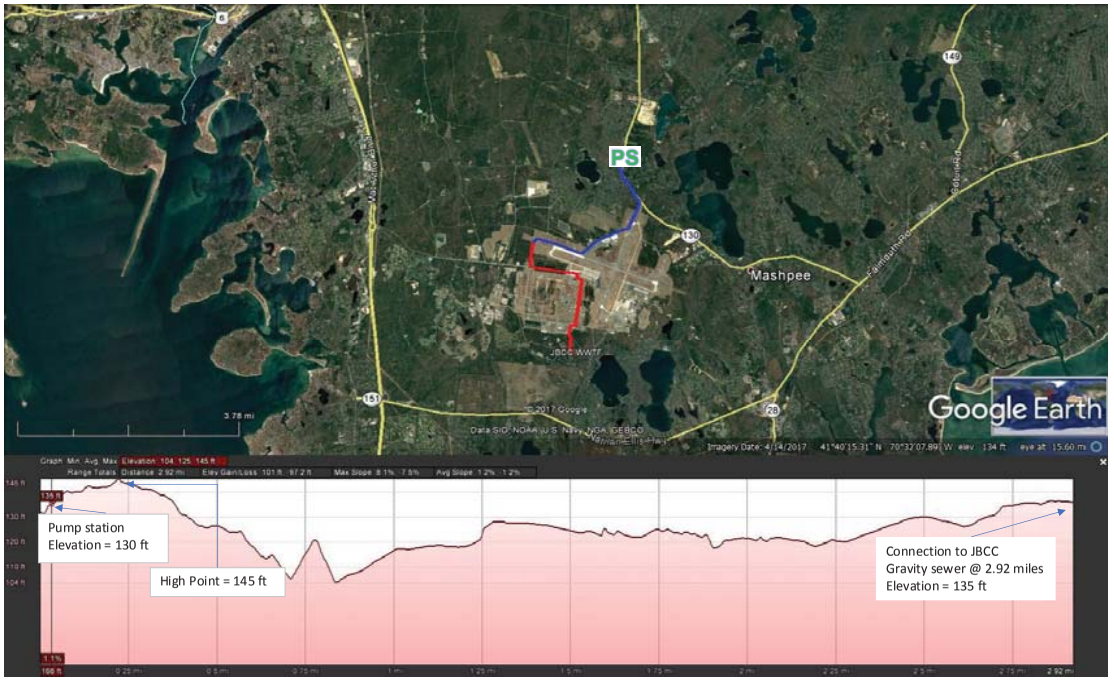
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Sandwich	-	-	-	-	100,000	278	340,000	944
Add'l flow for min v								100
Total	-	-	-	-	100,000	278	340,000	1,044
Flow(cfs)		0.00		0.00		0.62		2.33

Pipe Diameter Analysis

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
6	0.0	33	0.0	33	3.2	140	11.9	1278
8	0.0	33	0.0	33	1.8	59	6.7	340
10	0.0	33	0.0	33	1.1	42	4.3	137
12	0.0	33	0.0	33	0.8	37	3.0	76

Figure 5-1



Sandwich Option 2

Description: Sandwich force main for shared force main with Mashpee and shared gravity main with Mashpee and Bourne

Site Conditions:

Length (miles), (ft)

Sandwich	2.9	15312
Mashpee-Sandich FM	1.77	9345.6
Total Length	4.67	24657.6
Average C	130	
Low point (ft)	110	(Existing grade at pump station minus 25 feet)
High point(ft)	145	(Existing grade minus 5 feet)
Static Head(ft)	35	

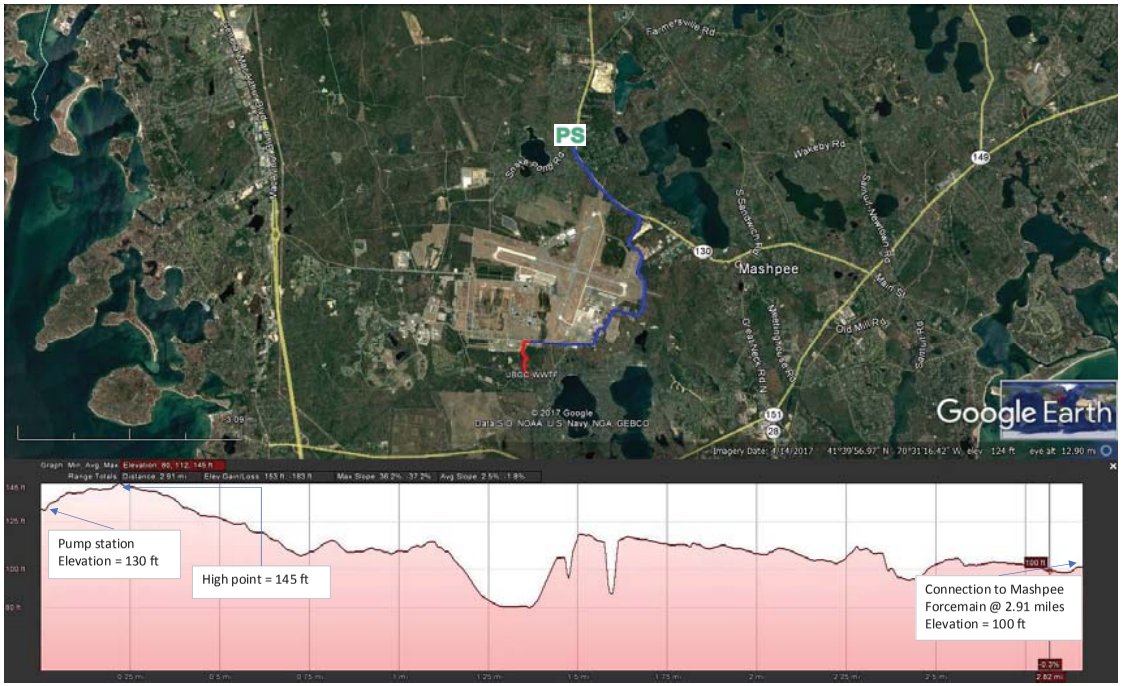
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Sandwich	-	-	-	-	100,000	278	340,000	944
Add'l flow for min v	-	-	-	-	-	0	-	100
Total	-	-	-	-	100,000	278	340,000	1,044
Flow(cfs)		0.00		0.00		0.62		2.33

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
6	0.0	35	0.0	35	3.2	207	11.9	2026
8	0.0	35	0.0	35	1.8	77	6.7	526
10	0.0	35	0.0	35	1.1	49	4.3	201
12	0.0	35	0.0	35	0.8	41	3.0	103

Figure 5-2



ATTACHMENT B

Conveyance Options Costs

JBCC SHARED WASTEWATER MANAGEMENT STUDY				ENR CCI	8600	Apr-10
ENGINEERING ASESSEMENT				ENR CCI	10800	Oct-17
Wright-Pierce, 26 Oct 2017						
COSTS FOR CONVEYANCE ALTERNATIVES				**Projected to October 2017 dollars**		
Capital Costs for Conveyance and Transport to Disposal						
Conveyance						
Conveyance-Bourne	Alt 1	Alt 2A	Alt 2B	Alt 3A	Alt 3B	
Sewers - Bourne - 50% Share with Sandwich						
Distance, 1000 ft	12.30	0.00	0.00	0.00	0.00	
Distance, miles	2.3	0.0	0.0	0.0	0.0	
Cost per foot - Rehabilitation	75	75	75	75	75	
Construction cost	920,000	0	0	0	0	
Pump Stations - Bourne						
Medium PS (200-1200 gpm)	1	1	1	1	1	
Unit Cost	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	
Large PS (1200+ gpm)	1	1	2	1	2	
Unit Cost	2,500,000	2,500,000	2,500,000	2,500,000	2,500,000	
Construction cost, pump stations	3,500,000	3,500,000	6,000,000	3,500,000	6,000,000	
Transport to Treatment - Public Way/Dense	12"	14"	12"	14"	12"	
Distance, 1000 ft	12.70	17.80	17.80	38.50	38.50	
Distance, miles	2.4	3.4	3.4	7.3	7.3	
Cost per foot	240	260	240	260	240	
Construction cost	3,050,000	4,630,000	4,270,000	10,010,000	9,240,000	
Transport to Treatment - Off Public Way/Less Dense	12"	14"	12"	14"	12"	
Distance, 1000 ft	14.50	32.20	32.20	13.50	13.50	
Distance, miles	2.7	6.1	6.1	2.6	2.6	
Cost per foot	160	180	160	180	160	
Construction cost	2,320,000	5,800,000	5,150,000	2,430,000	2,160,000	
ISWM Connection to Effluent Forcemain (LS)	100,000	100,000	100,000	100,000	100,000	
Construction cost, Total Conveyance- Bourne	9,890,000	14,030,000	15,520,000	16,040,000	17,500,000	
Total Route Distance, mile	7.4	9.5	9.5	9.9	9.9	
Conveyance-Falmouth	Alt 1	Alt 2	Alt 3			
Pump Stations-Falmouth						
Large PS (1200+ gpm)	1	1	1			
Unit Cost	2,500,000	2,500,000	2,500,000			
Construction cost, pump stations	2,500,000	2,500,000	2,500,000			
Transport to Disposal - Public Way/Dense	18"	18"	18"			
Distance, 1000 ft	25.90	20.10	13.80			
Distance, miles	4.9	3.8	2.6			
Cost per foot	280	280	280			
Construction cost	7,250,000	5,630,000	3,860,000			
Transport to Disposal - Railroad ROW	18"	18"	18"			
Distance, 1000 ft	0.00	0.00	14.20			
Distance, miles	0.0	0.0	2.7			
Cost per foot	380	380	380			
Construction cost	0	0	5,400,000			
Transport to Treatment - Off Public Way/Less Dense	18"	18"	18"			
Distance, 1000 ft	9.50	22.60	0.00			
Distance, miles	1.8	4.3	0.0			
Cost per foot	200	200	200			
Construction cost	1,900,000	4,520,000	0			
Construction cost, Total Conveyance-Falmouth	11,650,000	12,650,000	11,760,000			
Total Route Distance, mile	6.7	8.1	5.3			

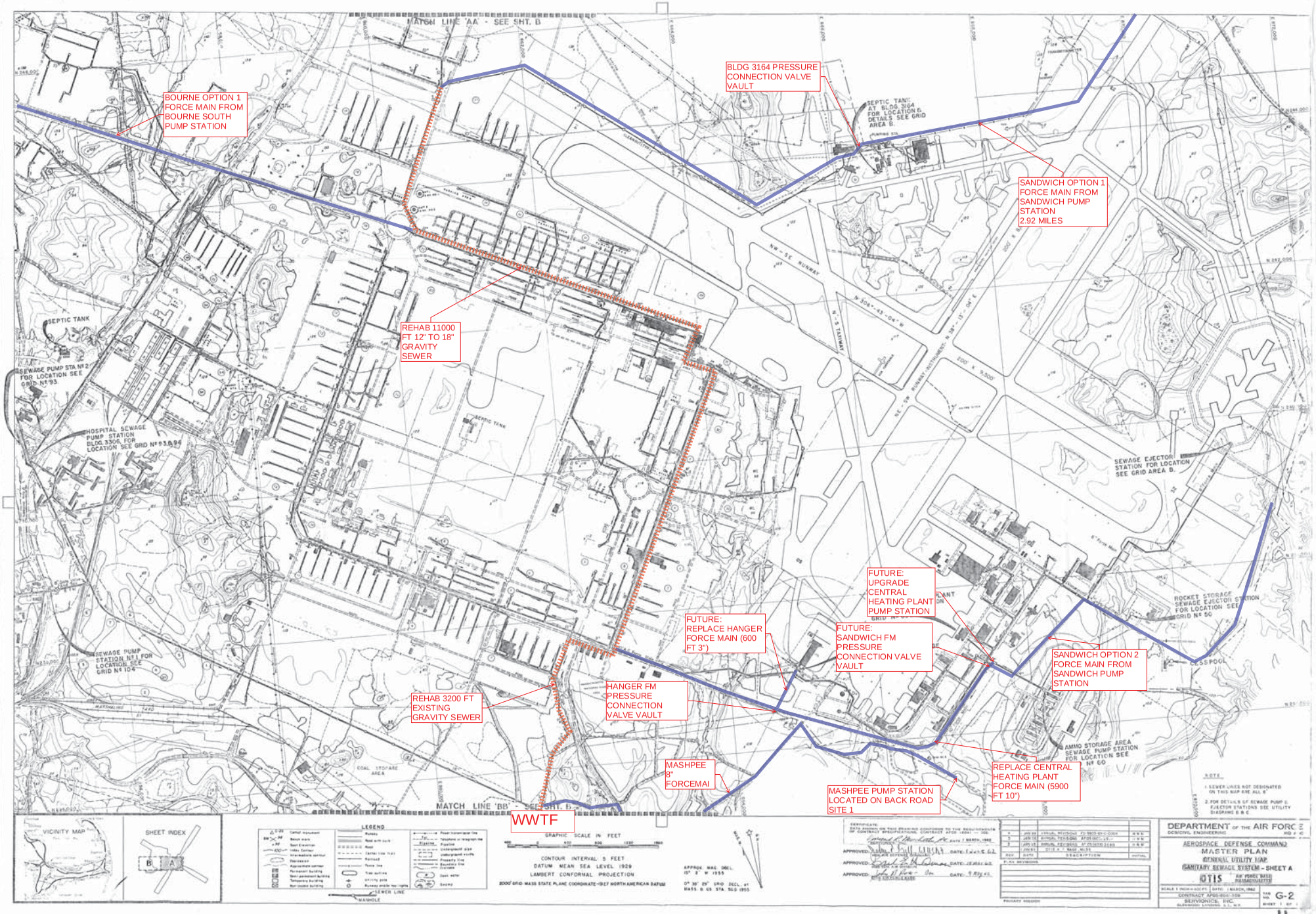
JBCC SHARED WASTEWATER MANAGEMENT STUDY				ENR CCI	8600	Apr-10
ENGINEERING ASESSEMENT				ENR CCI	10800	Oct-17
Wright-Pierce, 26 Oct 2017						
COSTS FOR CONVEYANCE ALTERNATIVES				**Projected to October 2017 dollars**		
Conveyance-Mashpee		Alt 1	Alt 2	Alt 3		
Sewers - Mashpee 33% Rehab						
Distance, 1000 ft		0.00	3.40	3.40		
Distance, miles		0.0	0.6	0.6		
Cost per foot (33% of 150)		50	50	50		
Construction cost		0	170,000	170,000		
Pump Stations-Mashpee						
Medium PS (200-1200 gpm)		1	1	1		
Unit Cost		1,000,000	1,000,000	1,000,000		
Large PS (1200+ gpm)		0	0	0		
Unit Cost		2,500,000	2,500,000	2,500,000		
Construction cost, pump stations		1,000,000	1,000,000	1,000,000		
Transport to Treatment - Public Way/Dense		8"	12"	12"		
Distance, 1000 ft		7.50	3.00	3.00		
Distance, miles		1.4	0.6	0.6		
Cost per foot		200	240	240		
Construction cost		1,500,000	720,000	720,000		
Transport to Treatment - Off Public Way/Less Dense			12"	12"		
Distance, 1000 ft		0.00	18.90	9.70		
Distance, miles		0.0	3.6	1.8		
Cost per foot		120	160	160		
Construction cost		0	3,020,000	1,550,000		
Transport to Treatment - Off Public Way/Less Dense - 50% Share with Sandwich			12"	12"		
Distance, 1000 ft		0.00	0.00	9.30		
Distance, miles		0.0	0.0	1.8		
Cost per foot		80	80	80		
Construction cost		0	0	740,000		
Construction cost, Total Conveyance-Mashpee		2,500,000	4,910,000	4,180,000		
Total Route Distance, mile		1.4	4.8	4.8		

JBCC SHARED WASTEWATER MANAGEMENT STUDY			ENR CCI	8600	Apr-10
ENGINEERING ASESSEMENT			ENR CCI	10800	Oct-17
Wright-Pierce, 26 Oct 2017					
COSTS FOR CONVEYANCE ALTERNATIVES			**Projected to October 2017 dollars**		
Conveyance-Sandwich	Alt 1	Alt 2			
Sewers - Sandwich - Dedicated					
Distance, 1000 ft	2.20	0.00			
Distance, miles	0.4	0.0			
Cost per foot	150	150			
Construction cost	330,000	0			
Sewers - Sandwich - 50% Share with Bourne					
Distance, 1000 ft	12.30	3.40			
Distance, miles	2.3	0.6			
Cost per foot	75	75			
Construction cost	920,000	260,000			
Pump Stations-Sandwich					
Medium PS (200-1200 gpm)	1	1			
Unit Cost	1,000,000	1,000,000			
Large PS (1200+ gpm)	0	0			
Unit Cost	2,500,000	2,500,000			
Construction cost, pump stations	1,000,000	1,000,000			
Transport to Treatment - Public Way/Dense	12"	12"			
Distance, 1000 ft	3.50	3.50			
Distance, miles	0.7	0.7			
Cost per foot	240	240			
Construction cost	840,000	840,000			
Transport to Treatment - Off Public Way/Less Dense	12"	12"			
Distance, 1000 ft	11.90	18.30			
Distance, miles	2.3	3.5			
Cost per foot	160	160			
Construction cost	1,900,000	2,930,000			
Transport to Treatment - Off Public Way/Less Dense - 50% Share with Mashpee	12"	12"			
Distance, 1000 ft	0.00	9.30			
Distance, miles	0.0	1.8			
Cost per foot	80	80			
Construction cost	0	740,000			
Construction cost, Total Conveyance-Sandwich	4,990,000	5,770,000			
Total Route Distance, mile	5.7	6.6			
Conveyance Cost Summary					
Sewers					
Construction cost	2,170,000				
Pump Stations					
Construction cost, pump stations	8,000,000				
Transport to Treatment					
Construction cost	18,860,000				
Construction Cost, Total Conveyance	29,030,000				
Cross Check	29,030,000				

ATTACHMENT C

JBBC Conveyance

Improvements Worksheet


BOURNE OPTION 1 FORCE MAIN FROM BOURNE SOUTH PUMP STATION
BLDG 3164 PRESSURE CONNECTION VALVE VAULT
SANDWICH OPTION 1 FORCE MAIN FROM SANDWICH PUMP STATION 2.92 MILES
REHAB 11000 FT 12" TO 18" GRAVITY SEWER
FUTURE: UPGRADE CENTRAL HEATING PLANT PUMP STATION
FUTURE: REPLACE HANGER FORCE MAIN (600 FT 3")
FUTURE: SANDWICH FM PRESSURE CONNECTION VALVE VAULT
SANDWICH OPTION 2 FORCE MAIN FROM SANDWICH PUMP STATION
REHAB 3200 FT EXISTING GRAVITY SEWER
HANGER FM PRESSURE CONNECTION VALVE VAULT
MASHPEE 8" FORCEMAI
REPLACE CENTRAL HEATING PLANT FORCE MAIN (5900 FT 10")
MASHPEE PUMP STATION LOCATED ON BACK ROAD SITE 1
WWTF
MATCH LINE 'AA' - SEE SHT. B
MATCH LINE 'BB' - SEE SHT. B
SEPTIC TANK AT BLDG 3164 FOR LOCATION & DETAILS SEE GRID AREA B.
SEWAGE EJECTOR STATION FOR LOCATION SEE GRID AREA B.
SEWAGE PUMP STA Nº 2 FOR LOCATION SEE GRID Nº 93
HOSPITAL SEWAGE PUMP STATION BLDG 3306 FOR LOCATION SEE GRID Nº 93 & 95
SEWAGE PUMP STATION Nº 1 FOR LOCATION SEE GRID Nº 104
ROCKET STORAGE SEWAGE EJECTOR STATION FOR LOCATION SEE GRID Nº 50
AMMO STORAGE AREA SEWAGE PUMP STATION FOR LOCATION SEE Nº 60
CESSPOOL
COAL STORAGE AREA
NW-SE RUNWAY
N-S TAXIWAY
VICINITY MAP
SHEET INDEX
LEGEND
GRAPHIC SCALE IN FEET
CONTOUR INTERVAL 5 FEET
DATUM MEAN SEA LEVEL 1929
LAMBERT CONFORMAL PROJECTION
DEPARTMENT OF THE AIR FORCE
AEROSPACE DEFENSE COMMAND
MASTER PLAN
GENERAL UTILITY MAP
SANITARY SEWAGE SYSTEM - SHEET A
OTIS AIR FORCE BASE MASSACHUSETTS
SERVIONICS, INC.
G-2

WRIGHT-PIERCE
Engineering a Better Environment

MEMORANDUM

TO:	File	**DATE:**	11/27/2017
FROM:	Ed Leonard	**PROJECT NO.:**	13839A
SUBJECT:	JBCC Shared Wastewater Management Study Cost Estimate Backup Materials		

Attached are the following cost estimate backup materials:

1. Costs for Conveyance Alternatives (Existing/ Short-Term/ Mid-Term/ Long-Term)
2. Costs for Treatment, Transport-to-Disposal and Disposal Alternatives (Long-Term)
3. Costs for Composite Wastewater Management Alternatives (Long-Term)
4. Cost Allocation for Composite Wastewater Alternative, Option 6 (All Phases)
5. Cost Comparison for Bourne and Sandwich

JBCC SHARED WASTEWATER MANAGEMENT STUDY			ENR CCI	8600		Apr-10
ENGINEERING ASESSEMENT			ENR CCI	10800		Oct-17
Wright-Pierce, 26 Oct 2017						
COSTS FOR CONVEYANCE ALTERNATIVES				**Projected to Oct 2017 dollars**		
EXISTING/ SHORT-TERM/ MID-TERM/ LONG-TERM						

	Selected Alignments for Each Town				COST	QUAN
	Existing	Short	Mid	Long	TOTAL	TOTAL
Capital Costs for Conveyance and Transport to Disposal						
Conveyance						
Conveyance-JBCC						
Sewers - JBCC						
Distance, 1000 ft	0.00	0.00	0.00	0.00		0.00
Cost per foot	300	300	300	300		
Construction cost	0	0	0	0		
Pump Stations - JBCC						
Medium PS (200-800 gpm)	0	0	0	0		0
Unit Cost	1,000,000	1,000,000	1,000,000	1,000,000		
Large PS (800+ gpm)	0	0	0	0		0
Unit Cost	2,500,000	2,500,000	2,500,000	2,500,000		
Construction cost, pump stations	0	0	0	0		
Transport to Treatment- JBCC						
Distance, 1000 ft	0.00	0.00	0.00	0.00		0.00
Cost per foot	200	200	200	200		
Construction cost	0	0	0	0		
Construction cost, Total Conveyance- JBCC	0	0	0	0	0	
Conveyance-Bourne						
Sewers - Bourne - 50% Shared with Sandwich						
Distance, 1000 ft	0.00	0.00	12.30	0.00		12.30
Cost per foot (33% of 150)	75	75	75	75		
Construction cost	0	0	920,000	0		
Pump Stations - Bourne						
Medium PS (200-800 gpm)	0	1	0	0		1
Unit Cost	1,000,000	1,000,000	1,000,000	1,000,000		
Large PS (800+ gpm)	0	0	1	0		1
Unit Cost	2,500,000	2,500,000	2,500,000	2,500,000		
Construction cost, pump stations	0	1,000,000	2,500,000	0		

JBCC SHARED WASTEWATER MANAGEMENT STUDY				ENR CCI	8600		Apr-10
ENGINEERING ASESSEMENT				ENR CCI	10800		Oct-17
Wright-Pierce, 26 Oct 2017							
COSTS FOR CONVEYANCE ALTERNATIVES					**Projected to Oct 2017 dollars**		
EXISTING/ SHORT-TERM/ MID-TERM/ LONG-TERM							
	Selected Alignments for Each Town				COST	QUAN	
	Existing	Short	Mid	Long	TOTAL	TOTAL	
Transport to Treatment - Bourne - Public Way/Dense			12"				
Distance, 1000 ft	0.00	0.00	12.70	0.00		12.70	
Cost per foot	240	240	240	240			
Construction cost	0	0	3,050,000	0			
Transport to Treatment - Bourne - Off Public Way/Less Dense		10"	12"				
Distance, 1000 ft	0.00	0.00	14.50	0.00		14.50	
Cost per foot	160	160	160	160			
Construction cost	0	0	2,320,000	0			
ISWM Connection to Effluent Forcemain (LS)	0	100,000	0	0			
Construction cost, Total Conveyance- Bourne	0	1,100,000	8,790,000	0	9,890,000		
Conveyance-Falmouth							
Sewers - Falmouth							
Distance, 1000 ft	0.00	0.00	0.00	0.00		0.00	
Cost per foot	300	300	300	300			
Construction cost	0	0	0	0			
Pump Stations-Falmouth							
Medium PS (200-800 gpm)	0	0	0	0		0	
Unit Cost	1,000,000	1,000,000	1,000,000	1,000,000			
Large PS (800+ gpm)	0	0	1	0		1	
Unit Cost	2,500,000	2,500,000	2,500,000	2,500,000			
Construction cost, pump stations	0	0	2,500,000	0			
Transport to Treatment - Public Way			18"				
Distance, 1000 ft	0.00	0.00	25.90	0.00		25.90	
Cost per foot	280	280	280	280			
Construction cost	0	0	7,250,000	0			
Transport to JBCC Effluent FM-Falmouth - Out of Public Way			18"				
Distance, 1000 ft	0.00	0.00	9.50	0.00			
Cost per foot	200	200	200	200			
Construction cost	0	0	1,900,000	0			
Construction cost, Total Conveyance-Falmouth	0	0	11,650,000	0	11,650,000		

JBCC SHARED WASTEWATER MANAGEMENT STUDY			ENR CCI	8600		Apr-10
ENGINEERING ASESSEMENT			ENR CCI	10800		Oct-17
Wright-Pierce, 26 Oct 2017						
COSTS FOR CONVEYANCE ALTERNATIVES				**Projected to Oct 2017 dollars**		
EXISTING/ SHORT-TERM/ MID-TERM/ LONG-TERM						

	Selected Alignments for Each Town				COST	QUAN
	Existing	Short	Mid	Long	TOTAL	TOTAL
Conveyance-Mashpee						
Pump Stations-Mashpee						
Medium PS (200-800 gpm)	0	1	0	0		1
Unit Cost	1,000,000	1,000,000	1,000,000	1,000,000		
Construction cost, pump stations	0	1,000,000	0	0		
Transport to Treatment - Mashpee - Public Way/Dense		8"				
Distance, 1000 ft	0.00	7.50	0.00	0.00		7.50
Cost per foot	240	200	240	240		
Construction cost	0	1,500,000	0	0		
Construction cost, Total Conveyance-Mashpee	0	2,500,000	0	0	2,500,000	
Conveyance-Sandwich						
Sewers - Sandwich - Dedicated						
Distance, 1000 ft	0.00	0.00	2.20	0.00		2.20
Cost per foot	150	150	150	150		
Construction cost	0	0	330,000	0		
Sewers - Sandwich - 50% Shared with Bourne						
Distance, 1000 ft	0.00	0.00	12.30	0.00		12.30
Cost per foot (33% of 150)	75	75	75	75		
Construction cost	0	0	920,000	0		
Pump Stations-Sandwich						
Medium PS (200-800 gpm)	0	0	1	0		1
Unit Cost	1,000,000	1,000,000	1,000,000	1,000,000		
Large PS (800+ gpm)	0	0	0	0		0
Unit Cost	2,500,000	2,500,000	2,500,000	2,500,000		
Construction cost, pump stations	0	0	1,000,000	0		
Transport to Treatment-Sandwich-Dedicated - Dense			12"			
Distance, 1000 ft	0.00	0.00	3.50	0.00		3.50
Cost per foot	240	240	240	240		
Construction cost	0	0	840,000	0		
Transport to Treatmen-Sandwich-Dedicated - Less Dense			12"			
Distance, 1000 ft	0.00	0.00	11.90	0.00		11.90

JBCC SHARED WASTEWATER MANAGEMENT STUDY			ENR CCI	8600		Apr-10
ENGINEERING ASESSEMENT			ENR CCI	10800		Oct-17
Wright-Pierce, 26 Oct 2017						
COSTS FOR CONVEYANCE ALTERNATIVES				**Projected to Oct 2017 dollars**		
EXISTING/ SHORT-TERM/ MID-TERM/ LONG-TERM						

	Selected Alignments for Each Town				COST	QUAN
	Existing	Short	Mid	Long	TOTAL	TOTAL
Cost per foot	160	160	160	160		
Construction cost	0	0	1,900,000	0		
Construction cost, Total Conveyance-Sandwich	0	0	4,990,000	0	4,990,000	
Conveyance Cost Summary					29,030,000	
Sewers						
Construction cost	0	0	2,170,000	0	2,170,000	
Pump Stations						
Construction cost, pump stations	0	2,000,000	6,000,000	0	8,000,000	
Transport to Treatment or Effluent Forcemain						
Construction cost	0	1,600,000	17,260,000	0	18,860,000	
Construction Cost, Total Conveyance	0	3,600,000	25,430,000	0	29,030,000	
Cross Check	0	3,600,000	25,430,000	0	29,030,000	

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ENGINEERING ASSESSMENT
Wright-Pierce, 31 Oct 2017 ENR CCI (10/2017) 10800

COSTS FOR TREATMENT, TRANSPORT-TO-DISPOSAL AND DISPOSAL ALTERNATIVES **Projected to Oct 2017 dollars**
LONG-TERM

			1	2	3	4	5	6
Items			**RIB**	**RIB/WICK**	**RIB/DWI**	**RIB/OUTFALL**	**DWI**	**OUTFALL**
CAPITAL COSTS								
	Unit Costs							
	Cost, ENR/SBR, Disinfection		$30.00	$30.00	$30.00	$32.00	$30.00	$32.00
	Cost, ENR/MBR, Disinfection	10%			$3.00		$3.00	
	Cost, Sand Filtration			$1.90				
	Cost, RO/Reject/Storage				$4.50		$4.50	
	Effluent PS, at 200'TDH		$1.50	$1.50	$1.00	$1.50	$1.00	$1.50
	Flow (Sewage = 1,200,000)							
	ENR/SBR/UV		1,210,000	1,210,000	1,210,000	1,210,000	1,210,000	1,210,000
	ENR/MBR-Adder				400,000		500,000	
	Sand Filtration	5%		1,270,000				
	RO/AO/Storage				3,100,000		3,850,000	
	Effluent PS		1,210,000	1,210,000	2,700,000	1,210,000	3,350,000	1,210,000
	Cost - Treatment-Baseline							
	Existing WWTF Upgrades		$2,570,000	$2,570,000	$2,570,000	$2,570,000	$2,570,000	$2,570,000
	ENR Baseline		$36,300,000	$36,300,000	$36,300,000	$38,720,000	$36,300,000	$38,720,000
	Subtotal - Treatment		**$38,900,000**	**$38,900,000**	**$38,900,000**	**$41,300,000**	**$38,900,000**	**$41,300,000**
	Cost - Treatment-Supplemental							
	ENR/MBR Adder		$0	$0	$13,200,000	$0	$16,500,000	$0
	Sand Filtration		$0	$2,413,000	$0	$0	$0	$0
	RO/AO/Storage		$0	$0	$13,950,000	$0	$17,325,000	$0
	Subtotal - Treatment		**$0**	**$2,400,000**	**$27,200,000**	**$0**	**$33,800,000**	**$0**
	Cost - Transport to Disposal							
	Existing Forcemain Upgrades		$300,000	$300,000	$300,000	$300,000	$1,000,000	$300,000
	New Forcemains		$22,600,000	$22,600,000	$4,860,000	$23,650,000	$5,340,000	$23,650,000
	Length	mi	10.7	10.7	2.3	11.2	2.3	11.2
	Number		2	2	2	2	2	2
	Length	ft	112,992	112,992	24,288	118,272	24,288	118,272
	Cost per Foot		200	200	200	200	220	200
	Subtotal - Transport to Disposal		**$22,900,000**	**$22,900,000**	**$5,160,000**	**$23,950,000**	**$6,340,000**	**$23,950,000**

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ENGINEERING ASSESSMENT
Wright-Pierce, 31 Oct 2017 ENR CCI (10/2017) 10800

COSTS FOR TREATMENT, TRANSPORT-TO-DISPOSAL AND DISPOSAL ALTERNATIVES **Projected to Oct 2017 dollars**
LONG-TERM

			1	2	3	4	5	6
Items			**RIB**	**RIB/WICK**	**RIB/DWI**	**RIB/OUTFALL**	**DWI**	**OUTFALL**
	Cost - Disposal							
	Existing RIB Upgrades		$500,000	$500,000	$500,000	$500,000	$500,000	$500,000
	Effluent PS		$1,815,000	$1,815,000	$2,700,000	$1,815,000	$3,350,000	$1,815,000
	New RIBs		$7,200,000		$2,210,000			
	New Wicks			$6,600,000				
	New DWI				$6,300,000		$9,000,000	
	New Outfall					$4,400,000		$6,120,000
	Subtotal - Disposal		**$9,500,000**	**$8,900,000**	**$11,700,000**	**$6,700,000**	**$12,900,000**	**$8,400,000**
	TOTAL		**$71,300,000**	**$73,100,000**	**$82,960,000**	**$71,950,000**	**$91,940,000**	**$73,650,000**
	Lowest plus +% higher for other Options		$71,300,000	3%	16%	1%	29%	3%
ANNUAL O&M								
	Basis flow		1,210,000	1,210,000	2,700,000	1,210,000	3,350,000	1,210,000
	Baseline, April 2014 (ENR CCI 9750)		$1.50	$1.50	$1.25	$1.50	$1.25	$1.50
	Baseline, Current (ENR CCI 10800)		$1.66	$1.66	$1.38	$1.66	$1.38	$1.66
	Adder for Filtration	5%		$0.08				
	Adder for SW Discharge	10%				$0.17		$0.17
	Adder for ENR/MBR	10%			$0.14		$0.14	
	Adder for RO/Storage	25%			$0.35		$0.35	
	Adder for Effluent Re-Pumping	5%	$0.08	$0.08	$0.07	$0.08	$0.07	$0.08
	Total		$1.74	$1.83	$1.94	$1.91	$1.94	$1.91
	Annual O&M		$2,110,000	$2,210,000	$5,230,000	$2,310,000	$6,490,000	$2,310,000
	Lowest plus +% higher for other Options		**$2,110,000**	5%	148%	9%	208%	9%

JBCC SHARED WASTEWATER MANAGEMENT STUDY				ENR CCI	8600		Apr-10
ENGINEERING ASSESSMENT				ENR CCI	10800		Oct-17
Wright-Pierce, 27 Nov 2017							
COSTS FOR COMPOSITE WASTEWATER MANAGEMENT ALTERNATIVES					**Projected to Oct 2017 dollars**		
LONG-TERM							
	1	2	3	4	5	6
	RIB	RIB/Wick	RIB/DWI	RIB/Outfall	DWI	Outfall
Capital Costs for Conveyance, Treatment, Transport to Disposal and Effluent Disposal						
Conveyance						
JBCC	0	0	0	0	0	0
Bourne	9,890,000	9,890,000	9,890,000	9,890,000	9,890,000	9,890,000
Falmouth	11,650,000	11,650,000	11,650,000	11,650,000	11,650,000	11,650,000
Mashpee	2,500,000	2,500,000	2,500,000	2,500,000	2,500,000	2,500,000
Sandwich	4,990,000	4,990,000	4,990,000	4,990,000	4,990,000	4,990,000
Construction cost, Total Conveyance	29,030,000	29,030,000	29,030,000	29,030,000	29,030,000	29,030,000
Treatment-Baseline						
Construction cost	38,900,000	38,900,000	38,900,000	41,300,000	38,900,000	41,300,000
Treatment-Supplemental for Disposal						
Construction cost	0	2,400,000	27,200,000	0	33,800,000	0
Transport to Disposal						
Construction cost	22,900,000	22,900,000	5,160,000	23,950,000	6,340,000	23,950,000
Effluent Disposal						
Construction Cost	9,500,000	8,900,000	11,700,000	6,700,000	12,900,000	8,400,000
Total Construction Cost	100,330,000	102,130,000	111,990,000	100,980,000	120,970,000	102,680,000
Contingencies,Technical, Legal/Admin/Financing	43	43	43	43	43	43
Cost	43,140,000	43,920,000	48,160,000	43,420,000	52,020,000	44,150,000
Land						
Cost	0	0	0	0	0	0
CAPITAL COST SUMMARY	**143,470,000**	**146,050,000**	**160,150,000**	**144,400,000**	**172,990,000**	**146,830,000**
Capital Cost per Thousand Gallons	117	119	131	118	141	120

JBCC SHARED WASTEWATER MANAGEMENT STUDY				ENR CCI	8600		Apr-10
ENGINEERING ASSESSMENT				ENR CCI	10800		Oct-17
Wright-Pierce, 27 Nov 2017							
COSTS FOR COMPOSITE WASTEWATER MANAGEMENT ALTERNATIVES					**Projected to Oct 2017 dollars**		
LONG-TERM							
	1	2	3	4	5	6
	RIB	RIB/Wick	RIB/DWI	RIB/Outfall	DWI	Outfall
Annual O&M Costs						
O&M cost for Overall T&D, $/yr	2,110,000	2,210,000	5,230,000	2,310,000	6,490,000	2,310,000
Annual O&M Cost Summary	**2,110,000**	**2,210,000**	**5,230,000**	**2,310,000**	**6,490,000**	**2,310,000**
Equivalent Annual Cost - TOTAL COST	1	1	1	1	1	1
Period, yr - Loan Public	20	20	20	20	20	20
Interest rate, % - Loan Public	2.0	2.0	2.0	2.0	2.0	2.0
Capital Recovery Factor - Loan Public	16.35	16.35	16.35	16.35	16.35	16.35
Capital Cost - Loan Public	143,470,000	146,050,000	160,150,000	144,400,000	172,990,000	146,830,000
Capital cost - Loan Private	0	0	0	0	0	0
O&M cost	2,110,000	2,210,000	5,230,000	2,310,000	6,490,000	2,310,000
Equivalent Annual Cost of Capital	8,770,000	8,930,000	9,790,000	8,830,000	10,580,000	8,980,000
EQUIVALENT ANNUAL COST SUMMARY	**10,880,000**	**11,140,000**	**15,020,000**	**11,140,000**	**17,070,000**	**11,290,000**
Flow, T&D, mgd	3.35	3.35	3.35	3.35	3.35	3.35
Million Gallons per year, T&D	1,223	1,223	1,223	1,223	1,223	1,223
Cost per thousand gallons (aggregate)	8.90	9.11	12.28	9.11	13.96	9.23
Equivalent Annual Cost - Treatment to Disposal						
Capital Recovery Factor - Loan Public	16.35	16.35	16.35	16.35	16.35	16.35
Capital Cost - Loan Public	101,960,000	104,530,000	118,630,000	102,890,000	131,470,000	105,320,000
Capital cost - Loan Private	0	0	0	0	0	0
O&M cost	2,110,000	2,210,000	5,230,000	2,310,000	6,490,000	2,310,000
Equivalent Annual Cost of Capital	8,350,000	8,600,000	12,490,000	8,600,000	14,530,000	8,750,000
Flow, T&D, mgd	3.35	3.35	3.35	3.35	3.35	3.35
Million Gallons per year, T&D	1,223	1,223	1,223	1,223	1,223	1,223
Cost per thousand gallons (aggregate)	6.83	7.03	10.21	7.03	11.88	7.16
Equivalent Annual Cost - Treatment to Disposal PLUS Conveyance						
Capital Recovery Factor - Loan Public	16.35	16.35	16.35	16.35	16.35	16.35

JBCC SHARED WASTEWATER MANAGEMENT STUDY				ENR CCI	8600		Apr-10
ENGINEERING ASSESSMENT				ENR CCI	10800		Oct-17
Wright-Pierce, 27 Nov 2017							
COSTS FOR COMPOSITE WASTEWATER MANAGEMENT ALTERNATIVES					**Projected to Oct 2017 dollars**		
LONG-TERM							
		1	2	3	4	5	6
		RIB	RIB/Wick	RIB/DWI	RIB/Outfall	DWI	Outfall
Capital Cost - Loan Public		143,470,000	146,050,000	160,150,000	144,400,000	172,990,000	146,830,000
Capital cost - Loan Private		0	0	0	0	0	0
O&M cost		2,110,000	2,210,000	5,230,000	2,310,000	6,490,000	2,310,000
Equivalent Annual Cost of Capital		10,880,000	11,140,000	15,020,000	11,140,000	17,070,000	11,290,000
Flow, T&D, mgd		3.35	3.35	3.35	3.35	3.35	3.35
Million Gallons per year, T&D		1,223	1,223	1,223	1,223	1,223	1,223
Cost per thousand gallons (aggregate)		8.90	9.11	12.28	9.11	13.96	9.23

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017

BLUE IS ENTRY

COST ALLOCATION OF OPTION 6 BY PHASE
PHASED COSTS FOR OPTION 6 (OUTFALL), MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS"

	COSTS ($MILLION)				CHECK	ALLOCATION, % OF FLOW				ALLOCATION OF FLOW			
	Existing	Short-Term	Mid-Term	Long-Term	TOTAL	Ex	ST	MT	LT	Ex	ST	MT	LT
Conveyance	$0	$3,600,000	$25,430,000	$0	$29,030,000					140,000	347,000	752,000	1,189,000
JBCC	$0	$0	$0	$0	$0					140,000	147,000	147,000	147,000
Bourne	$0	$1,100,000	$8,790,000	$0	$9,890,000					0	0	270,000	467,000
Falmouth	$0	$0	$11,650,000	$0	$11,650,000					0	0	22,000	22,000
Mashpee	$0	$2,500,000	$0	$0	$2,500,000					0	200,000	203,000	203,000
Sandwich	$0	$0	$4,990,000	$0	$4,990,000					0	0	110,000	350,000
Treatment-BASELINE	$0	$1,920,000	$25,600,000	$13,780,000	$41,300,000	100%	100%	100%	100%	140,000	347,000	1,189,000	1,189,000
JBCC	$0	$813,372	$3,165,013	$1,703,667	$5,682,051	100%	42%	12%	12%	140,000	147,000	147,000	147,000
Bourne	$0	$0	$10,054,836	$5,412,330	$15,467,166	0%	0%	39%	39%	0	0	467,000	467,000
Falmouth	$0	$0	$473,675	$254,971	$728,646	0%	0%	2%	2%	0	0	22,000	22,000
Mashpee	$0	$1,106,628	$4,370,732	$2,352,683	$7,830,043	0%	58%	17%	17%	0	200,000	203,000	203,000
Sandwich	$0	$0	$7,535,744	$4,056,350	$11,592,094	0%	0%	29%	29%	0	0	350,000	350,000
Treatment-SUPPLEMENT	$0	$0	$0	$0	$0	100%	100%	100%	100%	140,000	347,000	1,189,000	1,189,000
JBCC	$0	$0	$0	$0	$0	100%	42%	12%	12%	140,000	147,000	147,000	147,000
Bourne	$0	$0	$0	$0	$0	0%	0%	39%	39%	0	0	467,000	467,000
Falmouth	$0	$0	$0	$0	$0	0%	0%	2%	2%	0	0	22,000	22,000
Mashpee	$0	$0	$0	$0	$0	0%	58%	17%	17%	0	200,000	203,000	203,000
Sandwich	$0	$0	$0	$0	$0	0%	0%	29%	29%	0	0	350,000	350,000
Transport	$0	$300,000	$11,825,000	$11,825,000	$23,950,000	100%	100%	100%	100%	140,000	447,000	3,330,000	3,330,000
JBCC	$0	$98,658	$522,005	$522,005	$1,142,667	100%	33%	4%	4%	140,000	147,000	147,000	147,000
Bourne	$0	$67,114	$3,970,075	$3,970,075	$8,007,264	0%	22%	34%	34%	0	100,000	1,118,000	1,118,000
Falmouth	$0	$0	$5,369,189	$5,369,189	$10,738,378	0%	0%	45%	45%	0	0	1,512,000	1,512,000
Mashpee	$0	$134,228	$720,863	$720,863	$1,575,955	0%	45%	6%	6%	0	200,000	203,000	203,000
Sandwich	$0	$0	$1,242,868	$1,242,868	$2,485,736	0%	0%	11%	11%	0	0	350,000	350,000
Disposal	$0	$400,000	$4,610,000	$3,390,000	$8,400,000	100%	100%	100%	100%	140,000	447,000	3,330,000	3,330,000
JBCC	$0	$131,544	$203,505	$149,649	$484,697	100%	33%	4%	4%	140,000	147,000	147,000	147,000
Bourne	$0	$89,485	$1,547,742	$1,138,144	$2,775,371	0%	22%	34%	34%	0	100,000	1,118,000	1,118,000
Falmouth	$0	$0	$2,093,189	$1,539,243	$3,632,432	0%	0%	45%	45%	0	0	1,512,000	1,512,000
Mashpee	$0	$178,971	$281,030	$206,658	$666,659	0%	45%	6%	6%	0	200,000	203,000	203,000
Sandwich	$0	$0	$484,535	$356,306	$840,841	0%	0%	11%	11%	0	0	350,000	350,000
Conting/Tech/Legal/etc	$0	$2,675,000	$29,010,000	$12,468,000	$44,150,000	100%	100%	100%	100%	Pro-rata based on construction subtotal			
JBCC	$0	$448,804	$1,672,927	$1,021,400	$3,143,131	100%	17%	6%	8%	Pro-rata based on construction subtotal			
Bourne	$0	$540,419	$10,475,959	$4,523,890	$15,540,268	0%	20%	36%	36%	Pro-rata based on construction subtotal			
Falmouth	$0	$0	$8,422,018	$3,080,300	$11,502,318	0%	0%	29%	25%	Pro-rata based on construction subtotal			
Mashpee	$0	$1,685,778	$2,310,233	$1,410,505	$5,406,515	0%	63%	8%	11%	Pro-rata based on construction subtotal			
Sandwich	$0	$0	$6,128,864	$2,431,905	$8,560,768	0%	0%	21%	20%	Pro-rata based on construction subtotal			
TOTAL	$0	$8,895,000	$96,475,000	$41,463,000	$146,833,000								
JBCC	$0	$1,490,000	$5,560,000	$3,400,000	$10,450,000								
Bourne	$0	$1,800,000	$34,840,000	$15,040,000	$51,680,000								

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017

BLUE IS ENTRY

COST ALLOCATION OF OPTION 6 BY PHASE
PHASED COSTS FOR OPTION 6 (OUTFALL), MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS"

	COSTS ($MILLION)				CHECK	ALLOCATION, % OF FLOW				ALLOCATION OF FLOW			
	Existing	Short-Term	Mid-Term	Long-Term	TOTAL	Ex	ST	MT	LT	Ex	ST	MT	LT
Falmouth	$0	$0	$28,010,000	$10,240,000	$38,250,000								
Mashpee	$0	$5,610,000	$7,680,000	$4,690,000	$17,980,000								
Sandwich	$0	$0	$20,380,000	$8,090,000	$28,470,000								
Check	$0	$8,900,000	$96,470,000	$41,460,000	$146,830,000								
ANNUAL O&M	$510,000	$685,000	$1,460,000	$2,310,000		100%	100%	100%	100%	140,000	447,000	1,686,000	3,330,000
JBCC	$0.5	$0.23	$0.13	$0.10		100%	33%	9%	4%	140,000	147,000	147,000	147,000
Bourne	$0.0	$0.15	$0.62	$0.78		0%	22%	42%	34%	0	100,000	714,000	1,118,000
Falmouth	$0.0	$0.00	$0.44	$1.05		0%	0%	30%	45%	0	0	512,000	1,512,000
Mashpee	$0.0	$0.31	$0.18	$0.14		0%	45%	12%	6%	0	200,000	203,000	203,000
Sandwich	$0.0	$0.00	$0.10	$0.24		0%	0%	7%	11%	0	0	110,000	350,000
Check		$0.69	$1.46	$2.31									
DEBT SERVICE	CRF >>	16.35											
JBCC	$0.00	$0.09	$0.34	$0.21	$0.6								
Bourne	$0.00	$0.11	$2.13	$0.92	$3.2								
Falmouth	$0.00	$0.00	$1.71	$0.63	$2.3								
Mashpee	$0.00	$0.34	$0.47	$0.29	$1.1								
Sandwich	$0.00	$0.00	$1.25	$0.49	$1.7								
Check	$0.00	$0.54	$5.90	$2.54									
EQUIVALENT ANNUAL COST													
JBCC	$0.51	$0.32	$0.47	$0.31	$1.6								
Bourne	$0.00	$0.26	$2.75	$1.70	$4.7								
Falmouth	$0.00	$0.00	$2.16	$1.68	$3.8								
Mashpee	$0.00	$0.65	$0.65	$0.43	$1.7								
Sandwich	$0.00	$0.00	$1.34	$0.74	$2.1								
Check	$0.51	$1.23	$7.36	$4.85									
CAPITAL COST PER KGAL (DISPOSAL CAPACITY)										DISPOSAL CAPACITY			
JBCC	$0	$28	$131	$195	$195					140,000	147,000	147,000	147,000
Bourne		$49	$139	$54	$127					0	100,000	714,000	1,118,000
Falmouth		$0	$158	$31	$69					0	0	512,000	1,512,000
Mashpee		$77	$124	$158	$243					0	200,000	203,000	203,000
Sandwich		$0	$545	$119	$223					0	0	110,000	350,000
TOTAL		$0	$160	$64	$121						447,000	1,686,000	3,330,000

JBCC SHARED WASTEWATER MANAGEMENT STUDY
COMPARISON TO PREVIOUS PLANNING EFFORTS
Wright-Pierce, 27 Nov 2017

BOURNE
WASTEWATER MANAGEMENT STUDY, TIGHE & BOND, OCT 2007
RECOMMENDED PLAN >> 1B
INCLUDES 35% CONTINGENCY AND TECHNICAL SERVICES

		TOTAL	WWTF	DISPOSAL	T/D			T/D	T/D	
PHASE	**20YR FLOW**	**COSTS**	**COSTS**	**COSTS**	**COSTS**	**ENR CCI**	**ENR CCI**	**COSTS**	**COST/KGAL/YR**	**RATIO**
YEAR		**2007**	**2007**	**2007**	**2007**	**2007**	**2017**	**2017**	**2017**	
1	449,000	$47.1	$18.1	$4.1	$22.2	9000	10800	$26.6	$162	1.3
2	352,000	$56.2	$12.6	$3.2	$15.8	9000	10800	$19.0	$148	1.2
3	104,000	$17.0	$7.3	$0.8	$8.1	9000	10800	$9.7	$256	2.0
4	541,000	$50.0	$11.2	$2.4	$13.6	9000	10800	$16.3	$83	0.7
	1,446,000	$170.3	$49.2	$10.5	$59.7			$71.6	$136	1.1
				Compare with JBCC Option 6 Allocation to Bourne					$127	

SANDWICH
COMPREHENSIVE WATER RESOURCES MANAGEMENT PLAN, WRIGHT-PIERCE, AUG 2017
RECOMMENDED PLAN >> PLAN B
INCLUDES 35% CONTINGENCY AND TECHNICAL SERVICES

		TOTAL	WWTF	DISPOSAL	T/D			T/D	T/D	
PHASE	**20YR FLOW**	**COSTS**	**COSTS**	**COSTS**	**COSTS**	**ENR CCI**	**ENR CCI**	**COSTS**	**COST/KGAL/YR**	**RATIO**
YEAR		**2017**	**2017**	**2017**	**2017**	**2017**	**2017**	**2017**	**2017**	
1	340,000	$70.0	$33.9	in wwtf	$33.9	10300	10800	$35.53	$286	1.3
TOTAL	612,000									
				Compare with JBCC Option 6 Allocation to Sandwich					$223	

APPENDIX B
Supporting Materials – GeoHydroCycle

GeoHydroCycle, Inc.

Hazardous Waste
Water Supply

Assessment
Remediation
Analyses
Permitting
Modeling
Software

October 5, 2017

Mr. Edward J. Leonard, P.E.
Wright-Pierce
75 Washington Avenue, Suite 202
Portland, ME 04101

re: JBCC
Shared Wastewater Management Study
Hydrogeologic Considerations
GHC #17017

Dear Mr. Leonard:

At Wright-Pierce's request, GeoHydroCycle, Inc. (GHC) looked into the geohydrologic considerations related to Rapid Infiltration Basins, Wicks, and Deep Injection Wells at Joint Base Cape Cod (JBCC).

Rapid Infiltration Basins

GeoHydroCycle, Inc. (GHC) conducted groundwater mounding for the existing 4 Rapid Infiltration Beds (RIBs) located in the northern portion of JBCC near the Cape Cod Canal. The goal of this work has been to estimate the effects of groundwater mounding under wastewater loading conditions greater than the permitted rate. Groundwater mounding was accomplished with the finite difference model MODFLOW following MassDEP guidelines[1]. Input data for the model came from available data and information at JBCC and other available online sources.

Based on the modeling results, the assessment showed that the existing RIBs have the capacity to receive treated wastewater at 1.55 million gallons per day without causing: 1) mounding that would exceed MassDEP design requirements; or 2) breakout along the land surface in the down gradient direction toward the Cape Cod Canal.

Figure 1 shows a cross-section through the JBCC RIB area starting at the Cape Cod Canal and extending approximately one mile south away from the Canal. As the figure shows, natural groundwater flows toward the Cape Cod Canal, and beneath the RIB area there is at least 70 feet separation between groundwater and the land surface. Even as groundwater approaches the Canal, the vertical separation remains between 5 and 10 feet below ground surface.

151B California Street
Newton, Massachusetts
02458

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[1] Massachusetts DEP. November 2014. *Guidelines for the Design, Construction, Operation, and Maintenance of Small Wastewater Treatment Facilities with Land Disposal.*

GeoHydroCycle, Inc.

Figure 2 shows the results of a groundwater mounding simulation where wastewater was discharged into the 4 RIBs at a rate of 1.295 mgd, or 5 gpd/sf into all 4 beds. Because MassDEP allows the use of 80% of the daily maximum wastewater discharge in groundwater mounding models, the actual discharge would be 1.619 mgd, which is more than double the 0.800 mgd permitted for the RIBs. Figure 2 demonstrates that the discharge would only cause a 12 foot increase in groundwater levels beneath the 4 RIBs.

Figure 3 shows groundwater elevation contours that would result from adding the groundwater mound heights onto local groundwater. As Figure 3 shows, although the mounded groundwater is at elevation 30, it is still 60 feet below the land surface at the JBCC RIBs, and down gradient of the RIBs the mounded groundwater remains well below the land surface.

Existing information indicates that the hydrogeologic conditions beneath the adjacent property to the west is very similar to what exists beneath the JBCC RIBs. Based on this information, GHC would expect that additional sets of RIBs located on available property to the west of the existing RIBs would exhibit similar mound heights when the new RIBs are all loaded at 5.0 gpd/sf.

Wicks

Wicks, a relatively new technology in Massachusetts, provide a useful and cost effective disposal option. The significant depth to water table and glacial outwash soils at JBCC provide the conditions were wicks can be successful. Wicks can be thought of as large diameter wells that provide a vertical conduit transmitting wastewater down to the water table. For a given discharge, Wicks use less land area than conventional disposal technologies and can be used to transmit effluent vertically through tight soils to more conductive hydrogeologic formations.

Deep Well Discharge

GeoHydroCycle, Inc. compiled hydrogeologic information relative to three possible deep discharge well sites within the JBCC Cantonment Area. The goal of this work was to look at different types of hydrogeologic conditions that would either positively or negatively affect the placement of a deep well to discharge treated wastewater at a particular site. GHC downloaded and reviewed online USGS data to accomplish this goal.

Figure 4 shows JBCC in the western portion of Cape Cod and the five towns (Falmouth, Bourne, Sandwich, Barnstable and Mashpee) around the base. The Cantonment Area is located in the southern portion of JBCC, and Figure 4 shows the possible locations of three deep wells, DW-1, DW-2 and DW-3. Figures 5, 6 and 7 show the geologic makeup of the soils at the three deep well locations. Those figures also show the types of soil around the well, the hydraulic properties of the soils, and the depth range of the screened entrance for municipal wells in the vicinity of the deep well.

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Soil types can be used to infer the general ability of the well to discharge water to groundwater. Typically, sands and gravels provide a much better media for discharge wells than do silts or clays. Soil hydraulic conductivity is also a good indicator of a well's ability to act as a discharge well. The greater the hydraulic conductivity, the greater the well's ability to discharge to groundwater. A municipal well's screen is where water is drawn into the well, and the greater the separation depth between the deep well's screen and the municipal well's screen, the less likely it is for the municipal well to draw in deep well wastewater.

The placement of the deep wells took into consideration the location of municipal well Zone IIs or wellhead protection areas. Wells DW-1 and DW-2 were located outside Zone IIs and well DW-3 was located within a Zone II. A Zone II is defined by state regulations as that land area that provides water to a municipal well under drought conditions, and the location of a deep well discharging treated wastewater in a Zone II would be considered negatively under current regulations even with a large vertical separation. On a technical basis there should be a large enough vertical separation to allow deep well injection without impacting municipal wells.

Figure 8 presents possible groundwater pathways from each deep well to the ocean. This figure is based on general groundwater contours published by the Cape Cod Commission. As Figure 8 shows groundwater in the area of deep well DW-2 flows to the west toward Buzzards Bay, and could be expected to travel 15,000 feet in groundwater before reaching the Bay. Deep wells DW-1 and DW-3 travel with groundwater to the south toward Vineyard Sound, but the travel path for both wells is much longer, 7.4 and 8.4 miles respectively. The further travel distances, and times, provide more opportunity for the wastewater to be drawn upward and end up discharging to one of the many ponds or estuaries instead of the ocean. The longer flow paths also adversely change the natural groundwater quality of a much larger volume of groundwater than do shorter pathways.

Injection wells are a new technology for Cape Cod and the location, design and capacity of the wells would be determined only through large-scale testing. The ability to bypass coastal embayments would need to be further demonstrated through detailed groundwater modeling.

If you have any questions, please feel free to call me.

Sincerely,
GeoHydroCycle, Inc.

Stephen W. Smith, P.E., P.HGW.

Enclosures: Figures 1 - 8

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JBCC Shared Wastewater Management Study Hydrogeologic Considerations

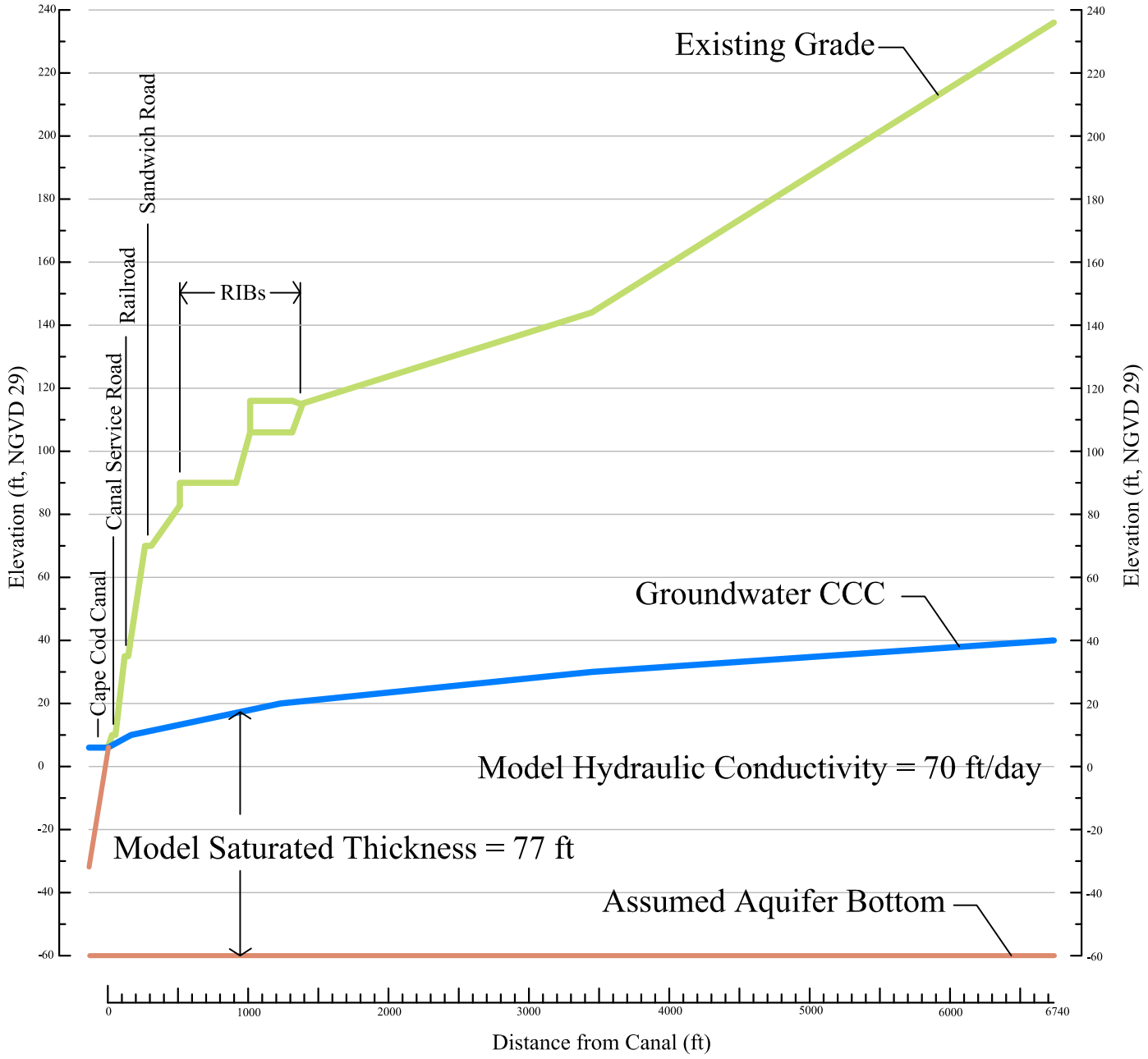


Figure 1. Hydrogeologic Cross-Section.

NOTES

1. Feature details obtained from Google Earth.

Vert/Horiz 22.5:1
Scales as Shown

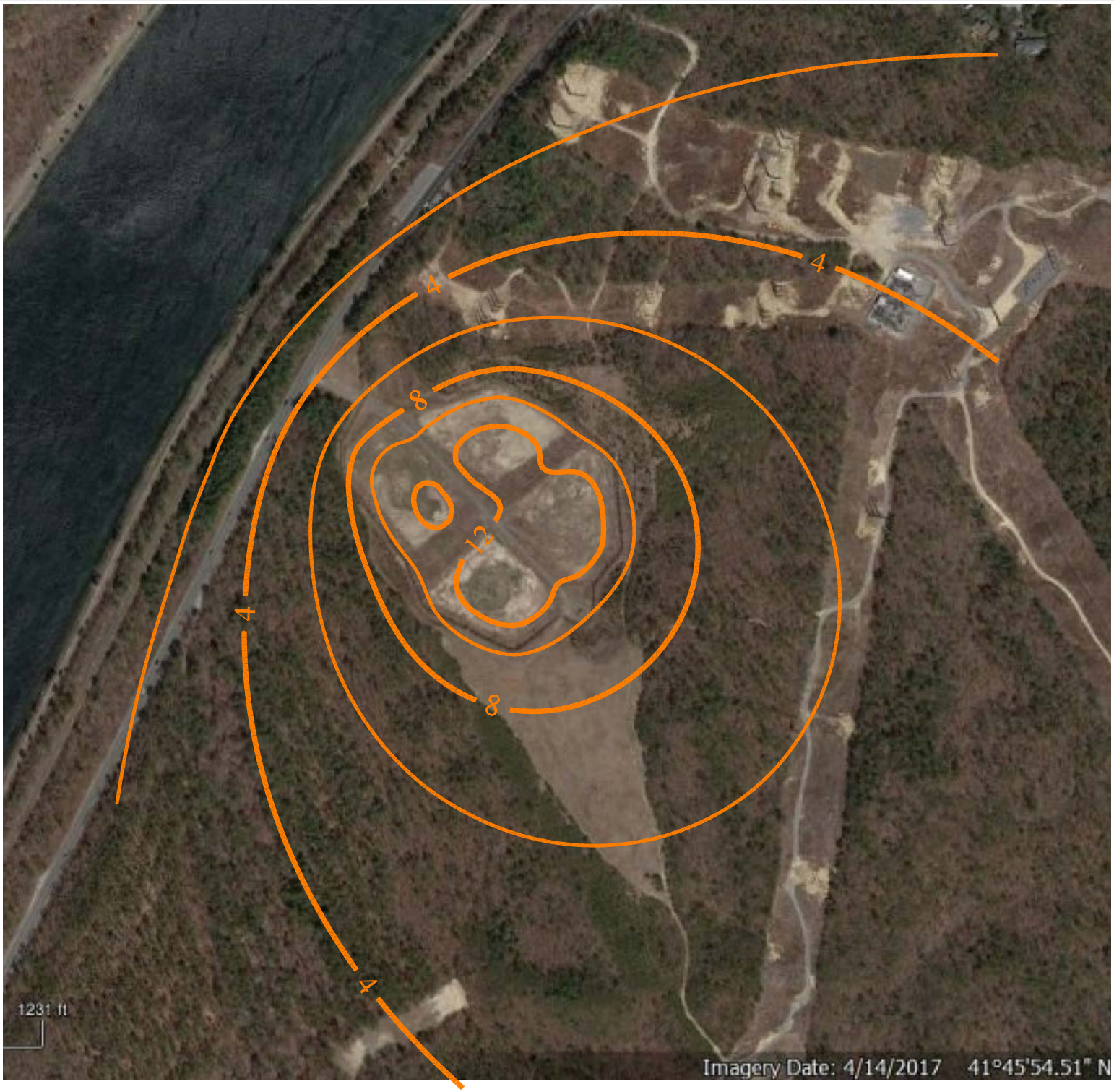
Project No. GHC#17017

Drafted SWS Checked

Date 9/17/17 Rev 10/4/17

Base Map: None.

GeoHydroCycle, Inc.



JBCC Shared Wastewater Management Study Hydrogeologic Considerations

Figure 2. Simulated Groundwater Mound Height Contours, Loading at 5 gpd/sf* or 1,295,800 gpd.

Notes

* based on loading all 4 beds.

0 300

Scale in feet

Project No. GHC#17017
Drafted SWS Checked
Date 9/20/17 Rev 10/4/17
Base Map: Google Earth

GeoHydroCycle, Inc.



JBCC Shared Wastewater Management Study Hydrogeologic Considerations

Figure 3. Simulated Groundwater Elevation Contours, Loading at 5 gpd/sf* or 1,295,800 gpd.

Notes

* based on loading all 4 beds.

0 300

Scale in feet

Project No. GHC#17017
Drafted SWS Checked
Date 9/20/17 Rev 10/4/17
Base Map: Google Earth

GeoHydroCycle, Inc.

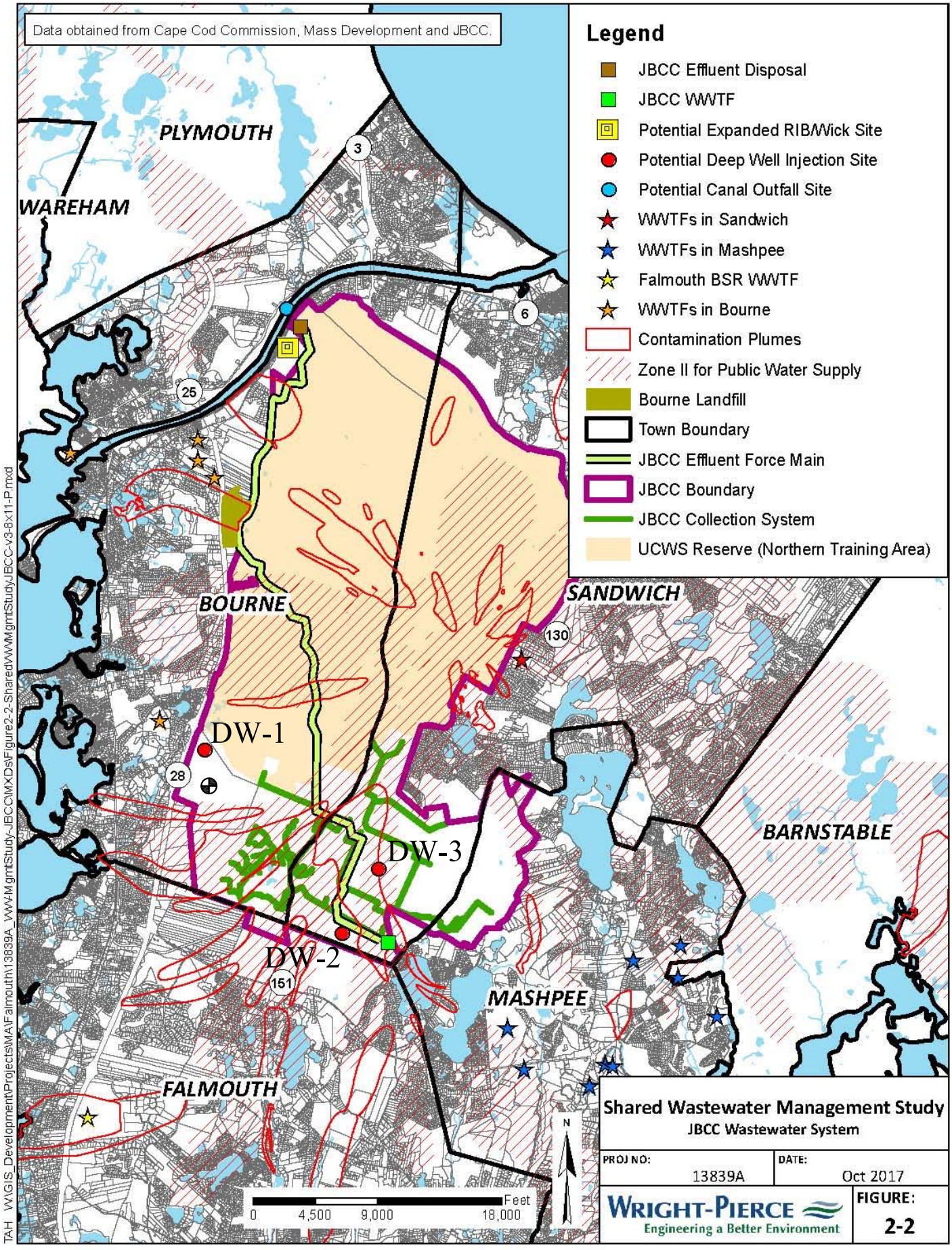


Figure 4. Potential Deep Well Locations.

JBCC Shared Wastewater Management Study Hydrogeologic Considerations

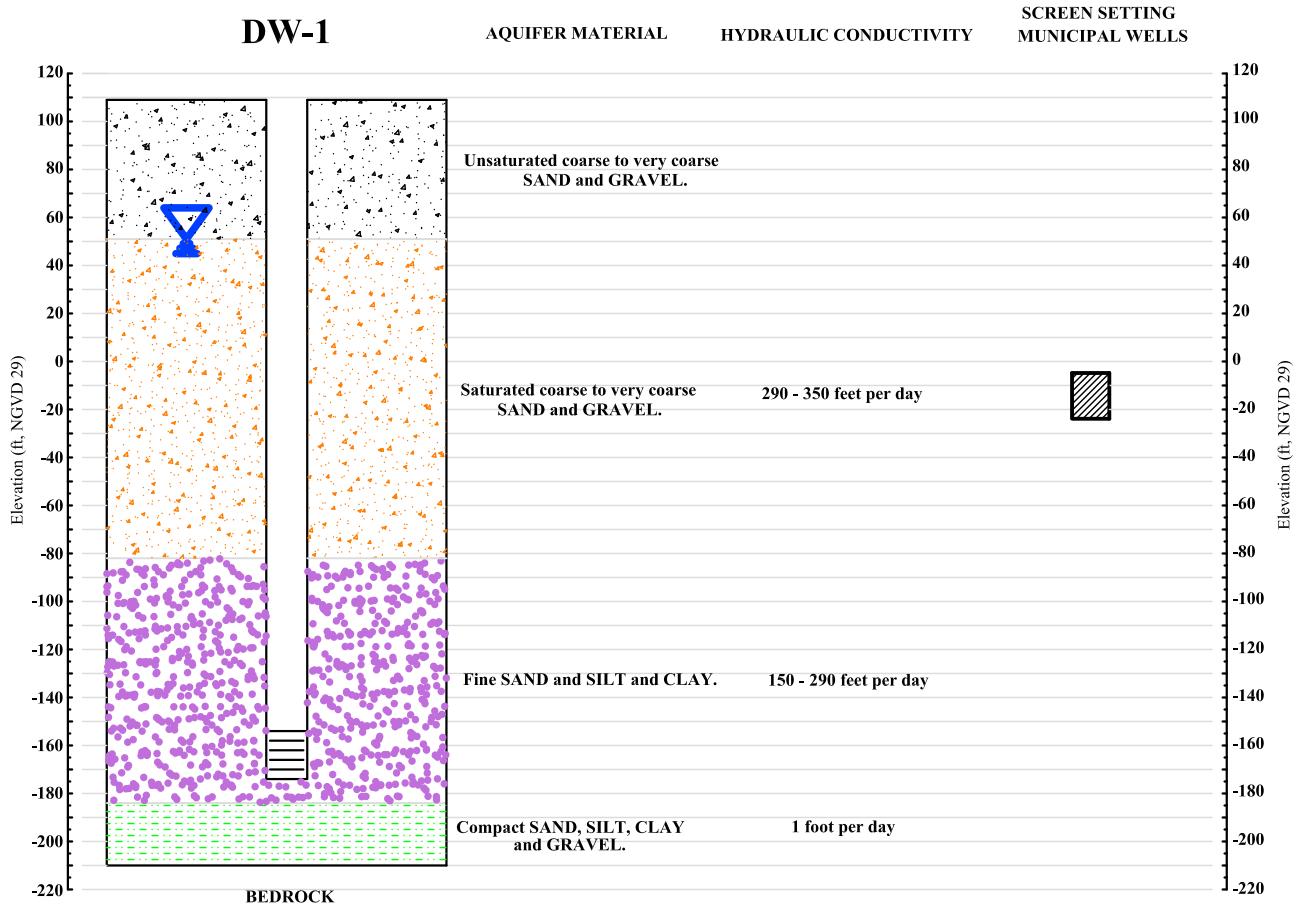


Figure 5. Potential Deep Discharge Well, DW-1.

Scales as Shown

Project No. GHC#17017

Drafted SWS Checked

Date 9/27/17 Rev 10/4/17

Base Map: None.

GeoHydroCycle, Inc.

JBCC Shared Wastewater Management Study Hydrogeologic Considerations

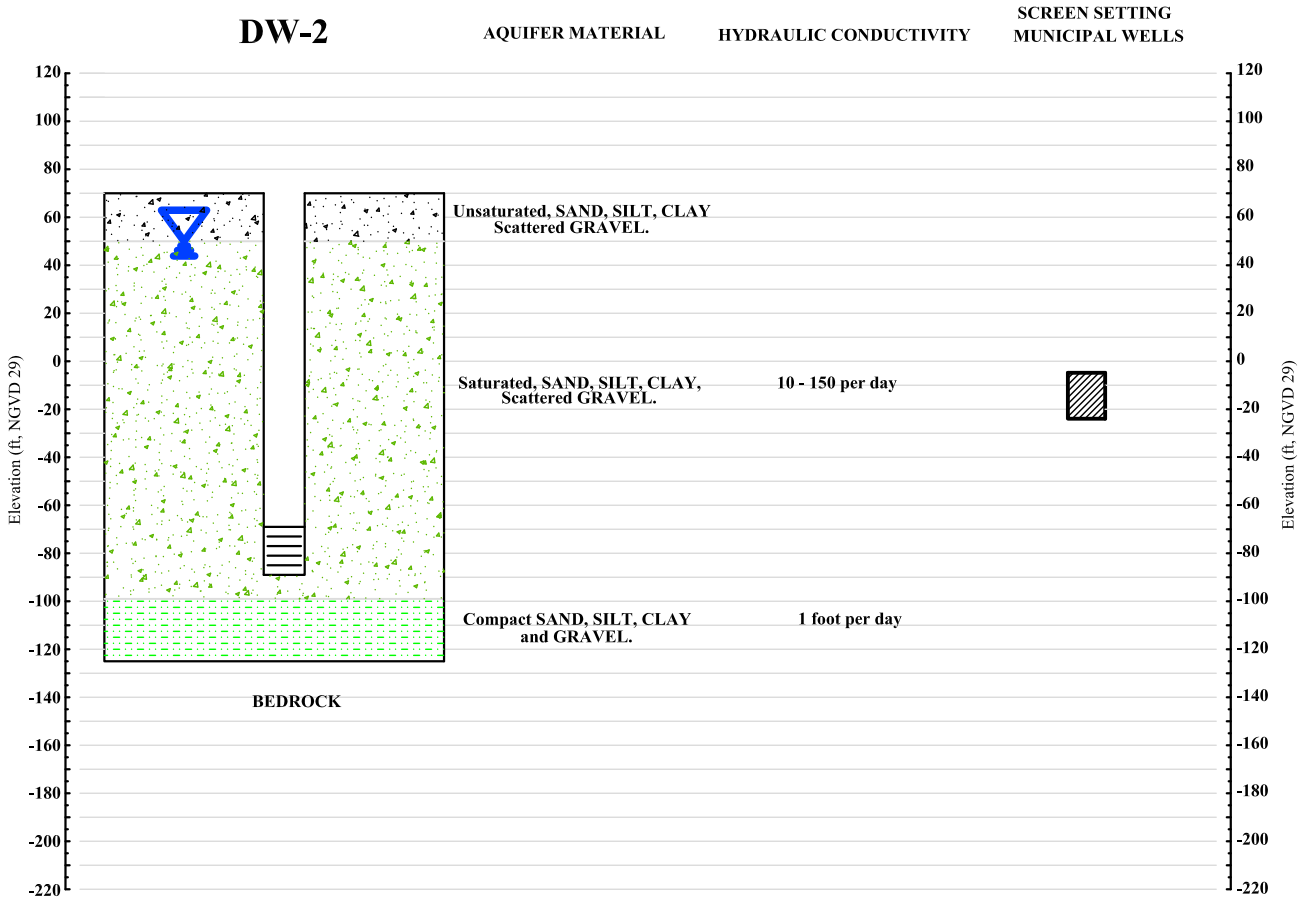


Figure 6. Potential Deep Discharge Well, DW-2.

Scales as Shown

Project No. GHC#17017

Drafted SWS Checked

Date 9/27/17 Rev 10/4/17

Base Map: None.

GeoHydroCycle, Inc.

JBCC Shared Wastewater Management Study Hydrogeologic Considerations

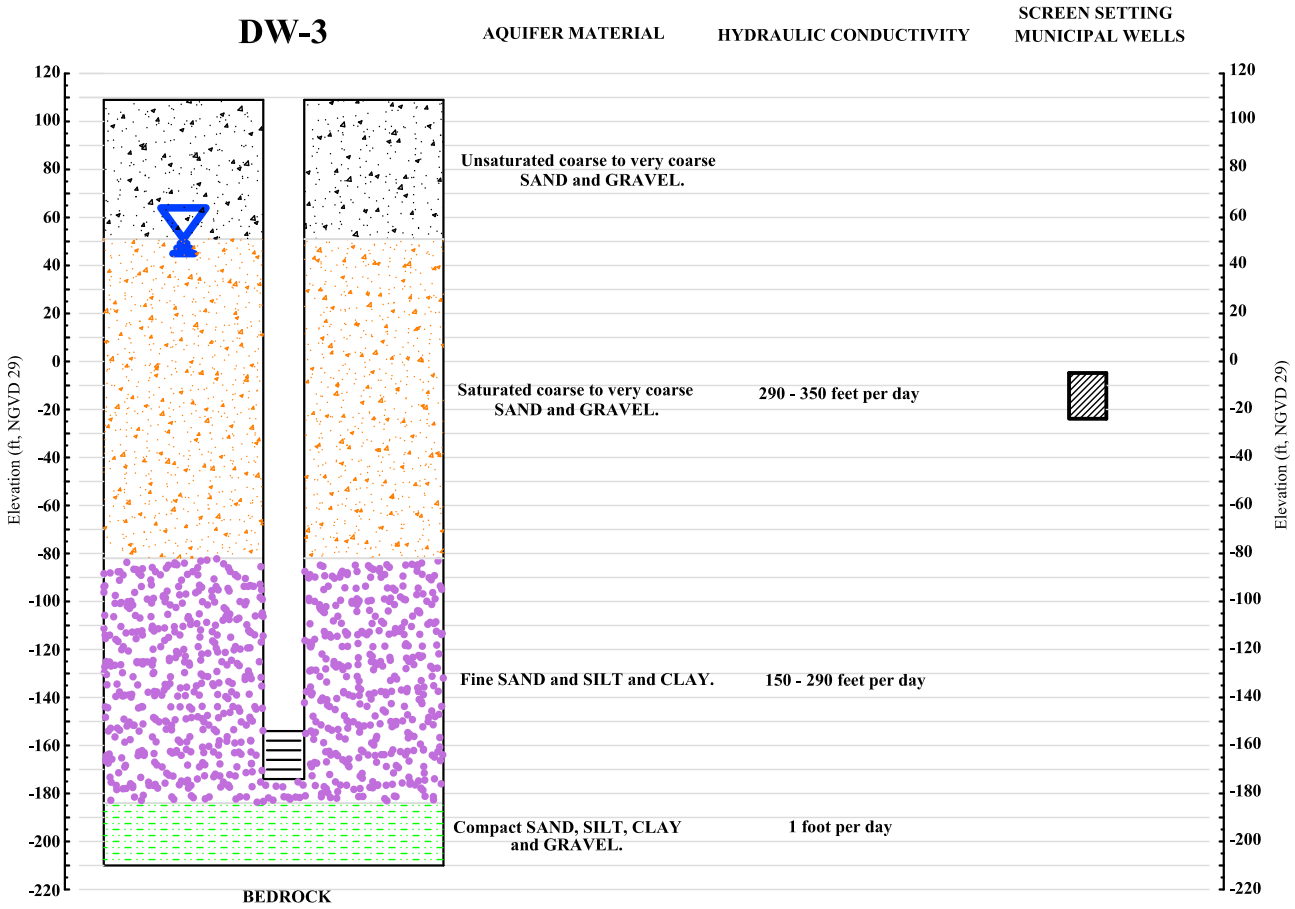


Figure 7. Potential Deep Discharge Well, DW-3.

Scales as Shown

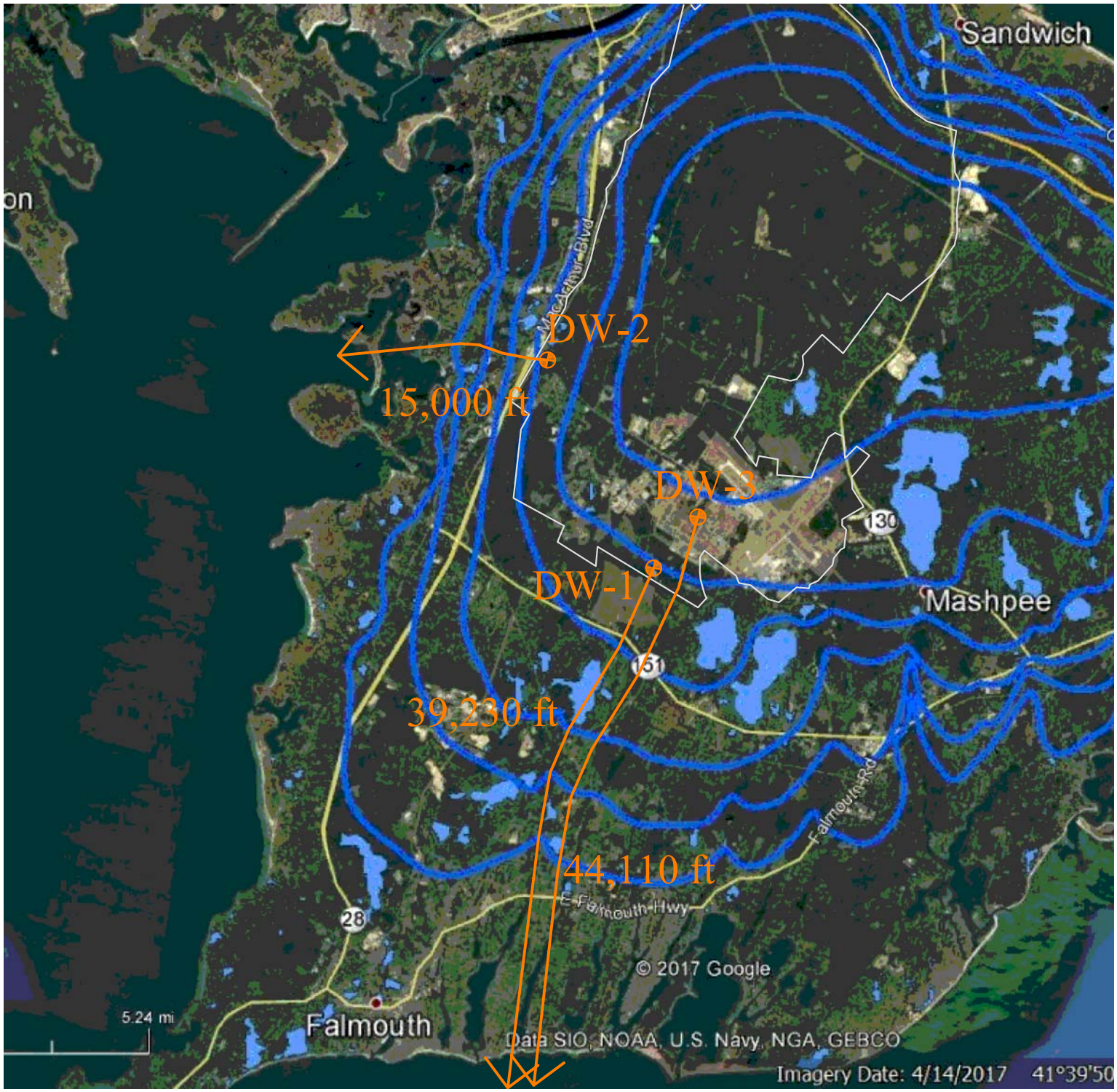
Project No. GHC#17017

Drafted SWS Checked

Date 9/27/17 Rev 10/4/17

Base Map: None.

GeoHydroCycle, Inc.



JBCC
Shared Wastewater Management Study
Hydrogeologic Considerations

Figure 8. Groundwater Flow from Three Possible Deep Wells, DW-1, DW-2 and DW-3.

0 10,000

Scale in feet

Project No. GHC#17017
Drafted SWS Checked
Date 9/24/17 Rev 10/4/17
Base Map: USGS Publication.

GeoHydroCycle, Inc.

APPENDIX C
Supporting Materials – GHD, Inc.

Memorandum

November 28, 2017

To:	Ed Leonard – Wright Pierce	Ref. No.:	11151818
From:	J. Jefferson Gregg, P.E., BCEE	Tel:	774-470-1640
CC:	Rodney Collins – Town of Mashpee, MA Amy Lowell – Town of Falmouth, MA		
Subject:	**Cost Review – JBCC Shared Wastewater Management Study** **Towns of Falmouth, MA and Mashpee, MA**		

1. Introduction

GHD Inc. was contracted by Wright Pierce for consulting services as part of their Joint Base Cape Cod (JBCC) Shared Wastewater Management Study through a grant received by the Town of Falmouth, MA. The data in this memorandum is provided subject to the limitations in Section 6.0.

GHD's tasks included review of draft documents provided by Wright Pierce related to their efforts on the project, attendance at a workshop held at the Mashpee Town Hall on October 18, 2017 with the other project participants, and then provide general comments on the draft documents and the costs presented. The general review of preliminary costs was done on behalf of the communities of Falmouth, MA and Mashpee, MA and would be based on existing planning documents developed by GHD for those two communities. No new costs were to be developed as part of this evaluation. Comparison was made following the Wright Pierce phasing framework of Short Term (2017 to 2020), Mid Term (2020 to 2040) and Long Term (2040+).

The existing planning documents referenced for comparison are as follows:

- "Shared Watershed Management Study: Towns of Bourne, Falmouth, Mashpee, Sandwich and Joint Base Cape Cod – Preliminary Strategy and Engineering Assessment Report – DRAFT", Town of Falmouth, Ma, October 2017, Wright Pierce. (JBCC Report)
- "Final Recommended Plan/ Final Environmental Impact Report", Town of Mashpee Sewer Commission, May 2015, GHD Inc. (WNMP)
- "Draft Comprehensive Wastewater Management Plan and Draft Environmental Impact Report, and Notice of Project Change – Little Pond, Great Pond, Green Pond, Bournes Pond, Eel Pond, and Waquoit Bay Watersheds and Recommendations for West Falmouth Harbor Watershed – Volume 1 and 2", Town of Falmouth, MA, July 2012, GHD Inc. (DCWMP/DEIR)

Supplemental information was also consulted as it related to the previous GHD planning efforts and past cost development for both Falmouth, MA and Mashpee, MA.

2. Task 3 General JBCC Report Review

On October 16, 2017, GHD was provided with the JBCC DRAFT Report for review and comment prior to the October 18, 2017 workshop. GHD identified the following comments summarized as follows: (Wright Pierce general responses are summarized in *italics*)

1. Section 1.3.3 "Mashpee" – GHD requested that reference to the July 31, 2015 Certificate of the Secretary of Energy and Environmental Affairs on the Final Environmental Impact Report be included in this section. *Reference will be included in final document.*
2. Section 1.4.8, last bullet – GHD suggested clarification be provided on where the 8-inch FM section is, as all other references to the effluent FMs at JBCC are of 12-inch pipe. *Clarification will be provided in final document.*
3. Section 1.6.3, first paragraph, 3rd sentence. Should read "advantageous", not "advantages". *Correction made in final document.*
4. Table 1-7 Requested Capacity By Wastewater Type, following discussions with the Town of Mashpee. Please revise two rows:
    a. Mid Term – High End (gpd) change from 200,000 gpd to 370,000 gpd
    b. Long Term – High End (gpd) change from 200,000 gpd to 850,000 gpd

    It is our understanding that these changes in values do not impact the Study Basis or Cost Estimations. *Table 1-7 will be modified per the request, and values do not impact Study Basis.*
5. Section 2.4.2, fourth bullet "Mashpee (sewage)"; Mashpee requested that the location of the lift station be made consistent with the approved WNMP. There is no lift station proposed at the Mashpee Rotary to convey wastewater to JBCC. GHD provided additional information during discussions with Wright Pierce regarding the location of the pumping station to JBCC. During that discussion, GHD suggested two potential options:. either at the "Back Road Site 1" location as shown on Figure 6-4, or at the proposed lift station location proposed for Subarea "L" off of Hooppole Road. *WP will show pumping station at Back Road Site 1.*
6. Section 2.4.2.3 – Preferred Mashpee Alignment Details. See Comment #5.
7. Table 2-4 Unit Processes – suggested that Deep Well Injection and Outfall would be the same for "Conventional Nitrogen" either both "yes" or both "no". *Correction made in final document.*
8. Sections 2.8.2, 2.84 and 2.8.6 – suggested that Mid-Term first bullet be clarified. Is the assumption that they currently meet these requirements, or that they will by the time of Mid-Term implementation. *Additional clarification will be provided in final document.*
9. GHD asked if there would be a table presenting the "Short-Term" breakdown. GHD suggested that a simple table of % contribution by each town under the Short-, Mid-, and Long-Term options be presented. *Updates provided by WP.*

10. Section 2.9.4 –"Conveyance", GHD asked if cost splitting by flow contribution was considered for shared infrastructure? *It was clarified that other methods were not considered for this report, but it is acknowledged that other methods could be used.*

11. Section 2.9.6 – Evaluation Criteria.

    a. Public perception – GHD asked why impact to surface water was considered "neutral", isn't there concern over ocean outfalls and the public perception – wouldn't this be the same as the "NGO" perception? *It was clarified that public perception was considered different than NGO perception on this topic, but that this is a subjective criteria.*

    b. Groundwater Protection – GHD suggested modifying this title or breaking into two categories, as it could be interpreted that "protection" and "sustainability" might be different relative to Zone IIs. *It was clarified that this would be changed to "Sustainability/Groundwater supply". Groundwater protection is covered by permitting.*

    c. Sustainability/chemical use – GHD asked if there was consideration of decrease in chemical use as the advantage. *It was clarified that chemical use was related to the number of processes, not chemical quantities*.

12. Appendix A – Evaluation Conveyance Options memo should be updated – see Comment #5. *Correction will be made in final document.*

3. Task 4 Mashpee Review

The following tables summarize the analysis used to look at capital costs for various options.

GHD has elected to evaluate the wastewater treatment and recharge option components at JBCC, and compare then to similar options identified as part of the Mashpee WNMP. As part of the Mashpee WNMP, JBCC was considered for treatment and recharge. In order to compare to the JBCC Report, the following considerations were made:

1. The WNMP considered treatment at JBCC using their existing facilities and presumed that only improvements to the existing WWTF would be necessary. Conveyance costs were included in their overall collection system costs and were not broken out separately. In addition, it was assumed for the JBCC option that the existing rapid infiltration basins (RIBs)/open sand beds would be sufficient to handle the flows recommended.

2. An alternative to the WNMP sending flow to JBCC was to construct new facilities at the "Back Road Site 1". This evaluation considers an MBR for treatment and recharge at open sand beds.

3. These WNMP options were then compared to the JBCC-Option 1 which included SBRs and RIBs.

4. Conveyance costs were not considered since they are considered each town's responsibility, thus these costs were not broken out in the WNMP..

5. Costs were then calculated on a dollars per thousand gallon treated ($/Kgal) per Wright-Pierce's request. Each component was calculated individually and then added up to consider those conditions where flow may change between what is being treated and what is being recharged.

Table 3.1 presents the summary of the Short-Term costs prepared by Wright-Pierce for the Treatment and Disposal options.

Table 3.2 presents the summary of the Mid-Term costs prepared by Wright-Pierce for the Treatment and Disposal options.

Table 3.3 presents the summary of the Long-Term costs prepared by Wright-Pierce for the Treatment and Disposal options.

Table 3.4 presents a summary of the WNMP costs prepared for the following three options:

1. Phase 2 (JBCC Option) – this option is the recommended plan, where 200,000 gpd would be sent to JBCC and treated using the existing facilities (expanded with a parallel oxidation ditch added), and recharged using the existing RIBs.
2. Phase 2 (Back Roads Site - MBR) – This option represents the "fall back" option presented in the Recommended Plan if the JBCC facility was not available to Mashpee. This would include a new WWTF and RIBs.

Table 3.5 presents the comparison between each option and identifies each option by high, medium, and lowest capital cost on a $/Kgal basis.

Table 3.1 Short-Term - Mashpee

Scenario	Flow (gpd)	Baseline Cost ($)	Contingency (43%)	Subtotal ($)	$/Kgal
Baseline Treatment Only					
WP-Option 6	200,000	$1,090,000	$468,700	$1,558,700	$21
Supplemental Treatment Only					
WP-Option 6	200,000	$-	$-	$-	$-
Disposal (with Transport) Only					
WP-Option 6	200,000	$309,734	$133,186	$442,920	$6
Total					
WP-Option 6 - WWTF and Recharge (RIB)					$27

Notes:
1. Costs are based on values prepared by Wright-Pierce in their Draft October 2017 report and appendices.
2. Conveyance Costs Not included, because locations could vary when compared to each alternative (including CWMPs) and all Costs by Town only.
3. Contingency column represents "Contingencies/Fiscal, Legal, Engineering" (43%) differ from those for the WNMP (40% assumed in WNMP).

Table 3.2 Mid-Term - Mashpee

Scenario	Flow (gpd)	Baseline Cost ($)	Contingency (43%)	Subtotal ($)	$/Kgal
Baseline Treatment Only					
WP-Option 6	203,000	$5,443,338	$2,340,635	$7,783,973	$105
Supplemental Treatment Only					
WP-Option 6	203,000	$-	$-	$-	$-
Disposal (w/ Transport) Only					
WP-Option 6	203,000	$1,310,126	$563,354	$1,873,480	$25
Total					
WP-Option 6 - WWTF and Recharge (RIB)					$130

Notes:
1. Costs are based on values prepared by Wright-Pierce in their Draft October 2017 report and appendices.
2. Conveyance Costs Not included, because locations could vary when compared to each alternative (including CWMPs) and all Costs by Town only.
3. Contingency column represents “Contingencies/Fiscal, Legal, Engineering” (43%) differ from those for the WNMP (40% assumed in WNMP).

Table 3.2 Long-Term - Mashpee

Scenario	Flow (gpd)	Baseline Cost ($)	Contingency (43%)	Subtotal ($)	$/Kgal
Baseline Treatment Only					
WP-Option 6	203,000	$7,786,169	$3,348,053	$11,134,222	$150
Supplemental Treatment Only					
WP-Option 6	203,000	$-	$-	$-	$-
Disposal (w/ Transport) Only					
WP-Option 6	203,000	$2,236,257	$961,591	$3,197,848	$43
Total					
WP-Option 6 - WWTF and Recharge (RIB)					$193

Notes:
1. Costs are based on values prepared by Wright-Pierce in their Draft October 2017 report and appendices.
2. Conveyance Costs Not included, because locations could vary when compared to each alternative (including CWMPs) and all Costs by Town only.
3. Contingency column represents “Contingencies/Fiscal, Legal, Engineering” (43%) differ from those for the WNMP (40% assumed in WNMP).

Table 3.3 Mashpee WNMP (2015)

Scenario	Flow (gpd)	Baseline Cost ($)	Contingency (43%)	Subtotal ($)	$/Kgal
Treatment Only					
Phase 2 JBCC Option	200,000	$4,000,000	$1,720,000	$5,720,000	$78
Phase 2 Back Roads Site	200,000	$9,860,000	$4,240,000	$14,100,000	$193
Disposal (w/ Transport) Only					
Phase 2 JBCC Option	200,000	$-	$-	$-	$-
Phase 2 Back Roads Site	200,000	$720,000	$310,000	$1,030,000	$14
Total					
Phase 2 (JBCC Option)					$78
Phase 2 (Back Roads Site - MBR)					$207

Notes:
1. Contingency column represents “Contingency/Fiscal, Legal, Engineering” changed to 43% to match JBCC evaluation (40% assumed in WNMP).
2. Base line cost adjusted from 2015 values (ENR 9922) to 2017 Costs per JBCC ENR (10800).
3. Mashpee Alternative assumed no improvements needed to effluent recharge facilities at JBCC.
4. Mashpee Alternative assumed existing JBCC WWTF could be used and expanded vs. construction of a new WWTF.

Table 3.4 Mashpee Summary ($/Kgal)

Option	Mashpee WNMP (JBCC)	Mashpee WNMP (Back Roads - MBR)	JBCC Short-Term	JBCC Mid-Term	JBCC Long-Term
WW Treatment and Recharge (RIB)	$78	$207	$27	$130	$193

Notes:
1. RIB = Rapid Infiltration Basin/Open Sand Bed
2. Green = Lowest Cost
3. Orange = Mid Cost
4. Red = High Cost

As can be seen in Table 3.4, the Mashpee WNMP recommended plan presents the lowest capital cost option. This is primarily because it does not call for an entirely new WWTF and does not require construction of new

RIBs. O&M costs were not compared directly as there was no breakout by “process”, “town”, and “option” provided for the JBCC report.

4. Task 5 – Falmouth Review

The following tables summarize the analysis used to look at capital costs for various options. Comparisons are strictly made in an effort to compare cost development for this JBCC Report relative to previous planning efforts in Falmouth, MA and are not intended to represent any recommended plan for Falmouth, MA as they are currently still in the midst of Comprehensive Planning.

GHD has elected to evaluate the wastewater treatment and recharge option components at JBCC and compare then to similar options identified as part of the evaluations performed in developing the Falmouth Draft CWMP/DEIR. As part of the Falmouth Draft CWMP planning efforts, several alternatives for JBCC were considered for treatment and recharge. The Town of Falmouth is still in planning, has been working on addressing their TMDLs through multiple approaches, and has not finalized any recommendation regarding the use of JBCC; therefore comparisons are made based on evaluations performed as part of the Draft CWMP development back in 2009 and 2012. In order to compare to the JBCC Report, the following considerations were made:

1. Conveyance costs were included in their overall collection system costs and were not broken out separately.
2. Costs for Falmouth were based on those developed as part of the DCWMP/DEIR. It should be noted that these were not the final recommendations of the Town; however they were used as they provided a group of comparable scenarios.
3. Costs were then calculated on a dollars per thousand gallon treated ($/Kgal) per Wright-Pierce request. Each component was calculated individually and then added up to consider those conditions where flow may change between what is being treated and what is being recharged.
4. Option 6 (as outlined in Section 2 of the JBCC Report was used as the evaluation point) – New WWTF at JBCC and ocean outfall (OO) (Falmouth continues treatment at the existing BSR WWTF)
5. O&M costs were not compared directly as there was no breakout by “process”, “town”, and “option” provided for the JBCC report.

Table 4.1 presents the summary of the Mid-Term costs prepared by Wright-Pierce for the Treatment and Disposal options, plus upgrade costs for the BSR WWTF to continue treatment in the long-term. Upgrade costs represent the portion of the costs that would be sent to JBCC for effluent disposal (i.e., Falmouth would have additional upgrade costs for the effluent flow that would stay in Falmouth).

Table 4.2 presents the summary of the Long-Term costs prepared by Wright-Pierce for the Treatment and Disposal options, plus upgrade costs for the BSR WWTF to continue treatment in the long-term. Upgrade costs represent the portion of the costs that would be sent to JBCC for effluent disposal (i.e., Falmouth would have additional upgrade costs for the effluent flow that would stay in Falmouth).

Table 4.3 presents a summary of the DCWMP/DEIR costs prepared for the following three options:

1. 3A - JBCC WWTF with Recharge at the Falmouth County Club (FCC).
2. 3C - JBCC WWTF with RO and Well Injection.
3. 1D – Blacksmith Shop Road (BSR) WWTF with Ocean Outfall.

These options were considered the most comparable to the JBCC Report options, based on their treatment and discharge technologies.

Table 4.4 presents the comparison between each option and identifies each option by high, medium, and lowest capital cost on a $/Kgal basis.

Table 4.1 Mid Term – Falmouth

Scenario	Flow (gpd)	Baseline Cost ($)	Contingency (43%)	Subtotal ($)	$/Kgal
Baseline Treatment Only					
WP-Option 6	512,000	$6,297,248	$2,707,816	$9,005,064	$48
Supplemental Treatment Only					
WP-Option 6	512,000	$-	$-	$-	$-
Disposal (w/ Transport) Only					
WP-Option 6	512,000	$7,451,190	$3,204,012	$10,655,202	$56
Total					
WP - Option 6 - WWTF and Recharge (OO)					$104

Notes:
1. Costs are based on values prepared by Wright Pierce in their Draft October 2017 report and appendices.
2. Conveyance Costs Not included, because locations could vary when compared to each alternative (including CWMPs) and all Costs by Town only.
3. Contingency column represents “Contingencies/Fiscal, Legal, Engineering” (43%) differ from those for the CWMP (50% assumed in DCWMP/DEIR).
4. Treatment flows and costs adjusted to account for off-site (not at JBCC) wastewater treatment. Estimated $/Kgal used based on Option 1D of the DCWMP/DEIR for 490,000 gpd balance.

Table 4.2 Long Term - Falmouth

Scenario	Flow (gpd)	Baseline Cost ($)	Contingency (43%)	Subtotal ($)	$/Kgal
Baseline Treatment Only					
WP-Option 6	1,512,000	$18,440,041	$7,929,218	$26,369,259	$48
Supplemental Treatment Only					
WP-Option 6	1,512,000	$-	$-	$-	$-
Disposal (w/ Transport) Only					
WP-Option 6	1,512,000	$14,349,266	$6,170,184	$20,519,450	$37
Total					
WP - Option 6 - WWTF and Recharge (OO)					$85

Notes:

1. Costs are based on values prepared by Wright Pierce in their Draft October 2017 report and appendices.
2. Conveyance Costs Not included, because locations could vary when compared to each alternative (including CWMPs) and all Costs by Town only.
3. Contingency column represents “Contingencies/Fiscal, Legal, Engineering” (43%) differ from those for the CWMP (50% assumed in DCWMP/DEIR).
4. Treatment flows and costs adjusted to account for off-site (not at JBCC) wastewater treatment. Estimated $/Kgal used based on Option 1D of the DCWMP/DEIR for 1,490,000 gpd balance.

Table 4.3 Falmouth DCWMP/DEIR (2009/2012)

Scenario	Flow (gpd)	Baseline Cost ($)	Contingency (43%)	Subtotal ($)	$/Kgal
Treatment Only					
3A (Phase 1 and 2) Table 5-1	1,800,000	$32,700,000	$14,100,000	$46,800,000	$71
3C (Phase 1 and 2) Table 5-4	1,800,000	$68,000,000	$29,200,000	$97,200,000	$148
1D (Phase 1 and 2) - Table 5-5	1,800,000	$21,400,000	$9,200,000	$30,600,000	$47
Disposal (w/Transport) Only					
3A (Phase 1 and 2) Table 5-1	1,800,000	$16,400,000	$7,100,000	$23,500,000	$36
3C (Phase 1 and 2) Table 5-4	1,800,000	$10,100,000	$4,300,000	$14,400,000	$22
1D (Phase 1 and 2) - Table 5-5	1,800,000	$47,900,000	$20,600,000	$68,500,000	$104
Total					
3A (Phase 1 and 2) Table 5-1					$107
3C (Phase 1 and 2) Table 5-4					$170
1D (Phase 1 and 2) - Table 5-5					$151

Notes:

1. 3A - JBCC WWTF with Recharge at FCC
2. 3C - JBCC WWTF with RO and Well Injection
3. 1D - BSR WWTF with Ocean Outfall
4. Conveyance cost based on Major PS and FM cost row from spreadsheets
5. Contingency column represents “Contingency/Fiscal, Legal, Engineering” changed to 43% to match JBCC evaluation
6. Base line cost adjusted from July 2009 values (ENR 8570) to 2017 Costs per JBCC ENR (10800)

Scenario Flow (gpd)	Estimated $/Kgal
DCWMP WW Treatment and Recharge (RIB)	$107
DCWMP WW Treatment and Recharge (DWI)	$170
DCWMP WW Treatment and Recharge (OO)	$151
Option 6 – Mid-Term (JBCC Report)	$104
Option 6 – Long-Term (JBCC Report)	$85

Notes:

1. RIB = Rapid Infiltration Basin/Open Sand Bed
2. DWI = Deep Well Injection
3. OO = Ocean Outfall
4. Green = Lowest Cost
5. Orange = Mid Costs
6. Red = High Costs

5. Summary

Based on this initial review of the documents and costs:

- The Mashpee WNMP recommendations (i.e., to send 200,000 gpd of sewage to JBCC upgaded for a smaller scale regional use) still appear to be the most cost effective for that community, however, the Mashpee WNMP was not intended to consider a larger scale regional use of the JBCC facility. If all of the communities were in agreement and a larger effluent discharge option were presented, the Town of Mashpee may consider requesting additional sewage treatment capacity in order to alleviate stress on its existing embayments. At this time the short-term goals of Mashpee appear consistent with the short-term goals presented in the JBCC report.
- The Falmouth DCWMP/DEIR costs indicate that it is slightly less cost effective for Falmouth to work independently in the long term and essentially the same under mid-term conditions. Irrespective of the term, the Town is in the middle of its planning efforts and changes and alternatives identified during that process may show the JBCC alternatives more cost effective. The alternatives for Falmouth were much closer in cost than those presented for Mashpee.
- There are still a significant number of unknowns regarding the use of JBCC which would influence each of these communities and their future decision making process; however, the planning-level cost estimates are indicative of potential cost savings in the long-term due to regionalization. Mashpee and Falmouth should continue to stay engaged on the potential regional use of the JBCC wastewater facilities.

6. Limitations

GHD has not been involved in the direct preparation of the JBCC Report and makes no statement in the JBCC Report other than the contents of this memorandum.

The Cost Estimates are a preliminary estimate only. Actual prices, costs, and other variables may be different to those used to prepare the Cost Estimate and may change. No detailed quotation has been obtained for actions identified herein. GHD does not represent, warrant or guarantee that the works/project can or will be undertaken at a cost which is the same or less than the Cost Estimates presented.

No information provided as part of this memorandum shall be used for design or construction.

WRIGHT-PIERCE

Engineering a Better Environment

Appendix MM

Conveyance Alternative Analysis

WRIGHT-PIERCE
Engineering a Better Environment

MEMORANDUM

TO:	File	**DATE:**	5/13/2019
FROM:	E. Whatley, J. Ducharme, J. Srey	**PROJECT NO.:**	13839/20008A
SUBJECT:	JBCC Shared Wastewater Management Study Evaluation of Conveyance Options		

This memorandum identifies the options for wastewater conveyance systems required to support shared wastewater management opportunities for the towns of Bourne, Falmouth, Mashpee, Sandwich, Joint Base Cape Cod (JBCC), and Barnstable. Supplemental information is included in the following attachments:

- Conveyance Option Worksheet with plan and profile figures
- Conveyance Options Costs
- JBCC Conveyance Improvement Worksheet

1.1 OBJECTIVES

The objectives of the conveyance study include the following:

- Identify alignments for conveyance of sewage from Barnstable, Bourne's southern section, Mashpee and Sandwich to JBCC WWTF for treatment and disposal;
- Identify alignments for conveyance of treated wastewater ("effluent") from the JBCC WWTF, the Bourne ISWM WWTF and the Falmouth BSR WWTF to the JBCC treated effluent conveyance system and disposal areas;
- Identify rehabilitation of sections of the JBCC gravity sewer system where shorter alignments and capital cost savings are available;
- Review conceptual profiles of each forcemain alignment to evaluate conceptual static and dynamic head on the pumping system;
- Develop preliminary hydraulic calculations to determine conceptual forcemain sizes; and
- Determine conceptual number and size of required lift stations.

1.1.1 Concept Design Criteria

The following key assumptions are used in this analysis:

- Elevation data was obtained from topographic information within Google Earth.
- Conceptual forcemain piping and wastewater lift station sizing are based on the conveyance flows in Tables 1 and 2.

TABLE 1: RAW WASTEWATER CONVEYANCE FLOWS

(Raw Wastewater Lift Station Peaking Factor: 4)
(Barnstable Raw Wastewater Lift Station Peaking Factor: 3.6)

Flow Source	Existing Flows		Short-Term Flows		Mid-Term Flows		Long-Term Flows	
	Avg.	Peak	Avg.	Peak	Avg.	Peak	Avg.	Peak
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
JBCC	140,000	389	152,000	422	152,000	422	152,000	422
Sandwich	-	-	-	-	100,000	278	340,000	944
Mashpee	-	-	200,000	556	200,000	556	200,000	556
Bourne-S	-	-	-	-	259,000	719	456,000	1,267
Barnstable	-	-	-	-	500,000	1,250	1,200,000	3,000
Subtotal- Raw WW to WWTF	**140,000**	**389**	**352,000**	**978**	**1,211,000**	**3,225**	**2,348,000**	**6,522**

TABLE 2: EFFLUENT CONVEYANCE FLOWS

(Effluent Lift Station Peaking Factor: 1.25)

Flow Source	Existing Flows		Short-Term Flows		Mid-Term Flows		Long-Term Flows	
	Avg.	Peak	Avg.	Peak	Avg.	Peak	Avg.	Peak
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
JBCC	140,000	122	152,000	132	152,000	132	152,000	132
Bourne Effluent	-	-	100,000	87	444,000	385	651,000	565
Bourne-S	-	-	-	-	270,000	234	467,000	405
Falmouth	-	-	-	-	512,000	444	1,512,000	1,313
Mashpee	-	-	200,000	174	203,000	176	203,000	176
Sandwich	-	-	-	-	110,000	95	350,000	304
Barnstable	-	-	-	-	500,000	434	1,200,000	1,042
Total Effluent Disposal	**140,000**	**122**	**452 ,000**	**392**	**2,191,000**	**1,902**	**4,535,000**	**3,937**

- Raw wastewater concept design criteria:
    - Peaking factor used for lift station flow: 4.0
    - Peaking factor used for Barnstable lift station flow: 3.6
    - Minimum forcemain velocity: 3 fps
    - Maximum forcemain design pressure: 275 ft (120 psi)
- Effluent concept design criteria:
    - Peaking factor used for lift station flow: 1.25
    - Minimum forcemain velocity: none
    - Maximum forcemain design pressure: 275 ft (120 psi)
- Forcemain materials:
    - Existing effluent forcemain: ductile iron
    - Proposed forcemains: C900/C905 DR 18 PVC (235 psi) or HDPE (200 to 255 psi)
- Pump calculations:
    - Method: Hazen-Williams with friction value of 130
    - Pump Horsepower approximation per Hydraulic Institute method
    - Assumed pump efficiency for sewage: 50%
    - Assumed pump efficiency for effluent: 65%
- Medium-sized wastewater and effluent lift stations:
    - Flow: up to 1200 gpm
    - Pumps: submersible, up to 75 hp
    - Wetwell and valve vault
    - Generator and control panel in pump house
    - Conceptual construction cost: $1M each

- Large-sized wastewater and effluent lift stations:
    - Flow: 1200 gpm to 2000 gpm
    - Pumps: drypit installation, greater than 75 hp
    - Generator and control panel in pump building over wetpit/drypit installation
    - Conceptual construction cost: $2.5M each
- Very large-sized wastewater and effluent lift stations:
    - Flow: 2000 gpm or more
    - Pumps: drypit installation
    - Horsepower: up to 200 hp
    - Generator and control panel in pump building over wetpit/drypit installation
    - Conceptual construction cost: $5M each
    - For pumps requiring 300 hp, add an additional $1M.
- Air release structures
    - Located at high points
    - Conceptual construction costs: $25,000 each
- Conveyance routes utilizing existing JBCC gravity conveyance systems assume the rehabilitation of those sections through trenchless methods for options that do not include Barnstable. Rehabilitation costs are assumed to be $150 per foot. For options that include Barnstable, new gravity sewers required accommodate large flows are assumed to be $300 per foot.
- Forcemain costs vary depending on the conditions of the route and are shown below in Table 3. “Public Way/Dense” refers to a route within a public way with heavy traffic volumes or dense development and has a higher cost than a route referred to as “Public Way/Less Dense” which includes routes within a public way with little traffic. Force main costs assume full-depth trench paving and full-width mill and overlay.
- For the large-diameter effluent force main routes through JBCC, the costs for 18-inch and 20-inch force mains are approximates $200 /LF and $210 / LF, respectively.

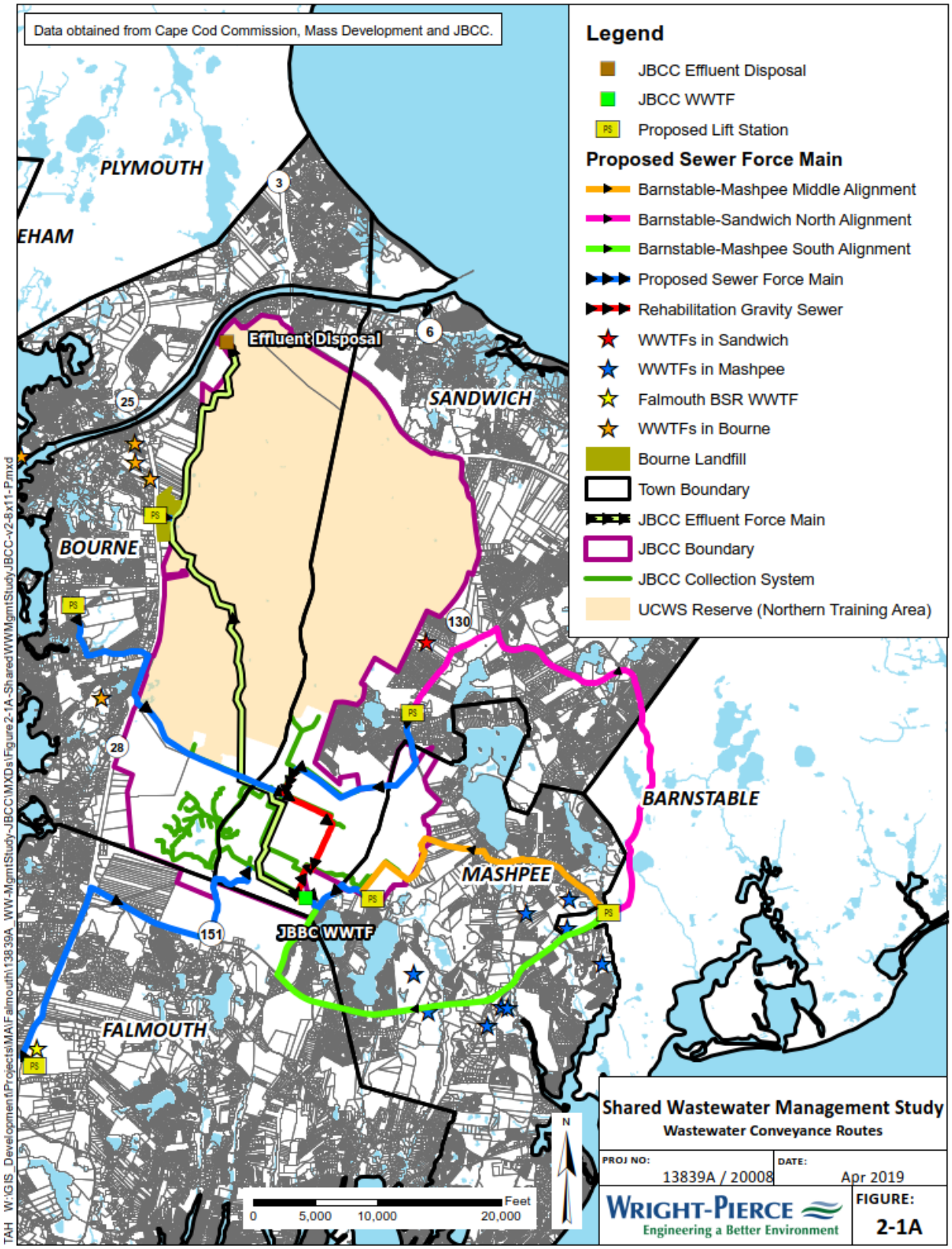
TABLE 3: FORCEMAIN UNIT COSTS

Forcemain Diameter	Route Characteristics		
	Public Way/Dense (Cost/ft)	Public Way/ Less Dense (cost/ft)	Railroad Right of Way (cost/ft)
8-inch	$200	$180	$300
10-inch	$215	$195	$320
12-inch	$230	$210	$340
14-inch	$245	$225	$360
16-inch	$260	$240	$360
18-inch	$280	$250	$380
20-inch	$300	$260	$400

1.2 SUMMARY OF PREFERRED CONVEYANCE OPTIONS

Current preferred conveyance routes are shown on **Figure 2-1A** and identified as follows:

- Bourne North (effluent) – Proposed lift station at ISWM WWTF connected to existing JBCC effluent forcemain, via a new 8" Bourne forcemain.
- Bourne South – Proposed lift station at the intersection of Valley Bars and County Roads to JBCC WWTF via a new 12" Bourne forcemain and rehabilitated gravity sewer (shared with Sandwich).
- Falmouth (effluent) – Proposed lift station at BSR WWTF connected to the JBCC effluent forcemain(s) via a new 18" Falmouth forcemain in Routes 28 and 151.
- Mashpee – Proposed lift station on Back Road Site 1 (Town lot) to JBCC WWTF via new 8" Mashpee forcemain.
- Sandwich – Proposed lift station on portion of Lot-06-236 at 40 Route 130 to JBCC WWTF via 12" Sandwich forcemain, and rehabilitated gravity sewers (shared with Bourne).
- Barnstable – Proposed lift station at intersection of Route 130 and Falmouth Road to JBCC WWTF via a new 20" Barnstable forcemain through Newton Road to a shared Sandwich forcemain and new gravity sewers (shared with Sandwich and Bourne).


Data obtained from Cape Cod Commission, Mass Development and JBCC.
Legend
JBCC Effluent Disposal
JBCC WWTF
Proposed Lift Station
Proposed Sewer Force Main
Barnstable-Mashpee Middle Alignment
Barnstable-Sandwich North Alignment
Barnstable-Mashpee South Alignment
Proposed Sewer Force Main
Rehabilitation Gravity Sewer
WWTFs in Sandwich
WWTFs in Mashpee
Falmouth BSR WWTF
WWTFs in Bourne
Bourne Landfill
Town Boundary
JBCC Effluent Force Main
JBCC Boundary
JBCC Collection System
UCWS Reserve (Northern Training Area)
PLYMOUTH
EHAM
SANDWICH
BOURNE
BARNSTABLE
MASHPEE
FALMOUTH
Effluent Disposal
JBBC WWTF
3
6
25
28
130
151
PS
N
0
5,000
10,000
20,000
Feet
Shared Wastewater Management Study
Wastewater Conveyance Routes
PROJ NO:
13839A / 20008
DATE:
Apr 2019
WRIGHT-PIERCE
Engineering a Better Environment
FIGURE:
2-1A
TAH W:\GIS_Development\Projects\MA\Falmouth\13839A_WW-MgmtStudy-JBCC\MXDs\Figure2-1A-SharedWWMgmtStudyJBCC-v2-8x11-P.mxd

1.3 CONVEYANCE ALIGNMENTS EVALUATED

1.3.1 Bourne Alignments

The following alignments were investigated for Bourne sewage flow from the southern sections of town. This piping is required in the mid-term.

- Option 1. Shortest route through the JBCC base, utilizing existing JBCC gravity sewer
    - 1 large lift station, 1250 gpm, 235 ft TDH, 150 hp
    - 12" forcemain, velocity 3.6 fps, 5.1 miles
    - JBCC rehabilitated gravity sewer, 2.3 miles
    - Total route length: 7.4 miles
    - Advantages
        - Least expensive - by $4.1M
        - Shortest route by 2.1 miles
        - Shortest length within public way / dense route
    - Disadvantages
        - Uncertainty of obtaining construction easements within federal lands for forcemains
        - Uncertainty of the level of rehabilitation required for JBCC gravity sewers
- Option 2A. Route utilizing the Shining Sea bike corridor, 1 lift station
    - 1 large lift station, 1400 gpm, 250 ft TDH, 175 hp
    - 14" forcemain, velocity 3.0 fps, 9.5 miles
    - Total route length, 9.5 miles
- Option 2B. Route utilizing the Shining Sea bike corridor, 2 lift stations
    - 2 large lift stations, 1250 gpm, 175 ft TDH, 100 hp
    - 12" forcemain, velocity 3.6 fps, 9.5 miles
    - Total route length, 9.5 miles
- Option 3A. Route primarily in public way
    - 1 large lift station, 1400 gpm, 250ft TDH, 175 hp

  - 14" forcemain, velocity 3.0 fps, 9.9 miles
  - Total route length, 9.9 miles

- Option 3B. Route primarily in public way
  - 2 large lift stations, 1250 gpm, 175 ft TDH, 120 hp
  - 12" forcemain, velocity 3.6 fps, 9.9 miles
  - Total route length, 9.9 miles

Bourne Option 2A, 2B, 3A and 3B appear to be less favorable option based on the following:

- Advantage
  - Avoids having to obtain extensive construction easements within federal lands for forcemains
  - Avoids concern over the level of rehabilitation required for JBCC gravity sewers
- Disadvantage
  - High costs

One alignment was investigated for Bourne effluent flow from the ISWM WWTF to the JBCC effluent forcemain. We assumed the construction of a medium sized lift station to accommodate long-term conditions.

  - 1 medium lift stations, 570 gpm, 180 ft TDH, 50 hp, Velocity 1.7 fps
  - Existing 8" Forcemain, 100 feet

A summary of the Bourne-South Options is shown below.

TABLE 4: BOURNE CONVEYANCE ALTERNATIVES COMPARISON

Conveyance Feature		Option 1	Option 2A	Option 2B	Option 3A	Option 3B
Cost (2019 Dollars)	$M	10.5	15.2	17.0	16.1	17.8
Rehabilitated JBCC sewer (50% Share)	1000 ft	12.3	0.0	0.0	0.0	0.0
Medium PS (Bourne – North)	Each	1	1	1	1	1
Large PS	Each	1	1	2	1	2
Forcemain - public way/dense	1000 ft	12.7	17.8	17.8	38.5	38.5
Forcemain – public way/ less dense	1000 ft	14.5	32.2	32.2	13.5	13.5

1.3.2 Falmouth Alignments

The following alignments were investigated for Falmouth effluent flow from the BSR WWTF to the JBCC WWTF effluent forcemain. This piping is required in the mid-term.

- Option 1. Route in public way
    - 1 Large lift station, 1300 gpm, 220 ft TDH, 150 hp
    - 18" Falmouth effluent forcemain, velocity 1.7 fps, 6.7 miles
    - Total route length, 6.7 miles
    - Advantages
        - Least expensive by $100,000
        - Eliminates potentially expensive railroad coordination costs in Option 3
    - Disadvantage
        - Lengthy section of the route is in right of way
- Option 2. Route in public way, with semi-utilization of the Shining Sea bike corridor
    - 1 Large lift station, 1300 gpm, 220 ft TDH, 150 hp
    - 18" Falmouth effluent forcemain, velocity 1.7 fps, 8.1 miles
    - Total route length. 8.1 miles
    - Advantages
        - Shorter section of the route is in right of way
        - Eliminates potentially expensive railroad coordination costs in Option 3
    - Disadvantage
        - More expensive than Option 1 by $1M
- Option 3. Route in public way and rail right of way
    - 1 Large lift station, 1300 gpm, 220 ft TDH, 150 hp
    - 18" Falmouth effluent forcemain, velocity 1.7 fps, 5.3 miles
    - Total route length, 5.3 miles
    - Advantages
        - Shortest route
        - Potential to be less expensive with favorable railroad coordination costs

- Disadvantages
  - Costs associated with railroad safety and flagmen expenses during construction and regular operation
  - Efficient access to the rail corridor during and after construction
  - Potential damage from vibration caused by rail traffic

A summary of the Falmouth Conveyance Options is shown below.

TABLE 5: FALMOUTH CONVEYANCE ALTERNATIVES COMPARISON

Conveyance Feature		Option 1	Option 2	Option 3
Cost (2019 Dollars)	$M	12.1	13.8	11.8
Large PS	Each	1	1	1
Forcemain - public way/dense	1000 ft	25.9	20.1	13.8
Forcemain - railroad right of way	1000 ft	0.0	0.0	14.2
Forcemain -public way/less dense	1000 ft	9.5	22.6	0.0

1.3.3 Mashpee Alignments

The following alignments were investigated for Mashpee sewage flow to the JBCC WWTF. This piping is required in the short-term.

- Option 1. Mashpee forcemain to connect directly to JBCC WWTF
  - Medium lift station, 560 gpm, 75 ft TDH, 20 hp
  - 8” Dedicated Mashpee forcemain, velocity 3.5 fps, 1.4 miles
  - Total route length: 1.4 miles
  - Advantages
    - Least expensive by $1.7M
    - Shortest forcemain route by 3.4 miles
    - Reduced lift station size
    - Smaller diameter force main
  - Disadvantages
    - None

- Option 2. Mashpee forcemain to shared rehabilitated gravity main with Sandwich and Bourne
    - Medium lift station, 1040 gpm, 140 ft TDH, 70 hp
    - 12" Dedicated Mashpee forcemain, velocity 3.0 fps, 4.2 miles
    - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne and Sandwich
    - Total route length: 4.8 miles
    - If the existing 10-inch JBCC forcemain serving JBCC lift stations at Rocket Storage, Central Heating Plant and Hanger was rehabilitated or decommissioned, there could be cost advantages for Mashpee.
    - Advantages
        - Forcemain would be dedicated to Mashpee and maintaining correct operating conditions would be easier for Mashpee.
        - If the existing 10-inch JBCC forcemain serving JBCC lift stations at Rocket Storage, Central Heating Plant and Hanger was rehabilitated or decommissioned, there could be cost advantages for Mashpee.
    - Disadvantages
        - More expensive than Option 1 by $2.4M. (Note: Mashpee Option 3 requires Sandwich to choose Option 2 which is $0.8M more expensive for Sandwich).
- Option 3. Mashpee forcemain to forcemain shared with Sandwich and rehabilitated gravity main shared with Sandwich and Bourne
    - Medium lift station, 1040 gpm, 140 ft TDH, 70 hp
    - 12" Dedicated Mashpee forcemain, velocity 3.0 fps, 2.4 miles
    - 12" S Outer Road forcemain, 0.7 miles, shared with Sandwich
    - 12" Reilly Rd/Grandville Ave forcemain, 1.1 miles, shared with Sandwich
    - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne and Sandwich
    - Total route length: 4.8 miles

- Advantages
  - If the existing 10-inch JBCC forcemain serving JBCC lift stations at Rocket Storage, Central Heating Plant and Hanger was rehabilitated or decommissioned, there could be additional cost advantages.
- Disadvantages
  - More expensive than Option 1 by $1.7M.

A summary of the Mashpee options is shown below.

TABLE 6: MASHPEE CONVEYANCE ALTERNATIVES COMPARISON

Conveyance Feature		Option 1	Option 2	Option 3
Cost (2019 Dollars)	$M	2.5	5.8	5.0
Rehabilitated JBCC sewer (33% Share)	1000 ft	0	3.4	3.4
Medium PS	Each	1	1	1
Forcemain - public way/dense	1000 ft	7.5	3.0	3.0
Forcemain – public way/less dense	1000 ft	0	18.9	9.7
Forcemain – public way/less dense - 50% share with Sandwich	1000 ft	0	0.0	9.3

1.3.4 Sandwich Alignments

The following alignments were investigated for Sandwich sewage flow to the JBCC WWTF. The conveyance system is required in the mid-term.

- Option 1. Sandwich forcemain to connect to shared rehabilitated gravity main with Bourne
  - Medium lift station, 1050 gpm, 75 ft TDH, 40 hp
  - 12” Dedicated Sandwich forcemain, velocity 3.0 fps, 2.9 miles
  - JBCC rehabilitated gravity sewer, 0.4 miles
  - JBCC rehabilitated gravity sewer, 1.7 miles, shared with Bourne
  - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne
  - Total route length: 5.7 miles
  - Advantages

        - Least expensive by $0.8M
    - Disadvantages
        - Uncertainty of obtaining construction easements within federal lands for forcemains
        - Uncertainty of the level of rehabilitation required for JBCC gravity sewer mains.

- Option 2. Sandwich forcemain to connect shared forcemain with Mashpee (Mashpee Option 2) and shared rehabilitated gravity main with Bourne and Mashpee
    - Medium lift station, 1050 gpm, 140 ft TDH, 60 hp
    - 12" Dedicated Sandwich forcemain, velocity 3.0 fps, 4.2 miles
    - 12" S Outer Road forcemain, 0.7 miles, shared with Mashpee
    - 12" Reilly Rd/Grandville Ave forcemain, 1.1 miles, shared with Mashpee
    - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne and Sandwich
    - Total route length: 6.6 miles
    - Advantages
        - If Mashpee implements Option 2, there would be cost savings with implementation of Sandwich Option 2.
        - Shortest forcemain route by 0.9 miles
    - Disadvantages
        - More expensive by $0.8M
- Option 3: Sandwich forcemain to connect to Snake Pond Road, then to rehabilitated gravity
    - Medium lift station, 1050 gpm, 105 ft TDH, 60 hp
    - 12" Dedicated Sandwich forcemain, velocity 3.0 fps, 2.4 miles
    - JBCC rehabilitated gravity sewer, 0.4 miles
    - JBCC rehabilitated gravity sewer, 1.7 miles, shared with Bourne
    - JBCC rehabilitated gravity sewer, 0.6 miles, shared with Bourne
    - Total Route length: 5.1 miles
    - Advantages
        - Utilize public way, rather than federal lands
        - Shortest route

- Disadvantages
  - Uncertainty of obtaining construction easements within federal lands for forcemains
  - Uncertainty of the level of rehabilitation required for JBCC gravity sewer mains.

TABLE 7: SANDWICH CONVEYANCE ALTERNATIVES COMPARISON

Conveyance Feature		Option 1	Option 2	Option 3
Cost (2019 Dollars)	$M	5.6	6.9	5.2
Rehabilitated JBCC sewer (100% Share)	1000 ft	2.2	0.0	2.2
Rehabilitated JBCC sewer (50% Share)	1000 ft	12.3	3.4	12.1
Medium PS	Each	1	1	1
Forcemain - public way/dense	1000 ft	3.5	3.5	12.7
Forcemain – public way/less dense	1000 ft	11.9	18.3	0.0
Forcemain – public way/less dense – share with Mashpee	1000 ft	0.0	9.3	0.0

1.3.5 Barnstable Alignments

The following alignments were investigated for Barnstable sewage flow to the JBCC WWTF. Options 1A, 2A and 3A include cost sharing while Options 1B, 2B and 3B do not include cost sharing. Cost sharing is pro-rated based on flow. Barnstable represents 80% of flow when combined with Sandwich and represents 70% of the flow when combined with both Sandwich and Bourne.

- Option 1: Central Alignment through Mashpee
  - 1 very large lift station, 3000 gpm, 70 TDH, 200 hp, located at the intersection of Route 130 and Falmouth Road.
  - 20” forcemain, velocity 3.1 fps, 6.2 miles
    - 2.3 miles on Route 130
    - 0.9 miles on Ashumet Road
    - 1.8 miles on Riley St and Grandville Ave (JBCC roads)

- 1.2 miles shared with Mashpee (19% of total length)

- Advantages
  - Shortest route
  - Potential shared costs with Mashpee
  - Fewer major terrain changes
- Disadvantages
  - Only 19% of route is shared
  - Uncertainty of obtaining construction easements within federal lands for forcemains

- Option 2: Southern Alignment through Mashpee
  - 1 very large lift station, 3000 gpm, 70 TDH, 200 hp, located at the intersection of Route 130 and Falmouth Road.
  - 20" forcemain, velocity 3.1 fps, 7.2 miles
    - 2.3 miles on Falmouth Road (Route 28)
    - 3.4 miles on Nathan Ellis Road (Route 151)
    - 1.2 miles on Sandwich Road
    - 0.3 miles on Simkins Road shared with Mashpee (4% of the route)
  - Advantages
    - Mid-length route
  - Disadvantages
    - Little potential for shared costs (4% of the route is shared with Mashpee)
    - Most of construction route in state highway on areas of high density (Route 28 and Route 151)
    - Terrain requires the installation of at least 6 air release structures.
- Option 3: Northern Alignment through Sandwich
  - 1 large lift station, 3000 gpm, 70 TDH, 300 hp, located at the intersection of Route 130 and Falmouth Road.
  - 20" forcemain, velocity 3.1 fps, 11.6 miles
    - 0.3 miles in Falmouth Road (Route 28)

- 3.7 miles in Santuit/Newtown Rd
- 2.3 miles in Farmersville Rd
- 0.5 miles in Cotuit Road
- 0.5 miles in Quaker Meeting House Road
- 1.3 miles in Route 130
- 3.0 miles shared with Sandwich (21% of the force main route)

- JBCC new gravity sewer, 0.6 miles shared with Sandwich (4% of the total route)
- JBCC new gravity sewer, 2.1 miles shared with Sandwich and Bourne (15% of the total route)
- Total route length: 14.3 miles
- Advantages
  - 40% of total route length is shared
  - Potential shared route with Sandwich and Bourne
  - Most shared cost
- Disadvantages
  - Longest route compared to shortest route by 8 miles.
  - Uncertainty of obtaining construction easements within federal lands for forcemains
  - Uncertainty of the level of rehabilitation or replacement required for JBCC gravity sewer mains.
  - Highest costs

TABLE 8: BARNSTABLE CONVEYANCE ALTERNATIVES COMPARISON WITH COST SHARING

Conveyance Feature – With Shared Casts		Option 1A	Option 2A	Option 3A
Cost (2019 Dollars)	$M	13.9	16.2	25.7
Rehabilitated JBCC sewer (80% Share with Sandwich)	1000 ft	0.0	0.0	3.2
Rehabilitated JBCC sewer (70% Share with Sandwich and Bourne)	1000 ft	0.0	0.0	11.1
Very Large PS	Each	1	1	1
Forcemain - public way/dense	1000 ft	14.3	30.1	31.2
Forcemain – public way/less dense	1000 ft	12.1	6.3	14.3
Forcemain – public way/less dense (80% shared with Sandwich)	1000 ft	0.0	0.0	15.8
Forcemain – public way/less dense (80% shared with Mashpee)	1000 ft	6.4	1.6	0.0

TABLE 9: BARNSTABLE CONVEYANCE ALTERNATIVES COMPARISON WITHOUT COST SHARING

Conveyance Feature – With No Shared Casts		Option 1B	Option 2B	Option 3B
Cost (2019 Dollars)	$M	14.2	16.3	27.7
Rehabilitated JBCC sewer (80% Share with Sandwich)	1000 ft	0.0	0.0	3.2
Rehabilitated JBCC sewer (70% Share with Sandwich and Bourne)	1000 ft	0.0	0.0	11.1
Very Large PS	Each	1	1	1
Forcemain - public way/dense	1000 ft	14.3	30.1	31.2
Forcemain – public way/less dense	1000 ft	12.1	6.3	14.3
Forcemain – public way/less dense (80% shared with Sandwich)	1000 ft	0.0	0.0	15.8
Forcemain – public way/less dense (80% shared with Mashpee)	1000 ft	6.4	1.6	0.0

1.3.6 Effluent Conveyance Systems

The effluent conveyance system will require improvements to accommodate anticipated flow increases in each phase.

- Existing Conveyance System Data

  The existing effluent forcemain will remain in service until dual forcemains and associated pumping capacity are constructed. Characteristics of the existing forcemain are listed below.

  - Existing forcemain
    - 12-inch diameter
    - 10.8 miles
    - Ductile iron
    - Design friction factor, C, 130
    - Distance to high point, 5.8 miles (30,600 feet)
    - Static head: 210 feet
  - Existing system design assumptions
    - Conveyance main operates as a forcemain to the high point and forcemain friction calculations are based on 5.8 miles.
    - From the high point, around 150 feet of head is available to drive flow to the RIB's. A flow of about 1500 gpm uses up the available head.
    - With one pump running at the JBCC WWTF, there is available capacity in the short term for Bourne to discharge treated effluent into the JBCC forcemain at the ISWM.

- Proposed Effluent Forcemains

  In the long-term, the design effluent pumping and conveyance system will be required to handle a flow of approximately 4,000 gpm. The construction of a single large-diameter forcemain will provide increased capacity and valuable redundancy in the event that the 12-inch force main experiences a failure. The construction of the second large-diameter force main will allow the existing 12-inch forcemain to be abandoned or maintained for capacity redundancy. Two alternate routes were identified as outlined below, a match of

the existing route and an alternate route with a lower static head and associated reduced pumping horsepower requirements and related operating costs.

- Proposed 20-inch forcemain (Following existing route)
    - Following existing route (parallel to existing 12-inch forcemain)
    - 20-inch diameter
    - 10.8 miles
    - Distance to high point, 5.8 miles (30,600 feet)
    - Static head: 210 feet
    - 160 HP required for pump station
- Proposed 18-inch forcemains (Alternate route with lower static head)
    - Following improved route with lower static head and TDH
    - 18-inch diameter
    - 10.9 miles
    - Distance to high point, 5.0 miles (26,400 feet)
    - Static head: 95 feet
    - 100 HP required for pump station

1.4 SCHEDULE OF IMPROVEMENTS

1.4.1 Short-term improvements:

- JBCC / All Participants
    - Maintain operation of existing lift station and forcemain
    - Accommodate flows from JBCC and Mashpee arriving at the effluent lift station (252,000 gpd / peaked pump flow of 320 gpm)
- Bourne
    - At the ISWM, install a lift station designed to accommodate mid-term and long-term flows
    - Make connection to existing JBCC forcemain
    - Install additional valves and stubs to make a future connection to new effluent forcemains without disrupting service.
- Falmouth – no changes
- Mashpee
    - Construct Mashpee lift station and forcemain conveying flow to the WWTF.
- Sandwich – no changes
- Barnstable – no changes

1.4.2 Mid-term improvements:

- JBCC / All Participants
    - Maintain operation of existing lift station and forcemain.
    - Accommodate effluent from JBCC, Bourne-South, Mashpee and Sandwich .in the existing effluent forcemain (peaked pump flow of 640 gpm).
    - Construct new 18-inch forcemain from Falmouth connection to the RIB's with interconnection valving with existing 12-inch forcemain.
- Bourne
    - Connect ISWM forcemain into new 18-inch forcemain (peaked flows increase from 87 to 385 gpm).

  - Construct Bourne Option 1 including lift station, forcemain and JBCC gravity sewer rehabilitation.

- Falmouth
  - Construct Falmouth 18-inch forcemain to valving interconnection with existing 12-inch forcemain and new 18-inch forcemain.
  - Direct Falmouth flow to new 18-inch forcemain (peaked pump flow of 444 gpm).
  - Make future provisions for future 18-inch effluent forcemain
- Mashpee – no changes
- Sandwich
  - Construct Sandwich lift station, forcemain and JBCC gravity sewer rehabilitation.

- Barnstable
  - Construct Barnstable lift station, forcemain, and new JBCC gravity sewers.

1.4.3 Long-term improvements

- JBCC / All Participants
  - Construct second 18-inch effluent forcemain and interconnections and connect Bourne and Falmouth to the second forcemain.

ATTACHMENT A

Conveyance Options Worksheets

LIST OF FIGURES

1-1 Bourne -N Effluent Disposal

2-1 Bourne-S Option 1

2-2 Bourne-S Option 2

2-3 Bourne-S Option 3

3-1 Falmouth Option 1

3-2 Falmouth Option 2

3-3 Falmouth Option 3

4-1 Mashpee Option 1

4-2 Mashpee Option 2

4-3 Mashpee Option 3

5-1 Sandwich Option 1

5-2 Sandwich Option 2

6-1 JBCC Effluent Forcemain- Existing Route

6-2 JBCC Effluent Forcemain- Alternate Route

7-1 Barnstable Option 1

7-2 Barnstable Option 2

7-3 Barnstable Option 3

Bourne-N Option 1 **Preferred**

Option 1. Bourne force main to existing JBCC effluent force main

Site Conditions:

Single Pump Station

Length (miles), (ft) - 100 total length Run friction calc only to high point

Average C 130

Low point (ft) 108 (Existing grade at pump station minus 25 feet)

High point(ft) 285 (Existing grade at pump station minus 5 feet)

Static Head(ft) 177

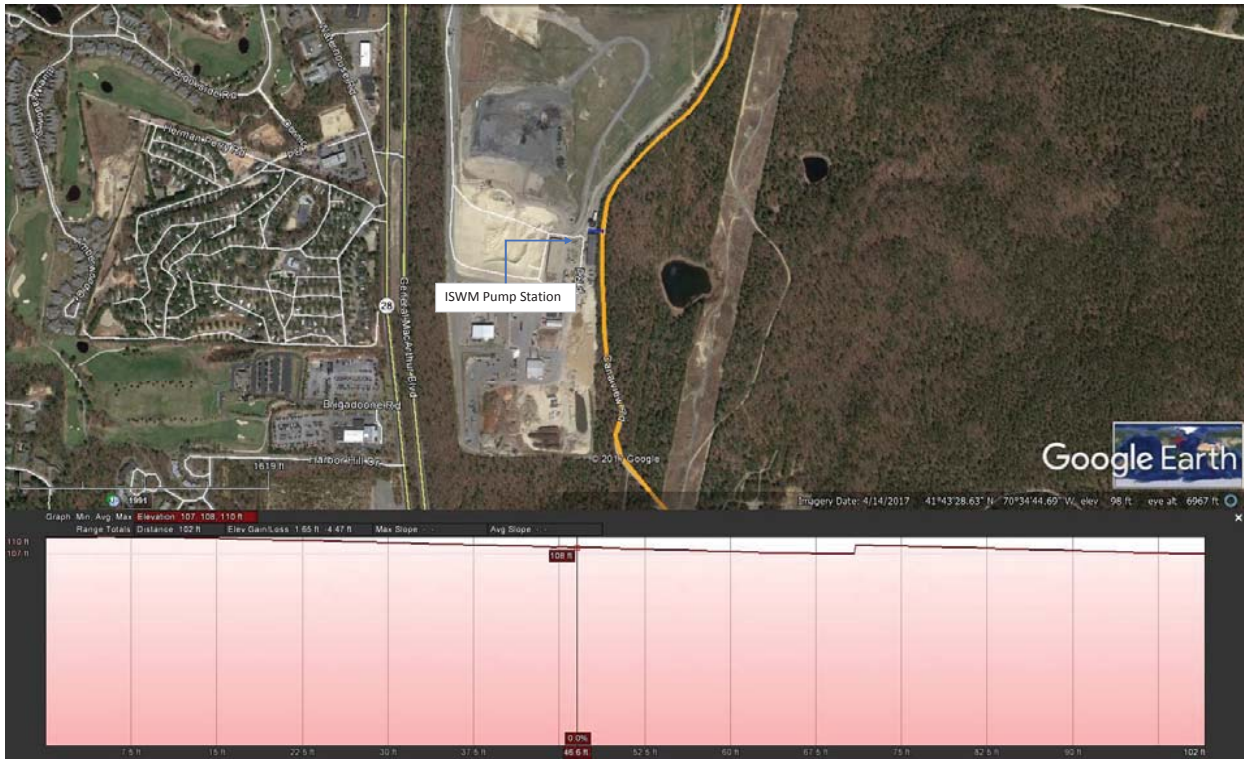
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Bourne-N	-	-	100,000	87	444,000	385	651,000	565
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	100,000	87	444,000	385	651,000	565
Flow(cfs)		0.00		0.19		0.86		1.26

Segment 1 Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
3	0.0	177	3.9	179	17.5	214	25.7	253
4	0.0	177	2.2	178	9.8	186	14.4	196
6	0.0	177	1.0	177	4.4	178	6.4	180
8	0.0	177	0.6	177	2.5	177	3.6	178
10	0.0	177	0.4	177	1.6	177	2.3	177
12	0.0	177	0.2	177	1.1	177	1.6	177

Figure 1-1



Bourne Option 1 **Preferred**

Option 1. Bourne force main to shared rehabilitated gravity main with Sandwich and Mashpee

Site Conditions:

Single Pump Station **Preferred**

Length (miles), (ft)	3.23	17054.4 total length	Run friction calc only to high point
Average C	130		
Low point (ft)	5	(Existing grade at pump station minus 25 feet)	
High point(ft)	175	(Existing grade at pump station minus 5 feet)	
Static Head(ft)	170		

Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Bourne-S	-	-	-	-	259,000	719	456,000	1,267
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	-	-	259,000	719	456,000	1,267
Flow(cfs)		0.00		0.00		1.60		2.82

Single FM Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
6	0.0	170	0.0	170	8.2	861	14.4	2137
8	0.0	170	0.0	170	4.6	340	8.1	655
10	0.0	170	0.0	170	2.9	227	5.2	334
12	0.0	170	0.0	170	2.0	194	3.6	237
14	0.0	170	0.0	170	1.5	181	2.6	202

Figure 2-1



Bourne Option 2

Description: Bourne Raw Wastewater Forcemain-Shining Sea Alternate Path.

Option 2A Single Pump Station Option

Length (miles), (ft)	9.48	50054.4
Average C	130	
Low point (ft)	5	
High Point (ft)	135	
Static Head(ft)	130	

Option 2B Two Pump Station Option

Segment 1 9.48 total length

Length (miles), (ft)	5.1	26928
Average C	130	
Low point (ft)	5	(Existing grade at pump station minus 25 feet)
High point(ft)	75	(Existing grade at pump station minus 5 feet)
Static Head(ft)	70	

$$H.L. = 3.02LD^{(-1.167)}(V/C_h)^{1.85}$$

Segment 2

Length (miles), (ft)	4.38	23126.4
Average C	130	
Low point (ft)	55	(Existing grade at pump station minus 25 feet)
High point(ft)	135	(Existing grade at pump station minus 5 feet)
Static Head(ft)	80	

Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Bourne-S	-	-	-	-	259,000	719	456,000	1,267
Add'l flow for min v	-	-	-	-	-	-	-	153
Total	-	-	-	-	259,000	719	456,000	1,420
Flow(cfs) - 14" FM		0.00		0.00		1.60		3.16
Flow(cfs) - 12" FM								2.82

Option 2A-Single Pump Station

Single Force Main Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	130	0.0	130	2.0	199	4.0	374
14	0.0	130	0.0	130	1.5	163	3.0	245

Option 2B- Two Pump Stations

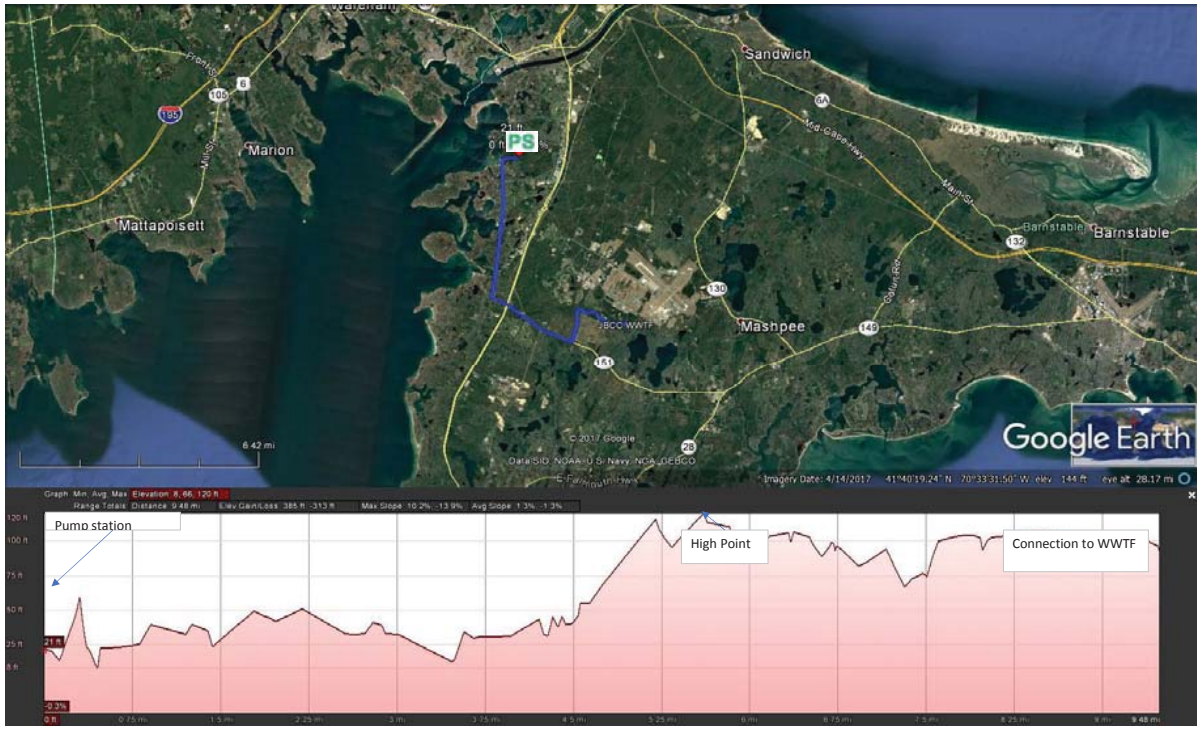
Segment 1: Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	70	0.0	70	2.0	107	3.6	176
14	0.0	70	0.0	70	1.5	88	2.6	120

Segment 2: Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	80	0.0	80	2.0	112	3.6	171
14	0.0	80	0.0	80	1.5	95	2.6	123

Figure 2-2



Bourne Option 3

Description: Force main dedicated to future Bourne Raw Wastewater pump flow.

Site Conditions:

Option 3A - Single Pump Station

Length (miles), (ft)	9.85	52008	5.5
Average C	130		
Low point (ft)	5	(Existing grade at pump station minus 25 feet)	
High point(ft)	135	(Existing grade at pum	100
Static Head(ft)	130		

$H.L. = 3.02LD^{(-1.167)}(V/C_h)^{1.85}$

Option 3B- Two Pump Stations

Segment 1 9.85 total length

Length (miles), (ft)	5.5	29040
Average C	130	
Low point (ft)	5	(Existing grade at pump station minus 25 feet)
High point(ft)	100	(Existing grade at pump station minus 5 feet)
Static Head(ft)	95	

$H.L. = 3.02LD^{(-1.167)}(V/C_h)^{1.85}$

Segment 2

Length (miles), (ft)	4.35	22968
Average C	130	
Low point (ft)	80	(Existing grade at pump station minus 25 feet)
High point(ft)	135	(Existing grade at pump station minus 5 feet)
Static Head(ft)	55	

Flow Conditions

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Bourne-S	-	-	-	-	259,000	719	456,000	1,267
Add'l flow for min v	-	-	-	-	-	-	-	153
Total	-	-	-	-	259,000	719	456,000	1,420
Flow(cfs)		0.00		0.00		1.60		3.16
Flow(cfs) - 12" FM								2.82

Option 3A -Single FM Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	130	0.0	130	2.0	202	4.0	384
14	0.0	130	0.0	130	1.5	164	3.0	250

Option 3B- Two Pump Stations Option

Segment 1: Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	95	0.0	95	2.0	135	3.6	210
14	0.0	95	0.0	95	1.5	114	2.6	149

Segment 2: Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
12	0.0	55	0.0	55	2.0	87	3.6	146
14	0.0	55	0.0	55	1.5	70	2.6	98

Figure 2-3



Falmouth Option 1 **Preferred**

Description: Force main dedicated to future Falmouth pump flow.

Site Conditions:

Length (miles), (ft)		
Falmouth	6.67	35217.6
JBBC to High Point	5.8	30624
Total Length	12.47	65841.6
Average C	130	
Low point (ft)	110	(Existing grade at pump station minus 10 feet)
High point(ft)	286	(effluent force main Highpoint)
Static Head(ft)	176	

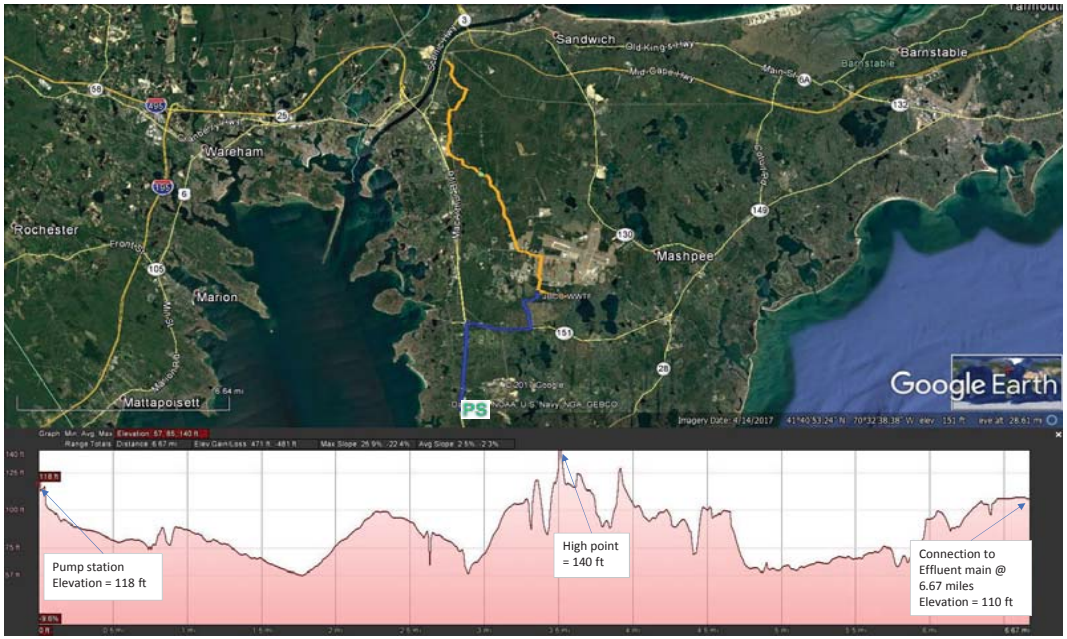
Flow Condtions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Falmouth	-	-	-	-	512,000	444	1,512,000	1,313
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	-	-	512,000	444	1,512,000	1,313
Flow(cfs)		0.00		0.00		0.99		2.92

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	176	0.0	176	2.8	446	8.4	2176
10	0.0	176	0.0	176	1.8	267	5.4	851
12	0.0	176	0.0	176	1.3	213	3.7	454
14	0.0	176	0.0	176	0.9	194	2.7	307
16	0.0	176	0.0	176	0.7	185	2.1	245
18	0.0	176	0.0	176	0.6	181	1.7	215
20	0.0	176	0.0	176	0.5	179	1.3	199
22	0.0	176	0.0	176	0.4	178	1.1	191
24	0.0	176	0.0	176	0.3	177	0.9	186

Figure 3-1



Falmouth Option 2

Description: Force main dedicated to future Falmouth disposal to JBCC using existing shining sea bikeway

Site Conditions:

Length (miles), (ft)		
Falmouth	8.09	42715.2
JBBC to High Point	5.8	30624
Total Length	13.89	73339.2 For TDH Calc
Average C	130	
Low point (ft)	110	(Existing grade at pump station minus 10 feet)
High point(ft)	286	(effluent force main Highpoint)
Static Head(ft)	176	

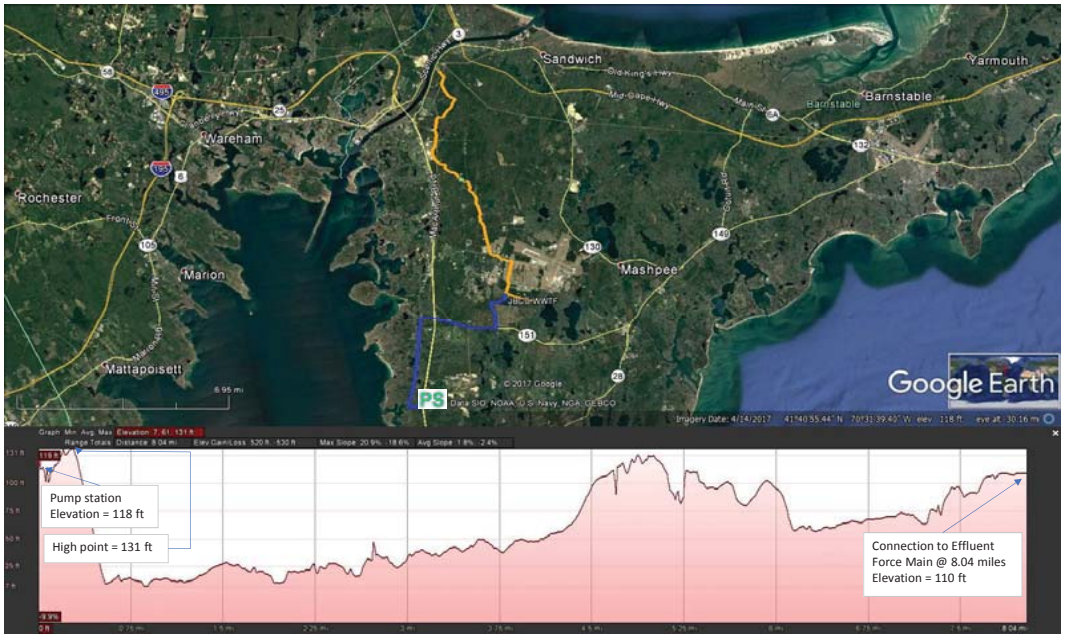
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Falmouth	-	-	-	-	512,000.00	444.44	1,512,000.00	1,312.50
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	-	-	512,000.00	444.44	1,512,000.00	1,312.50
Flow(cfs)		0.00		0.00		0.99		2.92

Pipe Diamter Anaylsis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	176	0.0	176	2.8	476	8.4	2404
10	0.0	176	0.0	176	1.8	277	5.4	928
12	0.0	176	0.0	176	1.3	218	3.7	486
14	0.0	176	0.0	176	0.9	196	2.7	322
16	0.0	176	0.0	176	0.7	186	2.1	252
18	0.0	176	0.0	176	0.6	182	1.7	219
20	0.0	176	0.0	176	0.5	179	1.3	202
22	0.0	176	0.0	176	0.4	178	1.1	192
24	0.0	176	0.0	176	0.3	177	0.9	187

Figure 3-2



Falmouth Option 3

Description: Force main dedicated to future Falmouth disposal to JBCC WWTF, routed along JBCC rail line

Site Conditions:

Length (miles), (ft)			
Falmouth	5.3	27984	
JBBC to High Point	5.8	30624	
Total Length	11.1	58608	For TDH Calc
Average C	130		
Low point (ft)	110	(Existing grade at pump station minus 10 feet)	
High point(ft)	286	(effluent force main Highpoint)	
Static Head(ft)	176		

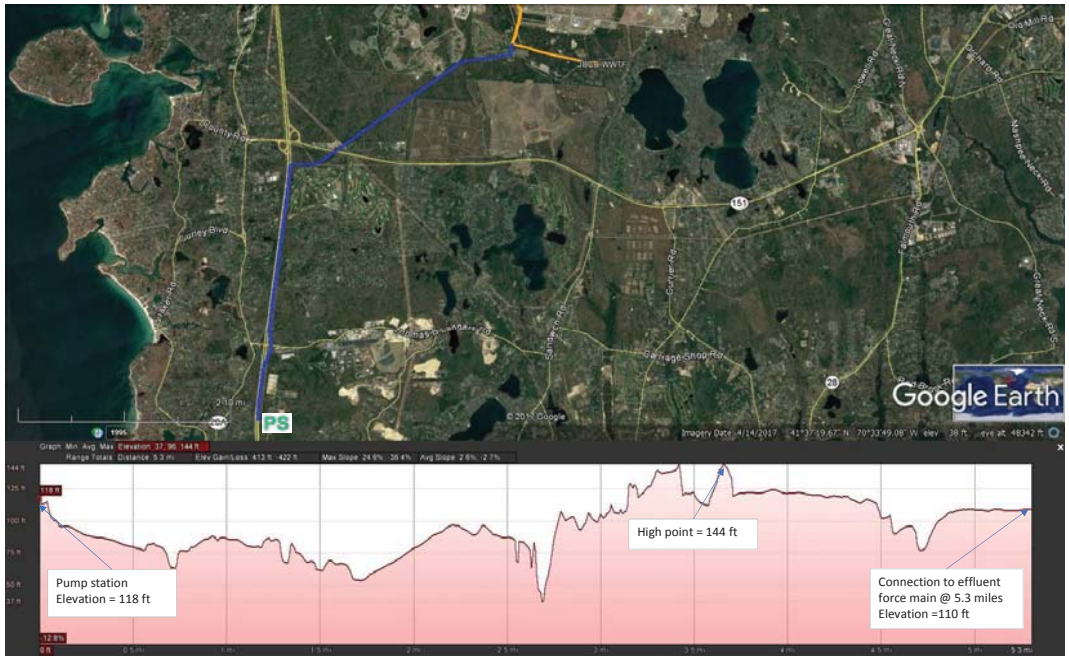
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Falmouth	-	-	-	-	512,000.00	444.44	1,512,000.00	1,312.50
Add'l flow for min v	-	-	-	-	-	-	-	-
Total	-	-	-	-	512,000.00	444.44	1,512,000.00	1,312.50
Flow(cfs)		0.00		0.00		0.99		2.92

Pipe Diamter Anaylsis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	176	0.0	176	2.8	416	8.4	1956
10	0.0	176	0.0	176	1.8	257	5.4	777
12	0.0	176	0.0	176	1.3	209	3.7	423
14	0.0	176	0.0	176	0.9	192	2.7	293
16	0.0	176	0.0	176	0.7	184	2.1	237
18	0.0	176	0.0	176	0.6	181	1.7	210
20	0.0	176	0.0	176	0.5	179	1.3	197
22	0.0	176	0.0	176	0.4	178	1.1	189
24	0.0	176	0.0	176	0.3	177	0.9	184

Figure 3-3



Mashpee Option 1 **Preferred**
Mashpee force main to JBCC WWTF

Site Conditions:

Length (miles), (ft)		
Mashpee	1.42	7497.6
Average C	130	
Low point (ft)	72	(Existing grade at pump station minus 25 feet)
High point(ft)	102	
Static Head(ft)	30	

Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Mashpee	-	-	200,000	556	200,000	556	200,000	556
Total	-	-	200,000	556	200,000	556	200,000	556
Flow(cfs)		0.00		1.24		1.24		1.24

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	30	3.5	76	3.5	76	3.5	76
10	0.0	30	2.3	46	2.3	46	2.3	46
12	0.0	30	1.6	36	1.6	36	1.6	36

Figure 4-1



Mashpee Option 2

Mashpee force main to shared force main and rehabilitated gravity main with Sandwich and Bourne

Site Conditions:

Length (miles), (ft)		
Mashpee	2.4	12672
Mashpee-Sandich FM	1.77	9345.6
Total Length	4.17	22017.6
Average C	130	
Low point (ft)	26	(Existing grade at pump station minus 25 feet)
High point(ft)	101	
Static Head(ft)	75	

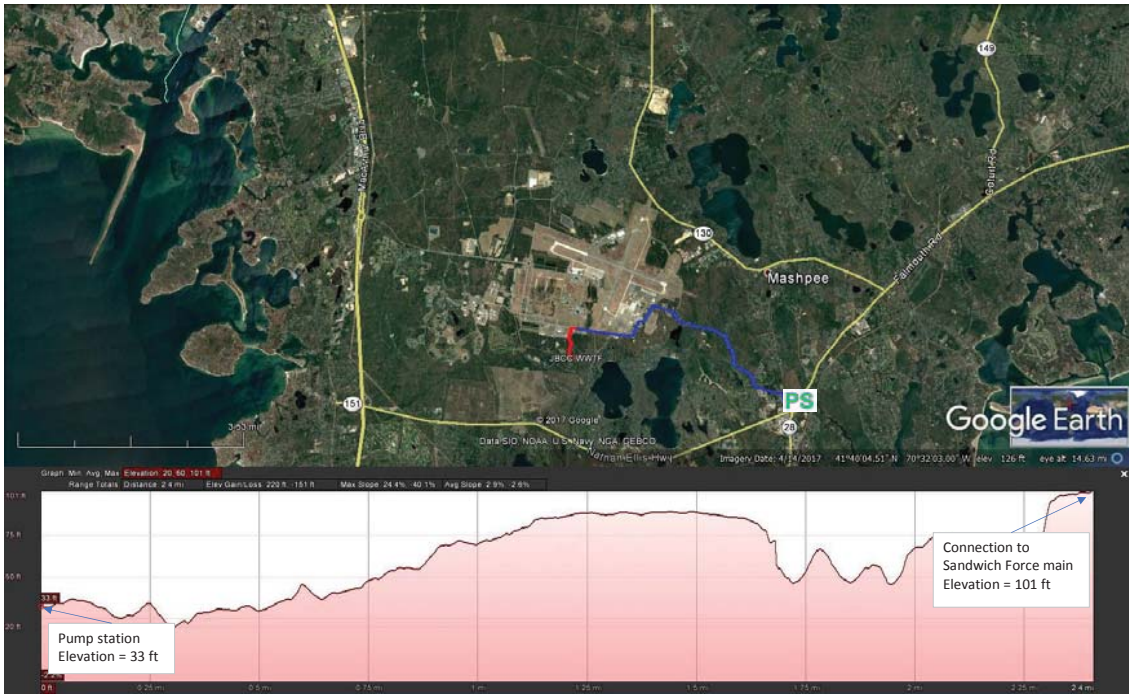
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Mashpee	-	-	200,000	556	200,000	556	200,000	556
Add'l flow for min v	-	-	-	-	-	-	175,000	486
Total	-	-	200,000	556	200,000	556	375,000	1,042
Flow(cfs)		0.00		1.24		1.24		2.32

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
10	0.0	75	2.3	121	2.3	121	4.3	222
12	0.0	75	1.6	94	1.6	94	3.0	136

Figure 4-2



Mashpee Option 3

Mashpee force mains to shared rehabilitated gravity main with Sandwich and Bourne

Site Conditions:

Length (miles), (ft)		
Mashpee	3.4	17952
Mashpee to Gravity	0.74	3907.2
Total Length	4.14	21859.2
Average C	130	
Low point (ft)	26	(Existing grade at pump station minus 25 feet)
High point(ft)	101	
Static Head(ft)	75	

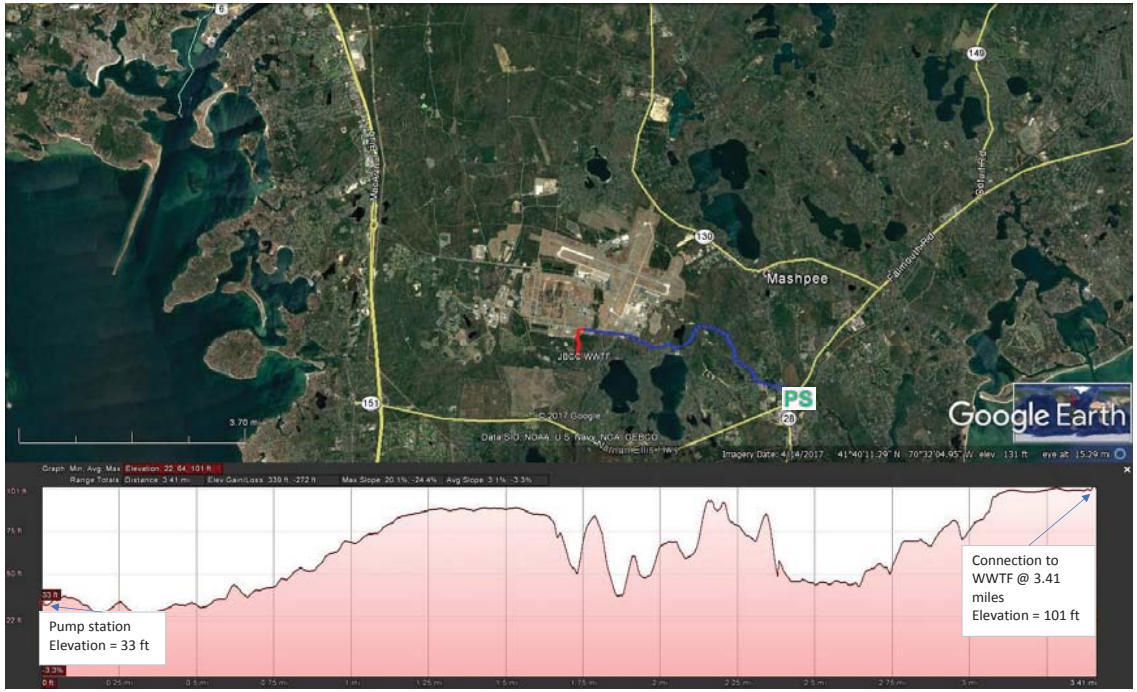
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Mashpee	-	-	200,000	556	200,000	556	200,000	556
Add'l flow for min v	-	-	-	-	-	-	175,000	486
Total	-	-	200,000	556	200,000	556	375,000	1,042
Flow(cfs)		0.00		1.24		1.24		2.32

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
10	0.0	75	2.3	121	2.3	121	4.3	221
12	0.0	75	1.6	94	1.6	94	3.0	135

Figure 4-3



Sandwich Option 1 **Preferred**

Description: Force main for Sandwich raw wastewater connection to existing system

Site Conditions:

Length (miles), (ft)	2.92	15417.6
Average C	130	
Low point (ft)	107	(Existing grade at pump station minus 25 feet)
High point(ft)	140	
Static Head(ft)	33	

Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Sandwich	-	-	-	-	100,000	278	340,000	944
Add'l flow for min v								100
Total	-	-	-	-	100,000	278	340,000	1,044
Flow(cfs)		0.00		0.00		0.62		2.33

Pipe Diameter Analysis

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
6	0.0	33	0.0	33	3.2	140	11.9	1278
8	0.0	33	0.0	33	1.8	59	6.7	340
10	0.0	33	0.0	33	1.1	42	4.3	137
12	0.0	33	0.0	33	0.8	37	3.0	76

Figure 5-1



Sandwich Option 2

Description: Sandwich force main for shared force main with Mashpee and shared gravity main with Mashpee and Bourne

Site Conditions:

Length (miles), (ft)		
Sandwich	2.9	15312
Mashpee-Sandich FM	1.77	9345.6
Total Length	4.67	24657.6
Average C	130	
Low point (ft)	110	(Existing grade at pump station minus 25 feet)
High point(ft)	145	(Existing grade minus 5 feet)
Static Head(ft)	35	

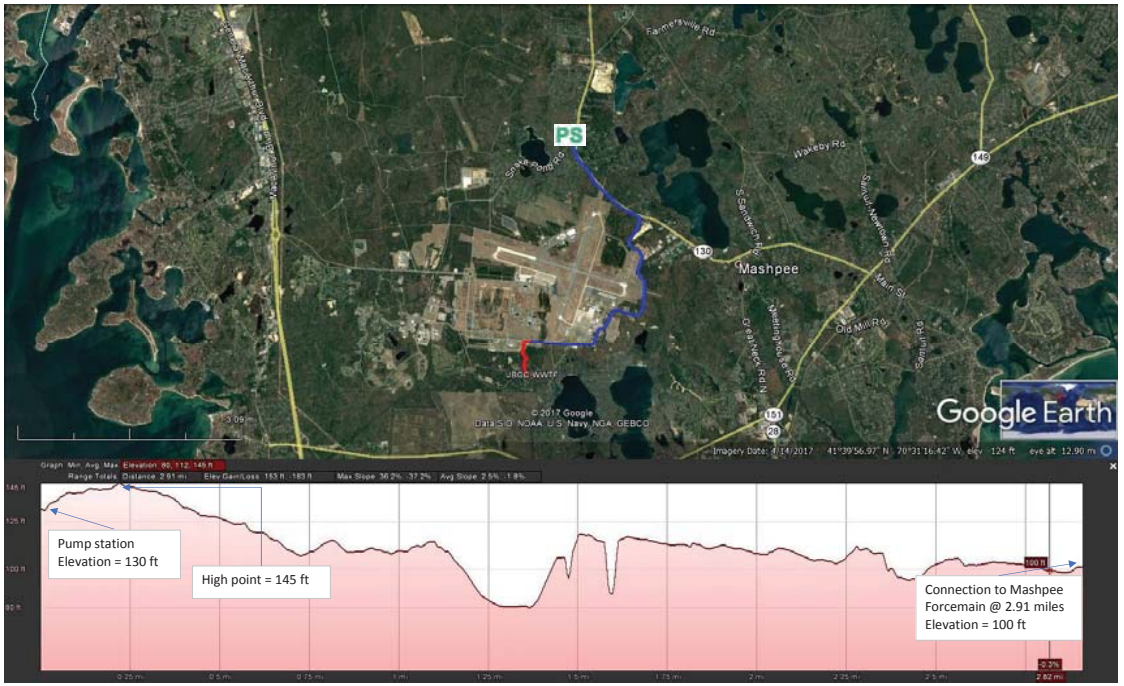
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Sandwich	-	-	-	-	100,000	278	340,000	944
Add'l flow for min v	-	-	-	-	-	0	-	100
Total	-	-	-	-	100,000	278	340,000	1,044
Flow(cfs)		0.00		0.00		0.62		2.33

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
6	0.0	35	0.0	35	3.2	207	11.9	2026
8	0.0	35	0.0	35	1.8	77	6.7	526
10	0.0	35	0.0	35	1.1	49	4.3	201
12	0.0	35	0.0	35	0.8	41	3.0	103

Figure 5-2



JBCC Effluent Disposal Force Main

Description: Existing force main for JBCC Effluent pumped flow.

	Miles	Ft	1000 ft	
Length	10.8	57,024	57.0	
Length	5.8	30,624	30.6	(Headloss Calc)
Average C	130			
Low point (ft)	75	(Existing grade at pump station minus 25 feet)		
High point(ft)	286			
Static Head(ft)	211			

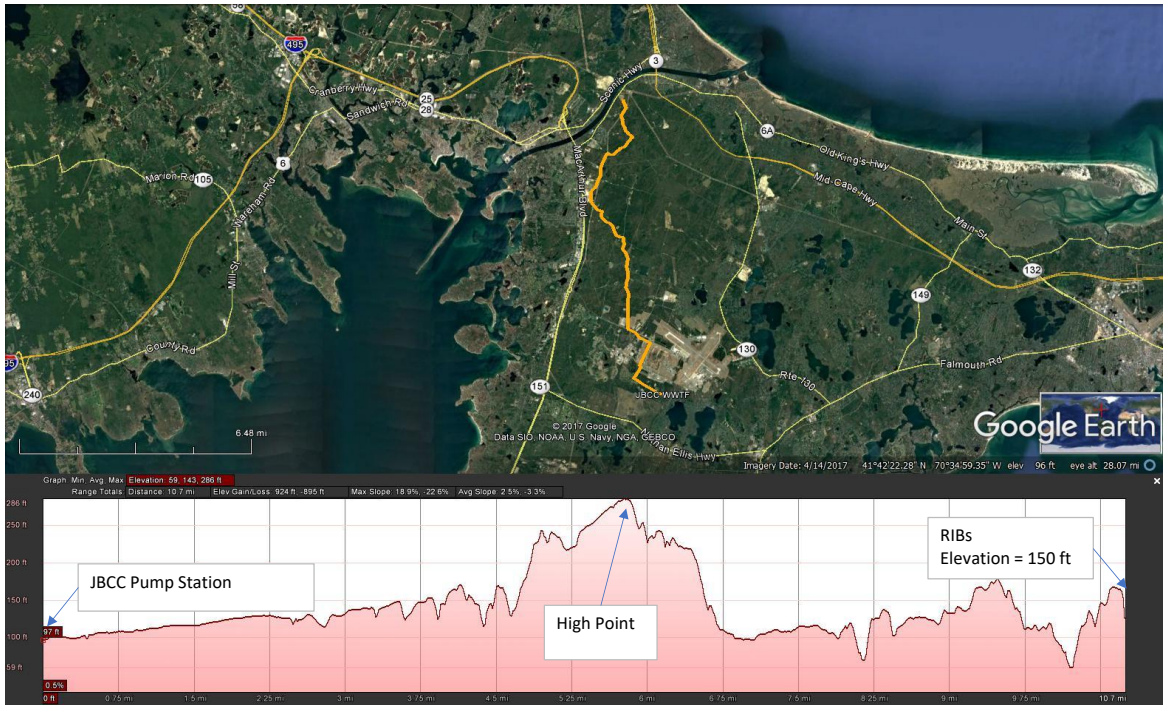
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
JBCC	140,000	122	152,000	132	152,000	132	152,000	132
Bourne-Effl	-	-	-	-	-	-	-	-
Bourne-S	-	-	-	-	270,000	234	467,000	405
Falmouth	-	-	-	-	512,000	444	1,512,000	1,313
Mashpee	-	-	200,000	174	203,000	176	203,000	176
Sandwich	-	-	-	-	110,000	95	350,000	304
Barnstable			-	-	500,000	434	1,200,000	1,042
Total Effluent I	140,000	122	352,000	306	1,747,000	1,516	3,884,000	3,372
Additional								183
Total Effluent I	140,000	122	352,000	306	1,747,000	1,516	3,884,000	3,555
50% Total Eff	70,000	61	176,000	153	873,500	758	1,942,000	1,777
Flow (cfs)		0.14		0.34		1.69		3.96

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
16	0.1	211	0.2	212	1.2	223	2.8	267
18	0.1	211	0.2	211	1.0	218	2.2	242
20	0.1	211	0.2	211	0.8	215	1.8	230
24	0.0	211	0.1	211	0.5	213	1.3	219

Figure 6-1



JBCC Effluent Disposal Force Main

Description: Existing force main for JBCC Effluent pumped flow.

	Miles	Ft	1000 ft	
Length (miles), (f	10.9	57,552	57.6	
Length (miles), (f	10.7	56,496	56.5	(Headloss Calc)
Average C	130			
Low point (ft)	75	(Existing grade at pump station minus 25 feet)		
High point(ft)	170			
Static Head(ft)	95			

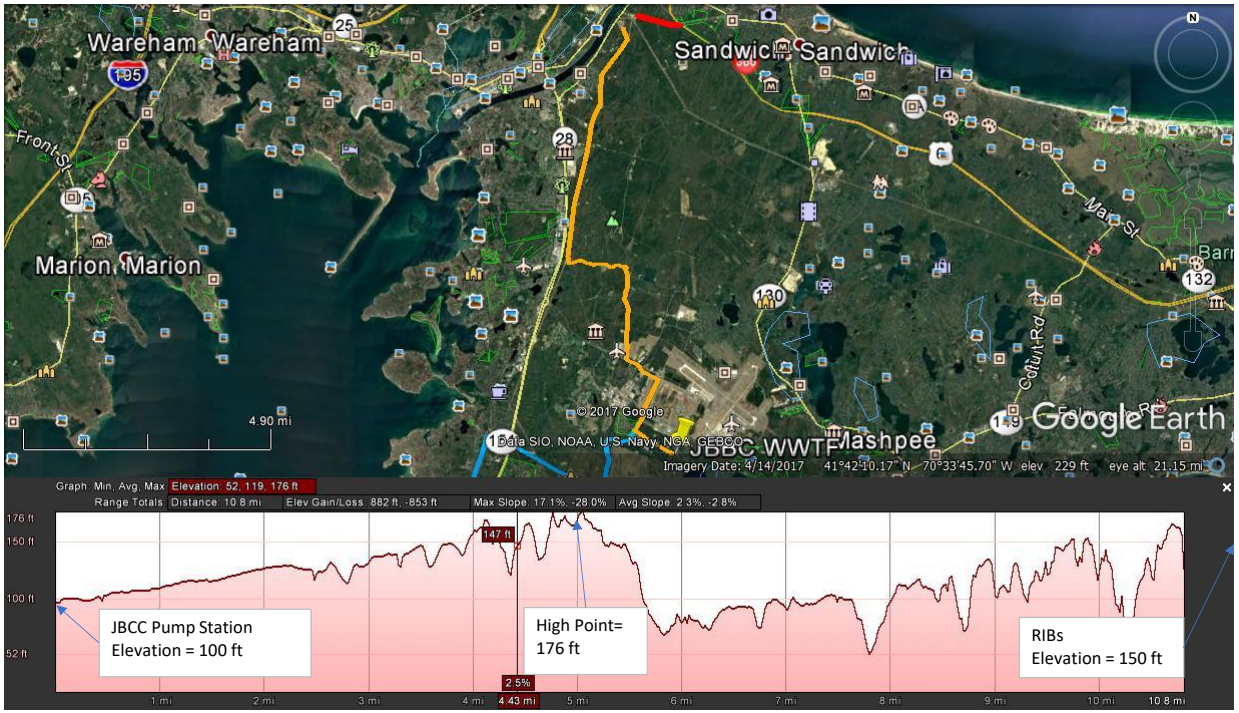
Flow Conditions:

Flow Source	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
JBCC	140,000	122	152,000	132	152,000	132	152,000	132
Bourne-Effl	-	-	-	-	-	-	-	-
Bourne-S	-	-	-	-	270,000	234	467,000	405
Falmouth	-	-	-	-	512,000	444	1,512,000	1,313
Mashpee	-	-	200,000	174	203,000	176	203,000	176
Sandwich	-	-	-	-	110,000	95	350,000	304
Barnstable			-	-	500,000	434	1,200,000	1,042
Total Effluent I	140,000	122	352,000	306	1,747,000	1,516	3,884,000	3,372
Additional								183
Total Effluent I	140,000	122	352,000	306	1,747,000	1,516	3,884,000	3,555
50% Total Eff	70,000	61	176,000	153	873,500	758	1,942,000	1,777
Flow (cfs)		0.14		0.34		1.69		3.96

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
16	0.1	95	0.2	96	1.2	116	2.8	198
18	0.1	95	0.2	96	1.0	107	2.2	153
20	0.1	95	0.2	95	0.8	102	1.8	130

Figure 6-2



Barnstable Option 1
Central Alignment through Mashpee

Site Conditions:

Length (miles), (ft)	Miles	1000 ft	
Barnstable FM	2.7	14.3	Public Way/Dense
Barnstable FM	2.3	12.1	Less Dense
Barnstable-Mashpee FM	1.2	6.3	Less Dense
Barnstable + mashpee	6.2	32.7	Length use for Calculation

Average C	130
Low point (ft)	35
High point(ft)	106
Static Head(ft)	71

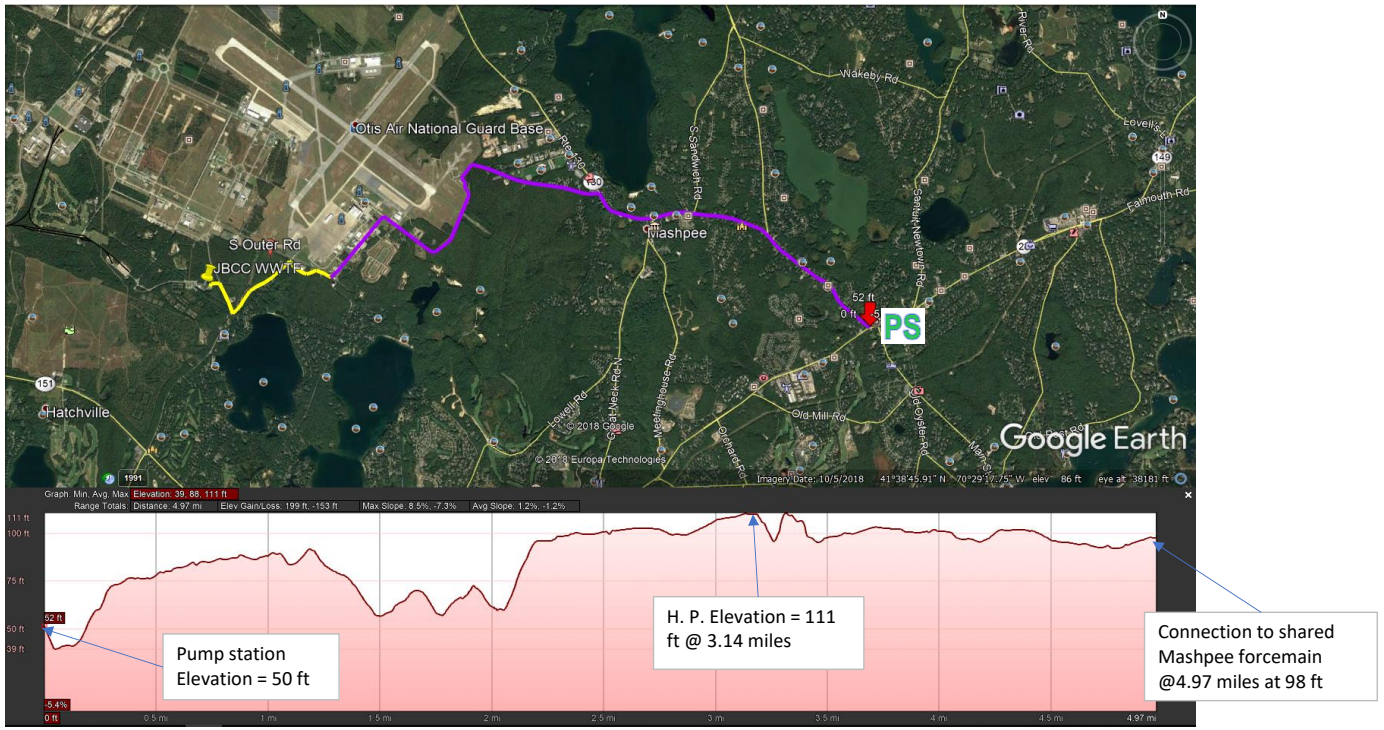
Flow Conditions:

Flow Sourc	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Barnstable	-	-	-	-	500,000	1,250	1,200,000	3,000
Total	-	-	-	-	500,000	1,250	1,200,000	3,000
Flow(cfs)		0.00		0.00		2.79		6.68

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
8	0.0	71	0.0	71	8.0	72	19.1	76
10	0.0	71	0.0	71	5.1	71	12.3	73
12	0.0	71	0.0	71	3.5	71	8.5	72
14	0.0	71	0.0	71	2.6	71	6.3	71
16	0.0	71	0.0	71	2.0	71	4.8	71
18	0.0	71	0.0	71	1.6	71	3.8	71
20	0.0	71	0.0		1.3	71	3.1	71
24	0.0	71	0.0	71	0.9	71	2.1	71

Figure 7-1



Barnstable Option 2

Southern Alignment through Mashpee

Site Conditions:

Length (miles), (ft)	Miles	1000 ft	
Barnstable FM	5.7	30.1	Public Way/Dense
Barnstable FM	1.2	6.3	Less Dense
Barnstable-Mashpee FM	0.3	1.6	Less Dense
Barnstable + mashpee	7.2	38.0	Length use for Calculation

Average C	130
Low point (ft)	33
High point(ft)	85
Static Head(ft)	70

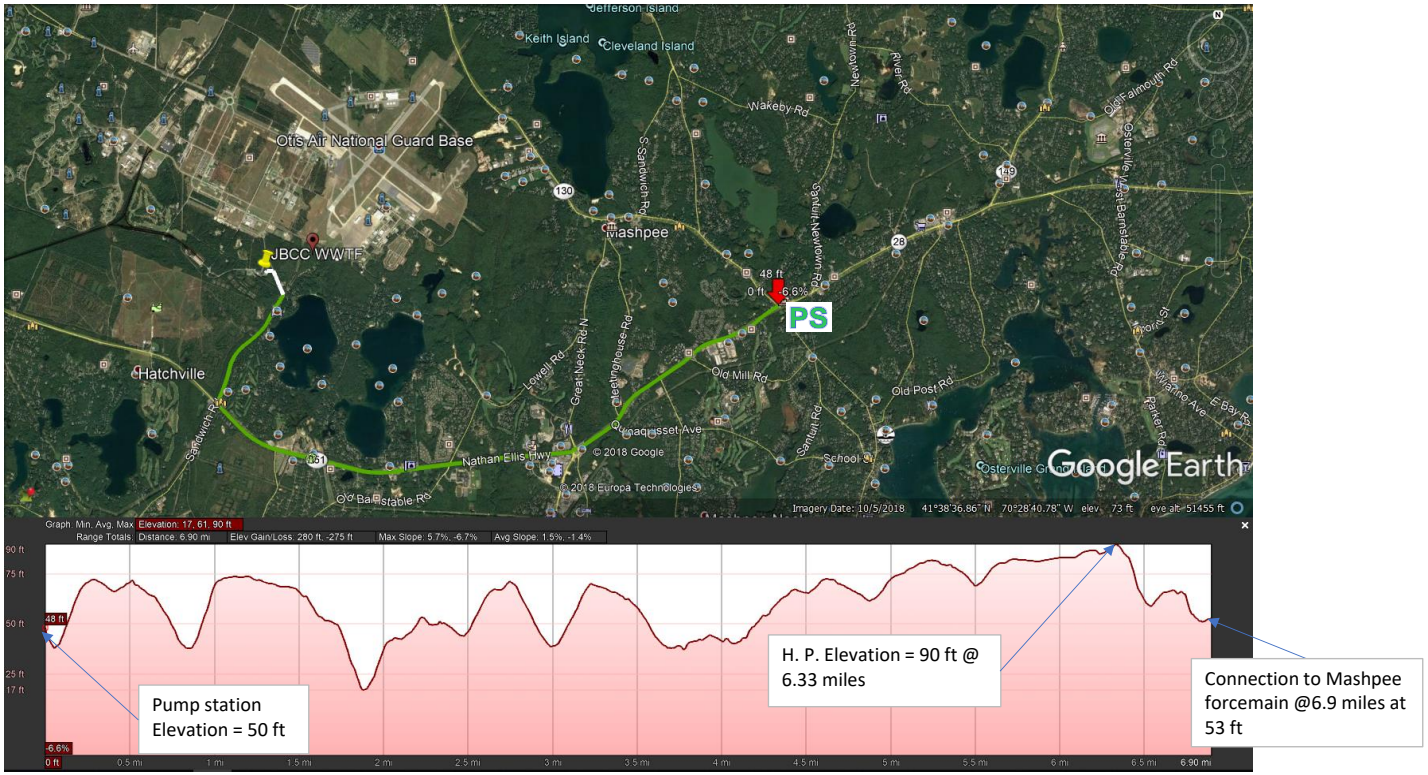
Flow Conditions:

Flow Sourc	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Barnstable	-	-	-	-	500,000	1,250	1,200,000	3,000
Add'l flow	-	-	-	-	-	-	-	-
Total	-	-	-	-	500,000	1,250	1,200,000	3,000
Flow(cfs)		0.00		0.00		2.79		6.68

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
10	0.0	70	0.0	70	5.1	70	12.3	72
12	0.0	70	0.0	70	3.5	70	8.5	71
14	0.0	70	0.0	70	2.6	70	6.3	70
16	0.0	70	0.0	70	2.0	70	4.8	70
18	0.0	70	0.0	70	1.6	70	3.8	70
20	0.0	70	0.0	70	1.3	70	3.1	70
24	0.0	70	0.0	70	0.9	70	2.1	70

Figure 7-2



Barnstable Option 3

Northern Alignment through Sandwich/Mashpee

Site Conditions:

Length (miles), (ft)	Miles	1000 ft	
Barnstable	5.9	31.2	Public Way/Dense
Barnstable	2.7	14.3	Less Dense
Barnstable to Gravity	3.0	15.8	Shared with Sandwich
Total FM Length	11.6	61.2	Length use for Calculation
gravity to wwtf	0.6	3.2	Shared with Sandwich
gravity to wwtf	2.1	11.1	Shared with Sandwich and Bourne
Total Route Length	14.3	75.5	

Average C	130
Low point (ft)	35
High point(ft)	151
Static Head(ft)	70

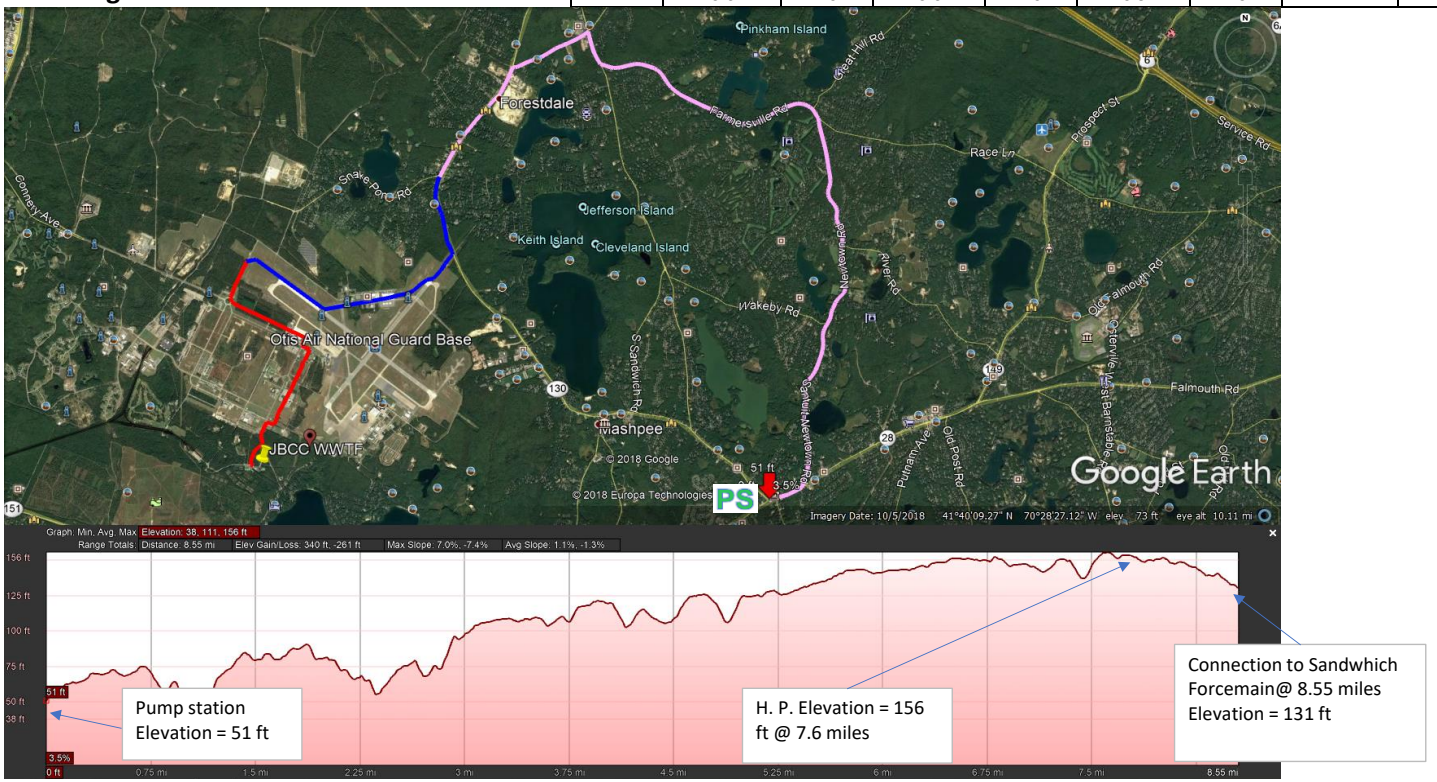
Flow Conditions:

Flow Sourc	Existing		Near-Term		Mid-Term		Long-Term	
	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q	Avg Q	Peak Q
	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)	(gpd)	(gpm)
Barnstable	-	-	-	-	500,000	1,250	1,200,000	3,000
Add'l flow	-	-	-	-	-	-	-	-
Total	-	-	-	-	500,000	1,250	1,200,000	3,000
Flow(cfs)		0.00		0.00		2.79		6.68

Pipe Diameter Analysis:

FM Dia (in)	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss	Velocity	Headloss
	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
10	0.0	70	0.0	70	5.1	71	12.3	73
12	0.0	70	0.0	70	3.5	70	8.5	71
14	0.0	70	0.0	70	2.6	70	6.3	71
16	0.0	70	0.0	70	2.0	70	4.8	70
18	0.0	70	0.0	70	1.6	70	3.8	70
20	0.0	70	0.0	70	1.3	70	3.1	70
24	0.0	70	0.0	70	0.9	70	2.1	70

Figure 7-3



ATTACHMENT B

Conveyance Options Costs

JBCC SHARED WASTEWATER MANAGEMENT STUDY								
ENGINEERING ASESSEMENT				ENR CCI	11228		Apr-19	
Wright-Pierce, 13 May 2019 - Preliminary Draft for Review								
COSTS FOR CONVEYANCE ALTERNATIVES					**Projected to October 2019 dollars**			
Capital Costs for Conveyance and Transport to Disposal								
Conveyance								
Conveyance-Bourne		Alt 1	Alt 2A	Alt 2B	Alt 3A	Alt 3B		Bourne Conveyance
Sewers - Bourne - 50% Share with Sandwich								
Distance, 1000 ft		12.3						
Distance, miles		2.3						
Cost per foot - Rehabilitation		75						
Construction cost		920,000						
Pump Stations - Bourne								
Medium PS (200-1200 gpm)		1	1	1	1	1		
Unit Cost		1,000,000	1,000,000	1,000,000	1,000,000	1,000,000		
Large PS (1200+ gpm)		1	1	2	1	2		
Unit Cost		2,500,000	2,500,000	2,500,000	2,500,000	2,500,000		
Construction cost, pump stations		3,500,000	3,500,000	6,000,000	3,500,000	6,000,000		
Transport to Treatment - Public Way/Dense		12"	14"	12"	14"	12"		
Distance, 1000 ft		12.7	17.8	17.8	38.5	38.5		
Distance, miles		2.4	3.4	3.4	7.3	7.3		
Cost per foot		230	245	230	245	230		
Construction cost		2,920,000	4,360,000	4,090,000	9,433,000	8,855,000		
Transport to Treatment - Public Way/Less Dense		12"	14"	12"	14"	12"		
Distance, 1000 ft		14.5	32.2	32.2	13.5	13.5		
Distance, miles		2.7	6.1	6.1	2.6	2.6		
Cost per foot		210	225	210	225	210		
Construction cost		3,050,000	7,250,000	6,760,000	3,038,000	2,835,000		
ISWM Connection to Effluent Forcemain (LS)		100,000	100,000	100,000	100,000	100,000		
Construction cost, Total Conveyance- Bourne		10,490,000	15,210,000	16,950,000	16,071,000	17,790,000		
Total Route Distance, mile		7.4	9.5	9.5	9.9	9.9		

JBCC SHARED WASTEWATER MANAGEMENT STUDY								
ENGINEERING ASESSEMENT				ENR CCI	11228		Apr-19	
Wright-Pierce, 13 May 2019 - Preliminary Draft for Review								
COSTS FOR CONVEYANCE ALTERNATIVES					**Projected to October 2019 dollars**			
Conveyance-Falmouth	Alt 1	Alt 2	Alt 3					Falmouth Conveyance
Pump Stations-Falmouth								
Large PS (1200+ gpm)	1	1	1					
Unit Cost	2,500,000	2,500,000	2,500,000					
Construction cost, pump stations	2,500,000	2,500,000	2,500,000					
Transport to Disposal - Public Way/Dense	18"	18"	18"					
Distance, 1000 ft	25.9	20.1	13.8					
Distance, miles	4.9	3.8	2.6					
Cost per foot	280	280	280					
Construction cost	7,250,000	5,630,000	3,860,000					
Transport to Disposal - Railroad ROW			18"					
Distance, 1000 ft			14.2					
Distance, miles			2.7					
Cost per foot			380					
Construction cost			5,400,000					
Transport to Treatment - Public Way/Less Dense	18"	18"						
Distance, 1000 ft	9.5	22.6						
Distance, miles	1.8	4.3						
Cost per foot	250	250						
Construction cost	2,380,000	5,650,000						
Construction cost, Total Conveyance-Falmouth	12,130,000	13,780,000	11,760,000					
Total Route Distance, mile	6.7	8.1	5.3					

JBCC SHARED WASTEWATER MANAGEMENT STUDY								
ENGINEERING ASESSEMENT				ENR CCI	11228		Apr-19	
Wright-Pierce, 13 May 2019 - Preliminary Draft for Review								
COSTS FOR CONVEYANCE ALTERNATIVES					**Projected to October 2019 dollars**			
Conveyance-Mashpee		Alt 1	Alt 2	Alt 3				Mashpee Conveyance
Sewers - Mashpee 33% Rehab								
Distance, 1000 ft			3.4	3.4				
Distance, miles			0.6	0.6				
Cost per foot (33% of 150)			50	50				
Construction cost			170,000	170,000				
Pump Stations-Mashpee								
Medium PS (200-1200 gpm)		1	1	1				
Unit Cost		1,000,000	1,000,000	1,000,000				
Construction cost, pump stations		1,000,000	1,000,000	1,000,000				
Transport to Treatment - Public Way/Dense		8"	12"	12"				
Distance, 1000 ft		7.5	3.0	3.0				
Distance, miles		1.4	0.6	0.6				
Cost per foot		200	230	230				
Construction cost		1,500,000	690,000	690,000				
Transport to Treatment - Public Way/Less Dense			12"	12"				
Distance, 1000 ft			18.9	9.7				
Distance, miles			3.6	1.8				
Cost per foot			210	210				
Construction cost			3,970,000	2,040,000				
Transport to Treatment - Public Way/Less Dense - 50% Share with Sandwich				12"				
Distance, 1000 ft				9.3				
Distance, miles				1.8				
Cost per foot				115				
Construction cost				1,070,000				
Construction cost, Total Conveyance-Mashpee		2,500,000	5,830,000	4,970,000				
Total Route Distance, mile		1.4	4.8	4.8				

JBCC SHARED WASTEWATER MANAGEMENT STUDY								
ENGINEERING ASESSEMENT			ENR CCI	11228		Apr-19		
Wright-Pierce, 13 May 2019 - Preliminary Draft for Review								
COSTS FOR CONVEYANCE ALTERNATIVES				**Projected to October 2019 dollars**				
Conveyance-Sandwich	Alt 1	Alt 2	Alt 3					Sandwich Conveyance
Sewers - Sandwich - Dedicated								
Distance, 1000 ft	2.2		2.2					
Distance, miles	0.4		0.4					
Cost per foot	150		150					
Construction cost	330,000		330,000					
Sewers - Sandwich - 50% Share with Bourne								
Distance, 1000 ft	12.30	3.40	12.14					
Distance, miles	2.3	0.6	2.3					
Cost per foot	75	75	75					
Construction cost	920,000	260,000	910,000					
Pump Stations-Sandwich								
Medium PS (200-1200 gpm)	1	1	1					
Unit Cost	1,000,000	1,000,000	1,000,000					
Construction cost, pump stations	1,000,000	1,000,000	1,000,000					
Transport to Treatment - Public Way/Dense	12"	12"	12"					
Distance, 1000 ft	3.50	3.50	12.67					
Distance, miles	0.7	0.7	2.4					
Cost per foot	230	230	230					
Construction cost	810,000	810,000	2,910,000					
Transport to Treatment - Public Way/Less Dense	12"	12"						
Distance, 1000 ft	11.9	18.3						
Distance, miles	2.3	3.5						
Cost per foot	210	210						
Construction cost	2,500,000	3,840,000						
Transport to Treatment - Public Way/Less Dense - 50% Share with Mashpee		12"						
Distance, 1000 ft		9.3						
Distance, miles		1.8						
Cost per foot		105						
Construction cost		980,000						
Construction cost, Total Conveyance-Sandwich	5,560,000	6,890,000	5,150,000					
Total Route Distance, mile	5.7	6.6	5.1					

JBCC SHARED WASTEWATER MANAGEMENT STUDY								
ENGINEERING ASESSEMENT			ENR CCI	11228		Apr-19		
Wright-Pierce, 13 May 2019 - Preliminary Draft for Review								
COSTS FOR CONVEYANCE ALTERNATIVES				**Projected to October 2019 dollars**				
Conveyance-Barnstable	Alt 1A	Alt 2A	Alt 3A	Alt 1B	Alt 2B	Alt 3B		
Sewers - Barnstable - New - 80% shared with Sandwich								
Distance, 1000 ft			3.2			3.2		
Distance, miles			0.6			0.6		
Cost per foot (80% of 300 for option 3)			240			300		
Construction cost			770,000			960,000		
Sewers - Barnstable - New 70% shared with Sandwich and Bourne								
Distance, 1000 ft			11.1			11.1		
Distance, miles			2.1			2.1		
Cost per foot (70% of 300 for option 3)			210			300		
Construction cost			2,330,000			3,330,000		
Pump Stations-Barnstable								
Very Large PS (>2500 gpm)	1	1	1	1	1	1		
Unit Cost	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000		
Additional cost for 300 hp requirement (Option 3)			1,000,000			1,000,000		
Construction cost, pump stations	5,000,000	5,000,000	6,000,000	5,000,000	5,000,000	6,000,000		
Transport to Treatment - Public Way/Dense	20"	20"	20"	20"	20"	20"		
Distance, 1000 ft	14.3	30.1	31.2	14.3	30.1	31.2		
Distance, miles	2.7	5.7	5.9	2.7	5.7	5.9		
Cost per foot	300	300	300	300	300	300		
Construction cost	4,290,000	9,030,000	9,360,000	4,290,000	9,030,000	9,360,000		
Transport to Treatment - Public Way/Less Dense	20"	20"	20"	20"	20"	20"		
Distance, 1000 ft	12.1	6.3	14.3	12.1	6.3	14.3		
Distance, miles	2.3	1.2	2.7	2.3	1.2	2.7		
Cost per foot	260	260	260	260	260	260		
Construction cost	3,150,000	1,640,000	3,720,000	3,150,000	1,640,000	3,720,000		
Transport to Treatment - Public Way/Less Dense -80% Shared with Sandwich			20"			20"		
Distance, 1000 ft			15.80			15.80		
Distance, miles			3.0			3.0		
Cost per foot (80% of 260 for option 3)			208			260		
Construction cost			3,290,000			4,110,000		
Transport to Treatment - Public Way/Less Dense - 80% Shared with Mashpee	20"	20"		20"	20"			
Distance, 1000 ft	6.4	1.6		6.4	1.6			
Distance, miles	1.2	0.3		1.2	0.3			
Cost per foot (80% of 260 for option 3)	208	208		260	260			
Construction cost	1,330,000	340,000		1,660,000	430,000			
Air Release Manholes	5	6	10	5	6	10		
Unit Cost	25,000	25,000	25,000	25,000	25,000	25,000		
Construction cost, Air Release Valves	130,000	150,000	250,000	130,000	150,000	250,000		
Construction cost, Total Conveyance-Barnstable	13,900,000	16,160,000	25,720,000	14,230,000	16,250,000	27,730,000		
Total Route Distance, mile	6.2	7.2	14.3	6.2	7.2	14.3		

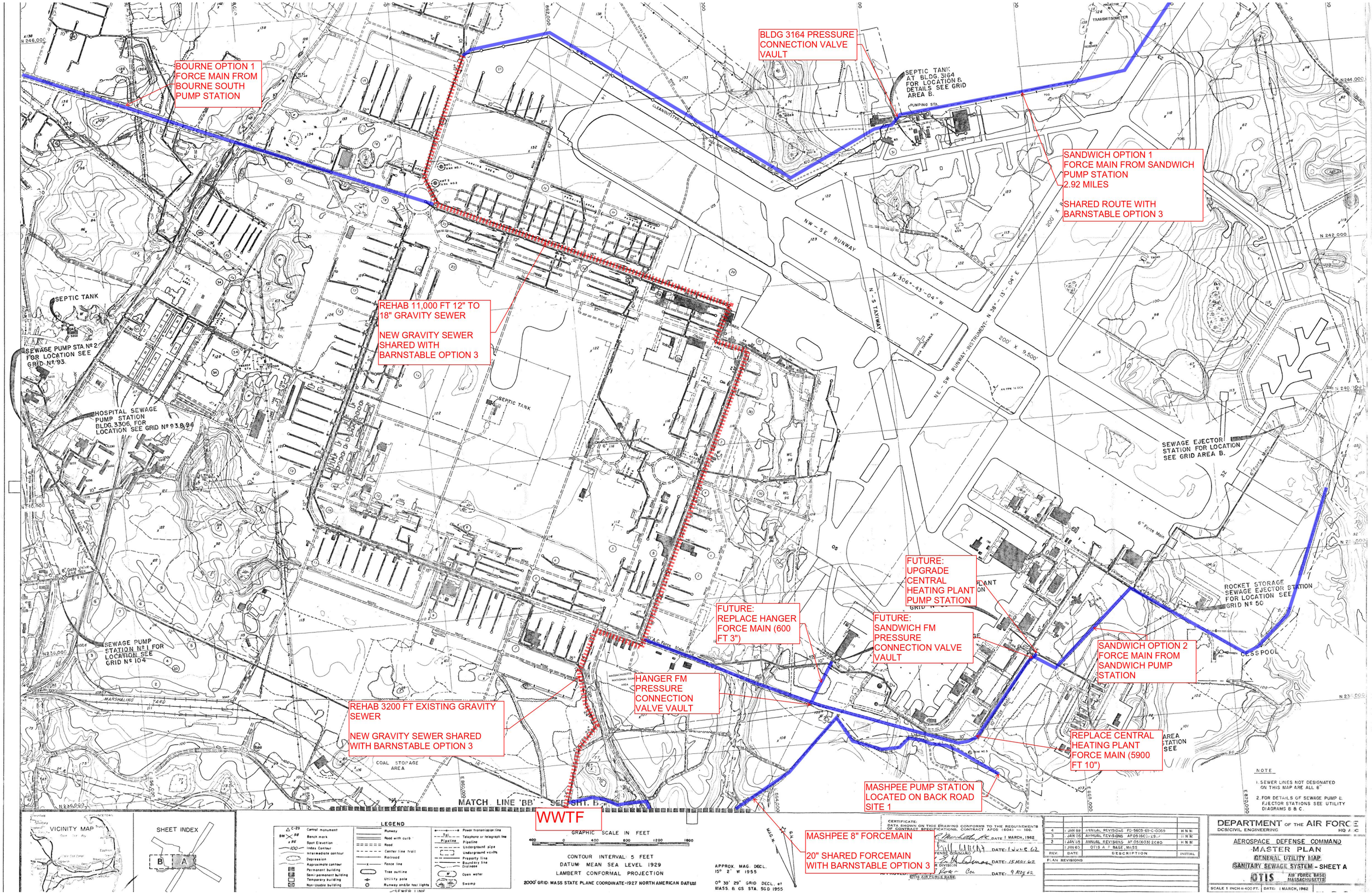
Barnstable Conveyance

JBCC SHARED WASTEWATER MANAGEMENT STUDY									
ENGINEERING ASESSEMENT				ENR CCI	11228		Apr-19		
Wright-Pierce, 13 May 2019 - Preliminary Draft for Review									
COSTS FOR CONVEYANCE ALTERNATIVES					**Projected to October 2019 dollars**				
									SUMMARY
Conveyance Cost Summary									
Sewers									
Construction cost		5,270,000							
Pump Stations									
Construction cost, pump stations		14,000,000							
Transport to Treatment									
Construction cost		37,130,000							
Construction Cost, Total Conveyance		56,400,000							
Cross Check		56,400,000							

ATTACHMENT C

JBBC Conveyance

Improvements Worksheet



BOURNE OPTION 1
FORCE MAIN FROM
BOURNE SOUTH
PUMP STATION
BLDG 3164 PRESSURE
CONNECTION VALVE
VAULT
SEPTIC TANK
AT BLDG. 3164
FOR LOCATION &
DETAILS SEE GRID
AREA B.
SANDWICH OPTION 1
FORCE MAIN FROM SANDWICH
PUMP STATION
2.92 MILES
SHARED ROUTE WITH
BARNSTABLE OPTION 3
REHAB 11,000 FT 12" TO
18" GRAVITY SEWER
NEW GRAVITY SEWER
SHARED WITH
BARNSTABLE OPTION 3
SEPTIC TANK
SEWAGE PUMP STA. Nº 2
FOR LOCATION SEE
GRID Nº 93.
HOSPITAL SEWAGE
PUMP STATION
BLDG. 3306, FOR
LOCATION SEE GRID Nº 93 & 94
SEWAGE EJECTOR
STATION FOR LOCATION
SEE GRID AREA B.
FUTURE:
UPGRADE
CENTRAL
HEATING PLANT
PUMP STATION
FUTURE:
REPLACE HANGER
FORCE MAIN (600
FT 3")
FUTURE:
SANDWICH FM
PRESSURE
CONNECTION VALVE
VAULT
ROCKET STORAGE
SEWAGE EJECTOR STATION
FOR LOCATION SEE
GRID Nº 50
SANDWICH OPTION 2
FORCE MAIN FROM
SANDWICH PUMP
STATION
SEWAGE PUMP
STATION Nº 1 FOR
LOCATION SEE
GRID Nº 104
HANGER FM
PRESSURE
CONNECTION
VALVE VAULT
REHAB 3200 FT EXISTING GRAVITY
SEWER
NEW GRAVITY SEWER SHARED
WITH BARNSTABLE OPTION 3
REPLACE CENTRAL
HEATING PLANT
FORCE MAIN (5900
FT 10")
MASHPEE PUMP STATION
LOCATED ON BACK ROAD
SITE 1
MATCH LINE 'BB' - SEE SHT. B
WWTF
MASHPEE 8" FORCEMAIN
20" SHARED FORCEMAIN
WITH BARNSTABLE OPTION 3
NOTE
1. SEWER LINES NOT DESIGNATED ON THIS MAP ARE ALL 8"
2. FOR DETAILS OF SEWAGE PUMP & EJECTOR STATIONS SEE UTILITY DIAGRAMS B & C.
VICINITY MAP
SHEET INDEX
LEGEND
GRAPHIC SCALE IN FEET
CONTOUR INTERVAL: 5 FEET
DATUM: MEAN SEA LEVEL 1929
LAMBERT CONFORMAL PROJECTION
2000' GRID: MASS STATE PLANE COORDINATE-1927 NORTH AMERICAN DATUM
APPROX. MAG. DECL. 15° 2' W 1955
0° 39' 29" GRID DECL. at MASS. & GS STA. 5GD 1955
CERTIFICATE:
DATA SHOWN ON THIS DRAWING CONFORMS TO THE REQUIREMENTS OF CONTRACT SPECIFICATIONS. CONTRACT AFOS (604) — 100.
DATE: 1 MARCH, 1962
DATE: 1 JUNE 62
DATE: 15 MAY 62
DATE: 9 May 62
OTIS AIR FORCE BASE
4 1 JAN 69 ANNUAL REVISIONS FO-5603-69-C-0059 H N M
3 1 JAN 66 ANNUAL REVISIONS AF05(603)-2967 H N M
2 1 JAN 65 ANNUAL REVISIONS AF05(603)2080 H N M
1 JAN 63 OTIS A. F. BASE, MASS
REV. DATE DESCRIPTION INITIAL
PLAN REVISIONS
DEPARTMENT OF THE AIR FORCE
DCS/CIVIL ENGINEERING HQ AFC
AEROSPACE DEFENSE COMMAND
MASTER PLAN
GENERAL UTILITY MAP
SANITARY SEWAGE SYSTEM - SHEET A
OTIS AIR FORCE BASE MASSACHUSETTS
SCALE 1 INCH = 400 FT.
DATE: 1 MARCH, 1962

Appendix NN

JBCC Section 2 Updates

SECTION 2

ENGINEERING ASSESSMENT (UPDATED FOR BARNSTABLE)

2.1 INTRODUCTION

The Town of Barnstable provided capacity requests by wastewater type via email dated March 8, 2019. The text and tables below present the information provided by Barnstable and the updates to the engineering assessment based on these capacity needs.

- Study Basis: The study basis includes a specified amount of sewage from Barnstable will be directed to the JBCC WWTF. For the study basis, the amount of capacity requested is intended to serve the village of Cotuit plus western portions of Barnstable Phases 1, 2 and 3.
- Low End: Same elements, however, for the mid-term, the identified capacity is reduced to just the amount required for Stages 1, 2 and 3 in the Popponesset Bay watershed and, for the long-term, the identified capacity is reduced to just the amount required for the village of Cotuit.
- High End: Same as the study basis, however, for the mid-term, the identified capacity is increased to include western portions of Phases 1 and 2 (for sewage) and, for the long-term, includes effluent flow allocation from the eastern portions of Barnstable following treatment at the Barnstable WPCF.

TABLE 1-7: REQUESTED CAPACITY BY WASTEWATER TYPE

	Capacity Requested – Annual Average Basis		
	Low End (gpd)	Study Basis (gpd)	High End (gpd)
BARNSTABLE			
Short-term (Year 0 to Year 3)			
Sewage Treatment	0	0	0
Effluent Disposal Only	0	0	0
Septage Treatment	0	0	0
Mid-term (Year 5 to Year 20)			
Sewage Treatment	100,000	500,000	800,000
Effluent Disposal Only	0	0	0
Septage Treatment	10,000	10,000	10,000
Long-term (Years 20+)			
Sewage Treatment	500,000	1,200,000	1,200,000
Effluent Disposal Only	0	0	900,000
Septage Treatment	10,000	10,000	10,000

Table 1-8 summarizes the needs of the five towns and JBCC for a 20+-year planning horizon.

The remainder of this section of the report identifies and evaluates the technical factors, costs and management considerations associated with potential shared wastewater facilities at JBCC.

2.2 WASTEWATER FLOWS USED IN THE ENGINEERING ASSESSMENT

Different components of a wastewater system are designed based on different process conditions (e.g., minimum day, annual average, maximum month, maximum multi-day, maximum day and peak instantaneous, etc.). In the absence of existing data on short-term peak flows, peaking factors are typically utilized to establish the other conditions. For the purposes of this study:

- Sewage peaking factors were established using the TR-16 Guides for the Design of Wastewater Treatment Works curves entitled "Relation of Extreme Discharges on Maximum and Minimum Days to the Average Daily Discharge of Domestic Sewage" (New England Interstate Water Pollution Control Commission, 2016) and were adjusted upward by 0.2 to account for seasonal population/flow variations on Cape Cod. Septage peaking factors were set assuming that equalization tanks would be provided.
- Effluent-only peaking factors were estimated by assuming that the remote facilities (i.e., Falmouth's Blacksmith Shop Road WWTF and Bourne's anticipated future Integrated Solid Waste Management Facility Leachate WWTF) have, or will have, effluent equalization tanks sized to meet these peaking factor limitations or will utilize existing or new effluent disposal systems local to the ISWM and BSR WWTFs to manage peak flows.

Table 2-1 summarizes the peaking factors which have been used for this project. The peaking factors from **Table 2-1** were applied to the annual average flows from **Table 1-8** in order to establish the wastewater flows that will be used for this engineering assessment. **Table 2-2** summarizes the annual average, maximum 3-day flows and the peak conveyance flows for the existing, short-term, mid-term and long-term conditions. The flows in **Table 2-2** have been used for the conceptual sizing and costing of proposed wastewater system components.

TABLE 1-8: SUMMARY OF CAPACITY REQUESTS TO BE USED IN ENGINEERING ASSESSMENT

	Capacity Requested - Annual Average Flows (gpd)								
	JBCC	**Bourne**	**Falmouth**	**Mashpee**	**Sandwich**	**Barnstable**	**Total**	**Capacity Provided**	**% Increase Existing Capacity**
Existing									
Sewage Treatment	140,000	0	0	0	0	0	140,000	**360,000**	n/a
Septage Treatment	0	0	0	0	0	0	0		
Effluent Disposal Only	0	0	0	0	0	0	0		
Effluent Disposal	140,000	0	0	0	0	0	140,000	**360,000**	n/a
Short-Term (5-year)									
Sewage Treatment	147,000	0	0	200,000	0	0	347,000	**360,000**	0%
Septage Treatment	0	0	0	0	0	0	0		
Effluent Disposal Only	0	100,000	0	0	0	0	100,000		
Effluent Disposal	147,000	100,000	0	200,000	0	0	447,000	**460,000**	28%
Mid-Term (10 year)									
Sewage Treatment	147,000	259,000	0	200,000	100,000	500,000	1,206,000	**1,260,000**	250%
Septage Treatment	0	11,000	22,000	3,000	10,000	10,000	56,000		
Effluent Disposal Only	0	444,000	490,000	0	0	0	934,000		
Effluent Disposal	147,000	714,000	512,000	203,000	110,000	510,000	2,196,000	**2,200,000**	511%
Long-Term (20 year)									
Sewage Treatment	147,000	456,000	0	200,000	340,000	1,200,000	2,343,000	**2,400,000**	567%
Septage Treatment	0	11,000	22,000	3,000	10,000	10,000	56,000		
Effluent Disposal Only	0	651,000	1,490,000	0	0	0	2,141,000		
Effluent Disposal	147,000	1,118,000	1,512,000	203,000	350,000	1,210,000	4,540,000	**4,550,000**	1164%
Notes	1	1	1	1	1			2, 4	3

1) Refer to Table 1-7 for additional information.

2) Existing Capacity based on WP 2014, GWDP and WWTF O&M.

3) Capacity for Short-Term, Mid-Term and Long-Term conditions are increases over the existing capacity.

4) Organic loading treatment capacity will need to account for concentrated nature of septage.

TABLE 2-1: PEAKING FACTORS FOR MIMIMUM AND MAXIMUM FLOW CONDITIONS

Ratio to Annual Average	Sewage	Septage	Effluent Only
Minimum Day	0.40	0.50	0.50
Minimum Month	0.75	0.75	0.75
Annual Average	1.00	1.00	1.00
Maximum Month	1.25	1.50	1.25
Maximum 3-Day	2.2 (LT) to 2.7 (ST)	1.75	1.25
Peak Instantaneous	3.5 (LT) to 4.7 (ST)	1.75	1.25

Note: LT = Long term; ST = Short term

TABLE 2-2: EFFLUENT DISPOSAL FLOWS USED IN ENGINEERING ASSESSMENT

Flows in gpd	Annual Average	Maximum 3-Day	Peak Conveyance
Existing	140,000	386,000	1,400,000
Short-Term	460,000	1,080,000	1,750,000
Mid-Term	2,200,000	4,160,000	6,090,000
Long-Term	4,550,000	7,930,000	10,980,000

Note: Refer to Appendix A for a breakdown of flows by category. Rounded to nearest 10,000 gpd

2.3 IDENTIFICATION OF FUTURE WASTEWATER SYSTEM COMPONENTS

This section identifies the components of the future wastewater system to address future wastewater needs at shared facilities. The analysis and costs are presented in these categories.

2.3.1 Conveyance

Each community will have a collection system that transports flow to the location of the regional conveyance facilities. This report addresses the conveyance system costs but will not address the collection system costs.

2.3.2 Treatment

The JBCC WWTF will require upgrade/replacement to serve the regional needs. This report considers the costs for WWTF upgrade/replacement at the current WWTF location or at the former WWTF location (immediately adjacent to the current location). Any potential future WWTF expansions to include more regional flow and/or regional biosolids processing and/or regional source separated organics digestion is beyond the scope of this study.

2.3.3 Transport to Effluent Disposal

WWTF effluent is conveyed to the existing RIBs via the existing 11-mile long, 12-inch diameter forcemain. This report considers the costs for upgrades to this forcemain as well as supplemental forcemain(s) to the supplemental or replacement effluent disposal methods.

2.3.4 Effluent Disposal

The JBCC RIBs will need to be supplemented or replaced in order to serve the regional needs. This report considers the costs for additional RIBs as well as other supplemental/replacement effluent disposal methods.

2.4 CONVEYANCE

This section identifies the options for wastewater conveyance systems required to support shared wastewater management opportunities for Bourne, Falmouth, Mashpee, Sandwich, Barnstable and JBCC. The objectives of the conveyance study include the following:

- Identify alignments for conveyance of sewage from Bourne's southern section, Mashpee, Sandwich and Barnstable to the JBCC WWTF for treatment and disposal;
- Identify alignments for conveyance of treated wastewater ("effluent") from the JBCC WWTF, the Bourne ISWM WWTF and the Falmouth BSR WWTF to the JBCC treated effluent conveyance system and disposal areas;
- Identify rehabilitation of sections of the JBCC gravity sewer system where shorter alignments and capital cost savings are available;
- Review conceptual profiles of each force main alignment to evaluate conceptual static and dynamic head on the pumping system;
- Develop preliminary hydraulic calculations to determine conceptual forcemain sizes; and
- Determine conceptual number and size of required pump stations.

2.4.1 Concept Design Criteria

No revised information (refer to 2017 Report).

2.4.2 Summary of Preferred Conveyance Options

No revised information (refer to 2017 Report).

2.4.2.1 Preferred Bourne Alignment Details

2.4.2.2 Preferred Falmouth Alignment Details

2.4.2.3 Preferred Mashpee Alignment Details

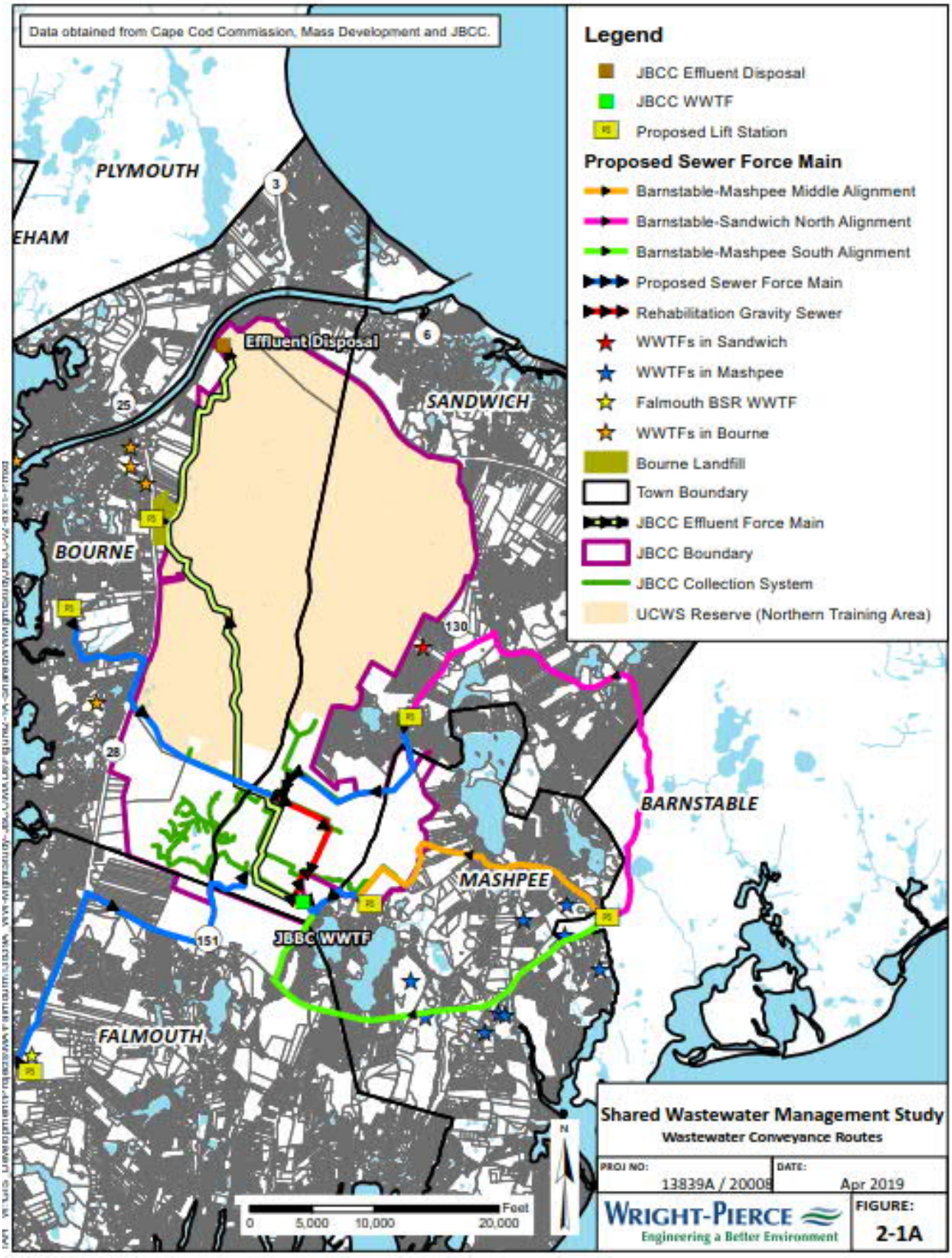
2.4.2.4 Preferred Sandwich Alignment Details

2.4.2.5 Preferred Barnstable Alignment Details

Three candidate alignments were identified by the Town via email dated March 15, 2019. These alignments consist of a central alignment through Mashpee (Option 1), a southern alignment through Mashpee (Option 2) and a northern alignment through Sandwich (Option 3). Refer to **Figure 2-1A** for locations of these alignments. The cost basis, advantages, and disadvantages of each alignment are described in a memorandum entitled *"JBCC Shared Wastewater Management Study, Evaluation of Conveyance Options"* (Wright-Pierce, May 13, 2019). A summary of the costs presented in that memorandum is tabulated below.

ENR CCI 11228, April 2019	Conceptual Cost without Cost Sharing	Conceptual Cost with Cost Sharing, Pro-Rata based on Flow
Option 1 – Central Alignment	$14.2M	$13.9M
Option 2 – Southern Alignment	$16.3M	$16.2M
Option 3 – Northern Alignment	$27.7M	$25.7M

Option 3 is carried forward in the costs presented herein (at a placeholder value of $25M) because it is the highest cost and most conservative of the three alignments.


Data obtained from Cape Cod Commission, Mass Development and JBCC.
Legend
JBCC Effluent Disposal
JBCC WWTF
Proposed Lift Station
Proposed Sewer Force Main
Barnstable-Mashpee Middle Alignment
Barnstable-Sandwich North Alignment
Barnstable-Mashpee South Alignment
Proposed Sewer Force Main
Rehabilitation Gravity Sewer
WWTFs in Sandwich
WWTFs in Mashpee
Falmouth BSR WWTF
WWTFs in Bourne
Bourne Landfill
Town Boundary
JBCC Effluent Force Main
JBCC Boundary
JBCC Collection System
UCWS Reserve (Northern Training Area)
PLYMOUTH
EHAM
SANDWICH
BOURNE
BARNSTABLE
MASHPEE
FALMOUTH
Effluent Disposal
JBBC WWTF
3
6
25
28
130
151
0
5,000
10,000
20,000
Feet
N
Shared Wastewater Management Study
Wastewater Conveyance Routes
PROJ NO:
13839A / 20008
DATE:
Apr 2019
WRIGHT-PIERCE
Engineering a Better Environment
FIGURE:
2-1A

2.5 TREATMENT

No revised information (refer to 2017 Report).

2.6 TRANSPORT TO EFFLUENT DISPOSAL

No revised information (refer to 2017 Report).

2.7 EFFLUENT DISPOSAL

No revised information (refer to 2017 Report).

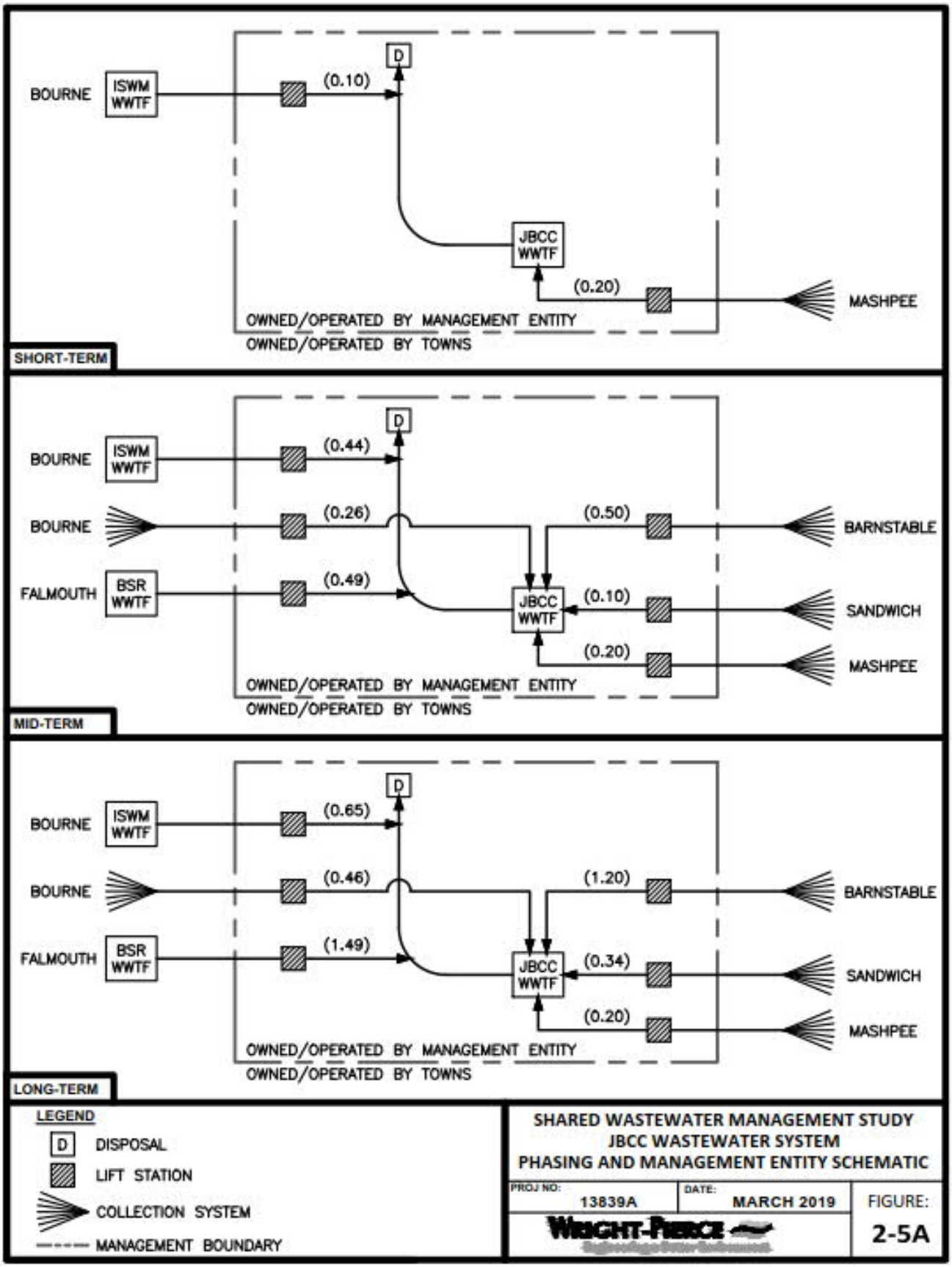
2.8 IDENTIFICATION OF COMPOSITE ALTERNATIVES

This section identifies and describes the following alternatives for the treatment and disposal aspects of the future wastewater system:

1) New WWTF with RIBs
2) New WWTF with RIBs and Wicks
3) New WWTF with RIBs and Deep Well Injection
4) New WWTF with RIBs and Canal Outfall
5) New WWTF with Deep Well Injection
6) New WWTF with Canal Outfall

Treatment process schematics for each alternative are shown on **Figure 2-4A**. Each of the alternatives includes limited upgrades to the existing JBCC wastewater facilities in order to maintain permit compliance and capacity in the short-term. All flow rates indicated in Section 2.8 reference the 3-day peak flow for the long term. Each of the alternatives includes a description of the anticipated phasing requirements. A summary of the upgraded and new facilities for each of the composite alternatives is presented on the following pages. The project phasing and management entity boundaries which are included in the planning-level cost estimates are shown on **Figure 2-5A**.

ALTERNATE 1 - NEW WWTF WITH RIB
INF/SEP (2.40)
ENR/SBR (2.40)
DISINFECTION (2.40)
EFF-FALMOUTH (1.49)
EFF-BOURNE (0.65)
RIB (3.89/6.38)
RIB (0.66/1.55)
ALTERNATE 2 - NEW WWTF WITH RIB AND WICKS
INF/SEP (2.40)
ENR/SBR (2.40)
SAND FILTRATION (2.40)
DISINFECTION (2.40)
EFF-FALMOUTH (1.49)
EFF-BOURNE (0.65)
WICKS (3.89/6.38)
RIB (0.66/1.55)
ALTERNATE 3 - NEW WWTF WITH RIB AND DEEP WELL INJECTION
INF/SEP (2.40)
ENR/MBR (2.98)
REVERSE OSMOSIS (4.47)
DISINFECTION (3.89)
EFF-FALMOUTH (1.49)
REJECT (0.58)
STORAGE 1-DAY
EFF-BOURNE (0.65)
STORAGE 1DAY
RIB (RESERVE)
DWI (3.89/6.38)
RIB (0.66/1.55)
ALTERNATE 4 - NEW WWTF WITH RIB AND CANAL OUTFALL
INF/SEP (2.40)
ENR/SBR (2.40)
DISINFECTION (2.40)
EFF-FALMOUTH (1.49)
EFF-BOURNE (0.65)
OUTFALL (3.89/6.38)
RIB (0.66/1.55)
ALTERNATE 5 - NEW WWTF WITH DEEP WELL INJECTION
INF/SEP (2.40)
ENR/MBR (3.08)
REVERSE OSMOSIS (5.22)
DISINFECTION (4.54)
EFF-FALMOUTH (1.49)
EFF-BOURNE (0.65)
REJECT (0.68)
STORAGE 1-DAY
STORAGE 1DAY
RIB (RESERVE)
DWI (4.55/7.93)
ALTERNATE 6 - NEW WWTF WITH CANAL OUTFALL
INF/SEP (2.40)
ENR/SBR (2.40)
DISINFECTION (2.40)
EFF-FALMOUTH (1.49)
EFF-BOURNE (0.65)
OUTFALL (4.55/7.93)
RIB (RESERVE)
WITH BARNSTABLE
NOTES:
(#.##/#.##) = LONG-TERM FLOW IN MGD. FIRST NUMBER IS ANNUAL AVERAGE FLOW BASIS. SECOND NUMBER IS 3-DAY MAXIMUM FLOW BASIS.
EXISTING = EXISTING PROCESS
PROPOSED = PROPOSED PROCESS
SHARED WASTEWATER MANAGEMENT STUDY
JBCC WASTEWATER SYSTEM
TREATMENT PROCESS SCHEMATICS
PROJECT NO. 13839A
DATE MARCH 2019
FIGURE 2-4A


SHORT-TERM
BOURNE
ISWM WWTF
(0.10)
D
JBCC WWTF
(0.20)
MASHPEE
OWNED/OPERATED BY MANAGEMENT ENTITY
OWNED/OPERATED BY TOWNS
MID-TERM
BOURNE
ISWM WWTF
(0.44)
BOURNE
(0.26)
(0.50)
BARNSTABLE
FALMOUTH
BSR WWTF
(0.49)
JBCC WWTF
(0.10)
SANDWICH
(0.20)
MASHPEE
OWNED/OPERATED BY MANAGEMENT ENTITY
OWNED/OPERATED BY TOWNS
LONG-TERM
BOURNE
ISWM WWTF
(0.65)
BOURNE
(0.46)
(1.20)
BARNSTABLE
FALMOUTH
BSR WWTF
(1.49)
JBCC WWTF
(0.34)
SANDWICH
(0.20)
MASHPEE
OWNED/OPERATED BY MANAGEMENT ENTITY
OWNED/OPERATED BY TOWNS
LEGEND
D DISPOSAL
LIFT STATION
COLLECTION SYSTEM
MANAGEMENT BOUNDARY
SHARED WASTEWATER MANAGEMENT STUDY
JBCC WASTEWATER SYSTEM
PHASING AND MANAGEMENT ENTITY SCHEMATIC
PROJ NO: 13839A
DATE: MARCH 2019
WRIGHT-PIERCE
FIGURE: 2-5A

2.8.1 New WWTF with RIBs

Short-Term: • Upgrades to existing JBCC wastewater facilities. • Upgrades to existing RIBs to achieve 1.55-mgd capacity. • Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).
Long-Term: • New ENR/SBR WWTF plus disinfection. • 16 new RIBs on the adjacent US Government parcel (ACOE) or in the Reserve to achieve an additional 6.38-mgd capacity. • 2 new effluent forcemains (11.0 miles) located parallel to existing (3 total forcemains). • Connect Falmouth BSR WWTF (effluent); Bourne, Sandwich and Barnstable (sewage).

2.8.2 New WWTF with RIBs and Wicks

Short-Term: • Upgrades to existing JBCC wastewater facilities. • Upgrades to existing RIBs to achieve 1.55-mgd capacity. • Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).
Long-Term: • New ENR/SBR WWTF plus sand filtration and disinfection. • Assume that Bourne ISWM WWTF and Falmouth BSR WWTF can meet the effluent TSS and turbidity requirements for wicks (i.e., no cost included herein). • 30 to 65 new wicks to achieve an additional 6.38-mgd capacity (63 based on 100,000 gpd per wick). • 2 new effluent forcemains (11.0 miles) located parallel to existing (3 total forcemains). • Connect Falmouth BSR WWTF (effluent); Bourne, Sandwich and Barnstable (sewage).

2.8.3 New WWTF with RIBs and Deep Well Injection

Short-Term:

- Upgrades to existing JBCC wastewater facilities.
- Upgrades to existing RIBs to achieve 1.55-mgd capacity.
- Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).

Long-Term:

- New ENR/MBR WWTF plus RO/Storage and disinfection.
- 8 to 10 new DWI wells in the Cantonment or the Reserve to achieve an additional 6.38-mgd capacity (9 based on 750,000 gpd per DWI well).
- Add RIBs or wicks to serve as reserve disposal (1.55 mgd)
- 2 new effluent forcemains (2.3 miles) located parallel to existing (3 total forcemains).
- Connect Falmouth BSR WWTF (effluent); Bourne, Sandwich and Barnstable (sewage).

2.8.4 New WWTF with RIBs and Canal Outfall

Short-Term:

- Upgrades to existing JBCC wastewater facilities.
- Upgrades to existing RIBs to achieve 1.55-mgd capacity.
- Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).

Long-Term:

- New ENR/SBR WWTF plus disinfection.
- Assume that Falmouth BSR WWTF and Bourne ISWM WWTF can meet the effluent requirements for a Canal outfall (i.e., no cost included herein).
- New Canal outfall sized for an additional 6.38-mgd capacity.
- 2 new effluent forcemains (11.5 miles) located parallel to existing (3 total forcemains).
- Connect Falmouth BSR WWTF (effluent); Bourne, Sandwich and Barnstable (sewage).

2.8.5 New WWTF with Deep Well Injection

Short-Term:
- Upgrades to existing JBCC wastewater facilities.
- Upgrades to existing RIBs to achieve 1.55-mgd capacity. Maintain existing RIBs to serve as reserve disposal.
- Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).

Long-Term:
- New ENR/MBR WWTF plus RO/Storage and disinfection. All Falmouth and Bourne effluent flow brought to JBCC WWTF site.
- 10 to 12 new DWI wells in the Cantonment to achieve an additional 7.93-mgd capacity (11 based on 750,000 gpd per DWI well).
- 2 new effluent forcemains (2.3 miles) located parallel to existing (3 total forcemains).
- Connect Falmouth BSR WWTF (effluent); Bourne, Sandwich and Barnstable (sewage).

2.8.6 New WWTF with Canal Outfall

Short-Term:
- Upgrades to existing JBCC wastewater facilities.
- Upgrades to existing RIBs to achieve 1.55-mgd capacity.
- Maintain existing RIBs to serve as reserve disposal.
- Connect Bourne ISWM WWTF (effluent) and Mashpee (sewage).

Long-Term:
- New ENR/SBR WWTF plus UV disinfection.
- Assume that Bourne ISWM WWTF and Falmouth BSR WWTF can meet the effluent requirements for a Canal outfall (i.e., no cost included herein).
- New Canal outfall sized for an additional 7.93-mgd capacity.
- 2 new effluent forcemains (11.5 miles) located parallel to existing (3 total forcemains).
- Connect Falmouth BSR WWTF (effluent); Bourne, Sandwich and Barnstable (sewage).

2.9 EVALUATION OF COMPOSITE ALTERNATIVES

The cost information presented herein is in **November 2017 dollars** and is based on ENR Index 10800. Planning-level cost estimates for the long-term flows are summarized in **Table 2-5** (without Barnstable) and **Table 2-5A** (with Barnstable).

2.9.1 Planning-Level Capital Costs

Planning-level capital cost estimates were developed using cost estimating procedures consistent with industry standards utilizing concept layouts, unit cost information, and planning-level cost curves, as necessary. The capital costs include the following key components: wastewater collection, transport-to-treatment, wastewater treatment, transport-to-disposal, effluent disposal, land acquisition, and technical services and contingencies. Key technical data were compiled for all plans, based on conceptual designs. Next, typical "unit costs" were applied (e.g., dollars per foot of pipe, or dollars per pump station) using recent experience from publicly-bid wastewater projects across New England. Unit costs for "baseline" treatment and disposal facilities (i.e., ENR/SBR and disinfection) were taken from the Barnstable County Cost Report ("*Comparison of Costs for Wastewater Management Systems Applicable to Cape Cod*", April 2010). Once basic construction costs were estimated, allowances were added for contingencies and technical services (40% of construction subtotal) and financing/legal/administration expenses (3% of construction subtotal). Land costs were excluded from this analysis.

2.9.2 Planning-Level Operation and Maintenance Costs

Annual operation and maintenance (O&M) costs were developed for each plan for the purposes of comparison among the plans. These planning-level O&M costs were developed using the anticipated wastewater flow rates for each plan. Unit O&M costs were taken from the Barnstable County Cost Report (April 2014). These O&M estimated include the following types of expenses: labor, including fringe benefits; electrical energy for powering pumps and treatment equipment; fuel for building heating and vehicular use; chemicals; disposal of dewatered sludge; laboratory testing and other permit compliance costs; administrative costs such as insurance; and equipment maintenance and replacement.

2.9.3 Equivalent Annual Cost

The “equivalent annual cost" (EAC) is a standard economic tool that allows for the calculation of a single "cost" to represent the combination of capital costs and annual expenses for O&M. The equivalent annual cost is the sum of the annual O&M cost plus the annualized debt service on the capital costs. For the purposes of this study, the present worth has been computed assuming a 2% interest rate and a 20-year loan based on presumed DEP CWSRF (Clean Water State Revolving Fund) loan financing.

2.9.4 Considerations for Composite Alternatives

No revised information

2.9.5 Evaluative Criteria

No revised information. **Table 2-6** was not updated or included herein.

2.9.6 Cost Breakdown by Phase

Option 6 (Outfall) was selected because it is the most conservative (i.e., most expensive) of the four composite alternatives that have relatively equivalent cost (i.e., Options 1, 2, 4 and 6). The cost breakdown is provided as follows:

- Short-Term Costs – These costs consist of the items identified in Section 1.4 of this report as well as the conveyance costs for Bourne ISWM WWTF and Mashpee sewage.
- Long-Term Costs – These costs consist of the remainder of the treatment, transport to disposal and disposal costs necessary to provide the requested capacity for the “study basis” flows.

The cost breakdown by phase is presented in **Table 2-7**. Additional information is provided in **Appendix A**.

2.9.7 Cost Allocation Among Participants

Costs for the various wastewater system components were allocated in the following ways:

- Conveyance – Costs were attributed to the individual towns, except where new or rehabilitated infrastructure is shared and except for baseline inflow removal at JBCC. When shared, the costs are split on a pro-rata flow basis among affected individual towns. None of the conveyance costs were attributed to JBCC. Inflow removal costs associated with the existing system are the responsibility of JBCC. Conveyance costs include the cost of the lift station to convey flow to the JBCC system.
- Transport and Disposal – Costs were attributed to the individual towns and JBCC on a pro-rata flow basis, in accordance with the requested effluent disposal capacity indicated in Section 1.
- Contingency/Technical/Legal/Administration/Finance – Costs were attributed to the individual towns and JBCC pro-rata based on the subtotal of the planning-level construction costs.

The percentage of total effluent flow by phase is presented in Table 2-8. These percentages are used to allocate O&M costs. The basis for allocation of capital costs is presented in Table 2-9. This allocation was used for the mid-term and long-term conditions. The allocations of capital cost, annual O&M, and equivalent cost are presented in Table 2-10, Table 2-11 and Table 2-12, respectively. Additional information is presented in Appendix A.

It is important to note that cost allocations per entity will change if not all entities ultimately elect to participate or if entities elect to participate at higher or lower flow rates than indicated in Section 1 of this report. Cost allocations will also change if different allocation assumptions are utilized.

2.9.8 Comparison of Costs to Previous Town Planning Documents

No revised information.

TABLE 2-5: SUMMARY OF PLANNING-LEVEL COST ESTIMATES AND COST ALLOCATION (BASED ON LONG-TERM, CONSTRUCTED AS A SINGLE PROJECT) (ENR CCI 11228, April 2019)

Option	1	2	3	4	5	6
Description of Effluent Disposal	**RIB**	**RIB & Wicks**	**RIB & DWI**	**RIB & Outfall**	**DWI**	**Outfall**
Capital Cost						
Construction - Conveyance	$29,030,000	$29,030,000	$29,030,000	$29,030,000	$29,030,000	$29,030,000
Construction - Treatment	$38,900,000	$41,300,000	$66,100,000	$41,300,000	$72,700,000	$41,300,000
Construction - Transport to Disposal	$22,900,000	$22,900,000	$5,160,000	$23,950,000	$5,160,000	$23,950,000
Construction - Disposal	$11,700,000	$11,400,000	$13,400,000	$11,900,000	$14,200,000	$13,400,000
Contingency, Technical, Legal/Admin/Finance	$44,090,000	$44,990,000	$48,890,000	$45,660,000	$52,070,000	$46,300,000
Total Capital Cost	**$146,620,000**	**$149,620,000**	**$162,580,000**	**$151,840,000**	**$173,160,000**	**$153,980,000**
Ratio to Lowest - Total Capital Cost	1.00	1.02	1.11	1.04	1.18	1.05
Ratio to Lowest - Capital Cost, excl. Conveyance	1.00	1.03	1.15	1.05	1.25	1.07
Annual Operation & Maintenance Cost	**$2,910,000**	**$3,010,000**	**$6,040,000**	**$3,110,000**	**$7,300,000**	**$3,110,000**
Ratio to Lowest - Annual O&M	1.00	1.03	2.08	1.07	2.51	1.07
Total Annual Debt Service on Capital Cost	$8,970,000	$9,150,000	$9,940,000	$9,290,000	$10,590,000	$9,420,000
Total Equivalent Annual Cost (Note 3)	**$11,880,000**	**$12,160,000**	**$15,980,000**	**$12,400,000**	**$17,890,000**	**$12,530,000**
Ratio to Lowest - Equivalent Annual Cost	1.00	1.02	1.35	1.04	1.51	1.05
EAC per thousand gallons of disposal capacity	$9.72	$9.94	$13.07	$10.14	$14.63	$10.25

Notes:

1) Costs are presented in current dollars based on Engineering News Record Construction Cost Index 11228 (April 2019).
2) Refer to Appendix A for supporting information.
3) Equivalent Annual Cost equals Annual O&M Cost plus the Annual Debt Service on Capital Cost.
4) Allocation for Conveyance is 100% to each town. Allocation for treatment/transport/disposal is pro-rated based on flow capacity requested.
5) Blue indicates lowest cost option, green indicates second lowest cost option and orange indicates third lowest cost option.

TABLE 2-5A: SUMMARY OF PLANNING-LEVEL COST ESTIMATES AND COST ALLOCATION (BASED ON LONG-TERM, CONSTRUCTED AS A SINGLE PROJECT) (ENR CCI 11228, April 2019)

Option	1	2	3	4	5	6
Description of Effluent Disposal	**RIB**	**RIB & Wicks**	**RIB & DWI**	**RIB & Outfall**	**DWI**	**Outfall**
Capital Cost						
Construction - Conveyance	$56,730,000	$56,730,000	$56,730,000	$56,730,000	$56,730,000	$56,730,000
Construction - Treatment	$58,000,000	$61,700,000	$92,800,000	$61,700,000	$98,800,000	$61,700,000
Construction - Transport to Disposal	$25,720,000	$25,720,000	$5,760,000	$26,910,000	$5,760,000	$26,910,000
Construction - Disposal	$13,200,000	$12,900,000	$16,600,000	$13,400,000	$18,400,000	$14,800,000
Contingency, Technical, Legal/Admin/Finance	$66,070,000	$67,530,000	$73,910,000	$68,260,000	$77,270,000	$68,860,000
Total Capital Cost	**$219,720,000**	**$224,580,000**	**$245,800,000**	**$227,000,000**	**$256,960,000**	**$229,000,000**
Ratio to Lowest - Total Capital Cost	1.00	1.02	1.12	1.03	1.17	1.04
Ratio to Lowest - Capital Cost, excl. Conveyance	1.00	1.04	1.19	1.05	1.27	1.07
Annual Operation & Maintenance Cost	**$4,290,000**	**$4,450,000**	**$7,100,000**	**$4,620,000**	**$8,150,000**	**$4,620,000**
Ratio to Lowest - Annual O&M	1.00	1.04	1.66	1.08	1.90	1.08
Total Annual Debt Service on Capital Cost	$13,440,000	$13,730,000	$15,030,000	$13,880,000	$15,710,000	$14,000,000
Total Equivalent Annual Cost (Note 3)	**$17,730,000**	**$18,180,000**	**$22,130,000**	**$18,500,000**	**$23,860,000**	**$18,620,000**
Ratio to Lowest - Equivalent Annual Cost	1.00	1.03	1.25	1.04	1.35	1.05
EAC per thousand gallons of disposal capacity	$14.50	$14.87	$18.10	$15.13	$19.51	$15.23

Notes:

1) Costs are presented in current dollars based on Engineering News Record Construction Cost Index 11228 (April 2019).
2) Refer to Appendix A for supporting information.
3) Equivalent Annual Cost equals Annual O&M Cost plus the Annual Debt Service on Capital Cost.
4) Allocation for Conveyance is 100% to each town. Allocation for treatment/transport/disposal is pro-rated based on flow capacity requested.
5) Blue indicates lowest cost option, green indicates second lowest cost option and orange indicates third lowest cost option.

TABLE 2-7: CAPITAL COST BY PHASE (ENR CCI 11228, April 2019)

	Short-Term	Long-Term w/o Barnstable	Long-Term w/ Barnstable
Conveyance	$3.6M	$29.0M	$56.7M
Treatment	$1.9M	$41.3M	$61.7M
Transport	$0.3M	$24.0M	$26.9M
Disposal	$0.4M	$13.4M	$14.8M
Contingency, Technical, Legal, Admin., Finance	$2.7M	$46.3M	$68.9M
Total	$8.9M	$154.0M	$229.0M

Note:
1) For the illustrative purposes, costs are allocated pro-rata based on flow, as described in Section 2.9.7.

TABLE 2-8: PERCENTAGE OF TOTAL EFFLUENT FLOW BY PHASE

	Short-Term	Long-Term w/o Barnstable	Long-Term w/ Barnstable
JBCC	33%	4%	3%
Bourne	22%	34%	25%
Falmouth	0%	45%	33%
Mashpee	45%	6%	4%
Sandwich	0%	11%	8%
Barnstable	0%	0%	27%
Total	100%	100%	100%

TABLE 2-9: BASIS FOR CAPITAL COST ALLOCATION (LONG-TERM FLOW)

	% of Total w/o Barnstable		% of Total w/ Barnstable	
	Treatment	**Transport/ Disposal**	**Treatment**	**Transport/ Disposal**
JBCC	12%	4%	6%	3%
Bourne	39%	34%	19%	25%
Falmouth	2%	45%	1%	33%
Mashpee	17%	6%	8%	4%
Sandwich	29%	11%	15%	8%
Barnstable	0%	0%	50%	27%
Total	100%	100%	100%	100%

TABLE 2-10: CAPITAL COST ALLOCATION (ENR CCI 11228, April 2019)

	Short-Term	**Long-Term w/o Barnstable**	**Long-Term w/ Barnstable**
JBCC	$1.5M	$10.8M	$8.7M
Bourne	$1.8M	$54.1M	$45.6M
Falmouth	$0M	$41.5M	$37.0M
Mashpee	$5.6M	$18.4M	$15.5M
Sandwich	$0M	$29.2M	$24.2M
Barnstable	$0M	$0M	$98.0M
Total	$8.9M	$154.0M	$229.0M

Note:
1) For the illustrative purposes, costs are allocated pro-rata based on flow, as described in Section 2.9.7.

TABLE 2-11: ANNUAL O&M ALLOCATION (ENR CCI 11228, April 2019)

	Short-Term	Long-Term w/o Barnstable	Long-Term w/ Barnstable
JBCC	$0.49M	$0.26M	$0.22M
Bourne	$0.33M	$1.14M	$1.02M
Falmouth	$0.00M	$0.74M	$0.79M
Mashpee	$0.66M	$0.36M	$0.30M
Sandwich	$0.00M	$0.62M	$0.52M
Barnstable	$0.00M	$0.00M	$1.77M
Total	$1.48M	$3.12M	$4.62M

Note:
1) For the illustrative purposes, costs are allocated pro-rata based on flow, as described in Section 2.9.7.
2) This table includes asset management, capital improvements and management entity administrative costs associated with the take-over of the existing JBCC wastewater systems.

TABLE 2-12: EQUIV. ANNUAL COST ALLOCATION (ENR CCI 11228, April 2019)

	Short-Term	Long-Term w/o Barnstable	Long-Term w/ Barnstable
JBCC	$0.58M	$0.83M	$0.65M
Bourne	$0.44M	$4.33M	$3.70M
Falmouth	$0.00M	$3.28M	$3.06M
Mashpee	$1.00M	$1.14M	$0.90M
Sandwich	$0.00M	$2.41M	$2.00M
Barnstable	$0.00M	$0.00M	$7.77M
Total	$2.02M	$11.99M	$18.08M

Note:
1) For the illustrative purposes, costs are allocated pro-rata based on flow, as described in Section 2.9.7.
2) Annual debt services on capital costs is calculated based on a CWSRF at 2% interest for 20 years (CRF 16.35).
3) This table includes asset management, capital improvements and management entity administrative costs associated with the take-over of the existing JBCC wastewater systems.

Based on the equivalent annual cost allocation presented in **Table 2-13**, each town and JBCC would have a reduction in equivalent annual cost if Barnstable were to participate. The amount of the reduction ranges from 21% to 27% for JBCC, Mashpee and Sandwich (sewage users), to 17% for Bourne (sewage and effluent user) to 7% for Falmouth (effluent user). Note that the additional costs for JBCC wastewater system, asset management, capital improvements and management entity administrative cost allowances would need to be allocated among the participants.

BASELINE

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ENGINEERING ASSESSMENT
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019 ENR CCI (10/2017) 10800

Scenario 1
Scenario 2
Scenario 3

COSTS FOR TREATMENT, TRANSPORT-TO-DISPOSAL AND DISPOSAL ALTERNATIVES **Projected to April 2019 dollars**

LONG-TERM

			1	2	3	4	5	6
Items			**RIB**	**RIB/WICK**	**RIB/DWI**	**RIB/OUTFALL**	**DWI**	**OUTFALL**
CAPITAL COSTS								
	Unit Costs							
	Cost, ENR/SBR, Disinfection	1.00	$30.00	$30.00	$30.00	$32.00	$30.00	$32.00
	Cost, ENR/MBR, Disinfection	10%			$3.00		$3.00	
	Cost, Sand Filtration	1.00		$1.90				
	Cost, RO/Reject/Storage	1.00			$4.50		$4.50	
	Cost, GAC/Reject/Storage	1.00						
	Effluent PS, at 200'TDH	1.00	$2.25	$2.25	$1.50	$2.25	$1.50	$2.25
	Flow (gpd, annual average basis)							
	ENR/SBR/UV		1,210,000	1,210,000	1,210,000	1,210,000	1,210,000	1,210,000
	ENR/MBR-Adder				400,000		500,000	
	Sand Filtration	5%		1,270,000				
	RO/AO/Storage				3,100,000		3,850,000	
	GAC/Reject/Storage				3,100,000		3,850,000	
	Effluent PS		1,210,000	1,210,000	2,700,000	1,210,000	3,350,000	1,210,000
	Cost - Treatment-Baseline							
	Existing WWTF Upgrades		$2,570,000	$2,570,000	$2,570,000	$2,570,000	$2,570,000	$2,570,000
	ENR Baseline		$36,300,000	$36,300,000	$36,300,000	$38,720,000	$36,300,000	$38,720,000
	Subtotal - Treatment		**$38,900,000**	**$38,900,000**	**$38,900,000**	**$41,300,000**	**$38,900,000**	**$41,300,000**
	Cost - Treatment-Supplemental							
	ENR/MBR Adder		$0	$0	$13,200,000	$0	$16,500,000	$0
	Sand Filtration		$0	$2,413,000	$0	$0	$0	$0
	RO/AO/Storage		$0	$0	$13,950,000	$0	$17,325,000	$0
	GAC/Reject/Storage		$0	$0	$0	$0	$0	$0
	Subtotal - Treatment		**$0**	**$2,400,000**	**$27,200,000**	**$0**	**$33,800,000**	**$0**
	Cost - Transport to Disposal							
	Existing Forcemain Upgrades		$300,000	$300,000	$300,000	$300,000	$300,000	$300,000
	New Forcemains		$22,600,000	$22,600,000	$4,860,000	$23,650,000	$4,860,000	$23,650,000
	Length	mi	10.7	10.7	2.3	11.2	2.3	11.2
	Number		2	2	2	2	2	2
	Length	ft	112,992	112,992	24,288	118,272	24,288	118,272
	Cost per Foot		200	200	200	200	200	200
	Subtotal - Transport to Disposal		**$22,900,000**	**$22,900,000**	**$5,160,000**	**$23,950,000**	**$5,160,000**	**$23,950,000**

BASELINE

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ENGINEERING ASSESSMENT
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019 ENR CCI (10/2017) 10800

Scenario 1
Scenario 2
Scenario 3

COSTS FOR TREATMENT, TRANSPORT-TO-DISPOSAL AND DISPOSAL ALTERNATIVES **Projected to April 2019 dollars**

LONG-TERM

			1	2	3	4	5	6
Items			**RIB**	**RIB/WICK**	**RIB/DWI**	**RIB/OUTFALL**	**DWI**	**OUTFALL**
	Cost - Disposal							
	Existing RIB Upgrades		$400,000	$400,000	$400,000	$400,000	$400,000	$400,000
	Effluent PS		$2,720,000	$2,720,000	$4,050,000	$2,720,000	$5,030,000	$2,720,000
	New RIBs		$8,600,000		$2,640,000			
	New Wicks			$8,300,000				
	New DWI				$6,300,000		$8,800,000	
	New Outfall					$8,800,000		$10,290,000
	Subtotal - Disposal		**$11,700,000**	**$11,400,000**	**$13,400,000**	**$11,900,000**	**$14,200,000**	**$13,400,000**
	TOTAL		**$73,500,000**	**$75,600,000**	**$84,660,000**	**$77,150,000**	**$92,060,000**	**$78,650,000**
	Lowest plus +% higher for other Options		$73,500,000	3%	15%	5%	25%	7%
ANNUAL O&M								
	Basis flow		1,210,000	1,210,000	2,700,000	1,210,000	3,350,000	1,210,000
	Baseline, April 2014 (ENR CCI 9750)	1.00	$1.50	$1.50	$1.25	$1.50	$1.25	$1.50
	Baseline, Current (ENR CCI 10800)		$1.66	$1.66	$1.38	$1.66	$1.38	$1.66
	Baseline Costs		$2,010,000	$2,010,000	$3,740,000	$2,010,000	$4,640,000	$2,010,000
	Adder for Existing Collection O&M		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
	Adder for Filtration	5%		$100,500				
	Adder for SW Discharge	10%				$201,000.00		$201,000.00
	Adder for ENR/MBR	10%			$374,000		$464,000	
	Adder for RO/Storage	25%			$935,000		$1,160,000	
	Adder for GAC/Storage	0%			$0		$0	
	Adder for Effluent Pumping	5%	$100,500	$100,500	$187,000	$100,500	$232,000	$100,500
	Annual O&M		$2,910,000	$3,010,000	$6,040,000	$3,110,000	$7,300,000	$3,110,000
	Lowest plus +% higher for other Options		$2,910,000	3%	108%	7%	151%	7%
	O&M Allocated to Sewage/Septage, %		50%	50%	50%	50%	50%	50%
	O&M Allocated to Effluent, %		50%	50%	50%	50%	50%	50%
	O&M Allocated to Sewage/Septage, $$		$1,460,000	$1,510,000	$3,020,000	$1,560,000	$3,650,000	$1,560,000
	O&M Allocated to Effluent, $$		$1,460,000	$1,510,000	$3,020,000	$1,560,000	$3,650,000	$1,560,000

BASELINE

TABLE 2-5: SUMMARY OF PLANNING-LEVEL COST ESTIMATES AND COST ALLOCATION (BASED ON LONG-TERM, CONSTRUCTED AS A SINGLE PROJECT) (ENR CCI 11228, April 2019)

Option	**1**	**2**	**3**	**4**	**5**	**6**
Description of Effluent Disposal	**RIB**	**RIB & Wicks**	**RIB & DWI**	**RIB & Outfall**	**DWI**	**Outfall**
Capital Cost						
Construction - Conveyance	$29,030,000	$29,030,000	$29,030,000	$29,030,000	$29,030,000	$29,030,000
Construction - Treatment	$38,900,000	$41,300,000	$66,100,000	$41,300,000	$72,700,000	$41,300,000
Construction - Transport to Disposal	$22,900,000	$22,900,000	$5,160,000	$23,950,000	$5,160,000	$23,950,000
Construction - Disposal	$11,700,000	$11,400,000	$13,400,000	$11,900,000	$14,200,000	$13,400,000
Contingency, Technical, Legal/Admin/Finance	$44,090,000	$44,990,000	$48,890,000	$45,660,000	$52,070,000	$46,300,000
Total Capital Cost	**$146,620,000**	**$149,620,000**	**$162,580,000**	**$151,840,000**	**$173,160,000**	**$153,980,000**
Ratio to Lowest - Total Capital Cost	1.00	1.02	1.11	1.04	1.18	1.05
Ratio to Lowest - Capital Cost, excl. Conveyance	1.00	1.03	1.15	1.05	1.25	1.07
Annual Operation & Maintenance Cost	**$2,910,000**	**$3,010,000**	**$6,040,000**	**$3,110,000**	**$7,300,000**	**$3,110,000**
Ratio to Lowest - Annual O&M	1.00	1.03	2.08	1.07	2.51	1.07
Total Annual Debt Service on Capital Cost	$8,970,000	$9,150,000	$9,940,000	$9,290,000	$10,590,000	$9,420,000
Total Equivalent Annual Cost (Note 3)	**$11,880,000**	**$12,160,000**	**$15,980,000**	**$12,400,000**	**$17,890,000**	**$12,530,000**
Ratio to Lowest - Equivalent Annual Cost	1.00	1.02	1.35	1.04	1.51	1.05
EAC per thousand gallons of disposal capacity	$9.72	$9.94	$13.07	$10.14	$14.63	$10.25

Notes:

1) Costs are presented in current dollars based on Engineering News Record Construction Cost Index 11228 (April 2019).
2) Refer to Appendix A for supporting information.
3) Equivalent Annual Cost equals Annual O&M Cost plus the Annual Debt Service on Capital Cost.
4) Allocation for Conveyance is 100% to each town. Allocation for treatment/transport/disposal is pro-rated based on flow capacity requested.
5) Blue indicates lowest cost option, green indicates second lowest cost option and orange indicates third lowest cost option.

BASELINE

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

File Name: CostAnalysis-20171127-BARN-20190327

ENR CCI 11228 (April 2019)

COST ALLOCATION OF "CANDIDATE PLAN" BY PHASE

USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Conveyance	$0	$3,600,000	$25,430,000	$29,030,000				140,000	347,000	1,189,000
JBCC	$0	$0	$0	$0				140,000	147,000	147,000
Bourne	$0	$1,100,000	$8,790,000	$9,890,000				0	0	467,000
Falmouth	$0	$0	$11,650,000	$11,650,000				0	0	22,000
Mashpee	$0	$2,500,000	$0	$2,500,000				0	200,000	203,000
Sandwich	$0	$0	$4,990,000	$4,990,000				0	0	350,000
Barnstable	$0	$0		$0				0	0	
Treatment-BASELINE	$0	$1,920,000	$39,380,000	$41,300,000	100%	100%	100%	140,000	347,000	1,189,000
JBCC	$0	$813,000	$4,869,000	$5,682,000	100%	42%	12%	140,000	147,000	147,000
Bourne	$0	$0	$15,467,000	$15,467,000	0%	0%	39%	0	0	467,000
Falmouth	$0	$0	$729,000	$729,000	0%	0%	2%	0	0	22,000
Mashpee	$0	$1,107,000	$6,723,000	$7,830,000	0%	58%	17%	0	200,000	203,000
Sandwich	$0	$0	$11,592,000	$11,592,000	0%	0%	29%	0	0	350,000
Barnstable	$0	$0	$0	$0	0%	0%	0%	0	0	0
Treatment-SUPPLEMENT	$0	$0	$0	$0	100%	100%	100%	140,000	347,000	1,189,000
JBCC	$0	$0	$0	$0	100%	42%	12%	140,000	147,000	147,000
Bourne	$0	$0	$0	$0	0%	0%	39%	0	0	467,000
Falmouth	$0	$0	$0	$0	0%	0%	2%	0	0	22,000
Mashpee	$0	$0	$0	$0	0%	58%	17%	0	200,000	203,000
Sandwich	$0	$0	$0	$0	0%	0%	29%	0	0	350,000
Barnstable	$0	$0	$0	$0	0%	0%	0%	0	0	0
Transport to Disposal	$0	$300,000	$23,650,000	$23,950,000	100%	100%	100%	140,000	447,000	3,330,000
JBCC	$0	$99,000	$1,044,000	$1,143,000	100%	33%	4%	140,000	147,000	147,000
Bourne	$0	$67,000	$7,940,000	$8,007,000	0%	22%	34%	0	100,000	1,118,000
Falmouth	$0	$0	$10,738,000	$10,738,000	0%	0%	45%	0	0	1,512,000
Mashpee	$0	$134,000	$1,442,000	$1,576,000	0%	45%	6%	0	200,000	203,000
Sandwich	$0	$0	$2,486,000	$2,486,000	0%	0%	11%	0	0	350,000
Barnstable	$0	$0	$0	$0	0%	0%	0%	0	0	0
Disposal	$0	$400,000	$13,000,000	$13,400,000	100%	100%	100%	140,000	447,000	3,330,000
JBCC	$0	$132,000	$574,000	$706,000	100%	33%	4%	140,000	147,000	147,000
Bourne	$0	$89,000	$4,365,000	$4,454,000	0%	22%	34%	0	100,000	1,118,000
Falmouth	$0	$0	$5,903,000	$5,903,000	0%	0%	45%	0	0	1,512,000
Mashpee	$0	$179,000	$792,000	$971,000	0%	45%	6%	0	200,000	203,000
Sandwich	$0	$0	$1,366,000	$1,366,000	0%	0%	11%	0	0	350,000
Barnstable	$0	$0	$0	$0	0%	0%	0%	0	0	0

BASELINE

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

File Name: CostAnalysis-20171127-BARN-20190327

ENR CCI 11228 (April 2019)

COST ALLOCATION OF "CANDIDATE PLAN" BY PHASE

USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Conting/Tech/Legal/etc	$0	$2,675,000	$43,628,000	$46,300,000	100%	100%	100%	Pro-rata based on construction subtotal		
JBCC	$0	$449,000	$2,789,000	$3,238,000	100%	17%	6%	Pro-rata based on construction subtotal		
Bourne	$0	$540,000	$15,722,000	$16,262,000	0%	20%	36%	Pro-rata based on construction subtotal		
Falmouth	$0	$0	$12,479,000	$12,479,000	0%	0%	29%	Pro-rata based on construction subtotal		
Mashpee	$0	$1,686,000	$3,852,000	$5,538,000	0%	63%	9%	Pro-rata based on construction subtotal		
Sandwich	$0	$0	$8,787,000	$8,787,000	0%	0%	20%	Pro-rata based on construction subtotal		
Barnstable	$0	$0	$0	$0	0%	0%	0%			
Check										
TOTAL	$0	$8,900,000	$145,090,000	$153,990,000						
JBCC	$0	$1,490,000	$9,280,000	$10,770,000						
Bourne	$0	$1,800,000	$52,280,000	$54,080,000						
Falmouth	$0	$0	$41,500,000	$41,500,000						
Mashpee	$0	$5,610,000	$12,810,000	$18,420,000						
Sandwich	$0	$0	$29,220,000	$29,220,000						
Barnstable	$0	$0	$0	$0						
Check	$0	$8,900,000	$145,090,000	$153,990,000						
ANNUAL O&M-SEW/SEPT	$0	$739,500	$1,560,000		100%	100%	100%	140,000	447,000	1,189,000
JBCC	$0.00	$0.24	$0.19		100%	33%	12%	140,000	147,000	147,000
Bourne	$0.00	$0.17	$0.61		0%	22%	39%	0	100,000	467,000
Falmouth	$0.00	$0.00	$0.03		0%	0%	2%	0	0	22,000
Mashpee	$0.00	$0.33	$0.27		0%	45%	17%	0	200,000	203,000
Sandwich	$0.00	$0.00	$0.46		0%	0%	29%	0	0	350,000
Barnstable	$0.00	$0.00	$0.00		0%	0%	0%	0	0	0
Check	$0.00	$0.74	$1.56							
ANNUAL O&M-EFF	$510,000	$739,500	$1,560,000		100%	100%	100%	140,000	447,000	3,330,000
JBCC	$0.51	$0.24	$0.07		100%	33%	4%	140,000	147,000	147,000
Bourne	$0.00	$0.17	$0.52		0%	22%	34%	0	100,000	1,118,000
Falmouth	$0.00	$0.00	$0.71		0%	0%	45%	0	0	1,512,000
Mashpee	$0.00	$0.33	$0.10		0%	45%	6%	0	200,000	203,000
Sandwich	$0.00	$0.00	$0.16		0%	0%	11%	0	0	350,000
Barnstable	$0.00	$0.00	$0.00		0%	0%	0%	0	0	0
Check	$0.51	$0.74	$1.56							
ANNUAL O&M-TOTAL	$510,000	$1,479,000	$3,120,000		100%	100%	100%	140,000	447,000	3,330,000
JBCC	$0.51	$0.49	$0.26		100%	33%	4%	140,000	147,000	147,000
Bourne	$0.00	$0.33	$1.14		0%	22%	34%	0	100,000	1,118,000
Falmouth	$0.00	$0.00	$0.74		0%	0%	45%	0	0	1,512,000

BASELINE

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

File Name: CostAnalysis-20171127-BARN-20190327

ENR CCI 11228 (April 2019)

COST ALLOCATION OF "CANDIDATE PLAN" BY PHASE

USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Mashpee	$0.00	$0.66	$0.36		0%	45%	6%	0	200,000	203,000
Sandwich	$0.00	$0.00	$0.62		0%	0%	11%	0	0	350,000
Barnstable	$0.00	$0.00	$0.00		0%	0%	0%	0	0	0
Check	$0.51	$1.48	$3.12							

DEBT SERVICE	CRF >>	16.35		
JBCC	$0.00	$0.09	$0.57	$0.66
Bourne	$0.00	$0.11	$3.20	$3.31
Falmouth	$0.00	$0.00	$2.54	$2.54
Mashpee	$0.00	$0.34	$0.78	$1.13
Sandwich	$0.00	$0.00	$1.79	$1.79
Barnstable	$0.00	$0.00	$0.00	$0.00
Check	$0.00	$0.54	$8.87	$9.42

EQUIVALENT ANNUAL COST			
JBCC	$0.51	$0.58	$0.83
Bourne	$0.00	$0.44	$4.33
Falmouth	$0.00	$0.00	$3.28
Mashpee	$0.00	$1.00	$1.14
Sandwich	$0.00	$0.00	$2.41
Barnstable	$0.00	$0.00	$0.00
Check	$0.51	$2.02	$11.99

CAPITAL COST PER KGAL (DISPOSAL CAPACITY)				
JBCC	$0	$28	$173	$201
Bourne		$49	$128	$133
Falmouth		$0	$75	$75
Mashpee		$77	$173	$249
Sandwich		$0	$229	$229
Barnstable		$0	#DIV/0!	#DIV/0!
TOTAL		$55	$119	$127

DISPOSAL CAPACITY		
140,000	147,000	147,000
0	100,000	1,118,000
0	0	1,512,000
0	200,000	203,000
0	0	350,000
	0	0
	447,000	3,330,000

STEP 3A

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ENGINEERING ASSESSMENT
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019 ENR CCI (10/2017) 10800

Scenario 1
Scenario 2
Scenario 3

COSTS FOR TREATMENT, TRANSPORT-TO-DISPOSAL AND DISPOSAL ALTERNATIVES **Projected to April 2019 dollars**

LONG-TERM

			1	2	3	4	5	6
Items			**RIB**	**RIB/WICK**	**RIB/DWI**	**RIB/OUTFALL**	**DWI**	**OUTFALL**
CAPITAL COSTS								
	Unit Costs							
	Cost, ENR/SBR, Disinfection	1.00	$30.00	$30.00	$30.00	$32.00	$30.00	$32.00
	Cost, ENR/MBR, Disinfection	10%			$3.00		$3.00	
	Cost, Sand Filtration	1.00		$1.90				
	Cost, RO/Reject/Storage	1.00			$4.50		$4.50	
	Cost, GAC/Reject/Storage	1.00						
	Effluent PS, at 200'TDH	1.00	$2.25	$2.25	$1.50	$2.25	$1.50	$2.25
	Flow (gpd, annual average basis)							
	ENR/SBR/UV		1,210,000	1,210,000	1,210,000	1,210,000	1,210,000	1,210,000
	ENR/MBR-Adder				400,000		500,000	
	Sand Filtration	5%		1,270,000				
	RO/AO/Storage				3,100,000		3,850,000	
	GAC/Reject/Storage				3,100,000		3,850,000	
	Effluent PS		1,210,000	1,210,000	2,700,000	1,210,000	3,350,000	1,210,000
	Cost - Treatment-Baseline							
	Existing WWTF Upgrades		$2,570,000	$2,570,000	$2,570,000	$2,570,000	$2,570,000	$2,570,000
	ENR Baseline		$36,300,000	$36,300,000	$36,300,000	$38,720,000	$36,300,000	$38,720,000
	Subtotal - Treatment		**$38,900,000**	**$38,900,000**	**$38,900,000**	**$41,300,000**	**$38,900,000**	**$41,300,000**
	Cost - Treatment-Supplemental							
	ENR/MBR Adder		$0	$0	$13,200,000	$0	$16,500,000	$0
	Sand Filtration		$0	$2,413,000	$0	$0	$0	$0
	RO/AO/Storage		$0	$0	$13,950,000	$0	$17,325,000	$0
	GAC/Reject/Storage		$0	$0	$0	$0	$0	$0
	Subtotal - Treatment		**$0**	**$2,400,000**	**$27,200,000**	**$0**	**$33,800,000**	**$0**
	Cost - Transport to Disposal							
	Existing Forcemain Upgrades		$300,000	$300,000	$300,000	$300,000	$300,000	$300,000
	New Forcemains		$22,600,000	$22,600,000	$4,860,000	$23,650,000	$4,860,000	$23,650,000
	Length	mi	10.7	10.7	2.3	11.2	2.3	11.2
	Number		2	2	2	2	2	2
	Length	ft	112,992	112,992	24,288	118,272	24,288	118,272
	Cost per Foot		200	200	200	200	200	200
	Subtotal - Transport to Disposal		**$22,900,000**	**$22,900,000**	**$5,160,000**	**$23,950,000**	**$5,160,000**	**$23,950,000**

STEP 3A

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ENGINEERING ASSESSMENT
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019 ENR CCI (10/2017) 10800

Scenario 1
Scenario 2
Scenario 3

COSTS FOR TREATMENT, TRANSPORT-TO-DISPOSAL AND DISPOSAL ALTERNATIVES **Projected to April 2019 dollars**

LONG-TERM

			1	2	3	4	5	6
Items			**RIB**	**RIB/WICK**	**RIB/DWI**	**RIB/OUTFALL**	**DWI**	**OUTFALL**
	Cost - Disposal							
	Existing RIB Upgrades		$400,000	$400,000	$400,000	$400,000	$400,000	$400,000
	Effluent PS		$2,720,000	$2,720,000	$4,050,000	$2,720,000	$5,030,000	$2,720,000
	New RIBs		$8,600,000		$2,640,000			
	New Wicks			$8,300,000				
	New DWI				$6,300,000		$8,800,000	
	New Outfall					$8,800,000		$10,290,000
	Subtotal - Disposal		**$11,700,000**	**$11,400,000**	**$13,400,000**	**$11,900,000**	**$14,200,000**	**$13,400,000**
	TOTAL		**$73,500,000**	**$75,600,000**	**$84,660,000**	**$77,150,000**	**$92,060,000**	**$78,650,000**
	Lowest plus +% higher for other Options		$73,500,000	3%	15%	5%	25%	7%
ANNUAL O&M								
	Basis flow		1,210,000	1,210,000	2,700,000	1,210,000	3,350,000	1,210,000
	Baseline, April 2014 (ENR CCI 9750)	1.00	$1.50	$1.50	$1.25	$1.50	$1.25	$1.50
	Baseline, Current (ENR CCI 10800)		$1.66	$1.66	$1.38	$1.66	$1.38	$1.66
	Baseline Costs		$2,010,000	$2,010,000	$3,740,000	$2,010,000	$4,640,000	$2,010,000
	Adder for Existing Collection O&M		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
	Adder for Filtration	5%		$100,500				
	Adder for SW Discharge	10%				$201,000.00		$201,000.00
	Adder for ENR/MBR	10%			$374,000		$464,000	
	Adder for RO/Storage	25%			$935,000		$1,160,000	
	Adder for GAC/Storage	0%			$0		$0	
	Adder for Effluent Pumping	5%	$100,500	$100,500	$187,000	$100,500	$232,000	$100,500
	Annual O&M		$2,910,000	$3,010,000	$6,040,000	$3,110,000	$7,300,000	$3,110,000
	Lowest plus +% higher for other Options		$2,910,000	3%	108%	7%	151%	7%
	O&M Allocated to Sewage/Septage, %		50%	50%	50%	50%	50%	50%
	O&M Allocated to Effluent, %		50%	50%	50%	50%	50%	50%
	O&M Allocated to Sewage/Septage, $$		$1,460,000	$1,510,000	$3,020,000	$1,560,000	$3,650,000	$1,560,000
	O&M Allocated to Effluent, $$		$1,460,000	$1,510,000	$3,020,000	$1,560,000	$3,650,000	$1,560,000

STEP 3A

TABLE 2-5: SUMMARY OF PLANNING-LEVEL COST ESTIMATES AND COST ALLOCATION (BASED ON LONG-TERM, CONSTRUCTED AS A SINGLE PROJECT) (ENR CCI 11228, April 2019)

Option	**1**	**2**	**3**	**4**	**5**	**6**
Description of Effluent Disposal	**RIB**	**RIB & Wicks**	**RIB & DWI**	**RIB & Outfall**	**DWI**	**Outfall**
Capital Cost						
Construction - Conveyance	$27,700,000	$27,700,000	$27,700,000	$27,700,000	$27,700,000	$27,700,000
Construction - Treatment	$38,900,000	$41,300,000	$66,100,000	$41,300,000	$72,700,000	$41,300,000
Construction - Transport to Disposal	$22,900,000	$22,900,000	$5,160,000	$23,950,000	$5,160,000	$23,950,000
Construction - Disposal	$11,700,000	$11,400,000	$13,400,000	$11,900,000	$14,200,000	$13,400,000
Contingency, Technical, Legal/Admin/Finance	$43,520,000	$44,420,000	$48,310,000	$45,090,000	$51,500,000	$45,730,000
Total Capital Cost	**$144,720,000**	**$147,720,000**	**$160,670,000**	**$149,940,000**	**$171,260,000**	**$152,080,000**
Ratio to Lowest - Total Capital Cost	1.00	1.02	1.11	1.04	1.18	1.05
Ratio to Lowest - Capital Cost, excl. Conveyance	1.00	1.03	1.15	1.05	1.25	1.07
Annual Operation & Maintenance Cost	**$2,910,000**	**$3,010,000**	**$6,040,000**	**$3,110,000**	**$7,300,000**	**$3,110,000**
Ratio to Lowest - Annual O&M	1.00	1.03	2.08	1.07	2.51	1.07
Total Annual Debt Service on Capital Cost	$8,850,000	$9,030,000	$9,830,000	$9,170,000	$10,470,000	$9,300,000
Total Equivalent Annual Cost (Note 3)	**$11,760,000**	**$12,040,000**	**$15,870,000**	**$12,280,000**	**$17,770,000**	**$12,410,000**
Ratio to Lowest - Equivalent Annual Cost	1.00	1.02	1.35	1.04	1.51	1.06
EAC per thousand gallons of disposal capacity	$9.62	$9.85	$12.98	$10.04	$14.53	$10.15

Notes:

1) Costs are presented in current dollars based on Engineering News Record Construction Cost Index 11228 (April 2019).
2) Refer to Appendix A for supporting information.
3) Equivalent Annual Cost equals Annual O&M Cost plus the Annual Debt Service on Capital Cost.
4) Allocation for Conveyance is 100% to each town. Allocation for treatment/transport/disposal is pro-rated based on flow capacity requested.
5) Blue indicates lowest cost option, green indicates second lowest cost option and orange indicates third lowest cost option.

STEP 3A

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

File Name: CostAnalysis-20171127-BARN-20190327

ENR CCI 11228 (April 2019)

COST ALLOCATION OF "CANDIDATE PLAN" BY PHASE

USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Conveyance	$0	$3,600,000	$53,130,000	$56,730,000				140,000	347,000	1,347,000
JBCC	$0	$0	$0	$0				140,000	147,000	147,000
Bourne	$0	$1,100,000	$8,790,000	$9,890,000				0	0	
Falmouth	$0	$0	$11,650,000	$11,650,000				0	0	
Mashpee	$0	$2,500,000	$0	$2,500,000				0	200,000	
Sandwich	$0	$0	$4,990,000	$4,990,000				0	0	
Barnstable	$0	$0	$27,700,000	$27,700,000				0	0	1,200,000
Treatment-BASELINE	$0	$1,920,000	$39,380,000	$41,300,000	100%	100%	100%	140,000	347,000	1,347,000
JBCC	$0	$813,000	$4,298,000	$5,111,000	100%	42%	11%	140,000	147,000	147,000
Bourne	$0	$0	$0	$0	0%	0%	0%	0	0	
Falmouth	$0	$0	$0	$0	0%	0%	0%	0	0	
Mashpee	$0	$1,107,000	$0	$1,107,000	0%	58%	0%	0	200,000	
Sandwich	$0	$0	$0	$0	0%	0%	0%	0	0	
Barnstable	$0	$0	$35,082,000	$35,082,000	0%	0%	89%	0	0	1,200,000
Treatment-SUPPLEMENT	$0	$0	$0	$0	100%	100%	100%	140,000	347,000	1,347,000
JBCC	$0	$0	$0	$0	100%	42%	11%	140,000	147,000	147,000
Bourne	$0	$0	$0	$0	0%	0%	0%	0	0	
Falmouth	$0	$0	$0	$0	0%	0%	0%	0	0	
Mashpee	$0	$0	$0	$0	0%	58%	0%	0	200,000	
Sandwich	$0	$0	$0	$0	0%	0%	0%	0	0	
Barnstable	$0	$0	$0	$0	0%	0%	89%	0	0	1,200,000
Transport to Disposal	$0	$300,000	$23,650,000	$23,950,000	100%	100%	100%	140,000	447,000	1,347,000
JBCC	$0	$99,000	$2,581,000	$2,680,000	100%	33%	11%	140,000	147,000	147,000
Bourne	$0	$67,000	$0	$67,000	0%	22%	0%	0	100,000	
Falmouth	$0	$0	$0	$0	0%	0%	0%	0	0	
Mashpee	$0	$134,000	$0	$134,000	0%	45%	0%	0	200,000	
Sandwich	$0	$0	$0	$0	0%	0%	0%	0	0	
Barnstable	$0	$0	$21,069,000	$21,069,000	0%	0%	89%	0	0	1,200,000
Disposal	$0	$400,000	$13,000,000	$13,400,000	100%	100%	100%	140,000	447,000	1,347,000
JBCC	$0	$132,000	$1,419,000	$1,551,000	100%	33%	11%	140,000	147,000	147,000
Bourne	$0	$89,000	$0	$89,000	0%	22%	0%	0	100,000	
Falmouth	$0	$0	$0	$0	0%	0%	0%	0	0	
Mashpee	$0	$179,000	$0	$179,000	0%	45%	0%	0	200,000	
Sandwich	$0	$0	$0	$0	0%	0%	0%	0	0	
Barnstable	$0	$0	$11,581,000	$11,581,000	0%	0%	89%	0	0	1,200,000

STEP 3A

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

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ENR CCI 11228 (April 2019)

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USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Conting/Tech/Legal/etc	$0	$2,675,000	$55,539,000	$58,210,000	100%	100%	100%	Pro-rata based on construction subtotal		
JBCC	$0	$449,000	$3,568,000	$4,017,000	100%	17%	6%	Pro-rata based on construction subtotal		
Bourne	$0	$540,000	$3,780,000	$4,320,000	0%	20%	7%	Pro-rata based on construction subtotal		
Falmouth	$0	$0	$5,010,000	$5,010,000	0%	0%	9%	Pro-rata based on construction subtotal		
Mashpee	$0	$1,686,000	$0	$1,686,000	0%	63%	0%	Pro-rata based on construction subtotal		
Sandwich	$0	$0	$2,146,000	$2,146,000	0%	0%	4%	Pro-rata based on construction subtotal		
Barnstable	$0	$0	$41,036,000	$41,036,000	0%	0%	74%			
Check										
TOTAL	$0	$8,900,000	$184,700,000	$193,600,000						
JBCC	$0	$1,490,000	$11,870,000	$13,360,000						
Bourne	$0	$1,800,000	$12,570,000	$14,370,000						
Falmouth	$0	$0	$16,660,000	$16,660,000						
Mashpee	$0	$5,610,000	$0	$5,610,000						
Sandwich	$0	$0	$7,140,000	$7,140,000						
Barnstable	$0	$0	$136,470,000	$136,470,000						
Check	$0	$8,900,000	$184,710,000	$193,610,000						
ANNUAL O&M-SEW/SEPT	$0	$739,500	$1,560,000		100%	100%	100%	140,000	447,000	1,347,000
JBCC	$0.00	$0.24	$0.17		100%	33%	11%	140,000	147,000	147,000
Bourne	$0.00	$0.17	$0.00		0%	22%	0%	0	100,000	
Falmouth	$0.00	$0.00	$0.00		0%	0%	0%	0	0	
Mashpee	$0.00	$0.33	$0.00		0%	45%	0%	0	200,000	
Sandwich	$0.00	$0.00	$0.00		0%	0%	0%	0	0	
Barnstable	$0.00	$0.00	$1.39		0%	0%	89%	0	0	1,200,000
Check	$0.00	$0.74	$1.56							
ANNUAL O&M-EFF	$510,000	$739,500	$1,560,000		100%	100%	100%	140,000	447,000	1,347,000
JBCC	$0.51	$0.24	$0.17		100%	33%	11%	140,000	147,000	147,000
Bourne	$0.00	$0.17	$0.00		0%	22%	0%	0	100,000	
Falmouth	$0.00	$0.00	$0.00		0%	0%	0%	0	0	
Mashpee	$0.00	$0.33	$0.00		0%	45%	0%	0	200,000	
Sandwich	$0.00	$0.00	$0.00		0%	0%	0%	0	0	
Barnstable	$0.00	$0.00	$1.39		0%	0%	89%	0	0	1,200,000
Check	$0.51	$0.74	$1.56							
ANNUAL O&M-TOTAL	$510,000	$1,479,000	$3,120,000		100%	100%	100%	140,000	447,000	1,347,000
JBCC	$0.51	$0.49	$0.34		100%	33%	11%	140,000	147,000	147,000
Bourne	$0.00	$0.33	$0.00		0%	22%	0%	0	100,000	
Falmouth	$0.00	$0.00	$0.00		0%	0%	0%	0	0	

STEP 3A

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

File Name: CostAnalysis-20171127-BARN-20190327

ENR CCI 11228 (April 2019)

COST ALLOCATION OF "CANDIDATE PLAN" BY PHASE

USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Mashpee	$0.00	$0.66	$0.00		0%	45%	0%	0	200,000	
Sandwich	$0.00	$0.00	$0.00		0%	0%	0%	0	0	
Barnstable	$0.00	$0.00	$2.78		0%	0%	89%	0	0	1,200,000
Check	$0.51	$1.48	$3.12							

DEBT SERVICE	CRF >>	16.35		
JBCC	$0.00	$0.09	$0.73	$0.82
Bourne	$0.00	$0.11	$0.77	$0.88
Falmouth	$0.00	$0.00	$1.02	$1.02
Mashpee	$0.00	$0.34	$0.00	$0.34
Sandwich	$0.00	$0.00	$0.44	$0.44
Barnstable	$0.00	$0.00	$8.35	$8.35
Check	$0.00	$0.54	$11.30	$11.84

EQUIVALENT ANNUAL COST			
JBCC	$0.51	$0.58	$1.07
Bourne	$0.00	$0.44	$0.77
Falmouth	$0.00	$0.00	$1.02
Mashpee	$0.00	$1.00	$0.00
Sandwich	$0.00	$0.00	$0.44
Barnstable	$0.00	$0.00	$11.13
Check	$0.51	$2.02	$14.42

CAPITAL COST PER KGAL (DISPOSAL CAPACITY)					DISPOSAL CAPACITY		
JBCC	$0	$28	$221	$249	140,000	147,000	147,000
Bourne		$49	#DIV/0!	#DIV/0!	0	100,000	
Falmouth		$0	#DIV/0!	#DIV/0!	0	0	
Mashpee		$77	#DIV/0!	#DIV/0!	0	200,000	
Sandwich		$0	#DIV/0!	#DIV/0!	0	0	
Barnstable		$0	$312	$312		0	1,200,000
TOTAL		$55	$376	$394		447,000	1,347,000

STEP 3B

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ENGINEERING ASSESSMENT
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019 ENR CCI (10/2017) 10800

Scenario 1
Scenario 2
Scenario 3

COSTS FOR TREATMENT, TRANSPORT-TO-DISPOSAL AND DISPOSAL ALTERNATIVES **Projected to April 2019 dollars**

LONG-TERM

			1	2	3	4	5	6
Items			**RIB**	**RIB/WICK**	**RIB/DWI**	**RIB/OUTFALL**	**DWI**	**OUTFALL**
CAPITAL COSTS								
	Unit Costs							
	Cost, ENR/SBR, Disinfection	1.30	$23.08	$23.08	$23.08	$24.62	$23.08	$24.62
	Cost, ENR/MBR, Disinfection	10%			$2.31		$2.31	
	Cost, Sand Filtration	1.30		$1.46				
	Cost, RO/Reject/Storage	1.30			$4.50		$4.50	
	Cost, GAC/Reject/Storage	1.30						
	Effluent PS, at 200'TDH	1.30	$1.73	$1.73	$1.15	$1.73	$1.15	$1.73
	Flow (gpd, annual average basis)							
	ENR/SBR/UV		2,400,000	2,400,000	2,400,000	2,400,000	2,400,000	2,400,000
	ENR/MBR-Adder				580,000		680,000	
	Sand Filtration	5%		2,520,000				
	RO/AO/Storage				4,470,000		5,220,000	
	GAC/Reject/Storage				4,470,000		5,220,000	
	Effluent PS		2,400,000	2,400,000	3,900,000	2,400,000	4,550,000	2,400,000
	Cost - Treatment-Baseline							
	Existing WWTF Upgrades		$2,570,000	$2,570,000	$2,570,000	$2,570,000	$2,570,000	$2,570,000
	ENR Baseline		$55,380,000	$55,380,000	$55,380,000	$59,080,000	$55,380,000	$59,080,000
	Subtotal - Treatment		**$58,000,000**	**$58,000,000**	**$58,000,000**	**$61,700,000**	**$58,000,000**	**$61,700,000**
	Cost - Treatment-Supplemental							
	ENR/MBR Adder		$0	$0	$14,723,077	$0	$17,261,538	$0
	Sand Filtration		$0	$3,683,077	$0	$0	$0	$0
	RO/AO/Storage		$0	$0	$20,115,000	$0	$23,490,000	$0
	GAC/Reject/Storage		$0	$0	$0	$0	$0	$0
	Subtotal - Treatment		**$0**	**$3,700,000**	**$34,800,000**	**$0**	**$40,800,000**	**$0**
	Cost - Transport to Disposal							
	Existing Forcemain Upgrades		$300,000	$300,000	$300,000	$300,000	$300,000	$300,000
	New Forcemains		$25,420,000	$25,420,000	$5,460,000	$26,610,000	$5,460,000	$26,610,000
	Length	mi	10.7	10.7	2.3	11.2	2.3	11.2
	Number		2	2	2	2	2	2
	Length	ft	112,992	112,992	24,288	118,272	24,288	118,272
	Cost per Foot		225	225	225	225	225	225
	Subtotal - Transport to Disposal		**$25,720,000**	**$25,720,000**	**$5,760,000**	**$26,910,000**	**$5,760,000**	**$26,910,000**

STEP 3B

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ENGINEERING ASSESSMENT
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019 ENR CCI (10/2017) 10800

Scenario 1
Scenario 2
Scenario 3

COSTS FOR TREATMENT, TRANSPORT-TO-DISPOSAL AND DISPOSAL ALTERNATIVES **Projected to April 2019 dollars**

LONG-TERM

			1	2	3	4	5	6
Items			**RIB**	**RIB/WICK**	**RIB/DWI**	**RIB/OUTFALL**	**DWI**	**OUTFALL**
	Cost - Disposal							
	Existing RIB Upgrades		$400,000	$400,000	$400,000	$400,000	$400,000	$400,000
	Effluent PS		$4,150,000	$4,150,000	$4,500,000	$4,150,000	$5,250,000	$4,150,000
	New RIBs		$8,600,000		$2,640,000			
	New Wicks			$8,300,000				
	New DWI				$9,100,000		$12,700,000	
	New Outfall					$8,800,000		$10,290,000
	Subtotal - Disposal		**$13,200,000**	**$12,900,000**	**$16,600,000**	**$13,400,000**	**$18,400,000**	**$14,800,000**
	TOTAL		**$96,920,000**	**$100,320,000**	**$115,160,000**	**$102,010,000**	**$122,960,000**	**$103,410,000**
	Lowest plus +% higher for other Options		$96,920,000	4%	19%	5%	27%	7%
ANNUAL O&M								
	Basis flow		2,400,000	2,400,000	3,900,000	2,400,000	4,550,000	2,400,000
	Baseline, April 2014 (ENR CCI 9750)	1.20	$1.25	$1.25	$1.04	$1.25	$1.04	$1.25
	Baseline, Current (ENR CCI 10800)		$1.38	$1.38	$1.15	$1.38	$1.15	$1.38
	Baseline Costs		$3,320,000	$3,320,000	$4,500,000	$3,320,000	$5,250,000	$3,320,000
	Adder for Existing Collection O&M		$800,000	$800,000	$800,000	$800,000	$800,000	$800,000
	Adder for Filtration	5%		$166,000				
	Adder for SW Discharge	10%				$332,000.00		$332,000.00
	Adder for ENR/MBR	10%			$450,000		$525,000	
	Adder for RO/Storage	25%			$1,125,000		$1,312,500	
	Adder for GAC/Storage	0%			$0		$0	
	Adder for Effluent Pumping	5%	$166,000	$166,000	$225,000	$166,000	$262,500	$166,000
	Annual O&M		$4,290,000	$4,450,000	$7,100,000	$4,620,000	$8,150,000	$4,620,000
	Lowest plus +% higher for other Options		$4,290,000	4%	66%	8%	90%	8%
	O&M Allocated to Sewage/Septage, %		50%	50%	50%	50%	50%	50%
	O&M Allocated to Effluent, %		50%	50%	50%	50%	50%	50%
	O&M Allocated to Sewage/Septage, $$		$2,150,000	$2,230,000	$3,550,000	$2,310,000	$4,080,000	$2,310,000
	O&M Allocated to Effluent, $$		$2,150,000	$2,230,000	$3,550,000	$2,310,000	$4,080,000	$2,310,000

STEP 3B

TABLE 2-5: SUMMARY OF PLANNING-LEVEL COST ESTIMATES AND COST ALLOCATION (BASED ON LONG-TERM, CONSTRUCTED AS A SINGLE PROJECT) (ENR CCI 11228, April 2019)

Option	1	2	3	4	5	6
Description of Effluent Disposal	**RIB**	**RIB & Wicks**	**RIB & DWI**	**RIB & Outfall**	**DWI**	**Outfall**
Capital Cost						
Construction - Conveyance	$56,730,000	$56,730,000	$56,730,000	$56,730,000	$56,730,000	$56,730,000
Construction - Treatment	$58,000,000	$61,700,000	$92,800,000	$61,700,000	$98,800,000	$61,700,000
Construction - Transport to Disposal	$25,720,000	$25,720,000	$5,760,000	$26,910,000	$5,760,000	$26,910,000
Construction - Disposal	$13,200,000	$12,900,000	$16,600,000	$13,400,000	$18,400,000	$14,800,000
Contingency, Technical, Legal/Admin/Finance	$66,070,000	$67,530,000	$73,910,000	$68,260,000	$77,270,000	$68,860,000
Total Capital Cost	**$219,720,000**	**$224,580,000**	**$245,800,000**	**$227,000,000**	**$256,960,000**	**$229,000,000**
Ratio to Lowest - Total Capital Cost	1.00	1.02	1.12	1.03	1.17	1.04
Ratio to Lowest - Capital Cost, excl. Conveyance	1.00	1.04	1.19	1.05	1.27	1.07
Annual Operation & Maintenance Cost	**$4,290,000**	**$4,450,000**	**$7,100,000**	**$4,620,000**	**$8,150,000**	**$4,620,000**
Ratio to Lowest - Annual O&M	1.00	1.04	1.66	1.08	1.90	1.08
Total Annual Debt Service on Capital Cost	$13,440,000	$13,730,000	$15,030,000	$13,880,000	$15,710,000	$14,000,000
Total Equivalent Annual Cost (Note 3)	**$17,730,000**	**$18,180,000**	**$22,130,000**	**$18,500,000**	**$23,860,000**	**$18,620,000**
Ratio to Lowest - Equivalent Annual Cost	1.00	1.03	1.25	1.04	1.35	1.05
EAC per thousand gallons of disposal capacity	$14.50	$14.87	$18.10	$15.13	$19.51	$15.23

Notes:

1) Costs are presented in current dollars based on Engineering News Record Construction Cost Index 11228 (April 2019).
2) Refer to Appendix A for supporting information.
3) Equivalent Annual Cost equals Annual O&M Cost plus the Annual Debt Service on Capital Cost.
4) Allocation for Conveyance is 100% to each town. Allocation for treatment/transport/disposal is pro-rated based on flow capacity requested.
5) Blue indicates lowest cost option, green indicates second lowest cost option and orange indicates third lowest cost option.

STEP 3B

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

File Name: CostAnalysis-20171127-BARN-20190327

ENR CCI 11228 (April 2019)

COST ALLOCATION OF "CANDIDATE PLAN" BY PHASE

USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Conveyance	$0	$3,600,000	$53,130,000	$56,730,000				140,000	347,000	2,389,000
JBCC	$0	$0	$0	$0				140,000	147,000	147,000
Bourne	$0	$1,100,000	$8,790,000	$9,890,000				0	0	467,000
Falmouth	$0	$0	$11,650,000	$11,650,000				0	0	22,000
Mashpee	$0	$2,500,000	$0	$2,500,000				0	200,000	203,000
Sandwich	$0	$0	$4,990,000	$4,990,000				0	0	350,000
Barnstable	$0	$0	$27,700,000	$27,700,000				0	0	1,200,000
Treatment-BASELINE	$0	$1,920,000	$59,780,000	$61,700,000	100%	100%	100%	140,000	347,000	2,389,000
JBCC	$0	$813,000	$3,678,000	$4,491,000	100%	42%	6%	140,000	147,000	147,000
Bourne	$0	$0	$11,686,000	$11,686,000	0%	0%	20%	0	0	467,000
Falmouth	$0	$0	$551,000	$551,000	0%	0%	1%	0	0	22,000
Mashpee	$0	$1,107,000	$5,080,000	$6,187,000	0%	58%	8%	0	200,000	203,000
Sandwich	$0	$0	$8,758,000	$8,758,000	0%	0%	15%	0	0	350,000
Barnstable	$0	$0	$30,028,000	$30,028,000	0%	0%	50%	0	0	1,200,000
Treatment-SUPPLEMENT	$0	$0	$0	$0	100%	100%	100%	140,000	347,000	2,389,000
JBCC	$0	$0	$0	$0	100%	42%	6%	140,000	147,000	147,000
Bourne	$0	$0	$0	$0	0%	0%	20%	0	0	467,000
Falmouth	$0	$0	$0	$0	0%	0%	1%	0	0	22,000
Mashpee	$0	$0	$0	$0	0%	58%	8%	0	200,000	203,000
Sandwich	$0	$0	$0	$0	0%	0%	15%	0	0	350,000
Barnstable	$0	$0	$0	$0	0%	0%	50%	0	0	1,200,000
Transport to Disposal	$0	$300,000	$26,610,000	$26,910,000	100%	100%	100%	140,000	447,000	4,530,000
JBCC	$0	$99,000	$864,000	$963,000	100%	33%	3%	140,000	147,000	147,000
Bourne	$0	$67,000	$6,567,000	$6,634,000	0%	22%	25%	0	100,000	1,118,000
Falmouth	$0	$0	$8,882,000	$8,882,000	0%	0%	33%	0	0	1,512,000
Mashpee	$0	$134,000	$1,192,000	$1,326,000	0%	45%	4%	0	200,000	203,000
Sandwich	$0	$0	$2,056,000	$2,056,000	0%	0%	8%	0	0	350,000
Barnstable	$0	$0	$7,049,000	$7,049,000	0%	0%	26%	0	0	1,200,000
Disposal	$0	$400,000	$14,400,000	$14,800,000	100%	100%	100%	140,000	447,000	4,530,000
JBCC	$0	$132,000	$467,000	$599,000	100%	33%	3%	140,000	147,000	147,000
Bourne	$0	$89,000	$3,554,000	$3,643,000	0%	22%	25%	0	100,000	1,118,000
Falmouth	$0	$0	$4,806,000	$4,806,000	0%	0%	33%	0	0	1,512,000
Mashpee	$0	$179,000	$645,000	$824,000	0%	45%	4%	0	200,000	203,000
Sandwich	$0	$0	$1,113,000	$1,113,000	0%	0%	8%	0	0	350,000
Barnstable	$0	$0	$3,815,000	$3,815,000	0%	0%	26%	0	0	1,200,000

STEP 3B

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

File Name: CostAnalysis-20171127-BARN-20190327

ENR CCI 11228 (April 2019)

COST ALLOCATION OF "CANDIDATE PLAN" BY PHASE

USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Conting/Tech/Legal/etc	$0	$2,675,000	$66,186,000	$68,860,000	100%	100%	100%	Pro-rata based on construction subtotal		
JBCC	$0	$449,000	$2,154,000	$2,603,000	100%	17%	3%	Pro-rata based on construction subtotal		
Bourne	$0	$540,000	$13,157,000	$13,697,000	0%	20%	20%	Pro-rata based on construction subtotal		
Falmouth	$0	$0	$11,132,000	$11,132,000	0%	0%	17%	Pro-rata based on construction subtotal		
Mashpee	$0	$1,686,000	$2,974,000	$4,660,000	0%	63%	4%	Pro-rata based on construction subtotal		
Sandwich	$0	$0	$7,274,000	$7,274,000	0%	0%	11%	Pro-rata based on construction subtotal		
Barnstable	$0	$0	$29,495,000	$29,495,000	0%	0%	45%			
Check										
TOTAL	$0	$8,900,000	$220,110,000	$229,010,000						
JBCC	$0	$1,490,000	$7,160,000	$8,650,000						
Bourne	$0	$1,800,000	$43,750,000	$45,550,000						
Falmouth	$0	$0	$37,020,000	$37,020,000						
Mashpee	$0	$5,610,000	$9,890,000	$15,500,000						
Sandwich	$0	$0	$24,190,000	$24,190,000						
Barnstable	$0	$0	$98,090,000	$98,090,000						
Check	$0	$8,900,000	$220,100,000	$229,000,000						
ANNUAL O&M-SEW/SEPT	$0	$739,500	$2,310,000		100%	100%	100%	140,000	447,000	2,389,000
JBCC	$0.00	$0.24	$0.14		100%	33%	6%	140,000	147,000	147,000
Bourne	$0.00	$0.17	$0.45		0%	22%	20%	0	100,000	467,000
Falmouth	$0.00	$0.00	$0.02		0%	0%	1%	0	0	22,000
Mashpee	$0.00	$0.33	$0.20		0%	45%	8%	0	200,000	203,000
Sandwich	$0.00	$0.00	$0.34		0%	0%	15%	0	0	350,000
Barnstable	$0.00	$0.00	$1.16		0%	0%	50%	0	0	1,200,000
Check	$0.00	$0.74	$2.31							
ANNUAL O&M-EFF	$510,000	$739,500	$2,310,000		100%	100%	100%	140,000	447,000	4,530,000
JBCC	$0.51	$0.24	$0.07		100%	33%	3%	140,000	147,000	147,000
Bourne	$0.00	$0.17	$0.57		0%	22%	25%	0	100,000	1,118,000
Falmouth	$0.00	$0.00	$0.77		0%	0%	33%	0	0	1,512,000
Mashpee	$0.00	$0.33	$0.10		0%	45%	4%	0	200,000	203,000
Sandwich	$0.00	$0.00	$0.18		0%	0%	8%	0	0	350,000
Barnstable	$0.00	$0.00	$0.61		0%	0%	26%	0	0	1,200,000
Check	$0.51	$0.74	$2.31							
ANNUAL O&M-TOTAL	$510,000	$1,479,000	$4,620,000		100%	100%	100%	140,000	447,000	4,530,000
JBCC	$0.51	$0.49	$0.22		100%	33%	3%	140,000	147,000	147,000
Bourne	$0.00	$0.33	$1.02		0%	22%	25%	0	100,000	1,118,000
Falmouth	$0.00	$0.00	$0.79		0%	0%	33%	0	0	1,512,000

STEP 3B

JBCC SHARED WASTEWATER MANAGEMENT STUDY
ALTERNATIVES ANALYSIS
Wright-Pierce, 27 Nov 2017, REV 27 Mar 2019

File Name: CostAnalysis-20171127-BARN-20190327

ENR CCI 11228 (April 2019)

COST ALLOCATION OF "CANDIDATE PLAN" BY PHASE

USE COSTS FOR OPTION 6 (OUTFALL), AS THE MOST CONSERVATIVE OF "FOUR ESSENTIALLY EQUIVALENT COST OPTIONS" (OPTIONS 1/2/4/6)

	COSTS ($MILLION)			CHECK	ALLOCATION, % OF FLOW			ALLOCATION OF FLOW		
	Existing	Short-Term	Long-Term	TOTAL	Ex	ST	LT	Ex	ST	LT
Mashpee	$0.00	$0.66	$0.30		0%	45%	4%	0	200,000	203,000
Sandwich	$0.00	$0.00	$0.52		0%	0%	8%	0	0	350,000
Barnstable	$0.00	$0.00	$1.77		0%	0%	26%	0	0	1,200,000
Check	$0.51	$1.48	$4.62							

DEBT SERVICE	CRF >>	16.35		
JBCC	$0.00	$0.09	$0.44	$0.53
Bourne	$0.00	$0.11	$2.68	$2.79
Falmouth	$0.00	$0.00	$2.26	$2.26
Mashpee	$0.00	$0.34	$0.60	$0.95
Sandwich	$0.00	$0.00	$1.48	$1.48
Barnstable	$0.00	$0.00	$6.00	$6.00
Check	$0.00	$0.54	$13.46	$14.00

EQUIVALENT ANNUAL COST			
JBCC	$0.51	$0.58	$0.65
Bourne	$0.00	$0.44	$3.70
Falmouth	$0.00	$0.00	$3.06
Mashpee	$0.00	$1.00	$0.90
Sandwich	$0.00	$0.00	$2.00
Barnstable	$0.00	$0.00	$7.77
Check	$0.51	$2.02	$18.08

CAPITAL COST PER KGAL (DISPOSAL CAPACITY)					DISPOSAL CAPACITY		
JBCC	$0	$28	$133	$161	140,000	147,000	147,000
Bourne		$49	$107	$112	0	100,000	1,118,000
Falmouth		$0	$67	$67	0	0	1,512,000
Mashpee		$77	$133	$209	0	200,000	203,000
Sandwich		$0	$189	$189	0	0	350,000
Barnstable		$0	$224	$224		0	1,200,000
TOTAL		$55	$133	$138		447,000	4,530,000

Appendix OO

Fresh Pond Restoration and Management
Benthic Nutrient Flux of Mill Pond

University of Massachusetts Dartmouth
The School for Marine Science and Technology

TECHNICAL MEMORANDUM

Fresh Pond Restoration and Management

Benthic Nutrient Flux of Mill Pond, Town of Barnstable

Quantifying the Rates of Nutrient Release/Uptake from Sediments in Mill Pond and Comparison to Historic Rates

Dr. Brian L. Howes,
Dr. David Schlezinger
Dr. Roland Samimy

Coastal Systems Program
School of Marine Science and Technology -UMD

FINAL October 25, 2017

Overview: The Three Bays Massachusetts Estuaries Project (MEP) Nitrogen Threshold Report indicated that the Marstons Mills River is one of the main collection points for freshwater and nitrogen (N) discharging to the headwaters of the Three Bays estuary.

The Three Bays estuary is presently impaired by nitrogen enrichment from nitrogen sources within its watershed. Restoration of impaired estuarine habitats will require a reduction in the nitrogen load from the watershed to meet the Mass DEP/USEPA Total Maximum Daily Load (TMDL) restoration threshold for the estuary. The example scenario included in the Three Bays MEP report indicated that to meet the N threshold for restoration, a 49% reduction in the load entering from the Marstons Mills River must be achieved. In surface water systems like the Marstons Mill River, a terminal fresh water pond generally removes about 50% of the entering nitrogen load prior to discharge to the down-gradient estuary.

MEP field measurements showed that Mill Pond is only removing about 22%-27% of the nitrogen passing through it. Analysis of Mill Pond itself indicates that this man-made pond has been filled with river-transported sediments over the past four centuries, and that re-establishment of the historic basin

depths is needed to restore pond function and a more typical level of nitrogen retention.

At present the retention time of water in Mill Pond is more than an order of magnitude lower than historically and lower than most ponds in the region. The very low retention time lowers the pond's nitrogen removal rate. Deepening the pond will enhance nitrogen removal likely from 25% to 35% up to 50% depending on the new basin depth and shape. This potential for a significant increase in nitrogen removal can be used by the Town of Barnstable to offset the need for wastewater infrastructure (sewers,) provided that the increase in nitrogen retention can be quantified and scientifically justified to Mass DEP.

The potential savings in restoration costs to the Town of deepening the pond is conservatively estimated to be in excess of $10 million. Critical to understanding the potential for enhanced natural attenuation in Mill Pond is quantifying the role sediments play in the uptake or release of nutrients to and from the water column, as this is where nitrogen removal occurs.

The main objective of the present biogeochemical investigation of Mill Pond sediments was to: a) conduct sediment sampling to quantify nitrogen recycling in the pond for comparison to earlier SMAST data, b) assess changes in sediment nitrogen dynamics, c) strengthen the baseline assessment prior to any deepening of the pond and d) provide a systems context for evaluating nitrogen removal by this fresh basin. The 2016 benthic nutrient regeneration effort was conducted using the same protocols and procedures used in the previous 2007 study, and in the MEP watershed loading and stream analysis.

Using the same approaches strengthens the reliability of comparisons and assessment of the degree to which nutrient flux rates may have changed over the past eight years. Reliable nutrient flux rates will then be available in the future should it be decided that a complete nutrient budget for the pond is needed to fully assess potential enhancement of nitrogen attenuation. In addition to the nutrient flux analysis, CSP/SMAST scientists also decided to bring together disparate datasets on nitrogen inputs and pond nitrogen flow-through to provide better context for restoration planning.

Measurements of Benthic Nutrient Regeneration, Sediment Oxygen Uptake and Denitrification

In order to determine the contribution of sediment regeneration to nutrient levels within Mill Pond and the potential nitrogen attenuation of watershed inputs to the headwaters of the Three Bays estuary, sediment samples were collected and incubated under *in situ* conditions during the period of maximum regeneration rates (summer interval, July-September). Time series measurements of total dissolved nitrogen, nitrate+nitrite, ammonium and ortho-phosphate, were made on each incubated core sample. The rate of oxygen uptake was also determined in order to evaluate sensitivity to oxygen depletion and general rates of organic matter decomposition. In 2008, assays were performed on two cores each for two sites (Cores 1 and 2; Cores 3 and 4, Figure 1). In 2016, cores were taken from the same two sites in duplicate, as in 2008, and a single core was taken from each of four additional sites to yield a more comprehensive overall pond-wide regeneration rate supportive of biogeochemical modeling.

In 2008, scientists from the Coastal Systems Program collected sediment samples from Mill Pond as part of the long-term water quality partnership with Three Bays Preservation, now known as Barnstable Clean Water Coalition. The focus of the effort was to determine sediment nutrient regeneration rates to assist potential restoration planning. While water samples associated with the flux study were collected and analyzed, the analytical data was not processed and synthesized into useful information on sediment nutrient regeneration rates.

Those data are presented herein along with data from the current project for comparison. Comparison of these two datasets will clarify the degree to which sediment biogeochemical conditions have changed or stayed the same in the pond and the potential effects on pond nitrogen attenuation. All assays were performed according to the same MEP protocols, with the exception of denitrification measurements which were not undertaken as part of the MEP.

2016 denitrification rates were determined by the state-of-the-art method of measuring excess N_2. N_2 excess was measured using membrane-inlet mass spectrometry (MIMS). N_2 produced by denitrification is precisely detected by analysis of its ratio with the inert gas Argon. Water samples were collected and stored to prevent gas exchange or bubble formation. In the laboratory, sample water was pumped at milliliter per minute rates through a gas permeable membrane to extract gas into the mass spectrometer inlet. The inlet is fitted with cryogenic traps to remove water vapor and CO_2 gas. Sample gas was analyzed by the mass spectrometer for molecular masses 28 and 40 for determining the N_2 to Ar ratio. Calibration was made by comparison with a reference gas of known composition. A quadrupole mass spectrometer (*e.g.*, Pfeiffer 422) was used for its sensitivity and speed of analysis.

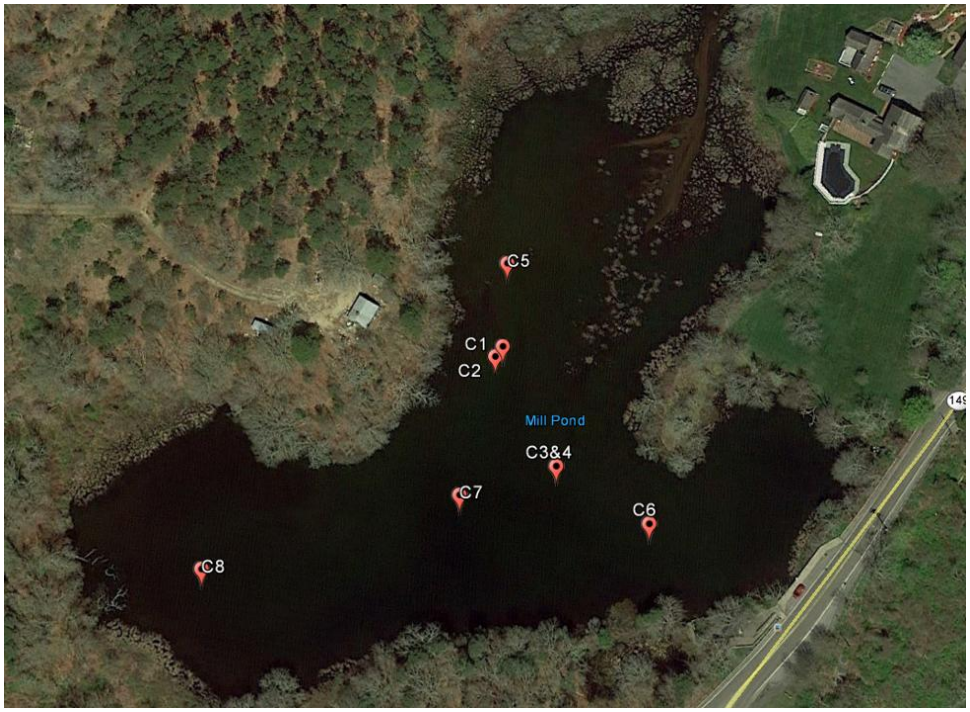

Figure 1. Map of Mill Pond showing locations of cores collected in 2008 (1,2,3,4) and 2016 (5,6,7,8) and the four additional sites sampled in 2016.

Results and Discussion

Input/Output Analysis: Building on the MEP analysis, it is possible to model the degree of nitrogen removal expected within Mill Pond. The MEP determined that the loading from the watershed based on land-use modeling was 11,657 kg/yr of nitrogen entering the watershed. Based upon modeled attenuation during transport of this input load, it was estimated that 6,984 kg/yr would reach Mill Pond via the Marstons Mills River. Measured flow and N load at the River discharge point to Mill Pond yielded

slightly more nitrogen removal in transport to the gauge than the model. However, both estimates show the importance of nitrogen removal within the upper watershed by natural wetlands, ponds and bogs consistent with the goal of increasing nitrogen removal in altered freshwater systems. At Mill Pond, the attenuation rate based on measured nitrogen load from the Marstons Mills River (measured over a hydrologic year) and from groundwater inflows directly to the pond from its watershed, yielded an estimate of nitrogen removal of 27%, much less than the average for freshwater ponds of >50%. The MEP Mill Pond attenuation rate is based upon measured Marstons Mill River nitrogen input load (4,690 kg/yr) and the direct watershed loading through groundwater (2,880 kg/yr) to Mill Pond which is unattenuated during transport. The measured outflow from Mill Pond (5,491 kg/yr) was used to determine pond-only attenuation.

Table 1. Modeled and measured nitrogen (N) loads that contribute to loads at the Marstons Mills River gauge above Mill Pond, groundwater loads to the pond from its watershed and nitrogen discharge from Mill Pond to the head of the Three Bays Estuary.

Modeled and Measured N Loads (MEP)	UnAtten N Load kg/yr	Atten %	Atten N Load kg/yr
All upper watershed flow to MMR gauge Modeled	11,657	40.1%	6,984
All upper watershed flow to MMR gauge **Measured**	--	59.8%	4,690
GW inflow to Mill Pond Modeled	2,880		2,880
GW to Pond + Stream Input **Modeled- Measured**	--		7,570
Stream outfow Mill Pond Modeled	--		6,369
Stream Output **Measured**	--	27%	5,491

SMAST Scientists working with Three Bays Preservation (now Barnstable Clean Water Coalition) staff conducted subsequent surface water flow studies to assess nitrogen removal by Mill Pond throughout the summer (critical management period.) These studies were conducted June through August 2007 and 2016, with nine evenly spaced sampling events during each summer. The concept was to evaluate seasonal attenuation of nitrogen during the period when the Three Bays estuary is most sensitive to nitrogen inputs. During these studies, flow and nitrogen load was determined at the Marstons Mills River discharge to Mill Pond (gauge site,) and at each of the two outflows from Mill Pond to the lower Marstons Mills River, which then discharges to the headwaters of the Three Bays estuary between Prince Cove and Warrens Cove. As measurements were only performed in summer, an annual attenuation cannot be determined from these measurements.

Summer 2016 was a low rainfall period with reduced recharge as seen in the lower river inflows and outflows. However, in both 2007 and 2016 the inflows to the pond were equal to the outflows within measurement error (4%). It appears that in both years, nitrate is significantly transformed to organic forms and likely denitrified within the anoxic surficial sediments, 25% and 35% nitrate-N attenuation in 2007 and 2016, respectively. However, total nitrogen removal in both years was low, only 2.1 kg/d loss within the pond, which translated to 7%-11% TN reduction (total nitrogen removal). The lower N retention is likely the result of a seasonal shift in nitrogen cycling as the sediments tend to release proportionately more nitrogen in warmer months, and retain remineralized nitrogen in the spring and fall. Given this likely seasonality, the lower values fit well with the annual attenuation derived from year-round measurements above (~25%).

Table 2. Input/Output analysis 2007 and 2016. Inputs from River and groundwater, outputsvia stream outflows			
2007 Summer			
	Flow (m3/d)	**NOx (kg/d)**	**TN (kg/d)**
River Inflow	**23,856**	**13.7**	**20.7**
GW Input	**3,933**	**7.9**	**7.9**
Total Input	**27,789**	**21.6**	**28.6**
Total Output	**28,924**	**16.2**	**26.5**
% N Removal	**--**	**25%**	**7%**
Outflow-Inflow	**1,135**	**-5.3**	**-2.1**
2016 Summer			
	Flow m3/d	**Nox kg/d**	**TN kg/d**
River Inflow	**16,406**	**6.6**	**10.2**
GW Input	**3,933**	**7.9**	**7.9**
Total Input	**20,339**	**14.5**	**18.1**
Total Output	**19,858**	**9.5**	**16.0**
% N Removal	**--**	**35%**	**11%**
Outflow-Inflow	**(481)**	**-5.1**	**-2.1**

Both nitrogen removal studies indicate rates of TN removal well below those typical of Cape Cod freshwater ponds, and indicate that restoration of Mill Pond will likely result in higher nitrogen capture. The low N removal rate is consistent with the residence time of water within Mill Pond. A simple analysis of residence time based upon the pond volume and average freshwater inflows yields a residence time of only about one day, compared to weeks to months for other similar acreage local fresh ponds.

Sediment Nitrogen Exchange Analysis: The sediment-water column nitrogen exchange rates measured in 2007 and 2016 are summarized in Table 3 and 4, respectively. The largest difference observed between the two years was in the rate of dissolved oxygen uptake. On cores collected in 2007 versus 2016 (cores 1, 2 and cores 3, 4) sediment oxygen demand (SOD) decreased 60%. Rates measured at the other four locations in 2016 cannot be directly compared as no prior data exists, however, the average rate is about 40% less than rates measured at the locations in 2007. Only a fraction of this difference can be explained by the difference in temperature between the years.

There is a simple explanation for this drop in oxygen demand. In the absence of any pond engineering or remediation work in the intervening years, the further shallowing of Mill Pond would result in less organic deposition to the sediments. Moreover, the lower flow conditions in the Marstons Mills River in 2016 would also result in less particulate organic matter inputs to the pond sediments. This lower particulate organic matter loading from the River was also seen in the 27% lower particulate carbon input in the summer stream analysis of 2007 and 2016, 14.8 kg/d and 11.7 kg/d, respectively. Adding to this is the secondary effect of lower organic carbon inputs from the River, and decreased in-pond production, resulting in a smaller pool of reduced compounds present within the sediment, which lowers oxygen demand. In other words, SOD rates in 2016 may have had a smaller oxygen uptake to support organic matter remineralization, and a smaller chemical oxygen demand combining for a lower measured SOD. The decreased deposition hypothesized for the observed change in SOD is supported by the observed parallel reduction in measured ammonium flux. Nitrate uptake, however, was nearly identical between

the two years as also seen in the inflow/outflow study (Table 2).

Denitrification rates were not made prior to those in 2016. Denitrification was relatively low with an average rate of 22 mg $N_2/m^2/d$ (0.78 mMol $N_2/m^2/d$). This value represents only 9% of the nitrogen cycling within the sediments and about 0.52 kg N/d.[1] This represents about 25% of the TN removal in the summer measurements; the remainder is almost certainly uptake by benthic algae, which should support coupled nitrification-denitrification after decay.[2] Enhancement of denitrification within Mill Pond should be possible in light of higher measured dentrification rates measured in other Cape Cod Ponds, the high nitrate concentrations remaining after passage through the pond. Enhancing nitrogen removal will depend on increasing the residence time for nitrate to be removed and the depth for settling of organic carbon and nitrogen particles.

Dredging the pond to increase the residence time of watershed inputs within the pond should result in greater attenuation of N loading to the Three Bays headwaters. However, this action alone may not be sufficient to meet the TMDL target load. Given the shallow depth of the water column, careful design consideration should be given to ensuring that restoration does not result in enhanced sediment resuspension and particulate N transport downgradient.

Conclusions

Synthesis of 2007 and 2016 nitrogen loading studies of Mill Pond supports some clear conclusions:

1. Mill Pond has been significantly altered by sediment inputs gradually filling it over the past four centuries, resulting in a very short water residence time (~1 day), which almost certainly results in a major reduction in the retention of nitrogen entering from the Marstons Mills River and the Pond's groundwater contributing area.

2. Removal of watershed derived total nitrogen by Mill Pond appears to be ~25% annually, but only 7%-11% in the June – August period, with mass removal being similar in the 2007 and 2016 summer stream studies (2.1 kg/d).

3. Nitrate entering Mill Pond is either removed (likely through denitrification) or transformed to organic nitrogen forms (25% - 35%), although most is discharged to the downgradient estuary. The high level of nitrate discharged from Mill Pond (0.5 mg/L even in summer) indicates there is strong potential for additional nitrogen removal within this basin.

4. Denitrification removes about 25% of the total nitrogen removed by Mill Pond in summer, a much lower fraction than other Cape Cod fresh ponds.

5. Enhancement of denitrification within Mill Pond should be possible in light of higher denitrification rates measured in other Cape Cod Ponds, the high nitrate remaining after passage through the pond and the low residence time.

[1] Pond area = 5.86 ac or 23,715 m2

[2] Hamersley, M.R. and B.L. Howes. 2005. Coupled nitrification-denitrification measured in situ in a *Spartina alterniflora* marsh with a $^{15}NH_4$ tracer. Marine Ecology Progress Series 299:123-135.

Table 3. Sediment flux rates measured in 2008. Incubation temperature 26 °C.

	SOD		NH4		PO4		NO3		TDN		N2	
	Rate	S.E.	Rate	S.E.	Rate	S.E.	Rate	S.E.	Rate	S.E.	Rate	S.E.
Core ID	(mMoles/m^2/d)		(mMoles/m^2/d)		(mMoles/m^2/d)		(mMoles/m^2/d)		(mMoles/m^2/d)		(mMoles/m^2/d)	
C1	-98.19	3.84	9.53	0.35	-0.09	0.02	-2.42	0.19	4.29	0.34	NA	NA
C2	-143.51	2.53	12.67	0.98	-0.11	0.02	-2.92	0.37	5.78	0.93	NA	NA
C3	-135.53	5.50	11.94	0.57	-0.09	0.01	-2.89	0.27	6.19	1.08	NA	NA
C4	-132.95	2.81	11.34	0.18	-0.09	0.01	-2.57	0.18	6.38	0.61	NA	NA

Table 4. Sediment flux rates measured in 2016. Incubation temperature 22 °C.

	SOD		NH4		PO4		NO3		TDN		N2	
	Rate	S.E.	Rate	S.E.	Rate	S.E.	Rate	S.E.	Rate	S.E.	Rate	S.E.
Core ID	(mMoles/m^2/d)		(mMoles/m^2/d)		(mMoles/m^2/d)		(mMoles/m^2/d)		(mMoles/m^2/d)		(mMoles/m^2/d)	
C1	-46.67	2.45	4.19	0.24	0.01	0.01	-2.47	0.12	0.37	0.51	1.02	0.09
C2	-51.62	2.51	6.18	0.30	0.04	0.00	-2.47	0.28	3.36	0.87	1.34	0.44
C3	-56.25	0.00	3.47	0.36	0.05	0.01	-3.02	0.26	1.46	0.13	0.49	0.21
C4	-50.04	2.11	3.96	0.36	0.00	0.01	-1.97	0.13	1.23	0.53	0.28	0.00
C5	-80.82	3.51	5.26	0.36	0.30	0.02	-3.85	0.19	2.37	0.46	0.38	0.14
C6	-83.40	1.83	6.43	0.25	0.06	0.01	-3.62	0.24	2.68	0.34	0.23	0.09
C7	-85.78	4.52	10.27	0.80	0.16	0.01	-3.94	0.40	4.52	0.43	0.37	0.05
C8	-70.74	1.66	7.84	1.07	0.07	0.01	-2.60	0.37	4.23	1.29	0.25	0.00

Appendix PP

Fertilizer Nitrogen and Phosphorous Control Ordinance (Barnstable Town Code Chapter 78)

Chapter 78

FERTILIZER NITROGEN AND PHOSPHOROUS CONTROL

GENERAL REFERENCES

Hazardous materials — See Ch. 108.

Toxic and hazardous materials — See Ch. 381.

Trees — See Ch. 221.

Wells — See Ch. 397.

Wetlands protection — See Ch. 237.

Wetlands buffer zone activity — See Ch. 704.

Herbicides — See Ch. 332.

§ 78-1. Purposes and intent.

A. Excessive nutrient enrichment of the region's groundwaters and surface waters may have significant public health ramifications, including direct detrimental effects on drinking water sources by increased concentrations of nitrates that can violate safe drinking water standards, and have negative impacts on economic, environmental and recreational resources and values in the Town and region.

B. The Town has significant glacially deposited sandy soils that are subject to rapid water infiltration, percolation, and leaching of nutrients.

C. This chapter incorporates by reference the University of Massachusetts Extension's Turf Management Best Management Practices. These practices, if followed, are deemed to protect the public health, safety and welfare and aid in achieving compliance with the total maximum daily loads (TMDL) for the Town's water resources prescribed by the Commonwealth of Massachusetts while allowing reasonable use of fertilizers for the enhancement and maintenance of turf quality.

§ 78-2. Applicability.

A. This chapter provides for a reduction of nitrogen and phosphorus entering the Town's waters and wetlands by means of an organized system of education, certification, standardization and regulation of practice. This chapter is not intended to eliminate the use of fertilizer.

B. This chapter adopts the best management practices as the normal operating procedures for turf management but not plants other than turf.

§ 78-3. Statutory authority.

This chapter is adopted as implementing regulations pursuant to and as authorized by the Fertilizer Management District of Critical Planning

Concern designation, Barnstable County Ordinance 13-07, and by Section 9 of Chapter 262 of the Acts of 2012.

§ 78-4. Definitions.

For the purposes of this chapter, the following words shall have the following meanings unless the context clearly indicates a different meaning:

AGRICULTURE/AGRICULTURAL USE — Farming in all of its branches, including the cultivation and tillage of the soil, the production, cultivation, growing, and harvesting of any agricultural, floricultural or horticultural commodities, including but not limited to cranberries.

BARNSTABLE — The Town and all of its waters.

BEST MANAGEMENT PRACTICES (BMP) — A sequence of activities designed to limit a nonpoint pollution source. For the purposes of this chapter and pursuant to § 78-5A of this chapter, "BMP" means the edition of Best Management Practices for Soil and Nutrient Management in Turf Systems, prepared by the University of Massachusetts Extension, Center for Agriculture, Turf Program in effect on September 18, 2014.

CERTIFIED FERTILIZER APPLICATOR — An applicator certified in the manner prescribed hereunder to apply fertilizer and manage turf in conformance with the BMP.

COMBINATION PRODUCTS — Sometimes known as "weed and feed," means any product that, in combination with fertilizer, contains pre- or post-emergence herbicides, insecticides, other pesticides or plant growth regulators.

COMPOST — The biologically stable humus-like material derived from composting, or the aerobic, thermophilic decomposition of organic matter, which is used as a fertility source for turf.

FERTILIZER — A substance that enriches turf with elements essential for plant growth, such as nitrogen, phosphorus, or other substances; fertilizer hereunder does not include dolomite, limestone, or lime, grass clippings, or compost/compost tea. "Fertilize, fertilizing, or fertilization" means the act of applying fertilizer to turf.

FERTILIZER APPLICATOR — Any person who applies fertilizer to turf and soils.

IMPERVIOUS SURFACE — A surface that has been compacted or covered with a layer of material so that it is highly resistant to infiltration by water, except for compacted areas on athletic fields, such as clay or baseball infields, intensely trafficked turf and the like.

LANDSCAPE PROFESSIONAL — A person, either as a sole proprietor or as part of a company, who, in exchange for money, goods, services, or other consideration, performs landscaping services. A landscape professional can include turf management staff at a private golf course operation or other private entity.

LANDSCAPING — For purposes of this chapter, establishment (including by sod, seeding, or transplanting), renovation, maintenance, management or fertilization of turf.

MUNICIPAL APPLICATOR — A public employee of a city, town, the county, or the state or federal government (or an employee of a department of and within such public entity) who fertilizes and manages turf located on property owned or controlled by a town, the county, the state or federal government (including publicly owned golf courses and athletic fields) within the scope of their official public employment responsibilities.

NONCERTIFIED FERTILIZER APPLICATOR — An applicator who is not certified in the manner prescribed hereunder to manage turf and apply fertilizer in conformance with the BMP.

NUTRIENT — Any of the following 17 elements needed for growth of a plant: the three nonmineral elements: carbon, hydrogen, and oxygen; the six macronutrients: nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur; and the eight micronutrients: boron, copper, iron, chloride, manganese, molybdenum, nickel and zinc.

NUTRIENT MANAGEMENT — The systematic control of the application and availability of nutrients to plants in order to minimize nutrient loss and to maintain the productivity of the soil.

READILY AVAILABLE NITROGEN — Any water-soluble nitrogen (WSN) that is readily available to turf after application.

SLOW-RELEASE, CONTROLLED-RELEASE, TIMED-RELEASE, or SLOWLY SOLUBLE/AVAILABLE NITROGEN — Nitrogen in a form that delays its availability for uptake and use after application, and is not rapidly available to turf.

SOIL — The uppermost layer of the earth's surface, comprised of mineral and organic matter, which can host biological communities.

SOIL TEST — A technical analysis of soil conducted by a soil testing laboratory that uses standards recommended by and in agreement with the University of Massachusetts Amherst Extension Program BMP, including a Modified Morgan soil testing procedure and extractable nutrient values.

TURF — Grass-covered soil held together by the roots of the grass, also known as "sod" or "lawn."

WATERS or WATER/BODIES — Includes, but are not limited to, streams, including intermittent streams, creeks, rivers, freshwater and tidal wetlands, ponds, lakes, marine waters, canals, lagoons, and estuaries within the Town, including without limitation all waters defined in Massachusetts General Laws, Chapter 131, Section 40, and the Town Wetland Ordinance or Regulations, with the exception of the following: coastal and inland banks, beaches, coastal dunes, dune fields, and lands subject to coastal storm flowage, inland or coastal flooding or inundation, or within 100 feet of the hundred-year storm line.

§ 78-5. Standards of performance.

A. Best management practices. The best management practices (BMP), as defined herein, shall be applied to the standards of performance.

B. Performance standards for noncertified fertilizer applicators. Fertilizer applicators who do not hold fertilizer certification issued in accordance with § 78-6B of this chapter shall comply with the following standards for fertilizer applications to turf:

(1) Noncertified fertilizer applicators shall not apply fertilizer during or immediately prior to heavy rainfall, such as but not limited to thunderstorms, hurricanes, or northeastern storms, or when the soil is saturated due to intense or extended rainfall;

(2) Noncertified fertilizer applicators shall not apply fertilizer or compost between November 12 and the following March 31;

(3) Noncertified fertilizer applicators shall not apply, spill, or deposit fertilizer on any impervious surface and fail to remove the applied, spilled, or deposited fertilizer immediately (and in which case the applicator shall then either contain, dispose of legally or apply the fertilizer as allowed), and shall not apply, spill or deposit fertilizer in a manner that allows fertilizer to enter into storm drains;

(4) Unless the Town's existing laws and regulations, including its Wetland Ordinance or Regulations, contain a stricter standard or other enforcement or approval mechanism such as through the Town's Conservation Commission, which shall control, noncertified fertilizer applicators shall not apply fertilizer closer than 100 feet to any water body, or within the Zone I of a public drinking water well unless permission is obtained through the enforcement authority set out in § 78-6D(1) herein allowing such activity;

(5) A noncertified fertilizer applicator shall not apply fertilizer that contains phosphorus, unless a soil test taken not more than three years before the proposed fertilizer application indicates that additional phosphorus is needed for growth of that turf, or unless establishing new turf or reestablishing or repairing turf after substantial damage or land disturbance, in which case the application shall be in compliance with the BMP;

(6) A single application of fertilizer that contains nitrogen shall not exceed 1.0 pounds of actual nitrogen per thousand square feet, shall consist of at least 20% slow-release nitrogen fertilizer (NOTE: This represents the minimum percentage: use of higher SRN content is generally preferable, especially on sandy root zones, during stress and pre-stress periods, and when there are fewer annual applications of nitrogen made to a lawn.) and the annual rate shall not exceed 3.2 pounds of actual nitrogen per thousand square feet. Single applications shall be done at intervals of no less than four weeks until the annual maximum is reached;

(7) The fertilizer application requirements of this § 78-5B shall apply with the same limitations to combination products, i.e., amount of nitrogen applied, vicinity of water bodies, etc;

(8) Noncertified fertilizer applicators shall not deposit grass clippings, leaves, or any other vegetative debris into or within 50 feet of water bodies, retention and detention areas, drainage ditches or stormwater drains, or onto impervious surfaces, such as, but not limited to, roadways and sidewalks, except during scheduled clean-up programs.

C. Performance standards for certified fertilizer applicators. Certified fertilizer applicators shall be exempt from the requirements set forth in § 78-5B of this chapter, provided that they shall manage turf and apply fertilizer to turf in accordance with the BMP. The burden shall be on the certified fertilizer applicator, if and as required, to show that he/she is applying fertilizer in accordance with the BMP.

D. Exemptions. The following activities shall be exempt from this chapter:

(1) Application of fertilizer as a fertility source for agriculture and agricultural use.

(2) Application of fertilizer as a fertility source to home gardens, landscape ornamentals, shrubs, trees bushes, vegetables, fruit and container plants.

§ 78-6. Education; certification; enforcement; penalties.

A. Fertilizer/turf management education. Fertilizer education may consist of, but is not limited to, collaboration with retailers to post in-store information on Town fertilizer regulations, the BMP and fertilizer certification requirements; mailings and flyers for the general public concerning Town fertilizer regulations, the BMP and fertilizer certification requirements; and outreach to landscape professionals and municipal applicators concerning fertilizer-related laws, the BMP and fertilizer certification requirements. The Town may rely on Cape Cod Cooperative Extension to assist in maintaining a program of fertilizer and turf management education that is based on the BMP.

B. Fertilizer certification.

(1) The Town may seek the assistance of the Cape Cod Cooperative Extension to establish application requirements for and the process required to obtain fertilizer certification and renewals thereof, including evidence that the applicant is proficient in the BMP. Any noncertified fertilizer applicator may then apply to the Town or Cape Cod Cooperative Extension, as the case may be, for fertilizer certification as a certified fertilizer applicator.

(2) Notwithstanding the requirement for a proficiency assessment set out in § 78-6B(1) above, municipal applicators or landscape

professionals who meet the following criteria shall be presumed to be proficient in the BMP and may become certified fertilizer applicators without the need for an additional proficiency assessment or fees:

(a) Current Massachusetts pesticide commercial applicator license (Category 00) or commercial applicator license with turf certification (Category 37) or commercial applicator license with shade tree and ornamentals certification (Category 36), with evidence of participation in a recognized continuing education program for turf management within the past year; or

(b) Active membership in the Cape Cod Landscapers Association, the Golf Course Superintendents Association of Cape Cod, Massachusetts Association of Lawn Care Professionals (MALCP) or a substantially similar organization and any one of the following:

[1] Associate's Degree or higher in turf management, or closely related field, with evidence of participation in a recognized continuing education program for turf management within the past year;

[2] Current Massachusetts Certified Landscape Professional (MCLP) certification or current Massachusetts Certified Arborist (MCA) certification, or substantially similar professional certification with emphasis on turf management, with evidence of participation in a recognized continuing education program for turf management within the past year;

[3] Certificate of Completion from the University of Massachusetts Extension Green School (Turf or Landscape sections) or the University of Massachusetts Winter School for Turf Managers, or a horticultural certificate from Cape Cod Community College, or substantially similar professional certification with emphasis on turf management, with evidence of participation in a recognized continuing education program for turf management within the past year.

(3) The Town may seek the assistance of the Cape Cod Cooperative Extension to help develop or administer an assessment to determine an applicator's proficiency in the BMP and to assist with or administer a fertilizer certification process, which if administered by the Extension, may be a county-wide process.

(4) Municipal applicators or landscape professionals who are noncertified fertilizer applicators may nonetheless apply fertilizer and manage turf pursuant to the standards for certified fertilizer applicators set out in § 78-5C of this chapter so long as they

fertilize and manage turf under the direct supervision of a manager or supervisor who has attained fertilizer certification hereunder. "Direct supervision" shall mean the instruction and control by such manager or supervisor who is responsible for fertilizer applications made and that person making them, and who is either physically present at the time and place the fertilizer is applied, or if not physically present, is available if and when needed.

(5) All certified fertilizer applicators shall ensure that a copy of the official documentation of said fertilizer certification is readily available when and at the location fertilizer is being applied, and shall provide such certification when requested to do so by an officer or agent of the enforcement authority set out in § 78-6D(1) herein.

(6) All certified fertilizer applicators who apply plant nutrients shall maintain records for three years of each application made. The following information shall be recorded, when applicable:

(a) Name of applicator;

(b) Date of application;

(c) Address or location description of the application site;

(d) Type and amount of nutrients applied;

(e) Size of the area being treated;

(f) Representative nutrient value or values (e.g., soil tests);

(g) Plant nutrient analysis of product used;

(h) Method and rate of application;

(i) Total amount used;

(j) An original or legible copy of the label of the plant nutrient; and

(k) The implementation of all activities or protocols recommended or required by the nutrient management plan, if applicable.

(7) The records required under this § 78-6B shall be made available for inspection by the Town's Director of Public Health.

C. Retailer requirements. Any retailer who sells, or offers for sale, phosphorus-containing fertilizer shall:

(1) Display the product separately from nonphosphorus plant nutrients;

(2) Post in a location where phosphorus-containing fertilizer is displayed a clearly visible sign, provided by the Town, at least 8 1/2 inches by 11 inches in dimension, which reads as follows:

"PHOSPHORUS RUNOFF POSES A THREAT TO WATER QUALITY. THEREFORE, UNDER GL Ch. 128 sec. 65A, PHOSPHORUS CONTAINING FERTILIZER MAY ONLY BE APPLIED TO LAWN OR NON-AGRICULTURAL TURF WHEN (i) a soil test indicates that additional phosphorus is needed for the growth of that lawn or non-agricultural turf; or (ii) it is used for newly established lawn or non-agricultural turf during the first growing season."

(3) Post education materials on proper soil testing and use of fertilizers in a prominent location where fertilizer is being sold.

D. Enforcement.

(1) Enforcement authority. This chapter shall be enforced by the Town's Board of Health, through its Director of Public Health; provided, however, that the Town's Conservation Commission shall enforce the provisions of § 78-5B(4) and (8).

(2) For first and second offense within a twelve-month period. After the first year from the effective date of this chapter, whoever violates any provision of this chapter by committing a first or second offense may be penalized as follows:

(a) First offense: a written warning shall be issued;

(b) Second offense within a twelve-month period: either by attending an education program under § 78-6A or by obtaining a certification under § 78-6B.

(3) Noncriminal disposition. After the first year from the effective date of this chapter, whoever violates any provision of this chapter three or more times in a twelve-month period may be penalized by a noncriminal disposition process as provided in MGL c. 40, § 21D and the Town's noncriminal disposition ordinance. If noncriminal disposition is elected, then any person who violates any provision of this chapter shall be subject to a penalty of not more than $300 for each violation.

(4) Other remedies. The Town's Board of Health, through its Director of Public Health, or the Town's Conservation Commission for violations of § 78-5B(4) and (8) may enforce this chapter or enjoin violations thereof through any lawful process, and the election of one remedy by the Town's Director of Public Health and the Conservation Commission shall not preclude enforcement through any other lawful means.

§ 78-7. Severability.

Should any section, part or provision of this chapter be deemed invalid by a court of competent jurisdiction, such decision shall not affect the validity of the remaining terms of this chapter as a whole or any part thereof, other

than the section, part or provision held invalid, which shall remain in full force and effect.

§ 78-8. Amendments.

A. No amendment to this chapter shall be adopted until such time as the Town Council shall hold a public hearing thereon, notice of the time, place and subject matter of which, sufficient for identification, shall be given by publishing in a newspaper of general circulation in the Town once in each of two successive weeks, the first publication to be not less than 14 days prior to the date set for such hearing. No such amendment shall be effective unless the proposed amendment has been approved by the Town Council.

B. Amendments shall also be subject to the procedures set out in Sections 10 and 11 of the Cape Cod Commission Act, Chapter 716 of the Acts of 1989, as amended. Specifically, amendments must also be consistent with the Fertilizer Management District of Critical Planning Concern designation, Barnstable County Ordinance 13-07 and the Guidelines for Implementing Regulations set out therein, including the requirement for consistency with the BMP.

§ 78-9. When effective.

The effective date of this chapter shall be the date the fertilizer certification process outlined in § 78-6B herein is implemented and in effect.

Appendix QQ

SMAST Summary of Barnstable Watershed Loading and Modeling Update, December 2019

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Technical Memorandum

To: Griffin Beaudoin, Town Engineer, Barnstable Department of Public Works

From: Brian Howes, Director, Coastal Systems Program, SMAST, UMassD
Ed Eichner, Principal Water Scientist, TMDL Solutions
John Ramsey, Principal Coastal Engineer, Applied Coastal Research and Engineering

Date: December 5, 2019

RE: MEP Scenarios: Town of Barnstable Wastewater Plan and Land Use Updates

I. Background

The Town of Barnstable in working to implement a Wastewater Plan that includes reducing excessive nitrogen loads to its coastal estuary waters. Among the key estuaries with watersheds within the Town boundaries are: Lewis Bay/Halls Creek, Centerville River, Three Bays, and Barnstable Great Marshes. Portions of each of these estuaries are impaired by excessive watershed nitrogen loads and all of the watersheds, except Centerville River, include adjacent towns. However, it is Barnstable's land use nitrogen sources, primarily wastewater, that are the primary determinants of the water quality characteristics within each of these estuaries.

Between 2001 and 2017, the Massachusetts Estuaries Project (MEP) completed assessments of estuaries throughout southeastern Massachusetts. These assessments determined whether the habitat and water quality within these estuaries was impaired and developed linked watershed/water quality models that could be used to reliably test potential nitrogen management strategies to restore acceptable water quality. The technical lead for these MEP assessments was the Coastal Systems Program from the School for Marine Science and Technology at UMass-Dartmouth (CSP/SMAST). MEP reports for Three Bays, Centerville River, Lewis Bay/Halls Creek, and Barnstable Great Marshes were completed in 2006[1], 2006[2], 2008[3], and 2017[4], respectively.

[1] Howes B., S.W. Kelley, J.S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner. 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts. Massachusetts Estuaries Project. Massachusetts Department of Environmental Protection. Boston, MA. 183 pp.

[2] Howes B., H.E. Ruthven, J.S. Ramsey, R. Samimy, D. Schlezinger, J. Wood, E. Eichner. 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Centerville River System, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 172 pp.

[3] Howes B., H. Ruthven, E. Eichner, J. Ramsey, R. Samimy, D. Schlezinger. 2008. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Lewis Bay System, Towns of Barnstable and Yarmouth, MA. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 253 pp.

[4] Howes B., E. Eichner, S. Kelley, R. Samimy, J. S. Ramsey, D. Schlezinger, P. Detjens. 2017. Massachusetts Estuaries Project Linked Watershed-Embayment Model to Determine the Critical Nitrogen Loading Threshold for the Barnstable Great Marshes - Bass Hole Estuarine System, Towns of Barnstable and Dennis, Massachusetts, Massachusetts Department of Environmental Protection. Boston, MA. 213 pp.

The federal Clean Water Act requires each impaired surface water to have a Total Maximum Daily Load (TMDL) developed for the contaminant causing its impairment. The Massachusetts Department of Environmental Protection (MassDEP) is using the MEP assessments as the technical basis to develop total nitrogen TMDLs for each impaired estuary or segments within these estuaries. These TMDLs must be jointly approved with the US Environmental Protection Agency (EPA) and, to date, EPA and MassDEP have approved nitrogen TMDLs for 21 estuarine systems (41 TMDL segments) in southeastern Massachusetts utilizing the associated MEP assessments. Final total nitrogen TMDLs have been approved for Three Bays[5], Centerville River[6], and Lewis Bay[7]; Barnstable Great Marshes does not currently have a nitrogen TMDL though a portion was identified through its MEP assessment as being impaired.

As mentioned, each MEP assessment included development of linked nitrogen watershed/water quality models and contemporaneous estuary-specific ecosystem measures. Each of the MEP models was calibrated and verified with independent datasets so that they could be used to accurately predict future water quality conditions throughout each system. These models have been used throughout southeastern Massachusetts in a variety of settings, including assessment of wastewater management plans. Each estuary-specific model provides a reliable tool for watershed communities to assess the impacts of potential nitrogen management actions.

The Town of Barnstable has proposed a 60-year, three-phased wastewater plan that uses and builds on the existing wastewater infrastructure, including the municipal Hyannis Water Pollution Control Facility (WPCF).[8] This proposed plan is flexible depending on future changes, but one of the key features is additional sewer connections to the WPCF. With this in mind, Town staff asked CSP/SMAST to use the MEP models for Lewis Bay/Halls Creek, Centerville River, Three Bays, and Barnstable Great Marshes to evaluate two scenarios for each estuary: 1) updated current watershed nitrogen loads based on current land use conditions and 2) reduced watershed nitrogen loads based upon the Town's Wastewater Plan after the plan is completely implemented. These scenarios were constructed so that only watershed nitrogen loads were changed in the MEP models; no changes were made to the bathymetry or tidal functions within the MEP models. Each of these scenarios required development and integration of updated data, including incorporation of changes in the wastewater plan as it evolved during the course of the project. The present Technical Memorandum builds on the watershed updated nitrogen loading Technical Memorandum of October 9, 2019[9], which indicated a high probability that the Wastewater Plan as proposed would meet the nitrogen loading reductions required to restore Barnstable's estuaries. The present Technical Memorandum combines the watershed nitrogen loading changes with each

[5] MassDEP. 2007. Three Bays System TMDLs for Total Nitrogen (Report # MA96-TMDL-10, Control # CN242.0). 35 pp. Approved by USEPA, February 13, 2008, 6 total nitrogen TMDLs, 1 pollution prevention total nitrogen TMDL.

[6] MassDEP. 2007. Centerville River-East Bay System TMDLs for Total Nitrogen (Report # 96-TMDL-14, Control # CN248.0). 35 pp. Approved by USEPA, December 20, 2007, 1 total nitrogen TMDL, 2 pollution prevention total nitrogen TMDLs.

[7] MassDEP. 2015. Lewis Bay System and Halls Creek TMDLs for Total Nitrogen (Report # 96-TMDL-18 Control #314). 55 pp. Approved by USEPA, April 15, 2015, 6 total nitrogen TMDLs, 4 pollution prevention total nitrogen TMDLs.

[8] Barnstable Department of Public Works, Presentation to Town Council, January 3, 2019. https://town.barnstable.ma.us/Departments/PublicWorks/Office_Resources_and_Updates/Wastewater-Update-Presentation---Town-Council.pdf

[9] Howes, B.L. and E. Eichner. Update on Watershed nitrogen loading and TMDL N thresholds at present and post-wastewater improvements for Barnstable estuaries: Three Bays, Centerville River, Lewis Bay and Barnstable Great Marshes. **October 8, 2019, Technical Memorandum to Town of Barnstable.**

estuaries nitrogen dynamics and hydrodynamics to yield the most accurate assessment of the effectiveness of the proposed Wastewater Plan.

II. Scenario Inputs: Updated Land Use Data and Wastewater Plan Sewering

In order to develop the updated land use and wastewater plan scenarios, project staff worked with Town DPW and GIS staff, as well as staff from the public water suppliers to obtain updated information for use in the MEP watershed models, including current parcels, assessor's land uses, water supplier water use accounts, current and planned connections to the sewer system, and road layouts. Project staff reviewed and cross-checked this data for consistency and other quality assurance/quality control issues. Each of the categories of updated information is discussed below.

II.1. Land Use and Water Use

Because the MEP assessments of Lewis Bay/Halls Creek, Centerville River, Three Bays, and Barnstable Great Marshes were completed in different years, the impact of changes in the land use and water use information obtained from the Town for each assessment were different. In addition, project staff needed to assess whether the provided data was reasonably consistent (*e.g.*, water use pumped by water suppliers balanced water billed within supplier service areas). These types of checks were also completed during the MEP to ensure that data was representative and, therefore, reliable for evaluating impacts of nitrogen management strategies.

In the MEP assessments, water use was used as a proxy for wastewater generation along with correction factors for consumptive use, such as lawn irrigation. Consumptive use will vary, however, based on a number of factors, including how frequently precipitation occurs, whether precipitation is clustered on a few days or spread over many days, and how long and when high temperatures occur during the summer/plant growing season. MEP assessments generally used average water use over a period of years in order to smooth out exceptionally high or low consumptive use years.

For the current project, project staff worked with Town staff to collect annual water pumping rates between 2002 and 2018 for all of the public water suppliers within the Town: Centerville Osterville Marstons Mills (COMM) Water Department, Barnstable Fire District (BFD), Town of Barnstable Water Supply Division (Hyannis), Cotuit Fire District Water Department (Cotuit). Data review included looking at annual pumping rates, rates per service connection, and annual averages over various timeframes. Review of individual annual pumping rates among the Barnstable public water suppliers showed high year-to-year variation (5 to 20%) from the average rates between 2002 and 2018 (**Figure 1**). Rolling averages of 3 to 5 years of pumping generally showed results close to the average between 2002 and 2007, a period of below average, declining pumping between 2008 and 2014, and then a period of above average pumping between 2015 and 2018. After additional discussion, Town and project staff decided that averaging water use between 2011 and 2016 would be appropriate. More restricted timeframes also approximated average conditions, but the 2011 to 2016 averages were reasonably recent, had been used in previous Wastewater Plan discussions, and were already linked to the town parcel dataset. Water supply well pumping during this period was slightly (<5%) above average, but it was thought in Town and project staff discussions that this small degree of conservatism would be a benefit in assessing the modeling projections.

Once 2011 to 2016 was determined to be an appropriate period for water use in the watershed nitrogen loading updates, project staff then compared total annual water use for all parcels within the respective service areas during this period with the well pumping rates for each of the individual public water suppliers. This quality control step was undertaken to ensure that the assigned water uses in the Town parcel database were in reasonable balance with the water pumped by the water suppliers and ensure that no significant water use/wastewater volumes were missed in the watershed nitrogen loading calculations. Usually water pumping rates are greater than water use due to standard maintenance of portions of the water supply system, such as blow-offs for hydrants and well pumps. The initial comparison for the Barnstable parcels found that pumping rates tended to be greater than parcel water use with annual pumping rates 3% to 22% higher than parcel water uses with variations from year to year and between suppliers. Project staff discussed these differences with the respective water superintendents and generally found estimated blowoff volumes resulted in narrowed differences between billed water use and pumping rates. The largest volume water supplier, COMM, had annual differences of only 3% to 6% between billed water use and well pumping rates. Cumulative town-wide differences between pumping rates and cumulative parcel water use varied between 7% and 9%. As a result of this analysis, the average 2011 to 2016 water use assigned to the parcels appears to be in reasonable balance with the pumping rates. As such, these average water uses were appropriate for use as a wastewater proxy for septic system flows in the update of the MEP watershed nitrogen loading models.

The next quality control step was to compare the effluent flows at the Hyannis Water Pollution Control Facility (WPCF) to the cumulative water use for parcels within the sewer collection area. Based on data provided by the Town, effluent flows and total nitrogen (TN) loads at the WPCF have increased between 2011 and 2018 (**Figure 2**). As such, comparing the cumulative water use within the service area to the effluent discharge from the WPCF needs to consider cumulative water use within the service areas and WPCF effluent flow within individual years.

Typically, it should be expected that water use should be greater than effluent discharge because of consumptive use of water (*e.g.*, irrigation water is delivered to a property, but is not discharged to the sewers). Although this is the usual relationship, there are factors that may modify this relationship, including groundwater or stormwater infiltration into the collection system and/or imperfect tally of sewer accounts (*e.g.*, unrecorded or illicit sewer connections). The initial comparison found that the total flow between 2011 and 2015 from parcels with sewer connections in the Town databases was less than the measured effluent flow at the WPCF. After identifying this issue, project and Town staff re-reviewed the GIS sewer assignments and water use in Hyannis, which is the predominant sewer service area, and found some mismatches in the two databases that suggest a more extensive review outside of the current project should be completed. After correction based on an initial sweep of the two databases, sewer service area water uses in 2011 and 2015 were greater than effluent flow at the WPCF, while 2012, 2013, and 2014 were still less than the measured effluent flow. While this is an on-going issue, the net cumulative difference across the five years is less than 1% and this is well within the estimated error in the past assessments of MEP water quality modeling results. After this QC review, the sewered properties GIS coverage was deemed reasonable for use in the scenarios.

In order to update the non-wastewater nitrogen loads in the MEP models, project staff also received updated Town databases of: a) building areas, b) road layouts, and c) areas of other impervious surfaces (*e.g.*, parking lots, patios, tennis courts, etc.). These databases were more refined than the

base data available at the time of the development of the MEP models, so they provided a more accurate representation of these areas and their associated nitrogen loads. Comparison of these areas to the Town parcels layouts found some overlaps of the buildings across parcel boundaries, especially in the Lewis Bay watershed; project staff corrected these as presented during the development of the watershed nitrogen loading models, but again this represents a GIS quality assurance task outside of the current project and something the Town should consider as a future task. Quality control checks comparing whole watershed building areas to cumulative subwatershed building areas were within 3%. In the current project, building, road, and other impervious surface areas within subwatersheds shared with adjacent towns were updated if they were within a watershed shared with Barnstable parcels, otherwise they retained the MEP building areas in the scenarios. No updates were made in the assumed fertilized lawn areas or turf areas at schools or golf courses. It should also be noted that the standardized state land use codes used by the Town Assessor and the MEP assessments generally changed from when the codes used in the original MEP assessments, especially for the Three Bays, Centerville River, and Lewis Bay assessments.

II.2. Wastewater Nitrogen Loads: Sewered Areas and Wastewater Flow, Denitrifying Septic Systems, and Small Wastewater Treatment Plants

The MEP assessments included available review of recorded effluent flows, nitrogen concentrations, and nitrogen loads for municipal wastewater treatment plants, private treatment plants and innovative/alternative denitrifying septic systems. This information was updated for current conditions scenarios and then adjusted based on the scenarios based on the Town's Wastewater Plan.

The Town has four wastewater treatment facilities within the study area (**Table 1**). Two of these are private and two are municipal, including the largest one: the Hyannis Water Pollution Control Facility (WPCF). The second municipal treatment facility is located in Marstons Mills and provides wastewater treatment for West Village Elementary School and Barnstable United Elementary School. The effluent from the smaller private facilities discharge to subwatersheds were the facilities are located, while the larger Hyannis WPCF discharge is spread over a number of subwatersheds because of the volume of treated effluent discharged and the associated groundwater mounding. The division of effluent flow among subwatersheds impacted by the Hyannis WPCF were determined as part of pre-208 groundwater modeling project between the US Geological Survey and the Cape Cod Commission.[10] This project used an adapted version of the regional USGS groundwater model of the Sagamore Lens to predict which surface waters and public water supply wells were impacted by effluent from existing and proposed municipal treatment facilities, including the Hyannis WPCF. Results from this USGS assessment were used in the Lewis Bay/Halls Creek MEP assessment and the apportionment is the same in the scenarios summarized in this memo. As mentioned above, properties currently connected to the municipal sewer systems were indicated in the Town-provided GIS parcel coverage, while properties connected to the private facilities were previously confirmed during the development of the MEP assessments (**Figure 3**).

For the completion of the current requested scenarios, Town staff provided recent treatment data for the two municipal facilities (*i.e.*, effluent flows and total nitrogen concentrations), while

[10] Walter, D.A. 2008. Use of Numerical Models to Simulate Transport of Sewage-Derived Nitrate in a Coastal Aquifer, Central and Western Cape Cod, Massachusetts: U.S. Geological Survey Scientific Investigations Report 2007-5259, 41 p.

MassDEP provided updated treatment data for the two private facilities: Cape Regency Nursing Home in the Centerville River watershed and Cotuit Landing in the Three Bays watershed.[11] Both of these private facilities have wastewater flows greater than the 10,000 gpd threshold required for Groundwater Discharge Permits from MassDEP and are required to regularly report monitoring of flow, nitrogen concentrations and other effluent characteristics. Under the Town's Management Plan scenario, the properties connected to these treatment facilities would be connected to the municipal sewer system.

In the 2019 Wastewater Plan scenarios for each of the four estuaries, future sewered properties were determined based on information provided by the Town. In addition to the properties that would be sewered under the Plan, Town staff also determined where collected wastewater would be treated and discharged. Wastewater collected for treatment at the WPCF included the current service area within the Lewis Bay, Barnstable Harbor, and Centerville River watersheds, the additional future sewered properties, and a service area within the Town of Yarmouth section of the Lewis Bay watershed (**Figure 4**). A collection system in the western portion of Town would also be developed, but this flow would be treated and discharged at an as-yet-undetermined wastewater treatment facility outside of the Town boundaries; wastewater in this area would be within both the Three Bays and Popponesset Bay watersheds. Wastewater to the east of this westernmost collection area would flow to the Hyannis WPCF.

The Plan also specifies where treated wastewater effluent will be discharged. Effluent discharge at the Hyannis WPCF site would be limited to 2 MGD (with a 3 mg/L TN concentration) under the Plan scenarios. Collected wastewater flow from the Yarmouth collection area would be treated at the Hyannis WPCF, returned to Yarmouth, and discharged outside of the Lewis Bay watershed. Remaining WPCF effluent greater than 2 MGD would be discharged at a location within the Barnstable Harbor watershed (see **Table 1)**. Total current wastewater effluent at the WPCF is 1.47 MGD, while treated wastewater at the WPCF will be 3.82 MGD under the Wastewater Plan.

In addition to updated performance data on the larger wastewater treatment facilities, project staff also obtained and incorporated monitoring performance data for innovative/alternative (IA) denitrifying septic systems from the Barnstable County Department of Health and Environment (BCDHE).[12] BCDHE maintains nitrogen monitoring results on IA septic systems and has results from 59 systems within the Town of Barnstable. Project staff determined average total nitrogen concentrations for each IA system that had data from three or more samplings and incorporated these results into the current conditions and Wastewater Plan scenarios for each associated property. If a property was selected for a sewer connection under the Wastewater Plan (including those with IA systems), no wastewater nitrogen load was assigned to that property under the Plan scenarios.

III. Scenario Results: Updated Current Conditions and Wastewater Plan Changes

Project scenarios were completed in pairs for each of the estuaries: a) one for a 2019 update of current land uses and associated watershed loading and b) another using the 2019 Wastewater Management Plan proposed sewer strategy coupled with the 2019 update of current land uses. Each scenario was run through the MEP Linked Watershed-Embayment Nitrogen Management Model for each estuary. Aside from the updated watershed nitrogen loads, the MEP water quality

[11] Brian Dudley and Christos Dimisioris, MassDEP, SERO (personal communications)

[12] Emily Michele Olmsted and Brian Baumgaertel, BCDHE (personal communications).

model, including the bathymetry and tidal movements developed during the MEP assessment, were not changed. For the purpose of comparing the results from the scenarios, only the watershed nitrogen loads were changed with the standard adjustment of the internal sediment nitrogen recycling related to changes in watershed load. Updated projections of future buildout within each watershed were also not included in the selected scenarios.

III.1. Three Bays Scenarios: Updated Current Conditions and Town Wastewater Plan Results

The final MEP assessment report on the Three Bays estuary system was completed in 2006. The Three Bays MEP watershed nitrogen loading model was based on digital parcels and land use data obtained from the watershed towns for the following years: 2004 for Barnstable, 2000 for Sandwich, and 2001 for Mashpee. Tidal data, bathymetry, and shoreline configuration for the Three Bays MEP water quality model were collected in 2002 and water quality data that was used was collected between 1999 and 2004. Measurements of dissolved oxygen, chlorophyll, macroalgae, eelgrass, and infauna found that portions of the system ranged in condition from severely degraded (Warrens Cove, Princes Cove, Upper North Bay) to moderately impaired (Cotuit Bay, West Bay).[13] The MEP team recommended target total nitrogen concentrations to address the impairments and used the linked MEP models to develop a potential watershed nitrogen reduction option to attain the target TN concentrations. In 2007, MassDEP/EPA approved a TMDL with nitrogen loading limits for six segments: Cotuit Bay, West Bay, North Bay, Prince Cove, Warren Cove, and Prince Cove Channel.[14]

The updated 2019 current watershed loading utilized the updated (current conditions) data inputs discussed above. Notable among these changes were: 1) more complete accounting of impervious surfaces (*e.g.*, road surfaces, building areas, parking lots), 2) changes in cranberry bog areas (*e.g.*, a number of bogs in the watershed became inactive in the past 15 years), 3) changes in land use (*e.g.*, change from undeveloped lots to singles family residences), 4) updated nitrogen loads from the capped Town landfill, and 5) increases in the number of properties connected to the public water supply systems (*e.g.,* the number of single family residences with public water supply accounts increased by 440 from the MEP count).

The updated current conditions increased the attenuated system nitrogen load by +8.2% over the MEP system load, while the system unattenuated load changed very little (+0.8%) compared to the MEP load (**Table 2**). Most of the changes were due to increased impervious surface loads, which were somewhat offset by decreased wastewater loads. The relatively higher increase in the attenuated loads was due to changes in the spatial distribution of the loads within the watershed with relatively greater loading increases in the lower portion of the watershed which does not attenuate watershed loads compared to the uppermost portion in the Prince Cove subwatershed.

The proposed 2019 Town Wastewater Plan scenario includes provisions to connect large portions of the Three Bays watershed to a municipal sewer system (see **Figure 4**). As mentioned above, the collected wastewater will be split with a portion transferred out of the watershed to an as-yet-undetermined site (*i.e.*, west sewered area) and the remaining portion would be transferred to the Hyannis WPCF (*i.e.*, east of the dividing line between the east and west areas). The nitrogen loads associated with the Town Wastewater Plan significantly decreased the watershed-wide attenuated

[13] See Table VIII-1 in Three Bays MEP Report (Howes and others, 2006).

[14] MassDEP. 2007. Three Bays System TMDLs for Total Nitrogen (Report # MA96-TMDL-10, Control # CN242.0).

updated load by -39% with the majority of the decrease occurring within the combined Prince Cove subwatershed.

The MEP used the watershed nitrogen loads with estimates of atmospheric nitrogen deposition on the estuary surface and measured nitrogen regeneration from the estuary sediments (*i.e.* benthic flux) as inputs to a linked watershed-water quality model that also used measurements of system hydrodynamics based upon bathymetry and tidal changes throughout the Three Bays system (**Table 3**). This model was calibrated and validated against water quality data collected at various monitoring stations in order to provide a predictive tool for future nitrogen management strategies. These results were compared to other measurements throughout the Three Bays system, including dissolved oxygen and habitat quality, to understand which portions of the system were impaired and what target threshold nitrogen concentrations should be goals to restore the water quality and habitat throughout the system. The MEP team selected a threshold water quality target of 0.38 mg/L total nitrogen (TN) for a sentinel station in the narrows between North Bay and Cotuit Bay. Estimates of nitrogen loads to attain this target was developed and incorporated in the MassDEP TMDL for Three Bays.[15]

Using the MEP Linked Watershed-Embayment Nitrogen Management Model, TN concentrations throughout the system were determined for the nitrogen loads from the 2019 updated land use and the loads associated with the Town's Wastewater Plan (**Table 4**). The increased nitrogen loads resulting from the 2019 updated land use resulted in increased TN concentrations throughout the system ranging from +1% at the North Bay (south) TB6 station to +25.6% at the West Bay (north) TB8 station. In contrast, the reduced nitrogen loads estimated from the proposed Wastewater Plan showed significant TN concentration reductions throughout the system generally in the -35% to -40% range. However, the TN concentration reduction at the sentinel station was insufficient to attain the 0.38 mg/L threshold concentration. This was expected as there are other nitrogen removal alternatives being planned for the upper watersheds to the Three Bays Estuary, particularly within the Marstons Mills River sub-watershed.

III.2. Centerville River Scenarios: Updated Current Conditions and Town Wastewater Plan Results

The final MEP assessment report on the Centerville River estuarine system was completed in 2006. The MEP watershed nitrogen loading model was based on digital parcels and land use data obtained from the Town of Barnstable in 2004; the Centerville River watershed is completely within the Town. Tidal data and bathymetry/shoreline configuration data for the Centerville River MEP Linked Watershed-Embayment Nitrogen Management Model were collected in 2004 and 2003, respectively. Water quality data that was used in the model was collected between 2001 and 2005 (five years). Measurements of dissolved oxygen, chlorophyll, macroalgae, eelgrass, and infauna found that portions of the system ranged in condition from significantly impaired (East Bay, Lower Centerville River) to healthy (Upper Centerville River, Bumps River).[16] The MEP team recommended site-specific target total nitrogen concentrations to address the nitrogen-related impairments and used the linked MEP models to develop a potential watershed nitrogen reduction option to attain the target TN concentrations. In 2007, MassDEP/EPA approved a TMDL with nitrogen loading limits for three segments: Centerville River, East Bay, and Scudder Bay.[17]

[15] MassDEP. 2007. Three Bays System TMDLs for Total Nitrogen (Report # MA96-TMDL-10, Control # CN242.0).

[16] See Table VIII-1 in Centerville River MEP Report (Howes and others, 2006).

[17] MassDEP. 2007. Centerville River-East Bay System TMDLs for Total Nitrogen (Report # 96-TMDL-14, Control # CN248.0).

The updated 2019 current watershed loading utilized the data inputs discussed above. Notable among these changes were: 1) more complete accounting of impervious surfaces (*e.g.*, road surfaces, building areas, parking lots), 2) changes in area of active cranberry bog (*e.g.*, a number of bogs in the watershed have been removed from cultivation (inactive) over the past 15 years), and 3) changes in land use (*e.g.*, increase of 396 single family residences).

The updated current conditions increased the attenuated nitrogen load of the overall system watershed by +5.3% over the MEP system load, while the system unattenuated load increased by a smaller percentage (+2.3%) (**Table 5**). Most of the changes were due to increased impervious surface loads, but fertilized lawns also increased +21%. Watershed wastewater loads decreased slightly (-4%), which may be due to changes in demographics[18] or may be due to lower water use due to lower flow toilets. The relatively higher increase in the attenuated loads was due to changes in spatial distribution of the loads within the watershed with relatively greater loading increases in the upper, eastern portion of the watershed (*i.e.*, the Centerville East subwatershed) which has higher attenuation.

The proposed Town Wastewater Plan includes provisions to connect large portions of the Centerville River watershed to a municipal sewer system (see **Figure 4**). All of the collected wastewater within the watershed would be sent to the Hyannis WPCF, effectively removing the associated wastewater nitrogen from the Centerville River watershed. The nitrogen loads associated with the 2019 Town Wastewater Plan significantly decreased the attenuated updated load by 41% with the majority of the decrease occurring within the Centerville East subwatershed (see **Table 5**).

The MEP used the watershed nitrogen loads with estimates of atmospheric nitrogen deposition on the estuary surface and measured nitrogen regeneration from the estuary sediments (*i.e.* benthic flux) as inputs to a water quality model that also used the hydrodynamics of this system based upon its bathymetry and tidal changes (**Table 6**). This MEP Linked Watershed-Embayment Nitrogen Management Model was calibrated and validated against multiyear water quality data collected at various monitoring stations in order to provide a predictive tool for future nitrogen management strategies. These results were compared to other measurements throughout the Centerville River system, including dissolved oxygen and habitat quality, to understand which portions of the system were nitrogen impaired and what target threshold nitrogen concentrations were needed to be attained to restore the water and habitat quality throughout the system. The MEP team selected a threshold water quality target of 0.37 mg/L total nitrogen (TN) for monitoring station BC-T (near the confluence of Bumps River and Centerville River) and target ranges of 0.4 to 0.5 mg/L TN at stations BC-3 in Scudder Bay and BC-7 near the Centerville River bridge. Estimates of nitrogen loads to attain these targets were developed and incorporated in the MassDEP TMDL for Centerville River.[19]

Using the MEP water quality model, TN concentrations throughout the system were updated based on the 2019 updated land use and the updated land use plus with the projected reduction in nitrogen

[18] US Census estimates of Town population have decreased by 7% since 2000, housing units counted as seasonal has increased by 3%, and the percentage of the population 65 years old or older (*i.e.*, less children in households) has increased by ~10% (www.census.gov accessed 9/19/19).

[19] MassDEP. 2007. Centerville River-East Bay System TMDLs for Total Nitrogen (Report # 96-TMDL-14, Control # CN248.0).

loads associated with the Town's Wastewater Plan (**Table 7**). The increased nitrogen loads resulting from the 2019 updated land use resulted in increased nitrogen concentrations throughout the system with the largest increase (+2.5%) in Scudder Bay. In contrast, the reduced nitrogen loads estimated from the proposed Wastewater Plan showed significant water column TN levels reductions throughout the system and, most importantly, attained the target TN concentrations at all three of the threshold stations. The results indicate that the 2019 Wastewater Plan when fully implemented for the Centerville River watershed is sufficient to restore water and habitat quality throughout the estuary.

III.3. Lewis Bay/Hall Creek Scenarios: Updated Current Conditions and Town Wastewater Plan Results

The final MEP assessment report on the Lewis Bay and Halls Creek estuary systems was completed in 2008. The MEP watershed nitrogen loading model was based on 2004 digital parcels and land use data obtained from the watershed towns of Barnstable and Yarmouth. Tidal data, bathymetry, and shoreline configuration for the Lewis Bay and Halls Creek MEP water quality models were collected in 2004 and water quality data that was used was collected between 2001 and 2006. Measurements of dissolved oxygen, chlorophyll, macroalgae, eelgrass, and infauna found that portions of the system ranged in condition from significantly impaired (Inner and Outer Lewis Bay, Uncle Roberts Cove) to moderately impaired (Hyannis Inner Harbor, Mill Creek).[20] Halls Creek, on the other hand, had measurements that were consistent with a high quality, unimpaired, salt marsh system.

The MEP team recommended target total nitrogen concentrations for Lewis Bay to address the observed impairments and used the MEP Linked Watershed-Embayment Nitrogen Management Model to develop a potential watershed nitrogen reduction option to attain the target TN concentrations needed to restore water and habitat quality. A similar step was completed for Halls Creek, but this assessment involved adding additional nitrogen up to a threshold limit greater than that measured to date, but consistent with maintaining a healthy salt marsh system (*i.e.* this salt marsh system does not need nitrogen remediation, it is below its nitrogen loading threshold). In 2015, MassDEP/EPA finalized a TMDL that included nitrogen loading limits for six impaired Lewis Bay segments: Hyannis Inner Harbor, Lewis Bay, Uncle Robert's Cove, Mill Creek, Mill Pond Creek, and Inner Harbor Creek.[21] Three other segments had "pollution prevention" nitrogen TMDL limits developed, but were not classified as impaired: Snow's Creek, Stewart's Creek, and Chase Brook. A pollution prevention TMDL was also established for Halls Creek based on the level of watershed loading and health status at the time (MEP "Present Conditions").

The updated 2019 current watershed loading for both Lewis Bay and Halls Creek utilized the data inputs discussed above. As noted, the Hyannis WPCF and the extensive sewer system are an important factor in the amount and distribution of watershed nitrogen loading. The 2019 nitrogen loading updates, included updates on the performance of the Hyannis WPCF (*i.e.*, effluent flows and total nitrogen concentrations), as well as the connection of additional properties to the sewer system since the MEP analysis. Other notable changes in the update were: 1) more refined accounting of impervious surfaces (*e.g.*, road surfaces, building areas, parking lots) and 2) changes in land use (*e.g.*, changes in uses for many of the commercial properties).

[20] See Table VIII-1 in Lewis Bay MEP Report (Howes and others, 2008).

[21] MassDEP. 2015. Lewis Bay System and Halls Creek TMDLs for Total Nitrogen (Report # 96-TMDL-18 Control #314).

Unlike Centerville River and Three Bays, the Hyannis WPCF reduces watershed nitrogen loads to Lewis Bay and Halls Creek because of higher treatment levels for wastewater collected within the watersheds, but it also adds nitrogen load because it imports wastewater from outside of the watershed, treats it, and discharges the treated effluent within the watershed to Lewis Bay. As indicated in **Table 2**, the Hyannis WPCF under both the MEP and the 2019 updated conditions scenario receives wastewater flow from sources within the Lewis Bay, Halls Creek, Centerville River, and Barnstable Harbor watersheds. Under the proposed Town 2019 Wastewater Plan scenario, the Hyannis WPCF will treat wastewater flow from all four of the Barnstable watersheds reviewed, as well as from the Yarmouth portion of the Lewis Bay watershed (see **Figure 4**). Based on Town staff direction, the effluent discharge at the WPCF site in the 2019 Plan scenario is limited to 2.0 MGD (with a TN concentration of 3.0 mg/L), all effluent from Yarmouth is returned to Yarmouth (0.62 MGD) for discharge, and any Barnstable volumes greater than 2 MGD are discharged within the Barnstable Harbor watershed (1.2 MGD). The discharge site within the Barnstable Harbor watershed is undefined at this point, but the discharge location was selected as occurring within subwatershed #20 (Barnstable Harbor LT10 Mid) and the volume and treatment level at the Hyannis WPCF results in an associated total load of 4,995 kg TN/yr.

The 2019 updated Lewis Bay current conditions increased the attenuated nitrogen load from the overall system watershed by +8.4% over the MEP system load, while the system unattenuated load increased by +6.7% compared to the MEP load (**Table 8**). The 2019 updated attenuated watershed nitrogen load to Halls Creek increased by +6.4% over the MEP system load (**Table 9**). Most of the changes were due to increased impervious surface loads, but there was also an increase in the Hyannis WPCF nitrogen loading (largely due to an increase in the effluent TN concentration under 2019 current conditions). The relatively higher increase in the attenuated loads was due to changes in the spatial distribution of the loads within the watershed with relatively greater loading increases in subwatersheds that discharge directly to the estuary and do not have attenuation during transport due to passage through streams and/or ponds (*i.e.*, the Main Bay subwatershed).

The proposed 2019 Town Wastewater Plan includes provisions to a) increase wastewater collection within the Lewis Bay watershed for treatment at the Hyannis WPCF, b) improve TN levels in the Hyannis WPCF effluent (current levels average 5.64 mg/L TN, while the Plan targets 3 mg/L TN), c) increase the wastewater volume treated at the Hyannis WPCF including import of wastewater from outside of the Lewis Bay watershed, and d) distribute most of the additional treated effluent to watersheds not associated with Lewis Bay. The Lewis Bay nitrogen loads associated with the 2019 Town Wastewater Plan significantly decreased the attenuated 2019 updated load by -43% with the majority of the decrease occurring within the Main Bay subwatershed (see **Table 8**). The Halls Creek nitrogen loads associated with the 2019 Town Wastewater Plan also decreased the attenuated 2019 updated load by -14% with all of the decrease within the watershed portions that discharge directly into the salt marsh/estuary (see **Table 9**).

The MEP used the watershed nitrogen loads with estimates of atmospheric nitrogen deposition on the estuary surface and measured nitrogen regeneration from the estuary sediments (*i.e.* benthic flux) as inputs to the MEP Linked Watershed-Embayment Nitrogen Management Model that also accounts for hydrodynamics based upon measurements of bathymetry and tidal changes throughout the estuarine system (**Table 10**). This model was calibrated and validated against water quality data collected at various monitoring stations throughout the estuary in order to provide a predictive tool for future nitrogen management strategies. These results were compared to other

measurements throughout the Lewis Bay and Halls Creek systems, including dissolved oxygen, macroalgae, chlorophyll *a* and benthic animal communities, to understand which portions of the system were impaired and what target threshold nitrogen concentrations needed to be attained to restore the water and habitat quality throughout the system. Based on the site-specific data, the MEP team selected a Lewis Bay threshold water quality target of 0.38 mg/L total nitrogen (TN) for monitoring station BHY-3, 0.4 mg/L TN in Uncle Roberts Cove (monitoring station BHY-4), and 0.5 mg/L in Hyannis Inner Harbor (average) and Mill Creek. Since Halls Creek had high quality salt marsh habitat at the time of the MEP assessment, the threshold target TN concentration was 1.0 mg/L TN at monitoring station BC-14 (this is approximately 2X the average MEP measured concentration). Estimates of nitrogen loads to attain the nitrogen concentrations thresholds were developed and incorporated in the MassDEP TMDL for Lewis Bay/Halls Creek.[22]

Using the MEP Linked Watershed-Embayment Nitrogen Management Model, TN concentrations throughout the Halls Creek and Lewis Bay Estuaries were determined for the nitrogen loads from the 2019 updated land use and the loads associated with the Town's 2019 Wastewater Plan (**Table 11**). The increased nitrogen loads resulting from the 2019 updated land use resulted in small increases in the nitrogen concentrations throughout the Lewis Bay system with the largest increases in Snow Creek (+11% at BH-4) and the outermost station in Hyannis Inner Harbor (+4.5% at BH-3). In contrast, the reduced nitrogen loads estimated from the 2019 proposed Wastewater Plan showed significant reductions throughout the system and, most importantly, attained the target TN concentrations at all five of the Lewis Bay threshold stations. In Halls Creek, the changes in the Town's 2019 proposed Wastewater Plan slightly reduced the TN concentration at the sentinel monitoring location and remained well below the TMDL threshold concentration. The results indicated that the 2019 Wastewater Plan, when fully implemented, will lower nitrogen inputs sufficiently to attain the TN threshold and restore water and habitat quality throughout the Lewis Bay Estuary, while continuing to provide adequate protection for Halls Creek. When fully implemented both Halls Creek and Lewis Bay estuarine systems will support high water and habitat quality.

III.4. Barnstable Great Marshes/Bass Hole Scenarios: Updated Current Conditions and Town Wastewater Plan Results

The final MEP assessment report on the Barnstable Great Marshes estuary system was completed in 2017, so it is easily the most recent of the Barnstable MEP reports and, as such, the system likely to have the smallest change in watershed nitrogen loads. The MEP watershed nitrogen loading model was based on digital parcels and land use data with base years between 2011 and 2012 that were obtained from the watershed towns of Barnstable, Yarmouth, Dennis, and Sandwich. Bathymetry and salt marsh topography for the Barnstable Great Marshes MEP water quality model were collected in 2015 and 2013, respectively. Water quality data between 2002 and 2014 was used in the development of the model. Measurements of dissolved oxygen, chlorophyll, macroalgae, eelgrass, and infauna found that the majority of the system had healthy habitat except for the Millway subembayment, which is a dredged boat basin with severely degraded habitat.[23] The MEP team recommended a target bioactive nitrogen concentration at the Millway to address its measured nitrogen-related impairments, but found that the majority of the Great Marshes system could accommodate a +39.6% increase in watershed nitrogen loads without

[22] MassDEP. 2015. Lewis Bay System and Halls Creek TMDLs for Total Nitrogen (Report # 96-TMDL-18 Control #314).

[23] See Table VIII-1 in Barnstable Great Marshes/Bass Hole MEP Report (Howes and others, 2017).

becoming impaired.[24] MassDEP has not developed a draft nitrogen TMDL for Barnstable Great Marshes or the Millway.

The 2019 current watershed loading utilized the updated data inputs discussed above. Portions of Barnstable Village, including parcels within the Millway subwatershed, are connected to the municipal sewer system and the Hyannis WPCF. The 2019 current conditions nitrogen loading update, included increases in the number of parcels connected to the municipal sewer system (+27), use of more complete accounting of impervious surfaces (*e.g.*, road surfaces, building areas, parking lots) and changes in land use (*e.g.*, changes from undeveloped to developed lots). Overall, the total system unattenuated and attenuated loads in the 2019 update changed the corresponding MEP loads by less than 1%.

The proposed Town 2019 Wastewater Plan includes provisions to a) collect more wastewater within the Barnstable Great Marshes watershed for treatment at the Hyannis WPCF, b) return of treated effluent from the Hyannis WPCF (at 3 mg/L TN) for discharge within the Great Marshes watershed, and a significant reduction (-53%) in wastewater nitrogen loads within the Millway subwatershed. Overall, the nitrogen loads associated with the Town Wastewater Plan increased the attenuated updated total watershed load to the Great Marshes system +1.3% (**Table 12**).

The MEP used the watershed nitrogen loads with estimates of atmospheric nitrogen deposition on the estuary surface and measured nitrogen regeneration from the estuary sediments (*i.e.* benthic flux) as inputs to a water quality model that also accounted for estuarine hydrodynamics based upon the bathymetry and tidal changes throughout the Barnstable Great Marshes system (**Table 13**). This model was calibrated and validated against water quality data collected at various monitoring stations in order to provide a predictive tool for future nitrogen management strategies. These results were compared to other measurements throughout the Barnstable Great Marshes system, including dissolved oxygen, chlorophyll, eelgrass, macroalgae and benthic animal communities, to understand which portions of the system were impaired and what target threshold nitrogen concentrations were needed to support high water and habitat quality throughout the estuary. The MEP team selected a threshold water quality target of 0.16 mg/L bioactive nitrogen (bioN) for three sentinel stations in the salt marsh-dominated basins and a 0.21 mg/L bioN threshold in the Millway basin. Bioactive N[25] was selected for the development of the threshold because other portions of the nitrogen pool appeared to be biologically inactive (*i.e.*, refractory) with similar concentrations inside and outside of the system.[26] Average bioN concentrations in the main basins of the Great Marshes were below the 0.16 mg/L bioN threshold, while average concentrations in the Millway were above the 0.21 mg/L bioN threshold.

Using the MEP Linked Watershed-Embayment Nitrogen Management Model, bioN concentrations throughout the system were determined for the nitrogen loads from the 2019 updated watershed land use and also for the loads associated with the Town's 2019 Wastewater Plan coupled with the 2019 updated land use (**Table 14**). The slightly increased nitrogen loads resulting from the 2019 updated land use generally resulted in small increases in nitrogen concentrations throughout the system (+0.2% to +1.7%), but there was a -5.6% decrease in the

[24] See Table VIII-3 in Barnstable Great Marshes/Bass Hole MEP Report (Howes and others, 2017).

[25] Bioactive N = ammonium, nitrate+nitrite, and the particulate organic nitrogen comprised primarily of phytoplankton (live and dead).

[26] This approach was also applied in the MEP assessment of Pleasant Bay.

Millway bioN concentration largely due to increased sewering of properties within its watershed. This decrease was insufficient to attain the MEP bioN threshold. In the proposed 2019 Wastewater Plan, the addition of an alternative wastewater discharge from the Hyannis WPCF within the watershed caused increased bioN concentrations throughout the overall system (+0.7% to +7.0%), but expanded sewering within the Millway watershed resulted in a significant decrease (-46.7%) in the Millway basin bioN concentration. This decrease in concentration resulting from the proposed changes in the 2019 Wastewater Plan allowed the Millway basin to attain the 0.21 mg/L bioN threshold concentration needed for water and habitat quality restoration. While the 2019 Wastewater Plan resulted in increases in bioN concentrations throughout the rest of Great Marshes system, the concentrations all remained below the bioN threshold concentrations. Overall, the proposed 2019 Wastewater Plan attained the bioN threshold concentrations at all four of the Barnstable Great Marshes threshold stations.

III. Conclusions/Discussion

At the request from the Town of Barnstable, project staff updated the watershed land use portions and associated nitrogen loads for MEP linked models for the following systems: Three Bays, Centerville River, Lewis Bay/Halls Creek, and Barnstable Great Marshes. The updated nitrogen loads were combined with the existing MEP hydrodynamic/water quality models, which were not updated, and the resulting nitrogen concentrations were compared to the MEP nitrogen thresholds/MassDEP TMDLs. Updating the 2019 current condition watershed nitrogen loads showed increased watershed nitrogen loads to all estuaries, due to increases in development, increased impervious surfaces, and in Hyannis, increased nitrogen loads from the Water Pollution Control Facility (WPCF). As a result, all systems remain impaired, having portions with watershed nitrogen loads and water column nitrogen concentrations in excess of the approved TMDLs and MEP thresholds.

The Town has proposed a 60-year, three-phased wastewater plan that uses and builds on the existing wastewater infrastructure, including the municipal Hyannis WPCF. Using the updated 2019 land uses, project staff also reviewed the impact of the proposed 2019 wastewater plan when fully implemented on the watershed nitrogen loads and the associated nitrogen concentrations in the Town's major estuaries. These scenarios incorporated the proposed sewering in each of the watersheds, along with the proposed distribution of treated effluent from the Hyannis WPCF. These scenarios also utilized the existing MEP hydrodynamic/water quality models without any updates to tidal measurements, sediment nitrogen regeneration or bathymetry. In most of the systems, the proposed Town wastewater plan resulted in the TMDLs/MEP thresholds being attained. The proposed strategy for the Three Bays system of sewering as put forward in the 2019 Wastewater Plan will require implementation of further nitrogen management, currently being planned, to attain the necessary nitrogen loading reductions to fully restore the water and habitat quality throughout the Three Bays Estuary.

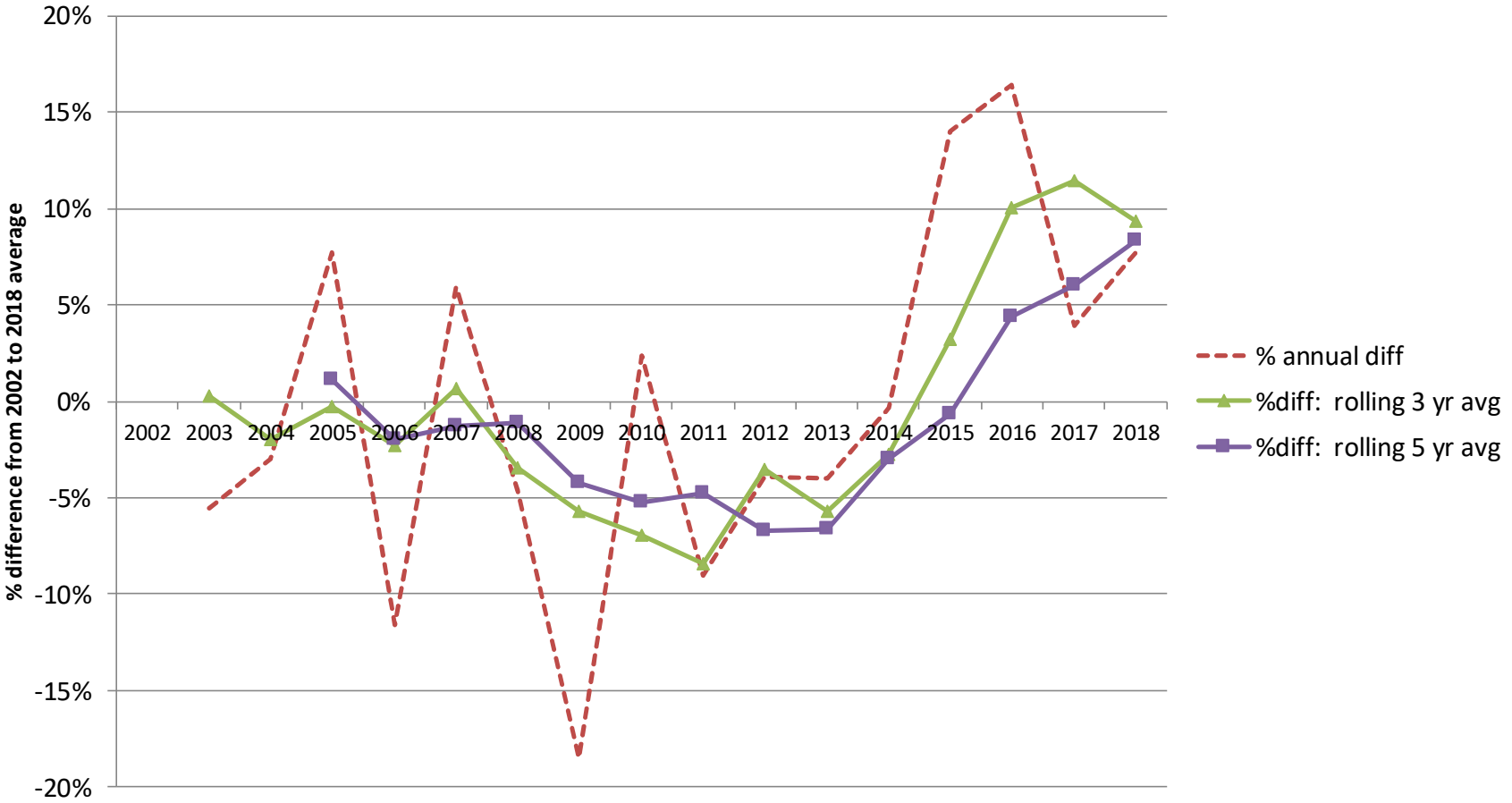

Figure 1. Annual Water Use Fluctuations and Rolling Averages: COMM Example. Town-wide water uses vary from year depending on irrigation needs and precipitation. In order to use water use as a proxy for wastewater generation, these fluctuations are generally smoothed out by averaging water uses over a number of years, which is also more reflective of groundwater processes, such as time of travel and flow path variability. Working with Town staff, project staff reviewed annual water uses for each of the public suppliers and selected an averaging period of 2011 to 2016 for the updating of the MEP watershed nitrogen loading models, as well as the evaluation of the estimated nitrogen loads associated with the Town Wastewater Management Plan. This graph shows how annual averages fluctuate significantly from year to year (red dashed line) for COMM, the largest water supplier within the Town. Rolling averages of 3 year and 5 year periods show below average water use from 2009 to 2013, an average year in 2014, and above average years from 2015 to 2018. The averaging period from 2011 to 2016 generally balances the below average years prior to 2014 with the subsequent above average years.

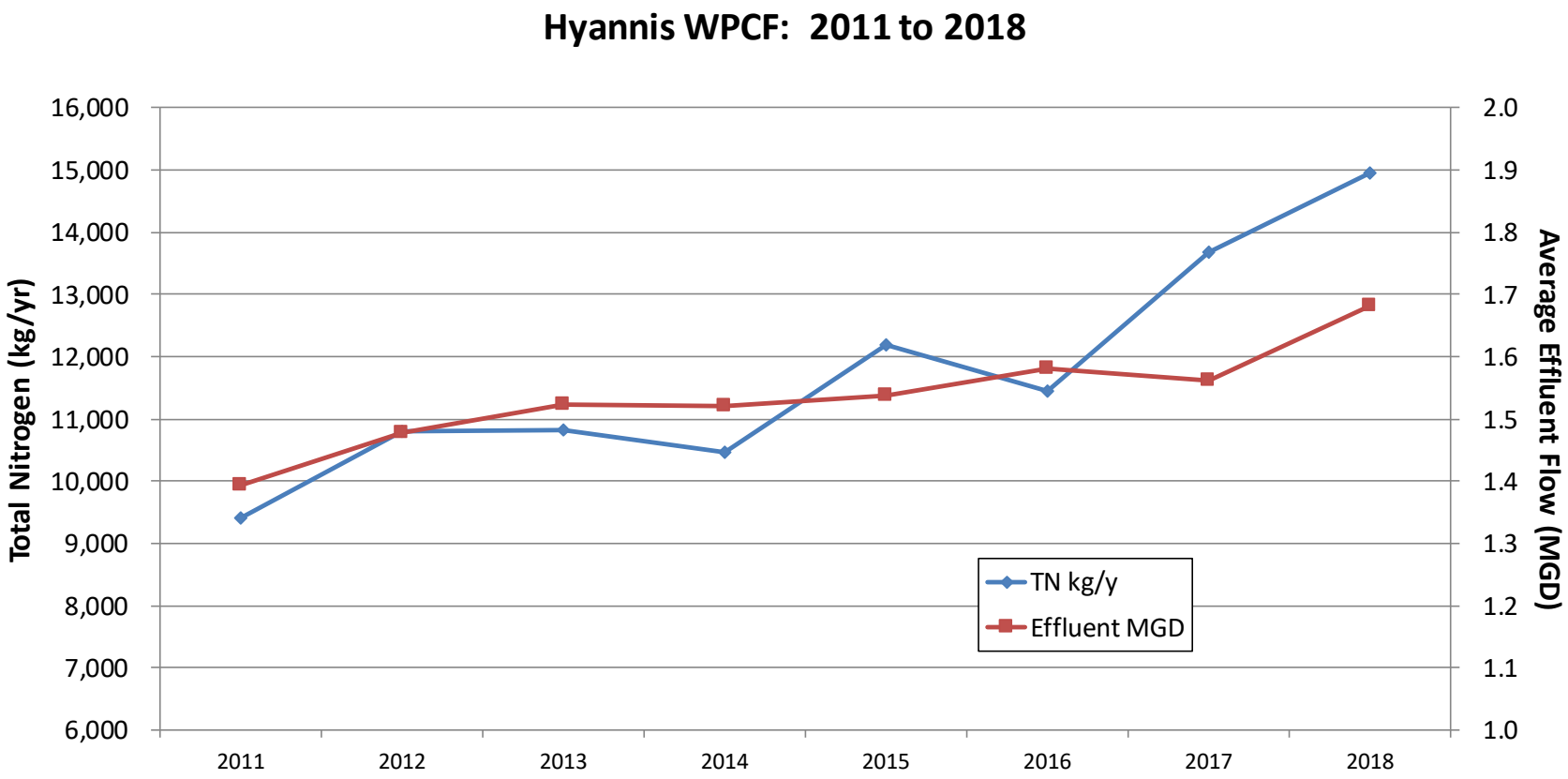

Figure 2. Hyannis Water Pollution Control Facility: Annual Nitrogen Load and Average Daily Effluent Flow (2011 to 2018). Based on data from the Town, the nitrogen load produced by the Hyannis WPCF increased at an average annual rate of +6% (R2=0.83), while effluent discharged increased by +2% per year (R2=0.86). Effluent flows were compared to water use from parcels within the sewer collection area as a QC step for the watershed nitrogen loads. This comparison found some issues that will require additional attention by the Town, but these generally were small. The increasing trends in flow and nitrogen load should be considered in near future projections of impacts. The existing conditions scenarios completed for this project utilized an average of the most recent three years (2015 to 2018), which resulted in an average effluent TN concentration of 5.95 mg/L TN, while the Wastewater Plan scenario based on direction from Town staff assumed that the WPCF effluent had an average effluent TN concentration of 3 mg/L TN.

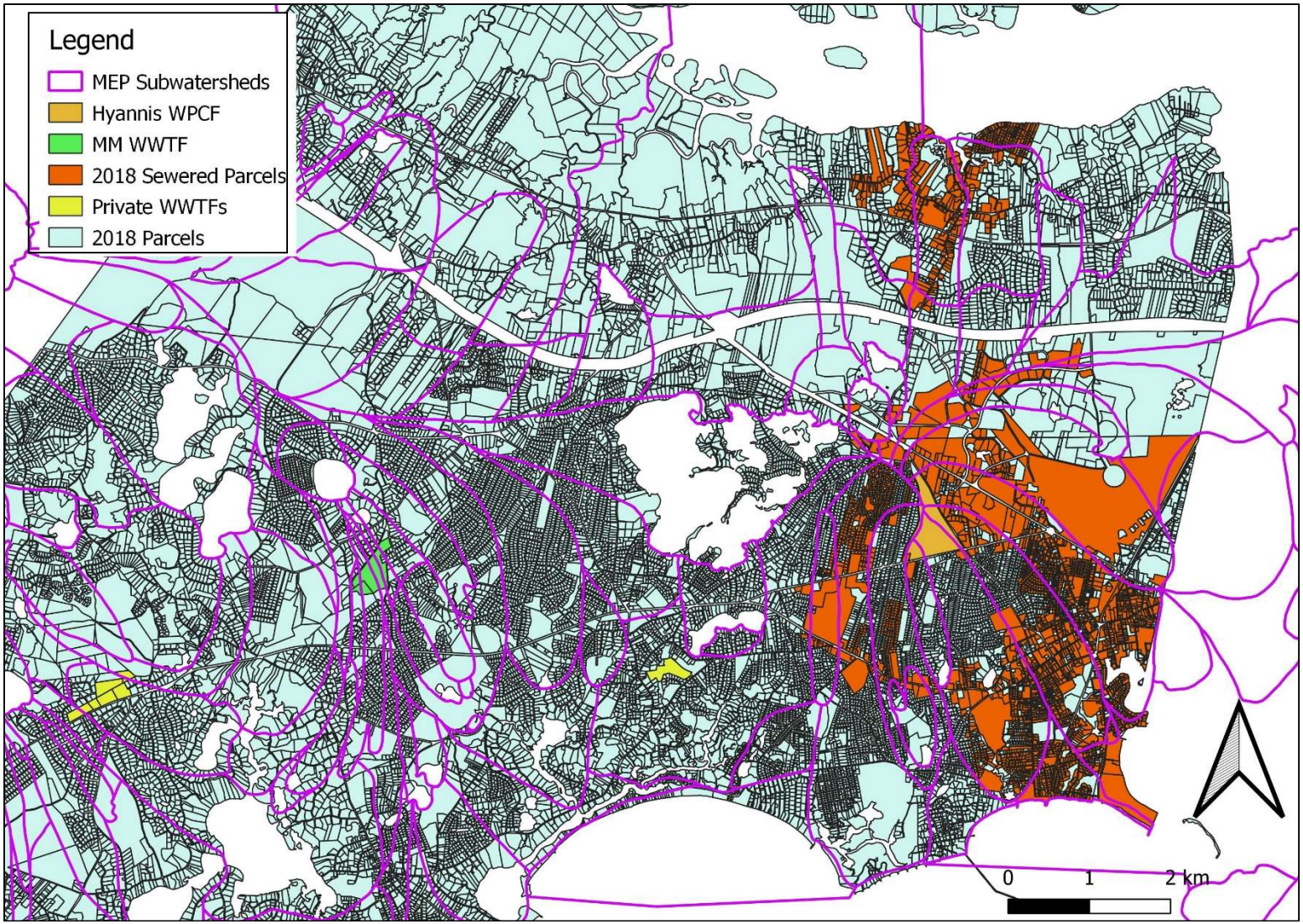

Figure 3. Current Sewered Parcels and Wastewater Treatment Facilities: Town of Barnstable (2018). Based on data supplied by the Town, parcels currently connected to the municipal sewer system are shown in orange. The collected wastewater from these parcels is treated and discharged at the at the Hyannis WPCF (shown in light orange). The Town also operates another municipal treatment facility (shown in green). The location of the two private treatment facilities within the study area are shown in yellow. All other wastewater on developed properties is treated by on-site septic systems.

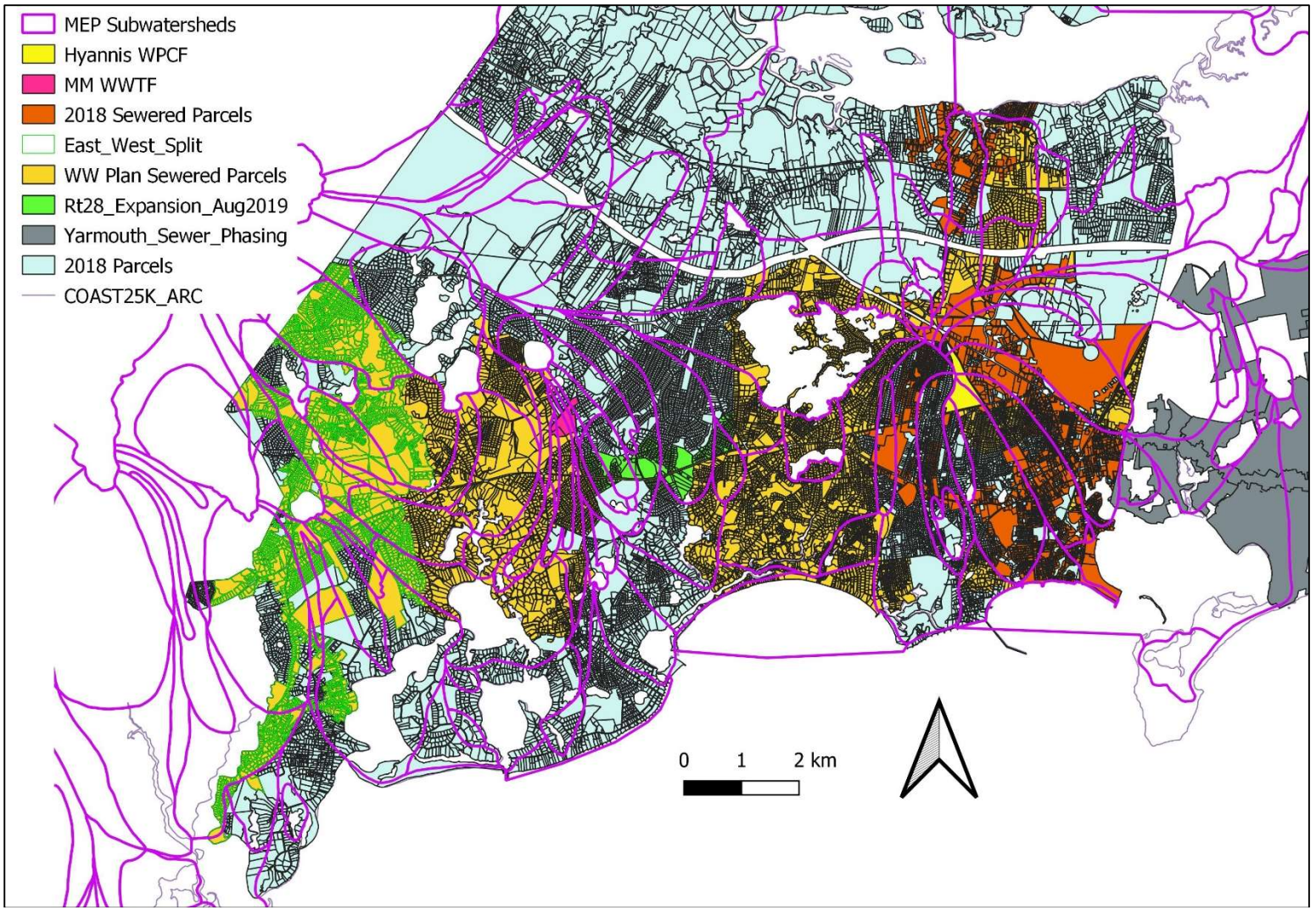

Figure 4. 2019 Town of Barnstable Wastewater Plan: Planned Sewered Parcels. Based on Town data, orange parcels are currently connected to the municipal sewer system, while yellow parcels will be connected in the future under the Wastewater Plan (including two current private treatment plants). In August 2019, the Town added: a) sewering of the green parcels along Route 28 in Centerville and b) different treatment for future sewered parcels in the Three Bays and Popponesset Bay watersheds (parcels outlined in green). Wastewater flow from green-outlined parcels (~0.45 MGD) will be treated and discharged at an as-yet-undetermined site outside of the town boundaries. Also shown are planned Yarmouth sewered areas; wastewater flow (~0.26 MGD) will be treated at the Hyannis WPCF and discharged outside of the Lewis Bay watershed. All other wastewater on developed properties will continue to be treated by on-site septic systems.

Table 1. Wastewater Treatment Facilities within the Barnstable Wastewater Plan study area watersheds. Within the four estuary watersheds reviewed in this project, there are two municipal wastewater treatment facilities and two private facilities. Based on data provided by the Town and MassDEP, project staff updated the associated nitrogen loads for each facility. The Hyannis Water Pollution Control Facility (WPCF) is by far the largest of the facilities (*e.g.*, N load >250X greater than next largest). In the current Wastewater Plan, the two sites with private facilities would be connected to the WPCF sewer system. In addition, the WPCF would treat a substantially greater volume (1.47 MGD is treated under current conditions, while 3.82 MGD will be treated under the Wastewater Plan), but effluent discharge would be distributed to other sites (effluent on the WPCF site would be limited to 2.0 MGD).

	MEP Effluent			2019 Update Effluent			2019 Wastewater Plan Effluent		
	Flow MGD TN load kg/yr	Sewer collection watersheds/ parcels	Key watersheds receiving N load	Flow MGD TN load kg/yr	Sewer collection watersheds/ parcels	Key watersheds receiving N load	Flow MGD TN load kg/yr	Sewer collection watersheds/ parcels	Key watersheds receiving N load
Municipal									
Hyannis WPCF	5.51 12,367	• Lewis Bay • Barnstable Great Marshes • Centerville River	• Lewis Bay • Stewarts Creek • Halls Creek	5.95 13,316	• Lewis Bay • Barnstable Great Marshes • Centerville River	• Lewis Bay • Stewarts Creek • Halls Creek	3.0 14,375	• Lewis Bay • Barnstable Great Marshes • Centerville River • Three Bays	• Lewis Bay • Stewarts Creek • Halls Creek • Barnstable Great Marshes • Yarmouth*
Marstons Mills WWTF	0.004 25	• Horace Mann Charter School	• West Bay	0.012 53	• West Village Elem. School • Barnstable United Elem. School	• Scudder Bay	0.012 53	• West Village Elem. School • Barnstable United Elem. School	• Scudder Bay
Private									
Cape Regency	Title 5 system	• Cape Regency	• Centerville River East	0.015 55	• Cape Regency	• Centerville River East	0	• Cape Regency	Flow to Hyannis WPCF
Cotuit Landing	0.005 34	• Cotuit Landing	• Prince Cove	0.004 46	• Cotuit Landing	• Prince Cove	0	• Cotuit Landing	Flow to Hyannis WPCF

Table 2. Watershed Nitrogen Loads for Three Bays Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan. The 2019 update of watershed parcels, water use, impervious surfaces, etc. increased the attenuated nitrogen load of the overall system watershed by 5.5% and the unattenuated load by 0.8% compared to the MEP loads. Most of the changes were due to increased impervious surface loads, which were somewhat offset by decreased wastewater loads. The relatively increased attenuated loads were due to relatively greater impervious surface increases in the lower portion of the watershed. The proposed Town Wastewater Plan would decrease the attenuated load by 44% with the majority of the decrease within the Prince Cove subwatershed. These loads do not include nitrogen deposition on the estuary surfaces.

Scenario	Description	Watershed/ Subwatershed	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
			Septic	WWTF					Unatten	Atten
			kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2000-2004	Overall – Whole System	53,584	39	7,920	2,828	2,841	1,641	68,853	48,943
		Cotuit Bay	9,739	0	1,086	589	254	352	12,020	9,541
		Seapuit River	1,066	0	235	39	0	35	1,375	1,375
		West Bay	5,832	6	913	260	78	97	7,185	6,960
		North Bay	9,898	0	994	477	83	221	11,673	10,748
		Prince Cove	27,050	34	4,692	1,463	2,426	935	36,599	20,319
2019 Current Conditions Update	Updated land use, water use, impervious surfaces, etc. to current conditions	Overall – Whole System	51,272	46	6,367	7,231	2,926	1,531	69,372	51,643
		Cotuit Bay	9,308	0	939	1,273	254	339	12,113	9,909
		Seapuit River	1,151	0	236	120	0	32	1,539	1,539
		West Bay	5,896	0	866	681	79	82	7,603	7,515
		North Bay	9,875	0	827	1,384	83	196	12,364	11,417
		Prince Cove	25,042	46	3,499	3,773	2,511	882	35,753	21,263
2019 Town Wastewater Plan	Use 2019 update with planned sewering	Overall – Whole System	24,491	0	6,367	7,231	2,926	1,531	42,545	29,039
		Cotuit Bay	6,183	0	939	1,273	254	339	8,988	7,143
		Seapuit River	1,151	0	236	120	0	32	1,539	1,539
		West Bay	5,804	0	866	681	79	82	7,511	7,456
		North Bay	2,105	0	827	1,384	83	196	4,504	4,191
		Prince Cove	9,338	0	3,499	3,773	2,511	882	20,003	8,710

Table 3. Watershed, Benthic Flux, and Direct Atmospheric Nitrogen Loads for Three Bays Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan Scenarios. These are the nitrogen loads used in the water quality modeling of each scenario. Subwatershed loads include all nitrogen sources, including septic wastewater loads, impervious surface runoff, and lawn fertilizers. Direct atmospheric deposition loads are nitrogen loads on the surface of each of the subembayments. Net benthic flux loads are nitrogen regenerated from sediments within each subembayment. MEP nitrogen loads from the 2006 Report are also shown for comparison. All nitrogen loads are presented as kilograms per day.

	Total Attenuated Watershed Loads (kg/d N)			Total Attenuated Watershed Loads (% change from MEP)		Benthic Flux Net (kg/d N)			direct atmospheric deposition (kg/day N)	
Sub-Embayment	MEP	2019 Land Use Update	2019 Wastewater Plan	2019 Land Use Update	2019 Wastewater Plan	MEP	2019 Land Use Update	2019 Wastewater Plan	MEP	Both scenarios
Cotuit Bay	21.778	23.027	16.274	+5.7%	-25.3%	-54.443	-55.961	-46.286	5.786	5.786
West Bay	19.068	20.589	20.427	+8.0%	+7.1%	3.815	3.866	3.565	4.233	4.227
Seapuit River	3.767	4.216	4.216	+11.9%	+11.9%	-5.418	-5.504	-4.973	0.452	0.455
North Bay	29.447	31.279	11.482	+6.2%	-61.0%	67.522	70.182	53.981	3.953	3.792
Prince Cove	13.362	12.718	5.449	-4.8%	-59.2%	0.512	0.543	0.384	1.230	1.225
Warrens Cove	12.027	13.441	4.041	+11.8%	-66.4%	8.830	9.204	6.894	-	-
Prince Cove Channel	5.537	7.022	1.677	+26.8%	-69.7%	2.345	2.441	1.811	-	-
Marstons Mills Crescent	7.293	7.164	3.507	-1.8%	-51.9%	-	-	-	-	-
Rivers and Streams										
Marstons Mills River	14.518	17.910	9.189	+23.4%	-36.7%	-	-	-	-	-
Little River	3.962	4.121	3.296	+4.0%	-16.8%	-	-	-	-	-
SYSTEM TOTAL	**130.759**	**141.488**	**79.559**	**+8.2%**	**-39.2%**	**23.163**	**24.771**	**15.376**	**15.654**	**15.485**

Table 4. Comparison of modeled average total N concentrations for Three Bays system: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan Scenarios. The sentinel station threshold is 0.38 mg/L TN at a sentinel station located in the narrows between North Bay and Cotuit Bay; this monitoring station and the threshold target are shown in **bold** print. 2019 Wastewater Plan scenario does not attain the threshold target. Note that other nitrogen removal alternatives are being planned for this watershed, but sewering was needed to lower the nitrogen load to complete the restoration.

Sub-Embayment	monitoring station	MEP Existing (mg/L)	MEP Threshold Goal (mg/L)	2019 Land Use Update (mg/L)	% change from MEP	2019 Wastewater Plan (mg/L)	% change from MEP
Prince Cove - south	TB2	0.695		0.712	+4.1%	0.511	-44.4%
Prince Cove - north	TB3	0.639		0.668	+8.1%	0.489	-41.6%
Warrens Cove	TB4	0.595		0.616	+7.0%	0.466	-41.0%
North Bay - north	TB5	0.518		0.531	+5.3%	0.426	-38.6%
North Bay - south	TB6	0.500		0.503	+1.0%	0.410	-40.9%
North Windmill Cove	TB7	0.511		0.524	+6.0%	0.424	-37.6%
West Bay - north	TB8	0.363		0.384	+25.6%	0.347	-19.0%
West Bay - west	TB9	0.327		0.327	+1.3%	0.312	-32.1%
Eel River	TB10	0.486		0.500	+6.5%	0.460	-12.8%
Seapuit River	TB11	0.295		0.296	+6.9%	0.290	-34.5%
Cotuit Bay - north	TB12	0.414		0.416	+1.1%	0.358	-42.0%
Cotuit Bay - south	TB13	0.321		0.324	+5.8%	0.303	-43.6%
South Windmill Cove	TB15	0.402		0.417	+11.8%	0.389	-10.7%
Mellon Cove	TB16	0.392		0.399	+6.3%	0.386	-4.9%
Dam Pond	TB17	0.523		0.538	+6.1%	0.430	-38.5%
Sentinel station (narrows between North Bay and Cotuit Bay)	**-**	0.487	**0.380**	0.499	+5.6%	0.408	-38.2%

Table 5. Watershed Nitrogen Loads for Centerville River Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan. The 2019 update of watershed parcels, water use, impervious surfaces, etc. increased the attenuated nitrogen load of the overall system watershed by 5.3% and the unattenuated load by 2.3% compared to the MEP loads. Most of the increased loads were due to increased impervious surface loads, which were somewhat offset by decreased wastewater loads. The relatively increased attenuated loads were due to relatively greater impervious surface increases in the upper portion of the watershed (Centerville East). The proposed Town Wastewater Plan would decrease the attenuated load by 41% with the majority of the decrease within the Centerville East subwatershed. These loads do not include nitrogen deposition on the estuary surfaces.

Scenario	Description	Watershed/ Subwatershed	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
			Septic	WWTF					Unatten	Atten
			kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2004	Whole System	48,493	47	3,155	3,972	4,069	921	60,657	47,189
		Centerville River East	23,544	47	1,150	2,006	3,595	402	30,744	22,302
		Scudder Bay	19,614	0	1,699	1,577	360	397	23,647	18,958
		Centerville River West	2,812	0	145	180	0	56	3,192	3,192
		East Bay	2,523	0	161	210	113	67	3,074	2,738
2019 Current Conditions Update	Updated land use, water use, impervious surfaces, etc.	Whole System	46,891	163	3,815	6,162	4,174	849	62,054	49,692
		Centerville River East	22,638	111	1,753	3,186	3,595	360	31,643	23,444
		Scudder Bay	18,901	53	1,754	2,299	400	376	23,784	19,972
		Centerville River West	2,763	0	145	338	64	51	3,362	3,362
		East Bay	2,589	0	162	338	113	62	3,265	2,913
Town Wastewater Plan	Use 2019 update with planned sewering	Whole System	22,574	109	3,815	6,162	4,174	849	37,682	29,323
		Centerville River East	5,610	56	1,753	3,186	3,595	360	14,560	9,348
		Scudder Bay	12,655	53	1,754	2,299	400	376	17,537	14,611
		Centerville River West	1,963	0	145	338	64	51	2,562	2,562
		East Bay	2,347	0	162	338	113	62	3,022	2,802

Table 6. Watershed, Benthic Flux, and Direct Atmospheric Nitrogen Loads for Centerville River Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan Scenarios. These are the nitrogen loads used in the water quality modeling of each scenario. Subwatershed loads include all nitrogen sources, including septic wastewater loads, impervious surface runoff, and lawn fertilizers. Direct atmospheric deposition loads are nitrogen loads on the surface of each of the subembayments. Net benthic flux loads are nitrogen regenerated from sediments within each subembayment. MEP nitrogen loads from the 2006 Report are also shown for comparison. All nitrogen loads are presented as kilograms per day.

	Total Attenuated Watershed Loads (kg/d N)			Total Attenuated Watershed Loads (% change from MEP)		Benthic Flux Net (kg/d N)			direct atmospheric deposition (kg/day N)
Sub-Embayment	MEP	2019 Land Use Update	2019 Wastewater Plan	2019 Land Use Update	2019 Wastewater Plan	MEP	2019 Land Use Update	2019 Wastewater Plan	MEP & both scenarios
Centerville River East	55.737	57.178	22.852	+2.6%	-59.0%	5.394	5.469	4.779	0.449
Scudder Bay	14.452	14.312	6.797	-1.0%	-53.0%	-2.125	-2.170	-1.834	0.685
Centerville River West	9.463	9.036	6.841	-4.5%	-27.7%	3.497	3.507	3.315	0.718
East Bay	8.627	7.981	7.679	-7.5%	-11.0%	12.694	12.869	12.067	1.126
Rivers and Streams									
Pine Street Stream	3.452	4.948	2.236	+43.3%	-35.2%	-	-	-	-
Lake Elizabeth Stream	2.274	2.104	0.523	-7.5%	-77.0%	-	-	-	-
Bumps River	16.912	19.074	16.397	+12.8%	-3.0%	-	-	-	-
Skunknet River	21.260	21.334	16.838	+0.3%	-20.8%	-	-	-	-

Table 7. Comparison of modeled average total N concentrations for Centerville River: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan Scenarios. The sentinel station threshold is 0.37 mg/L TN at BC-T with secondary threshold targets of 0.4 to 0.5 mg/L TN at BC-3 and BC-7 to support restoration of benthic infaunal habitat quality; these monitoring stations and threshold targets are shown in **bold** print. 2019 Wastewater Plan scenario attains the threshold targets at the selected monitoring stations, needed for restoration of estuarine habitat and water quality.

Sub-Embayment	monitoring station	MEP Existing (mg/L)	MEP Threshold Goal (mg/L)	2019 Land Use Update (mg/L)	% change from MEP	2019 Wastewater Plan (mg/L)	% change from MEP
Scudder Bay	**BC-3**	**0.524**	**0.4 - 0.5**	**0.538**	**+2.5%**	**0.443**	**-15.5%**
Bumps River	BC-4	0.451		0.455	+1.0%	0.390	-13.4%
Centerville River	BC-5	0.609		0.620	+1.8%	0.445	-26.9%
Centerville River	**BC-7**	**0.526**	**0.4 - 0.5**	**0.533**	**+1.2%**	**0.412**	**-21.7%**
Centerville River	BC-8	0.454		0.455	+0.3%	0.380	-16.4%
Centerville River	BC-9	0.389		0.389	-0.1%	0.350	-10.2%
East Bay	BC-10	0.349		0.349	+0.1%	0.329	-5.8%
Confluence of Bumps River and Centerville River	**BC-T**	**0.412**	**0.37**	**0.414**	**+0.5%**	**0.363**	**-12.1%**

Table 8. Watershed Nitrogen Loads for Lewis Bay Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan. The 2019 update of watershed parcels, water use, impervious surfaces, additional sewer connections, etc. increased the attenuated nitrogen load of the overall system watershed by 8.4% and the unattenuated load by 6.7% compared to the MEP loads. Most of the changes were due to increased impervious surface loads, but there was also increases in the WPCF load. Most of the increase was in the Mill Creek and Inner Harbor subwatersheds. The proposed Town Wastewater Plan would decrease the attenuated load by 43% with the largest decrease in the Main Bay subwatershed (shed #16). These loads do not include nitrogen deposition on the estuary surfaces.

Scenario	Description	Watershed/ Subwatershed	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
			Septic	WWTF					Unatten	Atten
			kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2004	Overall – Whole System	34,909	12,367	3,084	4,937	347	1,107	56,751	50,574
		Mill Creek	10,727	409	652	1,499	247	553	14,086	11,298
		Inner Harbor	2,496	627	290	885	10	128	4,436	4,429
		Main Bay	9,669	0	666	787	0	140	11,262	11,262
		Snow's Crk	2,559	4,219	366	621	34	77	7,875	5,517
		Stewart's Crk	6,170	7,112	782	749	39	106	14,959	14,232
2019 Current Conditions Update	Updated land use, water use, impervious surfaces, etc. to current conditions	Overall – Whole System	32,513	13,316	3,025	10,386	429	871	60,538	54,838
		Mill Creek	10,481	409	653	3,307	247	484	15,582	13,699
		Inner Harbor	1,731	677	264	2,786	10	49	5,517	5,501
		Main Bay	9,560	0	657	1,015	0	118	11,350	11,350
		Snow's Crk	2,196	4,554	344	1,450	34	39	8,617	6,038
		Stewart's Crk	4,442	7,676	778	1,234	39	79	14,248	13,510
2019 Town Waste-water Plan	Use 2019 update with planned sewering	Overall – Whole System	12,609	8,246	3,025	10,386	429	871	35,565	31,501
		Mill Creek	4,591	409	653	3,307	247	484	9,692	8,045
		Inner Harbor	748	402	264	2,786	10	49	4,259	4,242
		Main Bay	567	0	657	1,015	0	118	2,356	2,356
		Snow's Crk	597	2,702	344	1,450	34	39	5,165	3,622
		Stewart's Crk	3,063	4,734	778	1,234	39	79	9,926	9,188

Table 9. Watershed Nitrogen Loads for Halls Creek Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan. The 2019 update of watershed parcels, water use, impervious surfaces, additional sewer connections, etc. increased the attenuated nitrogen load of the overall system watershed by +6.4% and the unattenuated load by +6.6% compared to the MEP loads. Most of the changes were due to increased impervious surface loads, but there was also an increase in the WPCF load. Most of the increase was in the portion of the watershed that discharges directly to the estuary/salt marsh system. The proposed Town Wastewater Plan would decrease the attenuated load by -14%. These loads do not include nitrogen deposition on the estuary surfaces.

Scenario	Description	Watershed/ Subwatershed	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
			Septic	WWTF					Unatten	Atten
			kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2004	Overall – Whole System	6,221	988	1,554	731	39	160	9,694	8,833
		Halls Creek Stream	648	988	63	77	39	19	1,834	973
		Simmons Pond	515	0	52	64	33	17	680	319
2019 Current Conditions Update	Updated land use, water use, impervious surfaces, etc. to current conditions	Overall – Whole System	6,292	1,067	1,571	1,209	58	132	10,329	9,395
		Halls Creek Stream	630	1067	61	131	58	16	1,963	1,029
		Simmons Pond	504	0	50	112	52	14	732	321
2019 Town Waste-water Plan	Use 2019 update with planned sewering	Overall – Whole System	4,800	1,252	1,571	1,209	58	132	9,023	8,089
		Halls Creek Stream	630	1,067	61	131	58	16	1,963	1,029
		Simmons Pond	504	0	50	112	52	14	732	321

Table 10. Watershed, Benthic Flux, and Direct Atmospheric Nitrogen Loads for Lewis Bay and Halls Creek Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan Scenarios. These are the nitrogen loads used in the water quality modeling of each scenario. Subwatershed loads include all nitrogen sources, including septic wastewater loads, impervious surface runoff, and lawn fertilizers. Direct atmospheric deposition loads are nitrogen loads on the surface of each of the subembayments. Net benthic flux loads are nitrogen regenerated from sediments within each subembayment. MEP nitrogen loads from the 2008 Report are also shown for comparison. All nitrogen loads are presented as kilograms per day.

	Total Attenuated Watershed Loads (kg/d N)			Total Attenuated Watershed Loads (% change from MEP)		Benthic Flux Net (kg/d N)			direct atmospheric deposition (kg/day N)
Sub-Embayment	MEP	2019 Land Use Update	2019 Wastewater Plan	2019 Land Use Update	2019 Wastewater Plan	MEP	2019 Land Use Update	2019 Wastewater Plan	MEP & both scenarios
Lewis Bay									
Lewis Bay	30.855	31.592	6.622	+2.4%	-78.5%	25.999	26.520	23.396	13.507
Uncle Roberts Cove	0.540	0.633	0.633	+17.3%	+17.3%	12.771	13.166	10.556	0.759
Mill Creek	15.964	16.285	3.682	+2.0%	-76.9%	-15.355	-1.600	-1.176	0.627
Hyannis Inner Hbr	12.153	15.071	11.622	+24.0%	-4.4%	18.660	20.703	18.172	0.633
Snows Creek	15.115	16.542	9.923	+9.4%	-34.3%	-4.533	-4.356	-3.313	-
Stewarts Creek	38.992	37.014	25.173	-5.1%	-35.4%	-9.750	-10.296	-7.751	0.236
Rivers and Streams									
Chase Brook	3.345	3.460	2.329	+3.4%	-30.4%	-	-	-	-
Mill Pond	15.038	17.786	16.030	+18.3%	+6.6%	-	-	-	-
Hospital Creek	1.907	1.937	0.367	+1.6%	-80.7%	-	-	-	-
Halls Creek									
Halls Creek	21.534	22.921	19.340	+6.4%	-10.2%	5.252	5.535	5.164	0.630
Halls Creek Stream	1.597	2.819	2.819	+76.5%	+76.5%	-	-	-	-
SYSTEM TOTAL	23.132	25.740	22.159	+11.3%	-4.2%	5.252	5.535	5.164	0.630

Table 11. Comparison of modeled average total N concentrations for Lewis Bay and Halls Creek: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan Scenarios. The Lewis Bay sentinel station threshold is 0.38 mg/L TN at BHY-3 monitoring station with secondary threshold targets of 0.4 mg/L TN for eelgrass restoration in Uncle Roberts Cove and 0.5 mg/L in Mill Creek (MC-1) and an average of the two Hyannis Harbor stations (BH-1 and BH-2) to restore healthy infaunal habitat; these monitoring stations and threshold targets are shown in **bold** print. 2019 Wastewater Plan scenario attains the Lewis Bay threshold targets at the selected monitoring stations, needed for restoration of estuarine habitat and water quality.

Halls Creek has a higher threshold (1 mg/L TN) as a healthy salt marsh system and has TN concentrations at the sentinel station (BC-14) that are less than this threshold at the time of the MEP assessment and remain so under the 2019 scenarios with the land use update and the planned Wastewater Plan.

Sub-Embayment	monitoring station	MEP Existing (mg/L)	MEP Threshold (mg/L)	2019 Land Use Update (mg/L)	% change from MEP	2019 Wastewater Plan (mg/L)	% change from MEP
Lewis Bay							
Hyannis Inner Harbor	**BH-1**	**0.549**	**0.5 avg**	**0.572**	**+4.0%**	**0.517**	**-6.0%**
Hyannis Inner Harbor	**BH-2**	**0.496**		**0.516**	**+4.0%**	**0.470**	**-5.2%**
Hyannis Inner Harbor	BH-3	0.440		0.459	+4.5%	0.424	-3.6%
Snows Creek	BH-4	1.638		1.820	+11.2%	1.152	-29.6%
Lewis Bay	BH-5	0.387		0.391	+1.1%	0.368	-4.9%
Lewis Bay	BH-6	0.368		0.373	+1.5%	0.355	-3.5%
Stewarts Creek	BH-7	1.374		1.336	-2.8%	0.985	-28.3%
Lewis Bay	BHY-1	0.384		0.388	+1.1%	0.366	-4.8%
Lewis Bay	BHY-2	0.414		0.422	+2.0%	0.388	-6.3%
Lewis Bay	**BHY-3**	**0.407**	**0.380**	0.413	**+1.4%**	**0.380**	**-6.5%**
Uncle Roberts Cove	**BHY-4**	**0.431**	**0.4**	0.437	**+1.4%**	**0.402**	**-6.7%**
Mill Creek	**MC-1**	**0.531**	**0.5**	0.545	**+2.6%**	**0.476**	**-10.5%**
Mill Creek	MC-2	0.473		0.484	+2.2%	0.429	-9.3%
Halls Creek							
Halls Creek - stream	BC-13	1.189		1.73	+60.5%	1.7147	+58.8%
Halls Creek - mid	**BC-14**	**0.469**	**1.00**	**0.4855**	**+9.7%**	**0.4661**	**-1.4%**
Halls Creek - inlet	BC-15	0.385		0.3976	+13.5%	0.3871	+2.0%

Table 12. Watershed Nitrogen Loads for Barnstable Great Marshes Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan. The 2019 update of watershed parcels, water use, impervious surfaces, additional sewer connections, etc. had negligible impact on the overall unattenuated and attenuated system loads (<1% change), although the impervious surface load increased due to the more comprehensive accounting of these land uses. The proposed Town Wastewater Plan would increase the attenuated system load by 1.3%, but would decrease the Millway subwatershed load by 53%. *Millway is part of Great Marsh East subwatershed and was the only impaired portion of the Great Marsh system that was identified in the MEP assessment. These loads do not include nitrogen deposition on the estuary surfaces.

Scenario	Description	Watershed/ Subwatershed	Wastewater		Fertilizers + Farm Animals	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
			Septic	WWTF					Unatten	Atten
			kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2011-2012	Overall – Whole System	53,984	274	8,362	5,247	1,903	3,842	73,613	66,221
		Great Marshes -W	10,727	0	2,580	1,103	304	1,361	16,165	14,084
		Great Marshes -M	8,649	0	1,178	965	813	860	12,465	10,060
		Great Marshes - E	14,847	0	2,391	1,599	505	976	20,318	19,379
		Millway*	2,748	0	907	350	0	141	4,145	3,860
		Bass Hole	19,671	274	2,213	1,580	281	646	24,665	22,698
2019 Current Conditions Update	Updated land use, water use, impervious surfaces, etc.	Overall – Whole System	50,607	274	8,216	9,076	1,903	3,740	73,815	66,667
		Great Marshes -W	9,770	0	2,526	2,181	304	1,343	16,124	14,162
		Great Marshes -M	7,821	0	1,146	1,811	813	825	12,417	10,117
		Great Marshes - E	13,359	0	2,332	3,060	504	938	20,193	19,308
		Millway*	2,160	0	875	680	0	127	3,844	3,605
		Bass Hole	19,656	274	2,213	2,023	281	633	25,080	23,080
2019 Town Waste-water Plan	Use 2019 update with planned sewering	Overall – Whole System	46,388	5,268	8,216	9,076	1,903	3,740	74,591	67,597
		Great Marshes -W	9,770	0	2,526	2,181	304	1,343	16,124	14,162
		Great Marshes -M	6,073	4,995	1,146	1,811	813	825	15,663	13,442
		Great Marshes - E	10,889	0	2,332	3,060	504	938	17,723	16,912
		Millway*	215	0	875	680	0	127	1,898	1,700
		Bass Hole	19,656	274	2,213	2,023	281	633	25,080	23,080

Table 13. Watershed, Benthic Flux, and Direct Atmospheric Nitrogen Loads for Barnstable Great Marshes Scenarios: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan Scenarios. These are the nitrogen loads used in the water quality modeling of each scenario. Subwatershed loads include all nitrogen sources, including septic wastewater loads, impervious surface runoff, and lawn fertilizers. Direct atmospheric deposition loads are nitrogen loads on the surface of each of the subembayments. Net benthic flux loads are nitrogen regenerated from sediments within each subembayment. MEP nitrogen loads from the 2017 Report are also shown for comparison. All nitrogen loads are presented as kilograms per day.

	Total Attenuated Watershed Loads (kg/d N)			Total Attenuated Watershed Loads (% change from MEP)		Benthic Flux Net (kg/d N)			direct atmospheric deposition (kg/day N)
Sub-Embayment	MEP	2019 Land Use Update	2019 Wastewater Plan	2019 Land Use Update	2019 Wastewater Plan	MEP	2019 Land Use Update	2019 Wastewater Plan	MEP & both scenarios
Barnstable Harbor - west	38.586	38.801	38.801	+0.6%	+0.6%	5.304	5.304	5.523	2.422
Barnstable Harbor - mid	27.562	27.718	36.829	+0.6%	+33.6%	-11.497	-11.497	-11.488	13.800
Barnstable Harbor - east	42.600	43.109	41.764	+1.2%	-2.0%	-23.366	-23.366	-23.341	32.978
Millway	10.575	9.878	4.658	-6.6%	-56.0%	2.853	2.767	2.188	0.211
Chase Garden Creek - west	29.666	30.158	30.158	+1.7%	+1.7%	0.373	0.373	0.373	0.140
Chase Garden Creek - east	25.030	25.415	25.415	+1.5%	+1.5%				0.003
Bass Hole	7.408	7.572	7.572	+2.2%	+2.2%	-1.079	-1.079	-1.079	0.488
SYSTEM TOTAL	181.427	182.651	185.197	+0.7%	+2.1%	-27.412	-27.498	-27.823	50.041

Table 14. Comparison of modeled average bioactive N concentrations for Barnstable Great Marshes system: MEP, 2019 Land Use Update, Town of Barnstable Wastewater Plan Scenarios. The sentinel station thresholds are 0.16 mg/L bioactive N at sentinel stations located in salt marsh dominated basins and 0.21 mg/L bioactive N within the Millway, a dredged basin; the selected monitoring stations and the threshold targets are shown in **bold** print. 2019 Wastewater Plan scenario attained the threshold targets at each of the sentinel stations. Bioactive nitrogen is used instead of TN is large systems, like Barnstable Great Marshes and Pleasant Bay, where there is a lot of non-active dissolved organic nitrogen and habitat and water quality are determined by the most active forms (inorganic and particulate nitrogen).

Sub-Embayment	monitoring station	MEP Existing (mg/L)	MEP Threshold (mg/L)	2019 Land Use Update (mg/L)	% change from MEP	2019 Wastewater Plan (mg/L)	% change from MEP
Scorton Creek	BM-13	0.121	**0.16**	0.122	+0.3%	0.125	+5.5%
Spring Creek	BM-11	0.127	**0.16**	0.127	+0.2%	0.132	+7.9%
Barnstable Harbor – upper	BM-12	0.111		0.112	+0.4%	0.115	+7.0%
Barnstable Harbor – upper	BM-1	0.097		0.097	+0.3%	0.099	+5.9%
Barnstable Harbor – mid	BM-2	0.085		0.085	+0.5%	0.086	+5.4%
Barnstable Harbor – lower	BM-3	0.072		0.073	+1.1%	0.073	+5.3%
Broad Sound	BM-10	0.105		0.105	+0.0%	0.107	+4.5%
Bass Hole	BSH-1	0.093		0.093	+1.7%	0.093	+1.7%
Chase Garden Creek - lower	BSH-2	0.111		0.111	+1.5%	0.111	+1.5%
Chase Garden Creek	BSH-3	0.122		0.123	+1.5%	0.123	+1.5%
Chase Garden Creek	BSH-4	0.132	**0.16**	0.133	+1.6%	0.133	+1.6%
Chase Garden Creek	BSH-5	0.271		0.274	+1.4%	0.274	+1.4%
Chase Garden Creek – upper	BSH-6	0.571		0.575	+0.7%	0.575	+0.7%
Whites Brook	BSH-7	0.321		0.326	+1.7%	0.326	+1.7%
Millway	-	0.266	**0.21**	0.255	-5.6%	0.171	-46.7%

University of Massachusetts Dartmouth
The School for Marine Science and Technology

********** **Technical Memorandum** **********

To: **Mark Ells, Town Manager, Town of Barnstable**

From: **Brian Howes, Director Coastal Systems Program SMAST**
Ed Eichner, MEP Watershed Lead for CSP-SMAST and TMDL Solutions

Re: **Update on Watershed nitrogen loading and TMDL N thresholds at present and post-wastewater improvements for Barnstable estuaries: Three Bays, Centerville River, Lewis Bay and Barnstable Great Marshes.**

Date: October 8, 2019

****

This Tech Memo is being provided as an update on the nearly completed full watershed N loading updated analysis (completed) and water quality modeling (underway) of the 4 major Barnstable estuaries: Three Bays, Centerville River, Lewis Bay and Barnstable Great Marshes, and the loading reductions from proposed wastewater system implementation as developed by the Barnstable DPW. The watershed loading update and wastewater N loading reduction was developed as a joint effort between engineers within Barnstable DPW and SMAST scientists.

CSP-SMAST scientists analyzed updated land-use data from 2018 and average water uses, which is used as a proxy for wastewater generation, based on 2011 to 2016. These updates were extensive for Three Bays, Centerville River, Lewis Bay, which were completed for the MEP based on data from 2000 to 2004. The Barnstable Great Marshes MEP assessment was based on 2011 to 2012 data The land-use data was integrated with parcel based on average water use to yield the updated parcel based watershed N loads. The updated watershed N loads were then used in the MEP linked watershed-embayment management model to assess changes in projected nitrogen concentrations throughout each of the 4 Barnstable estuaries. The MEP hydrodynamic module and sediment regeneration rates, after adjustment to the new N loading, were used as the other inputs into the linked model.

In addition to updating the watershed N loading, the Barnstable DPW provided details for the Wastewater Implementation Scenarios for each of the 4 Barnstable estuaries, including the planned sewer areas, targeted effluent N concentrations and volumes and locations for discharge of treated effluent for the extensive use of the Hyannis WPCF. These post-wastewater implementation watershed loads were then used as input into the newly updated Linked Models. These loads were used to project changes in nitrogen concentrations throughout the 4 Barnstable estuaries relative to the nitrogen threshold targets put forward by EPA/DEP in the available TMDL's under the Clean Water Act, specific to each estuary.

While this is a preliminary analysis based primarily on the new watershed loads for present and post-wastewater implementation scenarios, there are some clear results relative to meeting the N loading targets specific to each estuary for restoration of water and habitat quality. Based upon the analysis to date, it appears that the Centerville River Estuary and the Lewis Bay Estuary should meet their restoration N targets once the Town's wastewater plan is fully implemented. The post-wastewater implementation N loads in both cases appears to be sufficiently below the TMDL target load so that the TMDL threshold TN concentration at the Sentinel Station should be met. This is particularly likely as the Linked Model when complete with the new watershed nitrogen loads also "adjusts" the sediment nitrogen regeneration for the new lower watershed loading and lower

phytoplankton production under that loading. This should further lower the final TN concentrations relative to the TMDL N threshold level.

The Barnstable Great Marshes as a whole are far below their acceptable restorative threshold watershed N load and TN threshold concentration at present. Wastewater N removals through sewers and WWTF treatment is targeted primarily on the loads to the Barnstable Harbor boat basin/Millway basin which are the small portion of this large estuary which are currently showing some nitrogen related impairments, primarily to benthic animal habitat. It does appear that the sewer plan when implemented will significantly reduce the N load to this small tributary basin.

Finally, the Three Bays Estuary may be slightly above its watershed TMDL target with implementation of the Town's wastewater plan alone. However, it should show significant improvement throughout its basins, with most of its tidal reaches fully restored. However, the Town's wastewater plan needs to be evaluated in the context of other watershed nitrogen removal efforts (Mill Pond restoration, Hamblin Bogs restoration/enhanced N removal, implementation of targeted I/A systems within the Marstons Mills River sub-watershed, and possible PRB installation, etc) as well as in estuary N removal through targeted shellfish aquaculture. Given that the watershed N load is close to the TMDL target, it is also possible that the Linked Model output will be even closer (if not achieve) the N concentration threshold at the Sentinel Station when the updated sediment regeneration rates for post-wastewater implementation are incorporated into the Linked Models. As noted above, sediment regeneration is a response to the level of phytoplankton production in these shallow estuaries, like Three Bays. Phytoplankton production is a direct result of nitrogen levels (controlled by watershed N loading and flushing). Therefore, as watershed N loading is lowered, estuarine N levels decline and there are less phytoplankton to settle and support sediment nitrogen release. This response has been directly measured in estuaries in southeastern Massachusetts, previously, by the MEP Technical Team and it a fundamental part of the MassDEP/SMAST MEP approach.

The final step in the present evaluation of these 4 estuaries and their specific wastewater plans is the completion of the Linked watershed-embayment modeling which is underway and will be completed very soon.

Three Bays: Whole System Watershed N Loads

Scenario	Description	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
		Septic	WWTF					Unatten	Atten
		kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2000-2004	53,584	39	7,920	2,828	2,841	1,641	68,853	48,943
MEP	Threshold								25,643
2019 Current	updated LU, WU, etc	51,272	46	6,367	7,231	2,926	1,531	69,372	51,643
Wastewater Plan	2019 update w/planned sewering	24,491	0	6,367	7,231	2,926	1,531	42,545	29,039

Centerville River: Whole System Watershed N Loads

Scenario	Description	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
		Septic	WWTF					Unatten	Atten
		kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2004	48,493	47	3,155	3,972	4,069	921	60,657	47,189
MEP	Threshold								34,833
2019 Current	updated LU, WU, etc	46,891	163	3,815	6,162	4,174	849	62,054	49,692
Wastewater Plan	2019 update w/planned sewering	22,574	109	3,815	6,162	4,174	849	37,682	29,323

Lewis Bay: Whole System Watershed N Loads

Scenario	Description	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
		Septic	WWTF					Unatten	Atten
		kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2004	34,909	12,367	3,084	4,937	347	1,107	56,751	50,574
MEP	Threshold								35,701
2019 Current	updated LU, WU, etc	32,513	13,316	3,025	10,386	429	871	60,538	54,838
Wastewater Plan	2019 update w/planned sewering	12,609	8,246	3,025	10,386	429	871	35,565	31,501

Barnstable Great Marshes: Whole System Watershed N Loads

Scenario	Description	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
		Septic	WWTF					Unatten	Atten
		kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline 2011-2012	53,984	274	8,362	5,247	1,903	3,842	73,613	66,221
MEP	Threshold								92,433
2019 Current	updated LU, WU, etc	50,607	274	8,216	9,076	1,903	3,740	73,815	66,667
Wastewater Plan	2019 update w/planned sewering	46,388	5,268	8,216	9,076	1,903	3,740	74,591	67,597

Appendix RR

Memo: Greenhouse Gas Review

Appendix RR

Action Plan for the Barnstable Ponds

WRIGHT-PIERCE
Engineering a Better Environment

MEMORANDUM

TO:	Griffin Beaudoin, PE – Town of Barnstable	**DATE:**	12/3/2019
FROM:	Edward Leonard, PE	**PROJECT NO.:**	20157A
SUBJECT:	Barnstable CWMP – Preliminary GHG Emissions Review		

BACKGROUND AND PURPOSE

The Barnstable CWMP describes a Recommended Plan (significant expansion of traditional wastewater management systems supplemented by non-traditional nitrogen removal measures) and a No Action Plan (continued widespread use of septic systems without expansion of traditional wastewater management systems).

The Recommended Plan and the No Action Plan will result in continued and increased long-term electrical energy and fossil fuel use related to septic systems, I/A systems, sewer system conveyance pumping, wastewater treatment, effluent disposal and sludge disposal.

The "Revised MEPA Greenhouse Gas Emissions Policy and Protocol" (Massachusetts EOEEA, effective dated May 2010) outlines requirements for a detailed, site-specific greenhouse gas (GHG) emissions comparative analysis. However, given that there are several big-picture items that warrant further consideration (e.g., the number and location of treatment plants, the number and location of effluent disposal facilities, the extent of regionalization with abutting municipalities in shared watersheds, etc.), it is premature to complete the type of GHG emissions analysis envisioned in the policy document at this time. Instead, a preliminary GHG emissions review was conducted.

The purpose of this memorandum is to summarize the inputs and results of the preliminary GHG emissions review for the Barnstable CWMP.

APPROACH

The approach used in this preliminary GHG emissions analysis was to apply unit emission rates to the town-wide estimates of the number of septic system, the number of I/A systems and the number of sewer connections under two conditions: "pre-CWMP" and "post-CWMP". Under both conditions, growth and economic development were excluded. Said another way, this analysis identifies the change in GHG emissions associated with implementing the CWMP for the existing level of development.

UNIT EMISSION RATES

The unit emissions rates were developed based on a literature search. The basis for the unit emission rates is summarized in Attachment A.

PRELIMINARY ESTIMATE OF GHG EMISSIONS

The parameters included and excluded from this analysis are summarized in Table 1 at the end of this memorandum. The estimated number of septic systems, I/A systems, sewer connections and sewer flows under pre-CWMP and post-CWMP conditions are summarized in Table 2 at the end of this memorandum. The estimated GHG emissions under pre-CWMP and post-CWMP conditions are summarized in Table 3 at the end of this memorandum.

The town-wide estimates for the two conditions are as follows: Pre-CWMP: 10,900,000 kg CO2-eq/year; and Post-CWMP: 14,700,000 kg CO2-eq/year. The preliminary GHG emissions analysis indicates that implementation of the CWMP will result in an estimated 35% increase in GHG emissions. This is the net result of a 52% in emissions from septic systems and a 93% increase in emissions from centralized wastewater treatment.

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TABLE 1 - PARAMETERS OF GREENHOUSE GAS EMISSION ANALYSIS

	Included in Analysis **	**Not Included in Analysis ****
Project Phase	Operation	Construction
Direct Emissions	CO2, CH4, N2O WWTF with nitrogen removal Individual septic systems Septage vehicles (to plant) Staff/Chemical/Sludge Vehicles (included in WWTF units)	SO_x, NOx, PFCs, HFCs Collection system Effluent disposal Non-traditional nitrogen removal measures
Indirect Emissions	Electricity for treatment and collection systems Electricity for nitrogen-removing septic systems	Electricity for effluent disposal Chemical production (e.g., methanol) Non-traditional nitrogen removal measures
Other Issues	-	Purchased offsets

NOTE: ** All "per unit" direct and indirect emissions data were obtained from a literature search. No site-specific direct or indirect emission calculations were developed for this review **

BARNSTABLE CWMP
GREENHOUSE GAS EMISSION ANALYSIS
Wright-Pierce, Nov 25, 2019

TABLE 2 - SYSTEMS, CONNECTIONS AND FLOWS FOR PRE-CWMP AND POST-CWMP CONDITIONS (EXCLUDING GROWTH)

	PRE-CWMP (EX. CONDITIONS)				CHANGE			CWMP/ NO GROWTH		
COMPONENT	NUMBER		FLOW		NUMBER		FLOW	NUMBER		FLOW
Septic Systems (town-wide)	20,400	EDU	-	-	-10,760	EDU	-	-	EDU	- -
I/A Systems (town-wide)	98	EDU	-	-	0	EDU	-	-	EDU	- -
Sewer Connections	9,220	EDU	-	-	10,760	EDU	-	-	EDU	- -
Total Equivalent Dwelling Units	29,718	EDU	-	-	0	EDU	-	-	EDU	- -
Sewers	55.0	miles	-	-	208.0	miles	-	-	miles	- -
Sewage Pumping Stations	27	ea	-	-	20	ea	-	-	ea	- -
Forcemains	25.5	miles	-	-	10.0	miles	-	-	miles	- -
Treatment Facilities										
Barnstable WCPF	1	ea	1.670	mgd	1	ea	1.960	mgd	1 ea	3.630 mgd
Marston Mills WWTP	1	ea	0.012	mgd	0	ea	-0.012	mgd	0 ea	0.000 mgd
Other WPCF - to be determined	0	ea	0.000	mgd	0	ea	0.000	mgd	1 ea	0.000 mgd
Total, Treatment Facilities	2	ea	1.682	mgd	1	ea	1.948	mgd	2 ea	3.630 mgd
Town-Wide Est. Wastewater Flow										
Existing	-	-	3.341	mgd	-	-	0.000	mgd	- -	3.341 mgd
Additional Future Residential	-	-	0.000	mgd	-	-	0.000	mgd	- -	0.000 mgd
Additional Future Commercial	-	-	0.000	mgd	-	-	0.000	mgd	- -	0.000 mgd
Total	-	-	5.341	mgd	-	-	0.000	mgd	- -	5.341 mgd
% Increase									0%	0%

Notes:
1) Refer to Draft CWMP, dated October 2019.

From CWMP
From Town, email correspondence 11/21/2019, 11/25/2019. Note, Town information indicates 3100 sewer connections, EDUs are estimated based on average town-wide water use.
Placeholder

Check >> Existing Town-wide WW flow/ total EDUs >> 5.341x106/29718	ok	180 gpd/EDU town-wide avg
Check >> BWPCF flow/ 183 gpd/edu >> 1,670,000/ 180	ok	9,292 EDU existing sewer system including comm/industrial/institutional
Check >> BWPCF flow/ sewer connection EDUs >> 1,670,000/9220	ok	181 gpd/EDU
Check >> Septic system removal (1-Post/Pre) >> 1-(20400/9640)	ok	53% removal town-wide
Check >> Added flow to BWPCF from septic to sewer (10760*180/1000000)	ok	1.934 mgd
Check >> Avg flow per sewer connection (1,670,000/ 3,100)	ok	539 gpd/sewer connection
Check >> Total residential dwelling units (Table 2-11)	ok	26,692 residential dwelling units
Check >> Total town-wide parcels (town correspondence, 11/25/2019)	ok	26,835

BARNSTABLE CWMP
GREENHOUSE GAS EMISSION ANALYSIS
Wright-Pierce, Nov 25, 2019

TABLE 3 - DIRECT AND INDIRECT EMISSIONS FOR PRE-CWMP AND POST-CWMP CONDITIONS (EXCLUDING GROWTH)

	PRE-CWMP GHG EMISSIONS (BASELINE)					CWMP GHG EMISSIONS (EXCLUDING GROWTH)				
	DIRECT	DIRECT	INDIRECT	INDIRECT	COMBINED	DIRECT	DIRECT	INDIRECT	INDIRECT	COMBINED
COMPONENT	kg CO2-eq Year-Unit	kg CO2-eq Year	kg CO2-eq Year-Unit	kg CO2-eq Year	kg CO2-eq Year	kg CO2-eq Year-Unit	kg CO2-eq Year	kg CO2-eq Year-Unit	kg CO2-eq Year	kg CO2-eq Year
Septic Systems (town-wide)	205	4,182,000	8	163,200	4,345,200	205	1,976,200	8	77,120	2,053,320
I/A Systems (town-wide)	205	20,090	83	8,134	28,224	205	20,090	83	8,134	28,224
Sewer Connections										
Total Equivalent Dwelling Units										
Sewers										
Sewage Pumping Stations	0	0	130,000	3,510,000	3,510,000	0	0	130,000	6,110,000	6,110,000
Forcemains										
Treatment Facilities										
Barnstable WCPF	333,000	556,110	1,450,000	2,421,500	2,977,610	333,000	1,208,643	1,450,000	5,202,862	6,471,505
Marston Mills WWTP	333,000	3,996	1,450,000	17,400	21,396	333,000	0	1,450,000	0	0
Other WPCF - to be determined	333,000	0	1,450,000	0	0	333,000	0	1,450,000	0	0
Total, Treatment Facilities										
Town-Wide Est. Wastewater Flow										
Existing										
Additional Future Residential										
Additional Future Commercial										
Total (kg CO2-eq/year)		4,800,000		6,100,000	**10,900,000**		3,200,000		11,500,000	**14,700,000**
% Increase										35%

Notes:
1) See GHG unit rates worksheet for backup information on unit rates and literature citations. Site-specific for direct/ indirect emissions were not developed for this review.

From literature search and conceptual calculations

Appendix RR

Action Plan for the Barnstable Ponds

Action Plan for the Barnstable Ponds

EcoLogic LLC
Stearns & Wheler GHD

December 31, 2009

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1 Introduction and Scope

This report summarizes the current water quality and aquatic habitat conditions of many freshwater ponds located in the Town of Barnstable, Massachusetts, and recommends priority actions to ensure the ponds' protection and restoration. The Town of Barnstable is currently working with Stearns & Wheler GHD of Hyannis, Massachusetts to prepare a comprehensive nutrient management strategy that will guide the community's development in a manner that protects natural resources, including the quality of the coastal embayments, inland freshwater ponds and groundwater. This action strategy for the freshwater ponds is one component of the overall nutrient management planning project.

As summarized in the July 2008 report to the Town of Barnstable Conservation Commission prepared by the Cape Cod Commission and the Coastal Resources Group of the UMASS School of Marine Science and Technology (Eichner et al. 2008), the Town of Barnstable has 182 freshwater ponds, totaling 1,856 acres. About half of the town's freshwater ponds are extremely small, occupying less than one acre. There are 93 ponds one acre or greater in surface area. Of these, only 25 are larger than 10 acres and are consequently classified as "Great Ponds" by the state. The location of the freshwater ponds is illustrated in Figure 1, which was prepared by Town of Barnstable GIS staff.

This report sets forth recommendations to the Town of Barnstable as they integrate management of the inland ponds into an overall nutrient management plan. The recommendations consider effectiveness (both short-term and long-term), cost, permitting issues and recreational impacts. The recommended actions include institutional, technical and public education components. Some recommendations are town-wide, while others are directed to specific ponds. An overall implementation strategy is presented that defines priority actions and sequencing of recommendations.



Hamblin Pond: Recreational use

In accordance with guidance from the Massachusetts Department of Environmental Protection (MA DEP), the analysis and recommendations in this report do not provide a foundation for defining a Total Maximum Daily Load for phosphorus input to the town's freshwater ponds.



Aerial Photo Taken April 19, 2008

Major Roads

Town Boundary

TOWN OF BARNSTABLE
MASSACHUSETTS

Comprehensive Wastewater and Nutrient Management Plan

Freshwater Ponds
Figure 1

SEAL OF THE TOWN OF BARNSTABLE, MASS. 1639. ADOPTED MAY 4, 1869

N
W E
S

Miles

0 0.25 0.5 1 1.5 2

CWNMP_Ponds_11x17.mxd J.A.B. 4/13/2010

TOWN OF BARNSTABLE GEOGRAPHIC INFORMATION SYSTEMS UNIT

FIGURE PREPARED FOR STEARNS & WHELER GHD

2 Nutrients and Eutrophication

> *"Lakes seem, on the scale of years or human life spans, permanent features of the landscape, but they are geologically transitory, usually born of catastrophe and mature and die quietly and imperceptibly" (Hutchinson 1957).*

This often-cited quote from a classic limnology text provides excellent context for reviewing the current and future conditions of the ponds of Barnstable. The ponds may be arrayed along a continuum from open, clear, water with little visible algal growth to extremely shallow, productive systems well on their way to becoming wetlands.



Shubael Pond – Deep, with exceptionally clear water, sandy bottom.



Aunt Betty's Pond – Ultra-shallow, very productive with submerged and floating-leaved plants evident.

Eutrophication, the term for both the process and the effects of enrichment of surface water systems (including lakes, ponds, estuaries, and reservoirs), is a significant water quality concern for many aquatic ecosystems. As aquatic systems become increasingly enriched with plant nutrients, organic matter and silt, the result is increased biomass of algae and plants, reduced water clarity, and ultimately, a reduction in volume. Aesthetic quality and habitat conditions are degraded, and affected waters may no longer be suitable for drinking water or recreation.

While eutrophication is a natural process, it can be greatly accelerated by human activities. There are numerous lakes and ponds included in state compendia of impaired waters; most are listed due to excessive nutrient inputs from nonpoint sources such as agricultural or urban runoff, or seepage from on-site wastewater disposal systems. Less frequently, the impairment of surface waters is attributed to excessive discharge of nutrients from point sources; these may be piped discharges of inadequately treated wastewater from industrial or municipal sources.

Water resources managers focus on identifying and controlling the sources of nutrients, organic material, and silt to aquatic ecosystems in an effort to slow the eutrophication process. Phosphorus is most often the limiting nutrient for primary productivity and algal growth in inland lakes and ponds. While phosphorus is the key to managing eutrophication of inland

ponds, nitrogen is usually the limiting nutrient for primary production of coastal ecosystems. Nitrogen enrichment has resulted in degradation of estuarine and marine water quality and habitat conditions, and wastewater is a major source of nitrogen. Scientists and regulators from the EPA, the MA DEP, the academic community and the Cape Cod Commission have supported the coastal municipalities in a systematic process to define the need for and extent of reductions in nitrogen loading (MA DEP 2003 "The Massachusetts Estuaries Project Embayment Restoration and Guidance for Implementation Strategies"). Findings of this analysis are now being incorporated into land use and facilities decisions across Cape Cod.



Mystic Pond (Indian Ponds)



Middle Pond (Indian Ponds)



Hamblin Pond (Indian Ponds)

3 Kettle Pond Ecosystems

Most of the inland freshwater ponds of Cape Cod are kettle ponds, formed as depressions left behind by ice blocks as the glacial ice retreated between 14,000 and 17,000 years ago. According to Portnoy et al (2001), while kettle ponds have a common glacial origin, their subsequent evolution differs based on the depth of the original ice block, landscape position relative to sea level, and the texture (particle size) of the soils in the ponds' watersheds. Cultural effects are also to be added to this list; the ponds of Cape Cod are influenced by the amount and type of development in the watershed, invasions of exotic species, application of lime to raise the naturally low pH of the waters, and fisheries management practices.

Unlike most lakes and ponds, kettle ponds do not have prominent tributary streams (inlets) and outlets (**Figure 2**). Groundwater seepage and direct precipitation, rather than surface water flows, are the source of water to the kettle ponds. The quality of the water in the ponds, therefore, is directly affected by the quality of the groundwater resource.

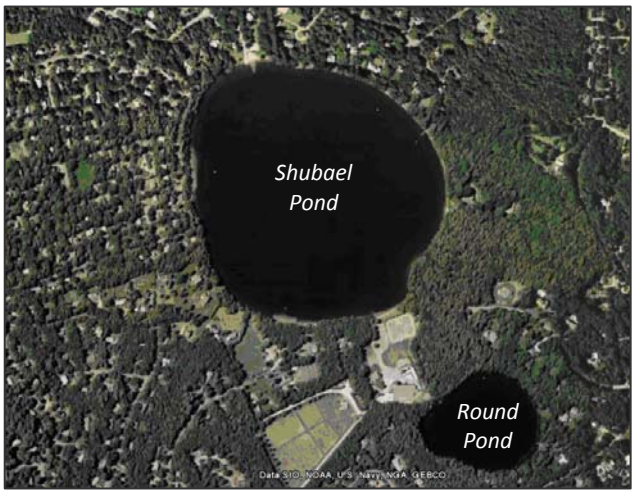

Figure 2. Aerial photograph of Shubael and Round Ponds illustrating hydrologic isolation of kettle ponds.

The lack of defined inlets and outlets for most kettle ponds has some important implications for the cycling of nutrients and organic material. Nitrogen and phosphorus enter the ponds primarily as dissolved nutrients where they are incorporated into biomass. Water leaves the ponds through groundwater seepage and evaporation. Particulate biomass consequently remains in the ponds, and the nutrients continue to cycle through the food web. Through this natural phenomenon, kettle ponds become more productive over time, as there is little opportunity for particulate material to leave the system. The Cape Cod Commission compiled dissolved oxygen (DO) measurements in the lower waters of 41 kettle ponds; data were from 1948 and 2001. Comparison of the data revealed that 76% of the measurements were lower in 2001 than 1948. These data provide strong evidence of an increasing level of productivity in the ponds over the intervening five decades (Cape Cod Commission, May 2003 p. 46).



Round Pond

Another important consideration for the kettle

ponds of Barnstable is that many of the ponds are shallow, with extensive wetland and littoral zones and macrophyte communities. Cooke et al. (1993) point out that the complexity of nutrient flux and food web interactions at the sediment-water interface in highly productive shallow regions of lakes and ponds cannot be ignored. Nutrient cycling and biological interactions in shallow, weedy sections of the ponds may contribute to maintaining elevated nutrient levels and undesirable plant growth long after external loading controls have been implemented.



Elizabeth Pond

4 Sources of Data and Information

A recent report summarizes the water quality status of the ponds of Barnstable (Eichner et al. 2008). After reviewing available data, the authors of this report concluded that:

> *"Available data for most ponds in Barnstable is limited. Other than the PALS Snapshots and sampling following the alum treatment at Hamblin Pond, sampling of most of the ponds has been sporadic. Given the sporadic available data and since the PALS Snapshots are designed to sample ponds during what is likely to be their worst water quality conditions, interpretation of available data must be approached with an understanding of these limitations."*

This Action Plan builds on the information provided in the 2008 report, and incorporates other data sources as summarized in **Table 1**. Of the 59 ponds listed in the table, data sources were available for 64% of the ponds.

Table 1. Data Sources Used to Develop Barnstable Ponds Action Plan

Named Pond[1]	CCC GIS ID[2]	Eichner, 2008[3]	Lake Wequaquet[4]	CCC Atlas: description[5]	Bathing beach bacteria testing[6]	2009 Visual Assessment[7]
1. Aunt Betty's	BA-756	✓				✓
2. Bearse	BA-617	✓		✓		
3. Bog	BA-802	✓				
4. Campground	BA-574					
5. Coleman	BA-819	✓				
6. Crystal	BA-878	✓				
7. Dunn's	BA-723	✓				
8. Eagle	BA-815	✓		✓		✓
9. Elizabeth	BA-795	✓				✓
10. Fawcett's	BA-748	✓				
11. Flax	BA-473					
12. Flint Rock	BA-614					
13. Flowing	BA-733					
14. Fresh	BA-701					
15. Garrett's	BA-510	✓		✓		✓
16. Hamblin	BA-668	✓		✓	✓	✓
17. Hathaway (North)	BA-565	✓		✓	✓	✓
18. Hathaway (South)	BA-594	✓				✓
19. Hinckley	BA-411	✓				
20. Israel	BA-585					
21. Joshua	BA-807	✓		✓	✓	✓
22. Lamson	BA-596					
23. Lewis	BA-881	✓				
24. Lewis (airport)	BA-670					
25. Little Israel	BA-608					
26. Little Parker	BA-841	✓				

Named Pond[1]	CCC GIS ID[2]	Eichner, 2008[3]	Lake Wequaquet[4]	CCC Atlas: description[5]	Bathing beach bacteria testing[6]	2009 Visual Assessment[7]
27. Little / Stony	BA-564	✓				
28. Long (C'ville)	BA-737	✓		✓		✓
29. Long (MM)	BA-675	✓		✓		✓
30. Lovell's	BA-759	✓		✓		✓
31. Lumbert	BA-719	✓				✓
32. Mary Dunn	BA-646	✓				
33. Micah	BA-797	✓		✓		
34. Middle	BA-640	✓				✓
35. Mill (MM)	BA-746	✓				✓
36. Mill (WB)	BA-391	✓				
37. Muddy	BA-694	✓				✓
38. Mystic	BA-584	✓				✓
39. Naomi	BA-812					
40. Neck	BA-874	✓				
41. No Bottom	BA-523	✓				
42. North (C'ville)	BA-752					
43. North (Ost)	BA-816					
44. Parker	BA-875	✓				
45. Patty's	BA-731					
46. Red Lily (North)	BA-782	✓				✓
Red Lily (South)	BA-782	✓				
47. Round (Bar)	BA-587					
48. Round (MM)	BA-691	✓				✓
49. Rushy Marsh	BA-914					
50. Sam	BA-820					
51. Sandy Hill	BA-542					
52. Schoolhouse	BA-806	✓				
53. Shallow	BA-626	✓				✓
54. Shubael	BA-664	✓		✓		✓
55. Simmons	BA-789					
56. Spruce	BA-535					
57. Upper Gate	BA-673					
58. Wequaquet	BA-605	✓	✓	✓	✓	✓
59. West	BA-764					

[1]Named ponds as listed in CCC Atlas 2003.

[2]CCC GIS ID: CCC GIS staff assigned a unique number to each waterbody digitized from a spring 1994 aerial photograph. The numbering system consisted of a two-letter town code and a unique number for each pond. These are presented in the CCC Atlas of 2003.

[3]Eichner, 2008: Eichner, E. 2008. Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities. School of Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA.

[4]Lake Wequaquet: SMAST. 2008. Lake Wequaquet Water Quality Assessment draft FINAL REPORT October, 2008 for the Town of

Named Pond[1]	CCC GIS ID[2]	Eichner, 2008[3]	Lake Wequaquet[4]	CCC Atlas: description[5]	Bathing beach bacteria testing[6]	2009 Visual Assessment[7]

Barnstable and Cape Cod Commission. Prepared by Coastal Systems Group School of Marine Science and Technology University of Massachusetts Dartmouth.

[5]CCC Atlas description: Cape Cod Commission. 2003. Cape Cod Pond and Lake Atlas. Project 2000-02. Prepared by Cape Cod Commission for Massachusetts Executive Office of Environmental Affairs, Community Foundation of Cape Cod, and School of Marine Science and Technology at University of Massachusetts Dartmouth. May 2003.

[7]Visual assessment conducted by EcoLogic staff on July 29, 2009.

4.1 Cape Cod Commission Reports

Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities (Eichner et al. 2008). In 2008, the Cape Cod Commission, in cooperation with the Coastal Systems Group School of Marine Science and Technology University of Massachusetts Dartmouth, issued a report on the current status, available data, and recommendations for future activities for the Barnstable Ponds. Data from 38 ponds were identified, which generally focused on two sources: 1) individual pond studies with intensive year-long data collection; and 2) data collect through the Pond and Lake Stewardship (PALS) Snapshots conducted through the CCC and the SMAST between 2001 and 2007. The report concluded that available datasets for Barnstable's ponds were generally insufficient for drawing conclusions regarding the sources of nutrients and other factors affecting water quality and habitat conditions in individual ponds, but were sufficient for comparing conditions among ponds.

Lake Wequaquet Water Quality Assessment draft FINAL REPORT October, 2008 for the Town of Barnstable and Cape Cod Commission (SMAST, 2008). The Town of Barnstable contracted with the Coastal Systems Program, School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth through the Cape Cod Commission (CCC) to update the analysis of water quality conditions in Lake Wequaquet and connecting waterways. Sampling was conducted in summer 2007. This report documents the sampling results and their interpretation, as well as an evaluation of the relationship of the lake to its watershed through water, nitrogen, and phosphorus budgets.

Cape Cod Pond and Lake Atlas, Final Report (CCC Water Resources Office, 2003). The Cape Cod Commission Water Resources Office published the Cape Cod Pond and Lake Atlas in May 2003; this document presents a summary and analysis of water quality status of twelve of the Barnstable ponds. The summaries provide an overview, indicating location, the nature of the shoreline, and predominant land uses. The fish community and stocking activities are described. Results of an August 2001 sampling program are tabulated for 35 ponds; chlorophyll-*a*, phosphorus and nitrogen concentrations are compared with thresholds for impaired ponds.

4.2 Visual field assessment

In July 2009, EcoLogic LLC conducted a field visit of 20 of the Barnstable ponds to observe water clarity and color, shoreline vegetation and development, public access and recreational uses, and the presence of algae and macrophytes.

4.3 Delineation of contributing areas

The Town of Barnstable GIS Unit developed a draft map delineating the recharge areas and land use in the Town. Information on this map included acreage of the recharge areas, number of parcels, existing residential units, and existing commercial building square footage. A build-out analysis was conducted to estimate the total extent of development possible under existing zoning regulations.

5 Inventory of ponds

The Barnstable ponds exhibit a range of physical characteristics (**Table 2**). Additional details are presented in Appendix A.

Table 2. Physical Characteristics of the Barnstable Ponds

Pond	Area (acres)	Access	Water Clarity	Shoreline	Aquatic Plants
Aunt Betty's	7.1	Very limited	--	Developed	Present
Fawcett's	11.9	--	--	Developed	--
Lumbert	9.7	Private	Tannic	Developed	Present
Mary Dunn	18	--	--	Undeveloped	--
Mill (Marstons Mills)	6.0	--	Clear	Undeveloped	Present
Mill (West Barnstable)	16.7	--	--	--	--
Red Lily	4.5	Very limited	--	Vegetated	Present
Bearse	66.8	Permission	Clear	Developed	--
Eagle	8.5	Conservation	Clear	Undeveloped	Present
Elizabeth	6.3	Very limited	--	--	Present
Garrett's	27.9	Permission	Tannic	Developed	Present
Hinckley	10.3	--	--	Developed	--
Joshua	14.7	Public	Clear	Undeveloped	--
Long (Centerville)	51	Limited	Clear	Developed	Not evident
Long (Marstons Mills)	54.8	Conservation	Clear	Developed	Not evident
Muddy	24.6	None	--	Developed	--
Parker	10.9	--	--	Developed	--
Round (Marstons Mills)	9.8	Private	Clear	Developed	Present
Shallow	78.4	--	Clear	Developed	Not evident
Crystal	10.1	--	--	Developed	--
Hamblin (Indian Ponds)	115.4	Public	V. Clear	Developed	Present
Hathaway (North)	20.9	Public	V. Clear	Undeveloped	--
Lovell's	55.5	Public	--	Developed	Not evident
Micah	16.0	Conservation	--	Undeveloped	--
Middle (Indian Ponds)	104.6	Public	V. Clear	Developed	Minimal
Mystic (Indian Ponds)	148.4	Public	Clear	Developed	Present
Neck	13.6	--	--	Developed	--
Shubael	55.1	Public	V. Clear	Developed	Present
Wequaquet	596.3	Public	--	Developed	--
Lamson	12.3	--	--	Undeveloped	--
West	10.1	--	--	--	--

5.1 Current Water Quality and Habitat Conditions

Ponds deeper than about 5 m typically exhibit some degree of thermal stratification during the summer. Bottom waters isolated from the atmosphere become depleted of oxygen (i.e., develop anoxia) as the microbial community decomposes organic material that settles to the lake bottom. As ponds become more productive, oxygen depletion is evident higher in the water column.

The shallowest ponds do not develop stable thermal stratification, because the winds are able to keep the water column mixed from top to bottom. As a consequence, oxygen added to the pond from the atmosphere and from photosynthesis mixes throughout the water column and the waters remain oxygenated.



Eagle Pond

Ponds deep enough to stratify and productive enough to experience seasonal anoxia have elevated concentrations of phosphorus in the lower waters, due to the chemical changes at the sediment surface that occur during anoxia. As a result of these chemical changes, phosphorus is released from sediments to the overlying waters. In some lakes, wind-induced mixing and internal waves (seiches) may draw the phosphorus-rich water into the upper sunlit layer where the nutrient can support algal growth (the photic zone) during the summer. Several of the shallower ponds are susceptible to the effects of internal phosphorus loading during summer. As waters cool in the fall, the density gradients that prevented wind mixing break down and the phosphorus-rich layer is mixed into the water column of all ponds, regardless of depth.

Limnologists have developed guidelines to delineate the transition between trophic states based on phosphorus, water clarity, chlorophyll-a, and deep water dissolved oxygen concentrations (**Table 3**). However, assigning a lake or pond to one category still requires professional judgment considering the cumulative evidence of water quality conditions and the level of productivity (**Table 4**).



Lovell's Pond, with algal bloom
July 2009

Table 3. Trophic State and Indicator Parameters

Trophic State	TSI Values	Attributes and Recreational Use	*TSI Calculation* *TSI(TP) = 14.42 ln(TP) + 4.15* Total Phosphorus	*TSI(CHL) = 9.81 ln(CHL) + 30.6* Chlorophyll-a	*TSI(SD) = 60 – 14.41 ln(SD)* Secchi disk transparency
Oligotrophic	<30-40	Clear water, oxygen throughout the year in the hypolimnion. At TSI >30, hypolimnia of shallower lakes may become anoxic. Salmonid fisheries.	<6 to 12 µg/l	<0.95 to 2.6 µg/l	>8 to 4 m
Mesotrophic	40-50	Water moderately clear; increasing probability of hypolimnetic anoxia during summer. Hypolimnetic anoxia results in loss of salmonids.	12 to 24 µg/l	2.6 to 7.3 µg/l	4 to 2 m
Eutrophic	50-70	Anoxic hypolimnia, macrophyte problems possible. At TSI >60, blue-green algae dominate, algal scums and macrophyte problems. Warm-water fisheries only. Bass may dominate. At TSI >60, nuisance macrophytes, algal scum, and low transparency may discourage swimming and boating.	24 to 96 µg/l	7.3 to 56 µg/l	2 to 0.5 m
Hypereutrophic	>70	Light limited productivity. Dense algae and macrophytes. Rough fish dominate; summer fish kills possible.	96 to 384 µg/l	56 to >155 µg/l	0.5 to <0.25 m

after Carlson and Simpson (1996); Carlson TSI developed in algal dominated, northern temperate lakes

Table 4. Summary of Trophic State Parameters, Barnstable Ponds

Trophic State	Depth Class		
	Ultra-Shallow	**Shallow**	**Deep**
Oligotrophic	Hathaway (South) Mary Dunn Mill (MM) Red Lily	Garrett's Joshua	Hamblin Hathaway (North) Micah Middle Neck Shubael
Mesotrophic	Aunt Betty's Bog Fawcett Lumbert	Bearse Coleman No Bottom Shallow	Crystal Lovell's Mystic Wequaquet
Eutrophic	Dunn's Little/Stony Mill (WB)	Eagle Elizabeth Hinckley Long (C'ville) Long (MM) Muddy Parker Round (MM)	
Hypereutrophic	Little Parker	Schoolhouse	

based on Eichner, 2008

The visual assessment conducted by EcoLogic in July 2009 confirmed that the Barnstable Ponds are in various stages of eutrophication.

While data are limited, they do provide a basis for making an assessment of trophic state using the standard indicators described in **Table 3**. Note that the concentrations of chlorophyll-a and phosphorus used to delineate trophic state (**Table 3**) are not the same as the concentrations used to define ecoregional reference lake conditions (**Table 5**). The ecoregional criteria are based on water quality conditions measured in eight pristine Cape Cod ponds.

Table 5. Ecoregional Criteria

Parameter	**Subecoregion 84 Reference Condition Threshold**	**Cape Cod Ponds based on 2001 PALS Data**
Secchi depth	2 m	Not calculated
Chlorophyll-a	6 µg/l	1.7 µg/l
Total Nitrogen	0.41 mg/l	0.31 mg/l
Total Phosphorus	9 µg/l	10 µg/l

EPA is encouraging development of ecoregional criteria, designed to reflect site-specific conditions of watershed geology, land use, and hydrologic setting. These values are used to define thresholds for impacted and non-impacted conditions and thus target levels. Ecoregional

criteria for Cape Cod ponds have been described in the Cape Cod Pond and Lake Atlas (Cape Cod Commission, May 2003); the ecoregional values (designated as subregion 84) are derived from a statistical evaluation of existing water quality conditions of "unimpacted" ponds for coastal New England, including Cape Cod. The 2001 PALS data were used to calculate thresholds for reference conditions using eight Cape Cod ponds. The eight ponds included a range of deep and shallow ponds; all were characterized with low nutrient and chlorophyll concentrations. One of these eight reference ponds was Barnstable's Micah Pond.

The status of the Barnstable Ponds with respect to the ecoregional criteria is summarized in **Table 6**, based on the data summaries provided by Eichner (2008).

Table 6. Status of Barnstable Ponds, based on Cape Cod Ponds Thresholds.

Pond	Impacted Criteria (Affected by Human Activities)		
	Chlorophyll-a >1.7 µg/l	Total N > 0.31 mg/l	Total P > 10 µg/l
Ultra-Shallow (0.5 and 1.2 m)			
Aunt Betty's	Impacted	Impacted	At Risk
Bog	Impacted	Impacted	At Risk
Dunn's	Impacted	Impacted	Impacted
Fawcett	Impacted	Impacted	At Risk
Hathaway (South)	Unimpacted	Unimpacted	Unimpacted
Little Parker	Impacted	Impacted	Impacted
Little/Stony	Impacted	Impacted	At Risk
Lumbert	Impacted	Impacted	At Risk
Mary Dunn	Impacted	Impacted	At Risk
Mill (MM)	Impacted	Impacted	Impacted
Mill (WB)	Impacted	Impacted	Impacted
Red Lily (North)	Impacted	Impacted	At Risk
Red Lily (South)	Impacted	Impacted	At Risk
Shallow (2.1 and 8.6 m)			
Bearse	Impacted	Impacted	At Risk
Coleman	Impacted	Impacted	Impacted
Eagle	At Risk	Impacted	At Risk
Elizabeth	Impacted	Impacted	Impacted
Garrett's	Impacted	Unimpacted	At Risk
Hinckley	Impacted	Impacted	Impacted
Joshua	At Risk	At Risk	At Risk
Long (C'Ville)	Impacted	Impacted	At Risk
Long (MM)	Impacted	Impacted	Impacted
Muddy	Impacted	At Risk	Impacted
No Bottom	Impacted	Impacted	Impacted
Parker	Impacted	Impacted	Impacted
Round (MM)	Impacted	Impacted	At Risk
Schoolhouse	Impacted	Impacted	Impacted
Shallow	Impacted	Impacted	At Risk

Table 6. Status of Barnstable Ponds, based on Cape Cod Ponds Thresholds.

Pond	Impacted Criteria (Affected by Human Activities)		
	Chlorophyll-a >1.7 µg/l	Total N > 0.31 mg/l	Total P > 10 µg/l
Deep (9.3 and 17.3 m)			
Crystal	Impacted	Impacted	Impacted
Hamblin	Impacted	At Risk	At Risk
Hathaway (North)	Impacted	Unimpacted	Impacted
Lovell's	Impacted	Impacted	Impacted
Micah	Impacted	At Risk	Impacted
Middle	Impacted	At Risk	At Risk
Mystic	Impacted	At Risk	Impacted
Neck	At Risk	Impacted	Impacted
Shubael	Impacted	Impacted	Impacted
Wequaquet	Impacted	Impacted	Impacted

In addition to grouping the ponds based on the degree to which human activities have altered them from their natural (pristine) condition, each state classifies surface waters for a desired "best use". This concept focuses on human use of the resource, but incorporates the ecological condition of the resource as well. Examples of designated use include public water supply, fishing, swimming (water contact recreation), aesthetic enjoyment and support of shellfish, wildlife and fisheries. The best use of Barnstable's inland kettle ponds is typically recreation in and on the water and fishing. It is important to note that the designation of a pond as showing evidence of impact by humans (i.e., "impacted" or "at risk") does not imply that the pond's designated uses are not being supported. Overall, the town's inland ponds fully support their designated use.

Based on this analysis, the Barnstable Ponds may be grouped into categories describing current water quality and habitat conditions. This grouping is presented in **Table 7.**

Table 7. Summary of Current Water Quality Conditions and Use Attainment.

Depth Categories:	Water Quality and Aquatic Habitat Status		
	Supports Desired Uses	**Currently Supports Desired Uses, with Evidence of Degradation**	**Does Not Support Desired Uses**
Ultra-shallow (less than 1.2 m maximum depth)	Aunt Betty's Hathaway (South) Lumbert Mary Dunn Mill (MM)	Red Lily Bog Dunn's Fawcett Little/Stony Mill (WB)	Little Parker
Shallow (from 2.1 to 8.6 m maximum depths)	Garrett's Joshua Eagle	Bearse Coleman Long(MM) Elizabeth No Bottom Round (MM) Shallow	Hinckley Long (C'ville) Muddy Parker Schoolhouse
Deep (from 9.3 to 17.3 m maximum depths)	Hathaway (North) Micah Middle Neck	Chrystal Hamblin Mystic Shubael Wequaquet	Lovell's

The nitrogen: phosphorus (N: P) ratio is another measure of pond conditions. Algae require many nutrients, and their nutritional requirements are within a relatively consistent range. As a general rule, higher N:P ratios are associated with lower productivity. When the elemental N:P ratio in the water column falls below about 16, nitrogen becomes the limiting nutrient for algal growth. Many species of cyanobacteria are able to fix atmospheric nitrogen (i.e., convert nitrogen gas (N_2) to ammonia and other more readily useable forms of nitrogen). As a consequence, growth of these species is not limited by the availability of nitrogen in the water, and cyanobacterial abundance can reach nuisance levels in eutrophic lakes.

The N:P ratio of the Barnstable ponds (**Table 8)** tends to be high. The N:P ratio, on average, decreases from more than 100 for the less productive ponds to less than 10 for the most nutrient-rich and productive ponds. Lovell's Pond, which was closed for swimming in July 2009 due to a cyanobacterial bloom, exhibited a relatively low N: P ratio of 25:1 in 2001.

Table 8. Nitrogen:Phosphorus Ratios, Barnstable Freshwater Ponds, 2001

Ultra-Shallow		Shallow		Deep	
Oligotrophic (>100)		*Oligotrophic (>100)*		*Oligotrophic (>100)*	
Red Lily (Lower)	179:1	Long (August)	112:1		
Mid-Range (<100 and >10)		*Mid-Range (<100 and >10)*		*Mid-Range (<100 and >10)*	
Aunt Betty's	29:1	Bearse	19:1	Crystal	52:1
Bog	26:1	Coleman	25:1	Hathaway North	65:1
Fawcett's	61:1	Elizabeth	16:1	Lovell's	25:1
Hathaway (South)	29:1	Garrett's	44:1	Micah	53:1
Little	51:1	Long (Sept.)	31:1	Middle	46:1
Mary Dunn	33:1	Muddy	22:1	Mystic	23:1
		Parker	72:1	Shubael	73:1
		Round	45:1	Wequaquet Middle	22:1
		Shallow	32:1		
Eutrophic (<10)		*Eutrophic (<10)*		*Eutrophic (<10)*	
Dunns	9:1	Schoolhouse	8:1		

Based on data from Cape Cod Pond and Lake Atlas, May 2003.

5.2 Data Gaps

The evaluation of the data in Eichner (2008) repeatedly emphasized that only limited data were available to analyze the status and trends of the Barnstable ponds.

> *"When looking at all of this data, there are two significant factors that must also be considered: all of these characterizations are based on very limited data and there are a number of Barnstable ponds that do not have any data. Except for Mystic, Middle, and Hamblin, the rest of the ponds have not had water quality samples collected since 1986 except for PALS Snapshots. The PALS Snapshot data is useful for what it was designed for, a Cape-wide picture of pond water quality, but it is not sufficient for definitively stating the status of individual ponds or designing remedial strategies." (Eichner, 2008)*

5.3 Land Use and Phosphorus Sources

Phosphorus can reach the inland kettle ponds from several sources. Runoff from impervious surfaces, such as roadways, can transport dissolved and particulate material, including phosphorus, to the ponds. Eroding shorelines can contribute particulate material as well. Groundwater seepage transports dissolved nutrients into ponds; the concentrations of dissolved nutrients can be elevated when groundwater is affected by sewage disposal. There are biological sources as well, including waterfowl and humans.

Maps of current land use, depicting the number and location of residences, were reviewed during preparation of this Action Plan for Barnstable. This coverage area of impervious surfaces is important to consider in quantifying phosphorus loading to the ponds from the surrounding watershed due to surface runoff. The density of development is a factor in phosphorus loading from septic systems.



Mill Pond – Conservation Area visitor location map.

Review of the map of government-owned land and protected open space (Town of Barnstable, 2009) indicates that the majority of parcels within the town are in private ownership and not under conservation protection. However, many of the smaller ponds have a substantial portion of the watershed in town-owned or conservation lands.

Most of the town is not served by sanitary sewers. Therefore, septic effluent is likely a contributing factor in phosphorus loading to most of the Barnstable ponds. Once the contributing area of groundwater flow into each pond is delineated, these data can be used to help quantify the potential contribution of septic effluent to each pond.

Parcels in the Town of Barnstable that have sewer accounts have been mapped. According to a map[1] dated October 2007, these parcels are predominantly located on the eastern side of town, east of the Lake Wequaquet region. One would anticipate that parcels with sewer accounts would have fewer active septic systems, and that septic contributions of phosphorus to the ponds adjacent to these parcels would be reduced. Ponds in this region include:

Aunt Betty's	Fawcett's	Lewis
Crooked	Fresh	Mary Dunn
Duck	Fresh Hole	Upper Gate
Dunn's	Hathaway (South)	

5.4 Build-out Analysis

Changes in land use over time will have an impact on the Barnstable ponds. To estimate the amount of development possible in the town, and thereby identify ponds likely to be most affected, a build-out analysis was conducted. The analysis grouped 29 ponds into 17 areas around Barnstable, and tallied the existing and build-out quantities for residential dwelling units and commercial building square footage (**Table 9**).

[1] http://www.town.barnstable.ma.us/InformationSystems/GIS/SEWERED.PDF

Table 9. Build-out Analysis of Residential Dwelling Units and Commercial Building Square Footage, Town of Barnstable.

Pond(s)	Residential Dwelling Units			Commercial Bldg Sq Footage		
	Existing	Build-out	Change	Existing	Build-out	Change
Lovell	245	353	+108	0	0	0
Muddy, Long (MM)	138	143	+5	0	0	0
Eagle	60	61	+1	0	0	0
Mystic, Middle, Hamblin, Shubael, Little	756	823	+67	0	0	0
Mill (WB)	53	71	+18	0	0	0
Bog	82	104	+22	2,202	9,478	+7,276
Micah, Joshua	207	216	+9	316,330	316,330	0
West, Flowing	210	218	+8	0	0	0
Garrett's	132	158	+26	1,477	1,477	0
Wequaquet, Bearse, Shallow, Long (C'ville)	927	1,002	+75	22,737	31,569	+8,832
Hinckley	21	26	+5	0	0	0
Hathaway	0	23	+23	9,820	90,450	+80,630
Simmons, Ben	215	219	+4	6,728	23,073	+16,345
Fawcett's	205	239	+34	7,768	19,089	+11,321
[Number 15 on map]	0	0	0	43,192	180,657	+137,465
Mary Dunn	0	0	0	1,410	1,410	0
Israel, Lamson	0	0	0	119,114	464,441	+345,327

from draft GIS map "Town of Barnstable Freshwater Ponds Recharge Areas", August 2009

Ponds that have potential for extensive future residential development, based on this build-out analysis, are:

Lovell	Mystic-Middle-Hamblin-Shubael-Little
Fawcett	Wequaquet-Bearse-Shallow-Long (C'ville)
Garrett's	Hathaway[2]

Other ponds exhibiting potential for extensive future commercial development, based on this build-out analysis, include:

[2] The lands around Hathaway Pond (both North and South) are predominantly owned by the Town and designated for conservation and recreation; therefore, the projected increase in development is unlikely.

Israel-Lamson	Wequaquet-Bearse-Shallow-Long (C'ville)
"Number 15"	Fawcett's
Simmons-Ben	

Given this assessment of potential for development, ponds which presently do not meet desired uses, and ponds with evidence of degradation are considered most at risk (**Table 10**).

Table 10. Water Quality Conditions of Ponds with Potential for Extensive Future Development.

	Water Quality and Aquatic Habitat Status		
Development	**Meets Desired Uses**	**Meets Desired Uses, with Evidence of Degradation**	**Does Not Meet Desired Uses**
Residential	Garrett's Middle	Bearse Fawcett Hamblin Little Mystic Shallow Shubael Wequaquet	Long (C'ville) Lovell's
Commercial		Bearse Fawcett Shallow Wequaquet	Long (C'ville)

Note: there were no data to categorize the water quality conditions of Israel, Lamson, "Number 15", Simmons or Ben.

5.5 Point and nonpoint sources of nutrients

There are no identified point sources of nutrients to the Barnstable Ponds; most of the nonpoint sources are direct inputs to the ponds: septic effluent, wildlife, swimmers, stormwater runoff, and shoreline erosion.

Septic effluent as a nonpoint source is the subject of investigation and debate. The extent to which phosphorus in septic effluent can reach surface waters is an issue of great importance to many communities. Research and monitoring indicates that subsurface phosphorus transport is influenced by depth to groundwater, soil texture, pH, geology, and groundwater quality, as well as by the nature of the on-site wastewater disposal systems (notably age, loading history, and maintenance).

5.6 Transport and attenuation from source to ponds

In general, phosphorus is considered relatively immobile in the subsurface environment. However, phosphorus transport through groundwater to surface waters has been documented; for example, phosphorus associated with the sewage plume from the Massachusetts Military Reservation on Cape Cod is reaching Ashumet Pond (McCobb et al 2003). Phosphorus from septic systems may reach surface waters when intervening distances and travel times are short, when the groundwater environment is reducing (anoxic), or when sites for sorption of phosphorus onto aluminum and iron oxides are already saturated with phosphorus (Portnoy et al 2001). The Ashumet Pond investigation by USGS documented that phosphorus can desorb from subsurface soils exposed to uncontaminated groundwater with low pH (McCobb et al. 2003). This implies that phosphorus from on-site systems remains a reservoir in the soil that may be slowly mobilized and transported to the ponds along with groundwater.

Controlled experiments by Cogger et al (1988) examined the movement of nutrients and bacteria from septic systems installed in the sandy soils of a coastal barrier island. They reported that phosphorus was most likely to be mobile in wet, sandy soils, and that both loading rate and water table location affected phosphorus concentrations in the groundwater surrounding the leach field. Data from this investigation were also consistent with two processes for adsorption occurring: a fast reaction and a slow reaction.

The ponds of Barnstable are situated in sandy soils, and the surrounding land areas have a variable depth to groundwater. Background pH is low, averaging 5.5 (McCobb et al. 2003). The sandy soils provide abundant iron and aluminum hydroxides for phosphorus adsorption. The reaction of soluble reactive phosphorus with sandy soil is described by two processes: a fast and reversible adsorption reaction on the surface of aluminum and iron oxides and a slow, diffusion-controlled process where the phosphorus either precipitates with aluminum or iron, or diffuses into micropores and becomes adsorbed to surfaces deep in the soil matrix (Shoumans and Breeuwsma 1997).

It appears that the soils of Barnstable have the cation exchange capacity and mineralogy to adsorb soluble phosphorus present in groundwater. However, phosphorus removal is not permanent. Under certain chemical conditions, phosphorus adsorbed to the surface aluminum and iron hydroxides may desorb and move with the groundwater towards the kettle ponds. Groundwater pH on Cape Cod is within the range where this desorption reaction will occur. Phosphorus movement from subsurface soils would be exacerbated by conditions such as high organic loading that contribute to microbial activity and de-oxygenation of the groundwater resource.

6 Summary of Findings

- **Water Quality Conclusions (Eichner, 2008).** The focus of the conclusions was centered on total phosphorus, chlorophyll-a, and dissolved oxygen as key data sets indicating pond health. In all cases, further data collection was recommended to refine the characterization of each pond. *Overall recommendation*: Standard best management practices to minimize stormwater runoff would help maintain/improve existing conditions.

    a. Ultra-shallow Ponds – Total phosphorus and chlorophyll-a concentrations were generally higher than threshold concentrations, while dissolved oxygen was compliant with the regulatory standards. Hathaway South and Mary Dunn Ponds are relatively pristine and undeveloped, and should be a priority for protection.

    b. Shallow Ponds – Total phosphorus and/or chlorophyll-a concentrations were excessively higher than threshold concentrations, while six of the 15 ponds exhibited dissolved oxygen concentrations in the deeper waters that were below the regulatory standards. Joshua was identified as a relatively pristine pond that should be protected.

    c. Deep Ponds - Total phosphorus and/or chlorophyll-a concentrations were higher than threshold concentrations, while eight of the 10 ponds exhibited dissolved oxygen concentrations in the deeper waters that were below the regulatory standard. None of the ponds may be considered relatively pristine, but several have only recently shown signs of water quality impairment: Micah, Middle and Neck. The alum treatment of Hamblin Pond continues to provide residual water quality benefits.

- **Impacted Waters.** The Barnstable Ponds are in various stages of eutrophication; many are considered "impacted waters" based on regional criteria developed from limited measurements of water quality conditions in eight pristine Cape Cod ponds. However, designated uses are generally met. The ponds are used for swimming, boating, recreational fishing and aesthetic enjoyment. While a few ponds exhibit visual degradation of water quality conditions, most are aesthetic assets and provide habitat for a diverse assemblage of aquatic plants and animals.

- **Phosphorus Loading.** Phosphorus is the limiting nutrient for primary production in the Barnstable Ponds, and therefore has an influence on water quality conditions and pond health.

    a. Unlike the nitrogen-limited coastal embayments, production of algae and macrophytes in inland ponds is limited by phosphorus. The ratio of nitrogen to

phosphorus in ponds is likely to influence the species composition of the algal community, particularly the importance of blue-green algae.

b. Phosphorus enters the Barnstable Ponds from several sources; few (if any) of these sources are easily controlled. External sources of phosphorus include: groundwater influx; wastewater disposal (septic sewage plumes in groundwater); surface runoff; atmospheric deposition; shoreline erosion; and users of the ponds (swimmers and wildlife).

c. In deeper ponds subject to seasonal anoxia, phosphorus held in sediments can be released to the overlying waters; this internal loading can be a significant fraction of the annual supply of phosphorus available to support algal growth.

d. Kettle ponds are susceptible to phosphorus accumulation, due in part to the lack of surface outlets.

e. The watershed area of many of the Barnstable ponds includes parcels with on-site wastewater disposal systems. Installation of sewers to collect domestic wastewater before it enters the groundwater would likely reduce phosphorus loading to these ponds.

f. Build-out analysis was used to identify ponds where there is a high potential for future residential and commercial development. Such future development could increase phosphorus loading from surface runoff and groundwater seepage of sewage plumes.

7 Recommendations

Given the nature of the kettle ponds and the sources of phosphorus to the Barnstable Ponds, there are no simple answers to long-term water quality protection and improvement. Strategies fall into several categories: reducing the inputs of nutrients and sediment, altering internal cycling, increasing the output of nutrients and sediment, and/or mitigating the symptoms of eutrophication. Feasible alternatives for protection and restoration of the Barnstable Ponds are summarized in **Appendix B**. The following actions are recommended.

- **Develop town-wide strategies for water quality protection.**

  Some of these strategies would be implemented through Town Codes and regulation, while other strategies could be implemented without regulatory involvement. Storm water runoff controls would be one example of a regulatory action. Public education would be an example where regulatory involvement is not required.

- **Develop pond-specific strategies to protect and/or restore individual Barnstable Ponds.**

  Each pond has its own unique situation, based on its size and depth, the nature of the surrounding watershed, and the extent of groundwater influences. With a more detailed understanding of the individual pond through additional data collection, it will become more apparent whether actions such as alum treatment or weed harvesting are appropriate in a given pond.

- **Obtain more detailed data on priority ponds.**

  As noted above, there are very limited recent data to characterize water quality and habitat conditions of the town's ponds Additional data collection should be prioritized to ponds that are the most impaired, and that provide the greatest opportunity for public uses. Moreover, data collection should be focused on closing data gaps needed to make effective management decisions.

7.1 Priority Ponds

An assessment of the priority status of the Barnstable Ponds **(Table 11) includes** Barnstable inland ponds reviewed as part of this assignment; the list is not inclusive of all town ponds.

Table 11. Summary of existing conditions, recommended actions, and priorities for managing Barnstable Ponds

Pond	Priority (low-moderate-high-protect)	Findings (Trophic States: O, M, E, H)	Recommended Actions
Ultra-Shallow			
Aunt Betty's	Low	M; Limited public access	Education, watershed BMP
Bog	Low	M; Impacted/at risk	Education, watershed BMP
Dunn's	Moderate	E; Impacted	Education, watershed BMP
Fawcett's	Low	M; Impacted/at risk; potential for increased residential development	Education, watershed BMP; guide future development to minimize nutrient export
Hathaway (South)	Protect	O; Unimpacted	Low impact recreational use & education in protected watershed
Little Parker	High	H; Impacted; does not support desired uses	Watershed BMPs; mitigate symptoms to improve aesthetics and recreational use: hand-pulling, benthic barriers
Little/Stony	Moderate	E; Impacted/at risk	Education, watershed BMP
Lumbert	Low	M; Private; Impacted/at risk	Education, watershed BMP
Mary Dunn	Low	O; Impacted/at risk	Education, watershed BMP
Mill(MM)	Protect	O; Impacted; Conservation area	Low impact recreational use & education in protected watershed
Mill (WB)	Moderate	E; Impacted	Education, watershed BMP
Red Lily (North, South)	Low	O; Impacted/at risk; Limited public access	Education, watershed BMP
Shallow			
Bearse	Moderate	M; Impacted/at risk; fanwort; potential for increased residential development	Macrophyte survey, strategies to control exotics; consider reducing density of future development

Pond	Priority (low-moderate-high-protect)	Findings (Trophic States: O, M, E, H)	Recommended Actions
Coleman	Low	M; Impacted	Mitigate symptoms of eutrophication in recreational areas (benthic mats, hand harvesting); watershed BMPs
Eagle	Protect	E; At risk; watershed in land trust	Consider hand pulling emergent vegetation to improve shoreline access; maintain trails and prevent erosion
Elizabeth	Moderate	E; Impacted; Limited public access	BMPs, control stormwater on roadways
Garrett's	Low	O; At risk; limited public access	Education, watershed BMPs
Hinckley	High	E; Impacted	Stormwater management, septic inspections
Joshua	High	O; At risk; Town beach, natural vegetation; reference pond indicative of pristine conditions	Priority for protection, education, BMPs
Long (C'Ville)	High	E; Impacted; Town beach, highly developed; Does not support desired uses	Stormwater management, septic inspections, mitigating measures to improve recreational use: benthic mats, hand-pulling
Long (MM)	Moderate	E; Impacted; Conservation area; moderately protected	Education, watershed BMPs
Muddy	Moderate	E; Impacted/at risk	Education, watershed BMPs
No Bottom	Low	M; Impacted	Education, watershed BMPs
Parker	Moderate	E; Impacted	Education, watershed BMPs
Round (MM)	Moderate	E; Impacted/at risk; Private	Education, watershed BMPs
Schoolhouse	High	H; Impacted; does not support desired uses	

Pond	Priority (low-moderate-high-protect)	Findings (Trophic States: O, M, E, H)	Recommended Actions
Shallow	Moderate	M; Impacted/at risk; vegetated shoreline; potential for increased residential development	Controls on future density and/or BMPs to minimize phosphorus migration to pond from surface runoff and groundwater
Deep			
Crystal	Low	M; Impacted	Education, watershed BMPs
Hamblin	High	O; At risk; Town Beach, conservation land; alum-treated; potential for increased residential development	Monitor for effectiveness of alum treatment; controls on future density and/or BMPs to minimize phosphorus migration to pond from surface runoff and groundwater
Hathaway (North)	High	O; At risk; Town beach, mix of conservation land and development	Continue acquisition of hydrologically important parcels in watershed
Lovell's	High	M; Impacted; Town beach closed; blue-green algal bloom; does not support desired uses	Priority for monitoring deep water phosphorus levels and N/P ratio; consider nutrient inactivation
Micah	Protect	O; At risk; Undeveloped, reference pond	Priority for monitoring deep water phosphorus levels
Middle	Protect	O; At risk; Public access, very clear	Priority for monitoring deep water phosphorus levels; consider acquisition of key parcels to control density
Mystic	High	M; Impacted/at risk; Public access, endangered mussels; permit phase for alum application; potential for increased residential development	Priority for alum treatment program; guide future development to minimize surface runoff and groundwater nutrient input

Pond	Priority (low-moderate-high-protect)	Findings (Trophic States: O, M, E, H)	Recommended Actions
Neck	Moderate	O; Impacted/at risk;	Period monitoring to detect symptoms of degradation; watershed BMPs;
Shubael	High	O; Impacted; Town beach, exceptionally clear water potential for increased residential development	Priority for monitoring deep water phosphorus levels; septic inspections; guide future development to minimize nutrient input from surface runoff and groundwater seepage
Wequaquet	High	M; Impacted; Town beach, potential for future residential and commercial growth	Priority for monitoring deep water phosphorus levels; septic inspection; consider density controls on future development

Trophic states: O – Oligotrophic; M – Mesotrophic; E – Eutrophic; H -Hypereutrophic
Higher priority assigned to ponds with town beach and/or public access
BMP- Best Management Practices

7.2 Protection Measures

The following are measures that may be taken to protect the Barnstable Ponds from further degradation in water quality and habitat conditions. These measures are typically implemented in the watershed surrounding the ponds, rather than within the pond itself. These protection measures may be applied to all the ponds, though more information regarding existing storm water infrastructure could help the town refine priorities.

- Storm water management. Stormwater basins with water quality controls; operations and maintenance are critical. Improved stormwater management on parking lots adjacent to ponds.

- Septic discharge. Regulatory programs for septic systems existing in similar environments to the Cape Cod area show a variety of setback requirements, as summarized in **Appendix C**. In addition to setbacks, there are alternative technologies, some of which show excellent phosphorus removal capabilities. The Massachusetts Alternative Septic Systems Test Center and the Barnstable County Department of Health are an informational resource. For a listing of current MADEP approved alternative systems, refer to the web site http://www.mass.gov/dep/water/wastewater/techsum.htm

- Public Education. Conduct forums to discuss pond ecology, range of conditions in Town ponds, and effective measure for improving water quality conditions. Educate the public regarding the importance of remaining on trails and protecting riparian (shoreline) areas. Also, educate land owners about the impacts of fertilizer and pesticide applications adjacent to ponds.

- Land acquisition. Pursue and acquire open space, while incorporating resource-based priorities into decisions. Place a high priority for acquisition of properties in riparian areas.

- Bioengineering. Revegetate shoreline areas to reduce shoreline erosion. Plan, install and maintain trails through public lands to reduce potential for erosion.

- Other structural measures. Implement wastewater collection to reduce phosphorus loading via septic systems. Install public toilet facilities for beach areas, and keep them cleaned and maintained to encourage use.

- Inspection and Monitoring. Inspection and maintenance of onsite septic systems. Routine participation in volunteer (PALS) water quality monitoring program. Additional monitoring suggestions are summarized in **Appendix D**.

7.3 Restoration Options

The following are measures that may be taken to restore the impacted Barnstable Ponds. These measures would be implemented as needed on a pond-by-pond basis. Additional data from the impacted ponds is required before selecting an appropriate restoration option.

- Alum treatment to seal bottom sediments. Alum application to seal bottom sediments and prevent phosphorus release. This treatment option is applicable to deep ponds that develop stable thermal stratification, and where internal (sediment) phosphorus release is a significant component of the annual TP budget.

- Mixing. Use aerators or mixers to keep the water column oxygenated and accelerate the rate of decomposition of organic material.

- Benthic barriers. To prevent the excessive growth of vegetation, a symptom of eutrophication. This technique may be applicable to limited areas to restore recreational use.

- Mechanical or hand removal of weeds. To eliminate invasive species and reduce the excessive growth of aquatic plants that impairs desired uses of the pond.

- Water level management (drawdown) to control aquatic plants.

8 Priority Actions Recommended for the Town of Barnstable for 2010-2011

Convene a public educational forum to discuss current water quality and habitat conditions of the ponds of Barnstable. Solicit public input on the desired future for the ponds (overall and for individual ponds). Major topics include:

- The eutrophication process
- The unique nature of the kettle ponds in nutrient cycling
- How conditions have changed in recent decades
- Alternatives for protection and restoration
- Why each pond requires a different strategy (no action, protection, active intervention) based on its physical characteristics, current conditions, and desired use
- The costs and benefits associated with alternatives
- How overall wastewater and facilities decisions may affect the ponds

Initiate a focused monitoring program to evaluate use attainment, confirm priorities for intervention, and assess the effectiveness of control measures.

The recommended monitoring plan is included as Appendix D.

Prepare an annual Pond Report Card to enhance public understanding of water quality conditions and contributing factors.

Consider a local law requiring periodic inspection and pump out of individual on-site wastewater treatment systems. The frequency can be linked to distance to ponds, with more stringent requirements within a defined buffer zone.

Review local erosion and sedimentation control laws and determine if they could be improved to prevent sediment loss to the ponds. If warranted, propose revisions for approval.

Convene technical committee (or engage a consultant) to initiate detailed planning and cost estimating, identify funding sources, secure non-local funding as available, and acquire permits for alum application to ponds as identified by the Town based on new data.

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10 Appendices

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Appendix B. Summary of Pond Management Alternatives

Appendix C. Summary of Regulatory Setbacks and Recommendations for Septic Systems in Coastal Areas

Appendix D. Recommended Water Quality Monitoring Program

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Ultra-shallow Ponds - depths between 0.5 and 1.2 m							
Aunt Bettys	7.1	N	VL		Buildings encroach, most of shoreline remains undisturbed	Submerged and yellow lilies	Very limited public access and recreational use
Fawcetts	11.9	Y	na	na	na	na	na
Lumbert	9.7	Y	Pv	Brown-tannin	Fully vegetated (from vantage point of survey)	More surface growth	Roadway pulloff Private
Mary Dunn	18	Y	na	na	na	na	na
Mill (Marston Mills)	6.0	N		Clear	Natural	Emergents	Roadway historical marker; impoundment. Conservation area.
Mill (West Barnstable)	16.7	N	na	na	na	na	na
Red Lily	4.5	N	VL		Vegetation mostly intact; few large homes	Extensive lilies	Connected to Elizabeth (to the south)

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Shallow Ponds: depths between 2.1 and 8.6 m							
Bearse	66.8	Y	Pm (2003)	2.3m Secchi (2003)	Residential development (2003)	Treated to limit growth of fanwort (2003)	Connected to Wequaquet High TP and chlorophyll suggest productive algal population (2003)
Eagle	8.5	Y	CA	Clear	Intact. Undeveloped	Pink water lilies, black benthic mat	Walking trails, full-land trust (Mary Barton Land Trust) "relatively clean, largely unimpacted lake" (2003)
Elizabeth	6.3	N	VL			Extensive lilies	Connected to Red Lily (to the north)
Garretts	27.9	N	Pm	Tannins	Some development, few cleared lawns	Yellow lilies	"relatively clean lake with uncertain deep water quality concerns" (2003)
Hinckley	10.3	N	na	na	na	na	na
Joshua	14.7	Y	TB	Clear water; brown benthic layer	Completely natural vegetation		town beach and bath house "relatively clean, largely unimpacted lake" (2003)

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Shallow Ponds: (continued)							
Long (Centerville)	51.0	Y	WTW; Limited	Clear	Highly developed, lots of clearing	Not evident (Sonar treatment)	Hydrilla, restricted access to reduce spread of this invasive Town Beach (2003) "impacted with water quality problems" (2003)
Long (Marstons Mills)	54.8	Y	CA	Clear	Mostly intact, some developed shoreline. Moderately protected	None evident	LI conservation area "impacted with water quality concerns" (2003)
Muddy	24.6	Y	None	--	--	--	Sand pile along shoreline
Parker	10.9	Y	na	na	na	na	na
Round (Marston Mills)	9.8	N	WTW	Clear	Vegetation present	Benthic algal mat, emergents (cattails)	Private. Good setbacks in riparian zone.
Shallow	78.4	Y	na	Clear	Shoreline mostly vegetated. Developed	Sandy bottom	Benthic detrital/ algal mat

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Deep Ponds: depths between 9.3 and 17.3 m							
Crystal	10.1	N	na	na	na	na	na
Hamblin (Indian Ponds)	115.4	Y	Yes	Very clear	Mostly intact, some cleared lawns. (2009) Beach conservation land (2003)	Emergent (fringe) Cranberry bog (2003)	Bath house, swimming, kayak access. 1995 alum treatment; 10hp motor limit. (2009) "clearly impacted" (2003)
Hathaway (North)	20.9	N	TB	Very clear	Extensive, overhanging vegetation. Development surrounds pond. (2009) Town-owned conservation land (2003)	sandy bottom; some benthic macroalgae	Town beach, bath house, swimming area. Stocked with fish (smallmouth and largemouth bass, perch, pickerel, and sunfish). (2009) "relatively clean, largely unimpacted lake" (2003)
Lovells	55.5	Y	TB	Evidence blue-green algal bloom	Mostly intact; some cleared lawns	Sandy bottom, little vegetation visible	Town beach (closed on 7/30/09 due to algal bloom) and bath house; "impacted with water quality concerns" (2003)

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Deep Ponds: (continued)							
Micah	16.0	Y	CA (2003)	--	Undeveloped public land (2003)	--	Selected as one of 8 reference ponds for Cape Cod during development of Cape Cod thresholds; "relatively clean, largely unimpacted" (2003)
Middle (Indian Ponds)	104.6	Y	Yes	Very clear		Minimal	Boating
Mystic (Indian Ponds)	148.4	Y	Yes	Clear	Mostly intact, more lawns than other ponds in the Indian Ponds group.	Pondweed	Public access, swimming and boating. Permit phase, alum. Endangered mussels.
Neck	13.6	N	na	na	na	na	na
Shubael	55.1	Y	TB	Exceptionally clear	Some Phragmites and cattails.	Sandy bottom, minimal benthic algal	Beaches, small boats. Horse farm (2009) Well-developed, stocked with fish; "impacted with water quality concerns" (2003)

Appendix A. Summary of Physical Characteristics: Barnstable Ponds

Pond	Surface Area (acres)	Delineated Watershed[1] (Y/N)	Physical Characteristics[2]				
			Access/ Use[3]	Water clarity and color	Shoreline	Macrophytes	Comments
Deep Ponds: (continued)							
Wequaquet	596.3	Y	TB		Densely developed (2003)		Bath house, beach, sailing, boat launch (2009) "relatively clean but impacted" (2003)
No depth information							
Lamson	12.3	Y	na	na	na	na	na
West	10.1	Y	na	na	na	na	na

[1]Delineated watershed based on information provided in Eichner, 2008.

[2]Physical characteristics are primarily from the 2009 field visual assessment conducted by EcoLogic, unless noted by "(2003)" to indicate the information was obtained from the CCC Lakes and Ponds Atlas published in May, 2003.

[3]CA – Conservation Area; Pm – Permission granted for public access; Pv – Private access; TB – Town Beach; VL – very limited access and/or recreational use; na – no information available; WTW – Way to Water posted.

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 1: Control Inputs from Watershed

	Option 1 – Wastewater Collection	Option 2 – Modifications to on-site wastewater disposal systems	Option 3 – Inspect/Maintain on-site wastewater disposal systems
Method	Reduce phosphorus from on-site wastewater disposal systems by centralized collection and disposal outside of watershed zone of influence	Various engineering alternatives to enhance removal of nitrogen, BOD, solids, and phosphorus (in various combinations) from domestic wastewater	Reduce phosphorus from on-site wastewater disposal systems by requiring frequent inspections and maintenance of systems
How does it work?	Collection system and treatment/disposal	Alternatives to conventional on-site wastewater disposal systems	Modification to local laws
Potential Benefits	Decreased loading of all wastewater contaminants, including pathogens	Decreased loading of nutrients and organic material to subsurface	Decreased loading of all wastewater contaminants, including pathogens
Potential Drawbacks	Could increase development pressure	More complex systems, more maintenance.	Public acceptance needs to be very high
Data gaps to make decision	Integrated with rest of wastewater decisions. Existing data do not define extent of problem	Existing data do not define extent of problem	Existing data do not define extent of problem
Costs (Relative)	High (likely to receive some public funds)	Moderate (may receive approval to install as a pilot system)	Low (borne by homeowners)
Permitting issues	Collection system will have environmental impact. Need to identify acceptable site for disposal to groundwater. Conservation Commission approval needed.	Massachusetts Alternative Septic System test center is in Sandwich, on Otis Air National Guard base. This is a cooperative program of the state, Barnstable County and SMAST	Dept. of Health & Conservation Commission approvals
Longevity	High	Moderate	Moderate
Ponds appropriate for this alternative	Ponds with high number of on-site systems. Insufficient data.	Impaired ponds with >20 residences. Non-impaired ponds, at least 15 residences. Based on water quality.	All ponds

*Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009*

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 1: Control Inputs from Watershed (continued)

	Option 4 – Infiltration Basins	Option 5 – Public Education	Option 6 – Wildlife Control
Method	Water quality inlets to stormwater infiltration basins	Public education and outreach	Discourage high populations of wildlife (especially gulls, geese) from spending long periods of time in ponds.
How does it work?	Stormwater collection and treatment prior to groundwater discharge	Educate public on importance of landscaping, erosion controls, beach sanitation	By using scare techniques to scare away birds, attain reduction of nutrient deposition from birds
Potential Benefits	Reduced loading	Reduced loading. Increase public awareness of ponds and their vulnerability	Reduced loading of nutrients and bacteria
Potential Drawbacks	Most systems designed to capture sediment. Higher maintenance	None	Scare tactics can be disruptive to human community.
Data gaps to make decision	No estimate of the contribution of soluble P from stormwater	None	Estimate maximum number of gulls, use research reported in Portnoy (1990)
Costs (Relative)	Low	Low	Low
Permitting issues	Requires siting, Conservation Commission approval needed.	None	Needs approvals from Fish and Wildlife, MADEP. Conservation Commission approval needed.
Longevity	Moderate	Moderate (prevention of incremental source likely to be a small source)	Likely to be effective only while active measures are taken, although birds may move to other areas
Ponds appropriate for this alternative	All, especially those with developed watersheds and evidence of sediment deposition from runoff. Insufficient data.	All	Insufficient data.

*Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009*

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 2: Alter Internal Cycling of Nutrients in Pond

	Option 1 – Alum Application	Option 2 – Sediment Oxidation	Option 3 - Circulation
Method	Alum application to remove phosphorus from water column	Sediment oxidation	Artificial circulation.
How does it work?	Alum hydrolyzes in water, forming a floc. As the floc settles it removes particulate material as well as any dissolved P. If applied properly, forms a barrier on sediment surface that continues to trap P.	Procedure injects calcium nitrate into top 10" sediment to break down organics and promote denitrification, and injecting ferric chloride to bind available phosphorus released from sediments.	Compressed air is injected into the lower waters. Eliminates thermal stratification. Oxygenates lower waters, more oxygen available to break down organic material.
Potential Benefits	Long history of use. Does not seem to affect other aquatic organisms. May create layer over sediments retarding future sediment P release. Long-term results. Readily available.	If successful will greatly reduce internal P loading from sediments	Reduces surface algal blooms, improved habitat for aquatic biota, may retard sediment P release
Potential Drawbacks	Low pH ponds, need buffering (sodium aluminate). Potential for aluminum toxicity if pH declines. Loss of benthic organisms.	Optimal pH of sediments 7 – 7.5; would require liming. Considered an experimental technique.	Results may be subtle. Requires energy source to power. May increase algal production throughout water column.
Data gaps to make decision	Sediment testing to estimate optimal dose	Sediment testing to calculate dose	DO profiles over growing season, history
Costs (Relative)	Can be high, application rate estimated at $70 per 40-lbs.(40 lbs. treats 1 acre-ft) * High initial cost - $100-$500 per acre.**	Can be high, $8,000 – $12,000 per acre *	Approximately $150/acre**. Variable, depending on power source. Solar-powered mixing devices: $25,000.
Permitting issues	Requires permit, testing for optimal dose. Conservation Commission approval needed.	Requires permit, testing for optimal dose. Conservation Commission approval needed.	Conservation Commission approval needed.
Longevity	Moderate (at least several years)	Moderate (at least several years)	Only effective when mixers working
Ponds appropriate for this alternative	Deeper ponds with elevated TP in lower waters. Insufficient data.	Impaired ponds with DO depletion. Insufficient data.	Insufficient data.

*Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009*

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 2: Alter Internal Cycling of Nutrients in Pond (continued)

	Option 4 - Dredging	Option 5 – Pond Drawdown
Method	Dredging	Drawdown of pond water level to expose sediments
How does it work?	Sediment is physically removed, also removing accumulated nutrients and organic material	Lowering water level will dry sediments and allow sediments to oxidize and compact.
Potential Benefits	Reduced internal nutrient supply, increases water depth, can reduce sediment oxygen demand	May alter nutrient availability for the better. Opportunity for shoreline cleanup. Nuisance plant species may die back.
Potential Drawbacks	Expensive if disposal site not nearby. Temporary turbidity, removes macroinvertebrates, temporarily interferes with recreation. Might reduce ponds' natural capacity for denitrification and thus allow more soluble nitrogen to make its way to coastal embayments.	Possible impacts on contiguous wetlands, may change habitat for amphibians. Desirable species of plants may die. Ponds with water level controls may be managed for herring. Temporary loss of waterfowl habitat. Potential to create highly unappealing aesthetic conditions for neighbors.
Data gaps to make decision	Quality of sediments affects disposal options and costs (e.g. hazardous waste). Detailed bathymetry required to estimate volumes and costs.	Water level control needed, therefore not feasible for most kettle ponds which lack such controls
Costs (Relative)	$15,000 - $50,000/acre*, depending on transportation needs to remove dredge spoils from site.	<$100/acre if structures adequate*
Permitting issues	Requires permit for dredging and disposal Conservation Commission approval needed.	Permit required, complexity depends on impacts on wetland and other ponds. Conservation Commission approval needed.
Longevity	Moderate to long-term	Moderate to long-term
Ponds appropriate for this alternative	Insufficient data.	Insufficient data.

*Sources for cost estimates: *Holdren et al. 2001; ** NYSFOLA, 2009*

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 3: Mitigate Symptoms of Eutrophication - Weeds and Algae

	Option 1 – Mechanical Harvesting of Weeds	Option 2 – Mechanical Weed Removal	Option 3 – Hand-Harvesting Weeds
Method	Mechanical harvesting of weeds	Mechanical removal of weeds, by rotovating (rototilling) or hydroraking.	Removal of plants by hand.
How does it work?	Upper part of plants cut in place, deeper waters; roots are not harvested. Cuttings collected and removed from pond.	Removes rooted aquatic plants from targeted areas by means of large cutters that dislodge roots and plants from sediment.	Removes rooted aquatic plants from targeted areas, using human labor.
Potential Benefits	Immediate results. Improved recreational access. Remaining lower part of plants continues to provide habitat.	More effective than mechanical harvesting, as the roots as well as plants are removed.	Effective rapid-response to invasive species. Selective plant management.
Potential Drawbacks	Non-selective, may alter plant communities, may remove native insects that help control plants.	Creates turbidity, disturbs the sediment, may spread some plants by fragmentation. Not selective; cuts all plants.	Labor intensive, restricted to small areas. May spread some plants by fragmentation.
Data gaps to make decision	Species and habitat affected, water depth. Equipment access, disposal.	Useful for shallower areas where recreational access is limited by weeds	Useful for small areas where recreational access is limited by weeds
Costs (Relative)	Leasing a harvester, $600-$2,400/acre**, depending on size of harvester.	Hydroraking or rotavation services $1,000** to $2,000* per acre	$100/acre* up to $1,000/acre**
Permitting issues	Minor, need to develop plan for harvesting and upland disposal sites. Conservation Commission approval needed.	Turbidity, avoidance of critical habitat areas and spawning/early life stages of fish community Conservation Commission approval needed.	Minimal; Conservation Commission approval needed.
Longevity	Two or more harvests during the recreational season.	Usually needs to be repeated several times year	Usually needs to be repeated once or twice a year
Ponds appropriate for this alternative	Insufficient data.	Insufficient data.	Areas where homeowners' access is diminishing. Insufficient data.

Source for cost estimates: *Holdren et al. 2001 ; ** NYSFOLA, 2009

Appendix B. Summary of Pond Management Alternatives

Appendix B - Category 3: Mitigate Symptoms of Eutrophication - Weeds and Algae (continued)

	Option 4 – Benthic Barriers	Option 5 – Chemical Control Algae	Option 6 – Aquatic Herbicides
Method	Benthic barriers, benthic screens	Chemical control of algae (several copper-based and organic compounds approved for this use)	Chemical control of weeds (Diquat, 2,4-D, Endothol, Glyphosate, Fluridone, Trichlopyr, copper-based herbicides)
How does it work?	Mat of variable composition laid on bottom of target areas. Blocks light and restricts space for plant growth.	Algaecides kill algae by direct toxicity or by metabolic interference	Toxins in contact with or taken up by plant; biochemical pathways disrupted. Ultimately results in plant senescence and death.
Potential Benefits	Used effectively in a variety of lake conditions; can be sited by homeowners.	Rapidly eliminates algae from water column	Reduces density of macrophytes in treated areas.
Potential Drawbacks	Cumbersome to place and anchor. Require maintenance.	Toxic to other organisms; decaying algae may release nutrients, increase oxygen demand. May restrict water uses.	Toxic to other organisms; decaying plants may release nutrients, increase oxygen demand. May restrict water uses.
Data gaps to make decision	Useful for areas where recreational access is limited by weeds	Water pH, alkalinity, background concentrations of metals; sediment quality (AVS and TOC)	Detailed species inventories needed to select most appropriate chemicals
Costs (Relative)	Professional installation $20,000/acre**	Depends on compound: Chelated copper $150 – 300/acre per application*. Copper sulfate $5-$25/acre-foot**.	$200 to $1,500 per acre** Some treatments may need to be repeated. Cost vary with chemical, dose rate, etc.
Permitting issues	Minimal, need to avoid critical habitat Conservation Commission approval needed.	Requires permit and approvals from environmental and public health agencies, including Conservation Commission.	Requires permit and approvals from environmental and public health agencies, including. Conservation Commission
Longevity	Need to be replaced every 1 – 2 years	Short-term (weeks to months)	Annual
Ponds appropriate for this alternative	Areas where homeowners' access is diminishing. Insufficient data..	Insufficient data.	Insufficient data.

Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009

Appendix B - Category 3: Mitigate Symptoms of Eutrophication - Weeds and Algae (continued)

	Option 7 – Biomanipulation	Option 8 – Barley straw
Method	Stocking or removing specific organisms to shift ecological conditions to improve lake for desired uses ("top-down" approach)	Dried barley straw
How does it work?	Stocking fish that eat plankton-eating fish to reduce predation on zooplankton. As a result, zooplankton species increase in size and abundance and feed on more algae, thus controlling algae populations and improving water clarity. Removing bottom-feeding fish that cause turbidity and increase nutrient concentrations by disturbing and consuming organic material at the bottom of the lake.	Dried barley straw, loosely netted to allow maximum oxygen exchange within the straw. Anchored floats hold the netted straw in place in the upper three to four feet of water. Not clearly understood how barley straw affects algae.
Potential Benefits	Serves to achieve multiple water quality objectives while increasing the population of desirable fish species.	Reduces algae levels in ponds and lakes, most effective in controlling new algae growth than at removing pre-existing algae. Public perception that it is "natural" method.
Potential Drawbacks	Results are not easily predictable. May cause unexpected side effects. May control palatable algae and leave blue-green algae.	Not practical for ponds greater than 100 acres. Inconsistent track record. Removing water-logged bales (150 lbs) labor-intensive.
Data gaps to make decision	Experimental procedure. Detailed food web analysis to evaluate appropriateness of using this method to achieve water quality objectives.	Experimental procedure. Water temperatures and temporal patterns of algal blooms during the growing season to optimize deployment of the bales..
Costs (Relative)	$100-$200 per hundred fish. Estimate 100 to 1,000 fish/acre**	Ranges from $20 to $400 per acre, depending on the cost and quantity of straw required.
Permitting issues	Class 2 public stocking license. Conservation Commission approval needed.	Uncertain
Longevity	Depends on whether stocked fish survive and reproduce.	30 to 90 days (based on rate of decomposition of bales)
Ponds appropriate for this alternative	Insufficient data.	Insufficient data.

Source for cost estimates: *Holdren et al. 2001; **NYSFOLA, 2009

Appendix C. Summary of Regulatory Setbacks and Recommendations for Septic Systems in Coastal Areas.

Buzzards Bay Watershed Management Plan	• Recommends 250 ft setback from surface waters and wetlands, (viral pollution) • Where this setback cannot be met, changes in system design and application rate are required to ensure removal of viruses.
New Hampshire's Shoreland Protection Act [3.10 Leach Field And Septic Tank Setback (Added 1990, Amended 1992)]	• "Where the naturally occurring receiving soil down-gradient of the leaching portions of a septic system is a porous sand and gravel material with a percolation rate faster than two (2) minutes per inch, the setback shall be at least 125 feet. • For naturally occurring receiving soils with restrictive layers within 18 inches of the surface, the setback shall be at least 100 feet; and • For naturally occurring receiving soils with any other characteristics the setback shall be at least 75 feet.."
CAMA Handbook For Development In Coastal North Carolina: Section 3	• Septic tanks and drainfields must be located at least 100 feet from waters classified as WS IV by the Environmental Management Commission. • No sewers, septic tank fields or other sources of pollution may be built within 500 feet of the edge of the Fresh Pond in the Nags Head/Kill Devil Hills Fresh Pond watershed. Between 500 feet and 1,200 feet from the pond, septic systems are limited to one system serving a single-family home with no more than four bedrooms (or an equivalent volume of sewage) on a tract of land at least 40,000 square feet in size.
Rhode Island towns:	
Burrillville:	200 ft from wetlands
Charlestown:	• 100 feet from a freshwater or coastal wetland. • 200 feet from a ten-foot-wide flowing body of water. • 100 feet from flowing bodies of water less than 10 feet wide. • 100 feet from intermittent streams. • 100 feet from floodplains.
Foster:	200 ft from any pond, stream, spring or brook
Glocester:	150 ft from ponds, streams or springs
Jamestown:	150 ft from any freshwater
Narrangasett:	Special use permits for septic systems within 150 ft. of coastal and freshwater wetlands.

Appendix C. Summary of Regulatory Setbacks and Recommendations for Septic Systems in Coastal Areas. (continued)

Rhode Island towns (continued):

New Shoreham:	• 150 feet of vegetated buffer shall be maintained from any septic system to a freshwater wetland or coastal feature. • 200 feet of vegetated buffer shall be maintained from any septic system to Sands Pond, Peckham Pond and Fresh Pond.
Scituate:	150 ft from surface waters
South Kingstown:	Requires special use permits for all septic systems located: • Within 50 feet of a bog, marsh, swamp or pond. • Within 200 feet of flowing bodies of water 10 feet or more in width. • Within 100 feet of flowing bodies of water less than 10 feet in width. • Within 150 feet of floodplains. • Within 150 feet of other freshwater wetlands
Warren:	150 ft from any body of water, including wetlands
West Greenwich:	200 ft from edge of any pond or stream

Appendix D. Recommended Water Quality Monitoring Program

As described in Eichner et al (2008), there is currently no on-going water quality monitoring program to track the condition of Barnstable's inland kettle ponds. Monitoring can be a costly and time-consuming endeavor; therefore, we recommend a focused monitoring program clearly linked to specific management objectives. This focused monitoring program will provide strategic information regarding the water quality and ecological status of the Barnstable freshwater ponds. Measuring various physical, chemical, and biological attributes of the inland ponds can help municipal leaders and other stakeholders evaluate use attainment, trends and the effectiveness of control measures.

- *Recommended Action: Conduct water quality monitoring using the established PALS protocol on a three-year rotation*

Objective: Develop a program to sample priority ponds on a three-year cycle. This will enable comparisons between ponds and within ponds over time.

- *Recommended Action: Measure water quality conditions in the upper and lower waters of Lovells, Wequaquet and Mystic Ponds from April – October, 2010*

Objective: Evaluate the magnitude and importance of sediment TP flux in deep ponds affected by increased productivity.

Rationale: Internal sediment TP can be remediated for a period of a decade or more with an alum treatment program. For this treatment to be effective, internal TP flux during summer anoxia must be a significant fraction of the TP budget. Moreover, TP released from sediment must reach the upper, sunlit waters where algal production occurs.

Parameter list:

Parameter	Depth	Frequency	Note
TP, TN, total alkalinity	3 m intervals through water column	Monthly (minimum) Biweekly(recommended)	Discrete samples
DO, temperature, pH, specific conductance	1 m intervals through water column	Monthly (minimum) Biweekly(recommended)	Field meter
Secchi disk transparency	From surface	Biweekly	Volunteer monitoring possibility
Chlorophyll-*a*	Composite sample through photic zone	Monthly (minimum) Biweekly(recommended)	

Recommended Action (2): Develop a surveillance program for cyanobacterial blooms

Objective: Adopt a reliable near-real time technique for evaluating whether the public is at risk from harmful algal blooms.

Rationale: Certain species of cyanobacteria (blue-green algae) can exude potentially harmful compounds. Restrictions on swimming during bloom conditions may be warranted to protect public health. Sampling and analysis of the algal community can be costly if in-house expertise is not available, and may extend over several days before results are received and interpreted. A field meter to screen for the presence and concentration of phycocyanin, a pigment associated with cyanobacterial blooms, may provide a screening tool.

Appendix SS

2020 Wastewater Plan MEP Scenarios: Additional 3 Bays Sewering and Barnstable Great Marshes Impact

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Technical Memorandum

To: Griffin Beaudoin, Town Engineer, Barnstable Department of Public Works

From: Brian Howes, Director, Coastal Systems Program, SMAST, UMassD
Ed Eichner, Principal Water Scientist, TMDL Solutions
Sean Kelley, Senior Coastal Engineer, Applied Coastal Research and Engineering
John Ramsey, Principal Coastal Engineer, Applied Coastal Research and Engineering

Date: November 1, 2020

RE: 2020 Wastewater Plan MEP Scenarios: Additional 3 Bays Sewering and Barnstable Great Marshes Impact

I. Background

The Town of Barnstable is working to evaluate and implement a Wastewater Plan that includes reducing excessive nitrogen loads to its coastal estuary waters. The Town of Barnstable has proposed a 30-year, three-phased wastewater plan that uses and builds on the existing wastewater infrastructure, including the municipal Barnstable Water Pollution Control Facility (WPCF).[1] This proposed plan is flexible depending on future changes.

At the request of the Town, the project team evaluated the estuarine water quality impacts of potential Wastewater Plan sewering within the watersheds to Lewis Bay, Centerville River, Three Bays, and Barnstable Great Marshes.[2] These 2019 evaluations included updating most watershed nitrogen loads to current conditions based on updates of land uses, impervious surfaces, and wastewater flows within the Massachusetts Estuaries Project (MEP) linked models for these estuaries.[3] Once this update was complete, the watershed loads were then adjusted to reflect planned sewering under the Wastewater Plan. The hydrodynamic portions of the linked models continued to use the MEP-developed versions.

[1] Barnstable Department of Public Works, Presentation to Town Council, January 3, 2019. https://town.barnstable.ma.us/Departments/PublicWorks/Office_Resources_and_Updates/Wastewater-Update-Presentation---Town-Council.pdf

[2] CSP/SMAST Technical Memorandum. December 5, 2019. MEP Scenarios: Town of Barnstable Wastewater Plan and Land Use Updates. To: G. Beaudoin, Town Engineer, Barnstable Department of Public Works. From: B. Howes, E. Eichner, and J. Ramsey. 36 pp.

[3] MEP assessments for Three Bays, Centerville River, Lewis Bay/Halls Creek, and Barnstable Great Marshes were completed in 2006, 2006, 2008, and 2017, respectively. During the 2019 project, land uses in adjacent towns that share the system watersheds were not updated and land uses and nitrogen loads within these towns continued to be those developed during the MEP.

These 2019 evaluations generally found that the planned sewering included in the Wastewater Plan attained the nitrogen reductions to restore the water quality[4] in these estuarine systems except for the Three Bays system. As a result, the Town has proposed additional sewering within the Three Bays watershed and has asked the project team to update some key watershed nitrogen loads. These changes would be incorporated into the updated 2019 Three Bay MEP model. Since a portion of the collected sewer flow with the Three Bays watershed would be treated at the municipal Barnstable Water Pollution Control Facility (WPCF) and discharged within the Barnstable Great Marshes watershed, the Town has also asked the project team to evaluate the impact of this additional nitrogen load on the Barnstable Great Marshes system as well.

II. Three Bays Scenario: Additional Watershed Sewering

The final MEP assessment report on the Three Bays estuary system was completed in 2006[5] and MassDEP used the MEP assessment to develop and approve a set of nitrogen TMDLs for restoring water quality in the Three Bays system in 2007.[6] The watershed nitrogen loading model portion of the linked Three Bays MEP models was based on digital parcels and land use data obtained from the watershed towns for the following years: 2004 for Barnstable, 2000 for Sandwich, and 2001 for Mashpee. Tidal data, bathymetry, and shoreline configuration for the linked Three Bays MEP water quality model were collected in 2002 and water quality data that was used was collected between 1999 and 2004. Measurements of dissolved oxygen, chlorophyll, macroalgae, eelgrass, and infauna found that portions of the system ranged in condition from severely degraded (Warrens Cove, Princes Cove, Upper North Bay) to moderately impaired (Cotuit Bay, West Bay).[7]

The 2019 watershed loading update showed an increased (+4.8%) *attenuated* system-wide nitrogen load under current conditions compared to the MEP system load. In contrast, there was little change (+0.6%) in the system *unattenuated* load compared to the MEP load. The relatively higher increase in the attenuated loads was due to changes in the spatial distribution of the loads within the watershed with relatively greater loading increases in the lower portion of the watershed closer to the estuary.

In order to attain the Three Bays TMDL restoration targets, the proposed 2019 Town Wastewater Plan scenario included provisions to decrease watershed nitrogen loads by connecting large portions of the Three Bays watershed to a municipal sewer system (**Figure 1**). Working with the project team, Town staff also included in this scenario an additional provision to split the collected wastewater between the Barnstable WPCF and an as-yet-undetermined site along a north/south line through the watershed. Any collected wastewater east of line would be treated at the WPCF. The proposed sewering in the 2019 Plan significantly decreased the watershed-wide attenuated load by -39% with the majority of the decrease occurring within the combined Prince Cove

[4] The Massachusetts Department of Environmental Protection has developed total nitrogen limits (Total Maximum Daily Loads or TMDLs) for Three Bays, Centerville River, and Lewis Bay based on MEP assessments. Portions of Barnstable Great Marshes were identified as impaired in its MEP assessment, but MassDEP has not developed a nitrogen TMDL for it yet.

[5] Howes B., S.W. Kelley, J.S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner. 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts. Massachusetts Estuaries Project. Massachusetts Department of Environmental Protection. Boston, MA. 183 pp.

[6] MassDEP. 2007. Three Bays System TMDLs for Total Nitrogen (Report # MA96-TMDL-10, Control # CN242.0). 35 pp. Approved by USEPA, February 13, 2008, 6 total nitrogen TMDLs, 1 pollution prevention total nitrogen TMDL.

[7] See Table VIII-1 in Three Bays MEP Report (Howes and others, 2006).

subwatershed. However, the reduction was insufficient to attain the 0.38 mg/L total nitrogen (TN) threshold concentration in the Three Bay TMDL at the sentinel water quality monitoring station.

In order to meet the TMDL target and further discussions with project staff, Town staff expanded the Three Bays sewer areas in the current 2020 scenario to include four new areas, mostly within the subwatersheds to the following waters: 1) West Bay, 2) Cotuit Bay, 3) Shubael Pond, and 4) Long Pond (Marstons Mills) (see **Figure 1**). Collectively, these additional sewered areas added 736 additional sewered parcels within the Three Bays watershed to those identified in the 2019 scenario. Water use at these parcels was 160,307 gallon per day (gpd) with 99,297 gpd of this flow to be treated at the WPCF and the remainder at an as-yet-undetermined site.

In addition to the new sewering, Town staff also asked CSP/SMAST staff to update nitrogen loads from the four golf courses in the watershed and the nitrogen load from the capped Town landfill. Town staff contacted all the golf superintendents and obtained recent nitrogen fertilizer application rates.[8] These updated nitrogen fertilizer application rates were all less than those used in the original MEP watershed nitrogen loading.[9] Updated Town landfill monitoring data from 2012 to 2016 was incorporated in the 2019 watershed nitrogen loading update, but the monitoring results suggested a decreasing nitrate-N trend. More recent data provided for this 2020 scenario confirmed that concentrations had decreased further since 2016 (**Figure 2**). The combined impact of incorporating the landfill and golf course fertilizer updates decreased the overall attenuated nitrogen loads in the Three Bays watershed by 1,540 kg/yr.

The total *unattenuated* nitrogen load removed from the Three Bays watershed as a result of this additional 2020 sewering and the landfill and golf course fertilizer updates was 6,343 kg/yr (**Table 1**). Most of this removal (42%) occurred in the West Bay subwatershed with similar portions in Cotuit Bay (23%) and Prince Cove (26%). As a result of the 2020 changes, the total *attenuated* nitrogen load removed from the Three Bays watershed was 5,325 kg/yr (see **Table 1**). Most of this attenuated removal (50%) occurred in the West Bay subwatershed with 20% removal in the Cotuit Bay subwatershed, 19% in Prince Cove, 10% in North Bay, and 1% in the Seapuit River. It should be noted that the attenuated nitrogen removals from sewering within the watersheds to Shubael Pond and Long Pond (Marstons Mills) were reduced because these ponds naturally attenuate 50% of the nitrogen within their watersheds, so sewering only removes half of the wastewater nitrogen compared to watersheds with direct discharge to the estuary without natural nitrogen attenuation. This upstream attenuation reduced the impact of sewering within the Prince Cove subwatershed. Overall, the 2019 plan attenuated watershed loads were a 44% reduction from the 2019 existing conditions update loads, while the 2020 plan loads were a 54% reduction (**Table 2**). The accompanying benthic loads also decreased.

As a result of the 2020 additional reductions, the TN concentration at the Three Bays sentinel station was attained (**Table 3**). The 2019 updated conditions caused TN concentrations to increase throughout the Three Bays system using the MEP Linked Watershed-Embayment Nitrogen Management Model; the TN concentration at the sentinel station increase from 0.487 mg/L under the MEP existing conditions to 0.499 mg/L TN with the updated conditions. The 2019 wastewater plan nitrogen reduction reduced the TN concentration throughout the Three Bays system, but had

[8] Personal communication, A. Unruh, Barnstable DPW.

[9] Project staff have found reduced golf course fertilizer applications in a number of other MEP updates in the region.

a 0.408 mg/L TN concentration at the sentinel station, which did not attain the 0.380 mg/L TN threshold target/TMDL. The additional nitrogen reductions included in the 2020 wastewater plan resulted in reduction in TN concentrations throughout the Three Bay system and attained the TN threshold at the sentinel station. The largest reductions in concentration were generally in the inner portions of the system: Prince Cove – south (-33%), Prince Cove – north (-31%), Warrens Cove (-28%) and North Bay – north (-22%).

It should be noted that the nitrogen loads and concentrations do not include buildout provisions or updates to Sandwich loads (except for the golf courses). The MEP buildout assessment for Three Bays estimated that the watershed load would increase by 12%.[10] Some of the projected portion of the buildout within the Town of Barnstable was included in the 2019/2020 updates, but Sandwich loads do not included any potential buildout since this portion of the watershed load was generally the same as the MEP load.

III. Barnstable Great Marshes/Bass Hole Scenario: Additional WPCF N Loading

The final MEP assessment report on the Barnstable Great Marshes estuary system was completed in 2017.[11] The watershed nitrogen loading model portion of the MEP linked models was based on digital parcels and land use data with base years between 2011 and 2012 that were obtained from the watershed towns of Barnstable, Yarmouth, Dennis, and Sandwich. Bathymetry and salt marsh topography for the water quality model portion of the MEP linked models were collected in 2015 and 2013, respectively. Water quality data between 2002 and 2014 was used in the development of the model. Measurements of dissolved oxygen, chlorophyll, macroalgae, eelgrass, and infauna found that the majority of the system had healthy habitat except for the Millway subembayment, which is a dredged boat basin with severely degraded habitat.[12] The MEP team recommended a target bioactive nitrogen concentration at the Millway to address its measured nitrogen-related impairments, but found that the majority of the Barnstable Great Marshes system could accommodate a +39.6% increase in watershed nitrogen loads without becoming impaired.[13] MassDEP has not developed a draft nitrogen TMDL for Barnstable Great Marshes or the Millway.

The 2019 watershed nitrogen loading model update included a number of revised inputs, including a new accounting of the municipal sewer connections to the Barnstable WPCF within Barnstable Village, which included parcels within the Millway subwatershed. Overall, the 2019 update had total system unattenuated and attenuated loads within 1% of the corresponding MEP loads.

The 2019 Town Wastewater Plan scenario included provisions that added treated effluent flows from the Barnstable WPCF to a location within the Barnstable Harbor watershed. The Plan scenario specified that treated wastewater at the Barnstable WPCF site would total 3.82 MGD, but effluent discharge at the WPCF site would be limited to 2 MGD (with a 3 mg/L TN concentration). The remaining treated effluent would include 1.2 MGD discharged within the Barnstable Great Marshes watershed and 0.62 MGD that would be collected within Yarmouth, treated at the WPCF,

[10] See Table IV-5 in Three Bays MEP Report (Howes and others, 2006).

[11] Howes B., E. Eichner, S. Kelley, R. Samimy, J. S. Ramsey, D. Schlezinger, P. Detjens. 2017. Massachusetts Estuaries Project Linked Watershed-Embayment Model to Determine the Critical Nitrogen Loading Threshold for the Barnstable Great Marshes - Bass Hole Estuarine System, Towns of Barnstable and Dennis, Massachusetts, Massachusetts Department of Environmental Protection. Boston, MA. 213 pp.

[12] See Table VIII-1 in Barnstable Great Marshes/Bass Hole MEP Report (Howes and others, 2017).

[13] See Table VIII-3 in Barnstable Great Marshes/Bass Hole MEP Report (Howes and others, 2017).

and returned to Yarmouth for discharge outside of the Lewis Bay watershed. Treated effluent discharge at the WPCF and the Barnstable Harbor watershed would include portions of the collected wastewater within the Three Bays, Centerville River, Lewis Bay, and Barnstable Great Marshes watersheds.

The additional collected wastewater within the Three Bays watershed in the 2020 scenario discussed in this memo would add 99,297 gpd to the WPCF treated effluent discharge within the Barnstable Great Marshes watershed. This addition would increase the treated effluent discharge from 1.2 MGD to 1.3 MGD. This change would result in a nitrogen loading increase of 412 kg/yr or a 0.6% increase in the overall attenuated watershed load from the 2019 Wastewater Plan scenario (**Table 4**). The benthic load also changes slightly too (**Table 5**).

As would be expected by such a small change in a large watershed load, the change in the impact of this addition generally does not change the TN concentrations throughout the Barnstable Great Marshes (**Table 6**). The only monitoring station with any change was the Broad Sound station (BM-10), which is predicted to increase from 0.107 mg/L TN to 0.108 mg/L TN. No changes were modeled at the sentinel stations as a result of the small addition of WPCF treated effluent and all projected concentrations remained below the MEP thresholds at these stations.

III. Conclusions/Discussion

At the request from the Town of Barnstable, project staff reviewed the impact of additional 2020 projected sewering within the Three Bays watershed. This scenario also included updates to the nitrogen loads from the town landfill, as well as updates of nitrogen fertilizer applications at the four golf courses within the Three Bays watershed. The additional projected sewering resulted in additional wastewater flow being transferred to the Water Pollution Control Facility (WPCF). This resulted in an additional scenario to evaluate the impact of this small amount of additional treated effluent being discharged within the Barnstable Great Marshes watershed.

These two scenarios were completed using the MEP linked models for the Three Bays and Barnstable Great Marshes systems. The Barnstable watershed nitrogen loading portions of these models were previously updated to 2019 land use and used to evaluate the impacts a 2019 version of the Town's Wastewater Plan within all four of the Town's estuary systems.[14]

The 2020 sewer additions and nitrogen loading updates within the Three Bays watershed allowed the Wastewater Plan scenario to attain the MEP nitrogen thresholds/MassDEP TMDLs at the Three Bays sentinel stations. The small nitrogen loading addition within the Barnstable Great Marshes system had little impact on the watershed nitrogen load and projected nitrogen concentrations continued to attain the MEP nitrogen thresholds throughout the Barnstable Great Marshes system.

[14] CSP/SMAST Technical Memorandum. December 5, 2019.

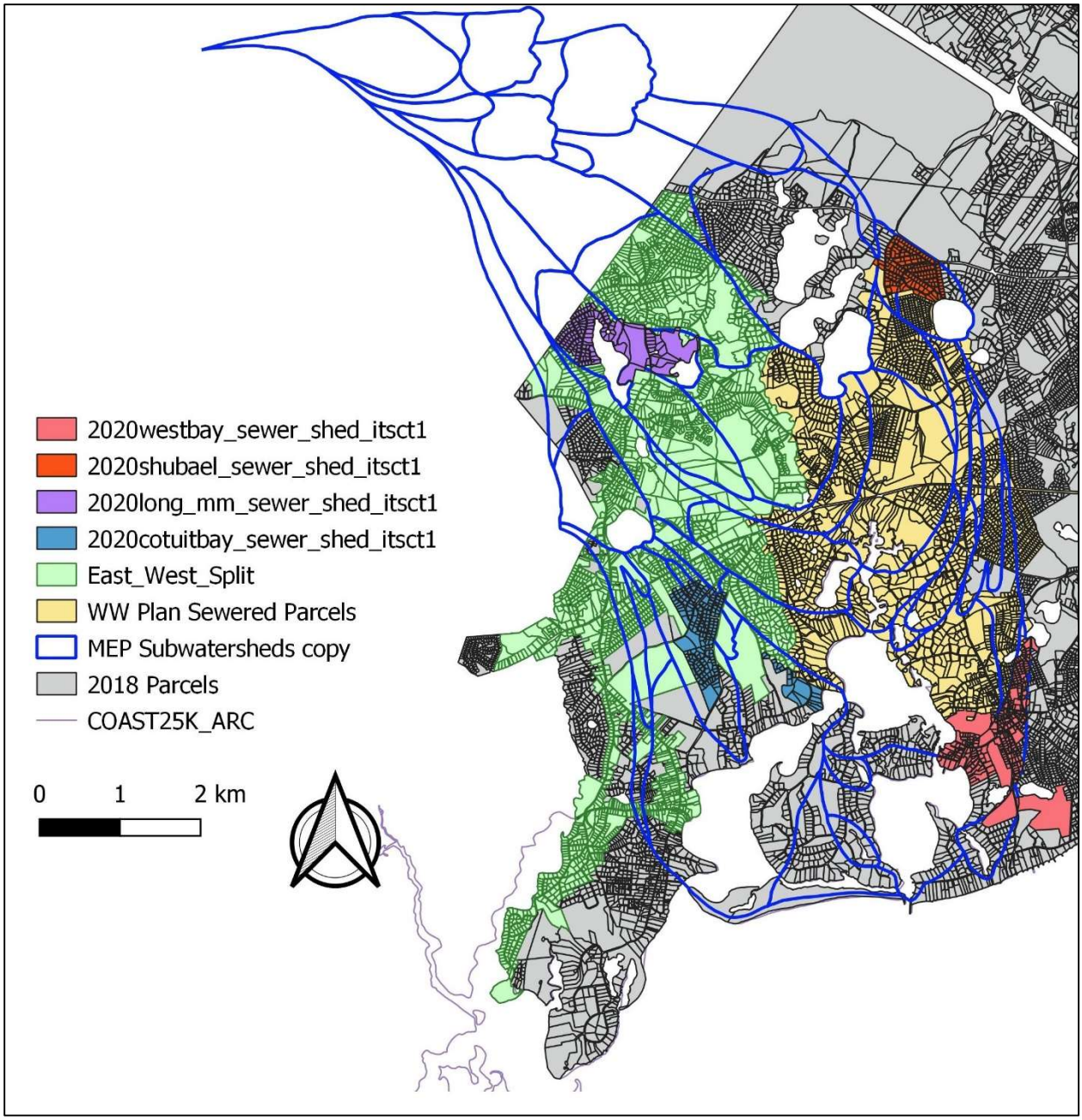


Figure 1. 2020 Sewer Area Additions to Three Bays Watershed. In 2019, the Town Wastewater Plan included connecting the yellow parcels (WW Plan Sewered Parcels) and the green parcels (East_West_Split) to a municipal sewer system. Wastewater from the yellow parcels would be treated at the Barnstable WPCF, while wastewater from the green parcels would be treated and discharged at an as-yet-to-be-determined site outside of the Three Bays watershed. In the 2020 scenario, Town staff have added additional sewered parcels in four areas generally within the subwatersheds to West Bay, Cotuit Bay, Shubael Pond, and Long Pond (Marstons Mills). Collected wastewater from the West Bay and Shubael Pond sewered areas would be treated at the Barnstable WPCF, while the wastewater from the Cotuit Bay and Long Pond (Marstons Mills) sewered area would be treated at as-yet-to-be-determined site outside of the Three Bays watershed.

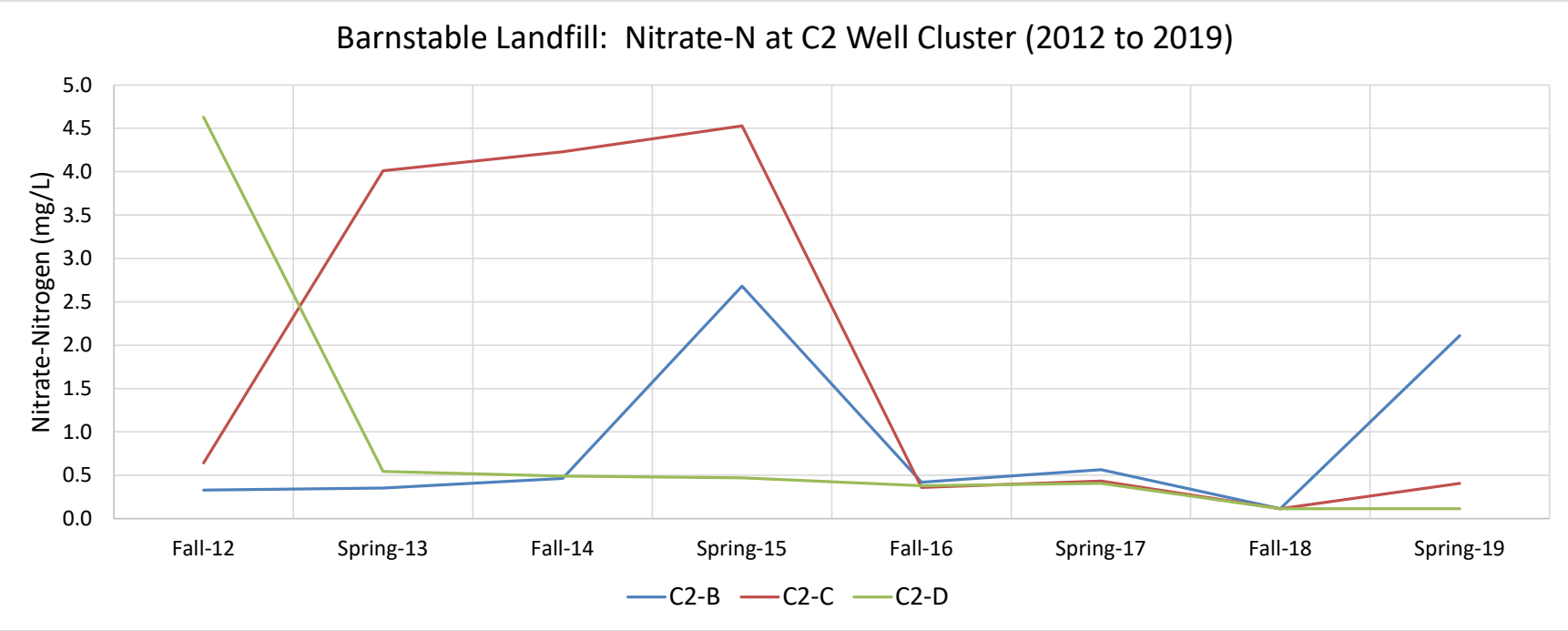


Figure 2. Nitrate-Nitrogen Concentrations in C2 Well Cluster at Barnstable Landfill (2012 to 2019). In the 2019 watershed nitrogen loading update of the Three Bay MEP model, project staff received monitoring data at the capped Town landfill from Town staff**.** The 2019 update included data from 2012 to 2016, but the low concentrations in Fall 2016 suggested that the nitrogen contamination from the landfill might be decreasing further. As part of the 2020 update discussed in this technical memo, project staff received data from three additional sampling runs at the landfill and included the resulting decreased landfill nitrogen load in the 2020 scenario (-560 kg/yr unattenuated nitrogen load).

Table 1. Watershed Nitrogen Loads for Three Bays Scenarios: 2019 Land Use Update, 2019 Town Wastewater Plan and 2020 Wastewater Plan with Sewer Additions. The 2019 update of watershed parcels, water use, impervious surfaces, etc. increased the attenuated nitrogen load of the overall system watershed by 5.5% and the unattenuated load by 0.8% compared to the MEP loads. The 2019 Town Wastewater Plan decreased the attenuated load by 44% with the majority of the decrease within the Prince Cove subwatershed. The 2020 Sewer Additions were in the subwatersheds to: West Bay, Cotuit Bay, Shubael Pond, and Long Pond (Marstons Mills). The additional sewering resulted in a 3,786 kg/yr reduction in the attenuated system load. Loads in this table do not include nitrogen deposition on the estuary surfaces.

Scenario	Description	Watershed/ Subwatershed	Wastewater		Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
			Septic	WWTF					Unatten	Atten
			kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
2019 Current Conditions Update	Updated land use, water use, impervious surfaces, etc. to current conditions	Overall – Whole System	51,272	46	6,367	7,231	2,926	1,531	69,372	51,643
		Cotuit Bay	9,308	0	939	1,273	254	339	12,113	9,909
		Seapuit River	1,151	0	236	120	0	32	1,539	1,539
		West Bay	5,896	0	866	681	79	82	7,603	7,515
		North Bay	9,875	0	827	1,384	83	196	12,364	11,417
		Prince Cove	25,042	46	3,499	3,773	2,511	882	35,753	21,263
2019 Town Wastewater Plan	Use 2019 current conditions update with planned sewering	Overall – Whole System	24,491	0	6,367	7,231	2,926	1,531	42,545	29,039
		Cotuit Bay	6,183	0	939	1,273	254	339	8,988	7,143
		Seapuit River	1,151	0	236	120	0	32	1,539	1,539
		West Bay	5,804	0	866	681	79	82	7,511	7,456
		North Bay	2,015	0	827	1,384	83	196	4,504	4,191
		Prince Cove	9,338	0	3,499	3,773	2,511	882	20,003	8,710
2020 Sewer Additions + golf course fertilizer updates + landfill update	Use 2019 update with expanded planned sewering	Overall – Whole System	19,311	0	5,204	7,231	2,926	1,531	36,202	23,714
		Cotuit Bay	4,824	0	841	1,273	254	339	7,530	6,092
		Seapuit River	1,151	0	176	120	0	32	1,480	1,480
		West Bay	3,600	0	423	681	79	82	4,864	4,809
		North Bay	1,702	0	584	1,384	83	196	3,950	3,638
		Prince Cove	8,034	0	3,179	3,773	2,511	882	18,378	7,696

Table 2. Watershed, Benthic Flux, and Direct Atmospheric Nitrogen Loads for Three Bays Scenarios: MEP, 2019 Current Conditions Land Use Update, 2019 Town Wastewater Plan and 2020 Wastewater Plan with Sewer Additions, Golf Course Fertilizer Updates, and Landfill Updates. These are the nitrogen loads used in the water quality modeling of each scenario, including the 2020 scenarios discussed in this Technical Memo. The 2020 sewer additions were within the West Bay, Cotuit Bay, Shubael Pond, and Long Pond (Marstons Mills) subwatersheds and were combined with updated nitrogen application rates for the four golf courses in the watershed and an updated nitrogen load from the capped Town landfill. Direct atmospheric deposition loads are nitrogen loads on the surface of each of the subembayments. Net benthic flux loads are nitrogen regenerated from sediments within each subembayment. The 2019 loads were described in a December 5, 2019 CSP/SMAST Technical Memo. Nitrogen loads from the 2006 MEP Report are also shown for comparison. All nitrogen loads are presented as kilograms per day and may not sum correctly due to rounding.

	Total Attenuated Watershed Loads (kg/d N)				% change from 2019 Current Conditions Update		Benthic Flux Net (kg/d N)			direct atmospheric deposition (kg/day N)	
Sub-Embayment	MEP	2019 Current Conditions Update	2019 WW Plan	2020 Plan w/Sewer Additions, GC and landfill changes	2019 WW Plan	2020 Plan w/Sewer Additions	2019 Update	2019 WW Plan	2020 Plan w/Sewer Additions	MEP	2019 Update + both scenarios
Cotuit Bay	21.78	23.03	16.27	14.90	-29%	-35%	-55.96	-46.29	-44.06	5.79	5.79
West Bay	19.07	20.59	20.43	13.18	-1%	-36%	3.87	3.56	3.51	4.23	4.23
Seapuit River	3.77	4.22	4.22	4.05	0%	-4%	-5.50	-4.97	-4.86	0.45	0.46
North Bay	29.45	31.28	11.48	9.97	-63%	-68%	70.18	53.98	50.15	3.95	3.79
Prince Cove	13.36	12.72	4.04	3.73	-68%	-71%	0.54	0.38	0.35	1.23	1.22
Warrens Cove	12.03	13.44	5.44	3.93	-60%	-71%	9.20	6.89	6.36	-	-
Prince Cove Channel	5.54	7.02	1.68	1.50	-76%	-79%	2.44	1.81	1.66	-	-
Marstons Mills Crescent	7.29	7.16	3.51	3.10	-51%	-57%	-	-	-	-	-
Rivers and Streams											
Marstons Mills River	14.52	17.91	9.19	8.82	-49%	-51%	-	-	-	-	-
Little River	3.96	4.12	3.30	1.79	-20%	-57%	-	-	-	-	-
SYSTEM TOTAL	**130.76**	**141.49**	**79.56**	**64.97**	**-44%**	**-54%**	**24.77**	**15.38**	**13.11**	**15.65**	**15.48**

Table 3. Comparison of modeled average total N concentrations for Three Bays system: MEP, 2019 Current Conditions Land Use Update, 2019 Town Wastewater Plan and 2020 Wastewater Plan with Sewer Additions. The sentinel station threshold is 0.38 mg/L TN at a sentinel station located in the narrows between North Bay and Cotuit Bay; this monitoring station and the threshold target are shown in **bold** print. Note that values shown are rounded. The 2020 Wastewater Plan with sewer additions attains the threshold target.

Sub-Embayment	monitoring station	MEP Existing (mg/L)	MEP Threshold Goal (mg/L)	2019 Current Conditions Update (mg/L)	% change from MEP	2019 Wastewater Plan (mg/L)	% change from 2019 Current Conditions	2020 WW Plan + sewer additions (mg/L)	% change from 2019 Current Conditions
Prince Cove - south	TB2	0.70		0.71	+2%	0.51	-28%	0.48	-33%
Prince Cove - north	TB3	0.64		0.67	+5%	0.49	-27%	0.46	-31%
Warrens Cove	TB4	0.60		0.62	+4%	0.47	-24%	0.44	-28%
North Bay - north	TB5	0.52		0.53	+3%	0.43	-20%	0.41	-22%
North Bay - south	TB6	0.50		0.50	+1%	0.41	-18%	0.40	-20%
North Windmill Cove	TB7	0.51		0.52	+3%	0.42	-19%	0.41	-22%
West Bay - north	TB8	0.36		0.38	+6%	0.35	-10%	0.33	-14%
West Bay - west	TB9	0.33		0.33	0%	0.31	-5%	0.31	-6%
Eel River	TB10	0.49		0.50	+3%	0.46	-8%	0.42	-16%
Seapuit River	TB11	0.30		0.30	+0%	0.29	-2%	0.29	-3%
Cotuit Bay - north	TB12	0.41		0.42	+0%	0.36	-14%	0.35	-15%
Cotuit Bay - south	TB13	0.32		0.32	+1%	0.30	-6%	0.30	-7%
South Windmill Cove	TB15	0.40		0.42	+4%	0.39	-7%	0.36	-13%
Mellon Cove	TB16	0.39		0.40	+2%	0.39	-3%	0.36	-10%
Dam Pond	TB17	0.52		0.54	+3%	0.43	-20%	0.41	-23%
Sentinel station (narrows between North Bay and Cotuit Bay)	**-**	0.49	**0.38**	0.50	+2%	0.41	-18%	**0.38**	-23%

Table 4. Watershed Nitrogen Loads for Barnstable Great Marshes Scenarios: MEP, 2019 Land Use Update, 2019 Town Wastewater Plan and 2020 Wastewater Plan with Sewer Additions. The 2019 current conditions update of watershed parcels, water use, impervious surfaces, additional sewer connections, etc. had negligible impact on the overall unattenuated and attenuated system loads (<1% change). The 2019 Town Wastewater Plan scenario increased the attenuated system load by 1.3%, but decreased the Millway subwatershed load by 53%. *Millway (part of Great Marshes – E) was the only portion of the Great Marsh system that was identified as impaired in the MEP assessment. The 2020 Sewer Additions scenario included additional sewering within the Three Bays watershed and discharge of the treated flows (99,297 gallons per day) within the Barnstable Great Marshes watershed. Under the Wastewater Plan, these flows are treated at the WPCF, but site effluent discharge is capped at 2 million gallons per day. The additional Three Bays sewering in the 2020 Wastewater Plan increases the Barnstable Great Marshes watershed nitrogen load by 412 kg/yr (wastewater only) or a 0.6% increase in the overall watershed load from the 2019 Wastewater Plan scenario. Loads in this table do not include nitrogen deposition on the estuary surfaces.

Scenario	Description	Watershed/ Subwatershed	Wastewater		Fertilizers + Farm Animals	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load	
			Septic	WWTF					Unatten	Atten
			kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
2019 Current Conditions Update	Updated land use, water use, impervious surfaces, etc. to current conditions	Overall – Whole System	50,607	274	8,216	9,076	1,903	3,740	73,815	66,667
		Great Marshes -W	9,770	0	2,526	2,181	304	1,343	16,124	14,162
		Great Marshes -M	7,821	0	1,146	1,811	813	825	12,417	10,117
		Great Marshes - E	13,359	0	2,332	3,060	504	938	20,193	19,308
		Millway*	2,160	0	875	680	0	127	3,844	3,605
		Bass Hole	19,656	274	2,213	2,023	281	633	25,080	23,080
2019 Town Waste-water Plan	Use 2019 current conditions update with planned sewering	Overall – Whole System	46,388	5,268	8,216	9,076	1,903	3,740	74,591	67,597
		Great Marshes -W	9,770	0	2,526	2,181	304	1,343	16,124	14,162
		Great Marshes -M	6,073	4,995	1,146	1,811	813	825	15,663	13,442
		Great Marshes - E	10,889	0	2,332	3,060	504	938	17,723	16,912
		Millway*	215	0	875	680	0	127	1,898	1,700
		Bass Hole	19,656	274	2,213	2,023	281	633	25,080	23,080
2020 Sewer Additions	Use 2019 update with expanded planned sewering	Overall – Whole System	46,388	5,680	8,216	9,076	1,903	3,740	75,003	68,009
		Great Marshes -W	9,770	0	2,526	2,181	304	1,343	16,124	14,162
		Great Marshes -M	6,073	5,406	1,146	1,811	813	825	16,075	13,854
		Great Marshes - E	10,889	0	2,332	3,060	504	938	17,723	16,912
		Millway*	215	0	875	680	0	127	1,898	1,700
		Bass Hole	19,656	274	2,213	2,023	281	633	25,080	23,080

Table 5. Watershed, Benthic Flux, and Direct Atmospheric Nitrogen Loads for Barnstable Great Marshes Scenarios: MEP, 2019 Land Use Update, 2019 Town Wastewater Plan and 2020 Wastewater Plan with Sewer Additions. These are the nitrogen loads used in the water quality modeling of each scenario. Subwatershed loads include all nitrogen sources, including septic wastewater loads, impervious surface runoff, and lawn fertilizers. Direct atmospheric deposition loads are nitrogen loads on the surface of each of the subembayments. Net benthic flux loads are nitrogen regenerated from sediments within each subembayment. MEP nitrogen loads from the 2017 Report are also shown for comparison. The 2020 Wastewater Plan with Sewer Additions scenario had small watershed and benthic load additions to the Barnstable Harbor – mid subembayments. All nitrogen loads are presented as kilograms per day.

	Total Attenuated Watershed Loads (kg/d N)				% change from 2019 Current Conditions Update		Benthic Flux Net (kg/d N)			direct atmospheric deposition (kg/day N)
Sub-Embayment	MEP	2019 Current Conditions Update	2019 WW Plan	2020 Plan w/Sewer Additions	2019 WW Plan	2020 Plan w/Sewer Additions	2019 Update	2019 WW Plan	2020 Plan w/Sewer Additions	MEP, 2019 & both scenarios
Barnstable Harbor - west	38.59	38.80	38.80	38.80	0%	0%	5.30	5.52	5.52	2.42
Barnstable Harbor - mid	27.56	27.72	36.83	37.96	+33%	+37%	-11.50	-11.49	-11.71	13.80
Barnstable Harbor - east	42.60	43.11	41.68	41.68	-3%	-3%	-23.37	-23.34	-23.34	32.98
Millway	10.58	9.88	4.66	4.66	-53%	-53%	2.77	2.19	2.19	0.21
Chase Garden Creek - west	29.67	30.16	30.16	30.16	0%	0%	0.37	0.37	0.37	0.14
Chase Garden Creek - east	25.03	25.42	25.42	25.42	0%	0%	-	-	-	0.003
Bass Hole	7.42	7.57	7.57	7.57	0%	0%	-1.08	-1.08	-1.08	0.49
SYSTEM TOTAL	181.43	182.65	185.20	186.33	+1%	+2%	-27.50	-27.82	-28.04	50.04

Table 6. Comparison of modeled average bioactive N concentrations for Barnstable Great Marshes system: MEP, 2019 Land Use Update, 2019 Town Wastewater Plan and 2020 Wastewater Plan with Sewer Additions. The sentinel station thresholds are 0.16 mg/L bioactive N at sentinel stations located in salt marsh dominated basins and 0.21 mg/L bioactive N within the Millway, a dredged basin; the selected monitoring stations and the threshold targets are shown in **bold** print. Both the 2019 Wastewater Plan scenario and the 2020 Wastewater Plan with Sewer Additions attained the threshold targets at each of the sentinel stations. Bioactive nitrogen is used instead of TN in large systems, like Barnstable Great Marshes and Pleasant Bay, where there is a lot of non-active dissolved organic nitrogen and habitat and water quality are determined by the most active forms (inorganic and particulate nitrogen). Note that values shown are rounded.

Sub-Embayment	monitoring station	MEP Existing (mg/L)	MEP Threshold (mg/L)	2019 Current Conditions Update (mg/L)	% change from MEP	2019 Wastewater Plan (mg/L)	% change from 2019 Current Conditions	2020 WW Plan + sewer additions (mg/L)	% change from 2019 Current Conditions
Scorton Creek	BM-13	0.12	**0.16**	0.12	+0%	0.12	+2%	0.12	+2%
Spring Creek	BM-11	0.13	**0.16**	0.13	0%	0.13	+4%	0.13	+4%
Barnstable Harbor – upper	BM-12	0.11		0.11	+0%	0.12	+3%	0.12	+3%
Barnstable Harbor – upper	BM-1	0.10		0.10	0%	0.10	+2%	0.10	+2%
Barnstable Harbor – mid	BM-2	0.08		0.08	0%	0.09	+1%	0.09	+2%
Barnstable Harbor – lower	BM-3	0.07		0.07	+1%	0.07	0%	0.07	0%
Broad Sound	BM-10	0.10		0.10	0%	0.11	+0%	0.11	+3%
Bass Hole	BSH-1	0.09		0.09	0%	0.09	0%	0.09	0%
Chase Garden Creek - lower	BSH-2	0.11		0.11	0%	0.11	0%	0.11	0%
Chase Garden Creek	BSH-3	0.12		0.12	+1%	0.12	0%	0.12	0%
Chase Garden Creek	BSH-4	0.13	**0.16**	0.13	+1%	0.13	0%	0.13	0%
Chase Garden Creek	BSH-5	0.27		0.27	+1%	0.27	0%	0.27	0%
Chase Garden Creek – upper	BSH-6	0.57		0.58	+1%	0.58	0%	0.58	0%
Whites Brook	BSH-7	0.32		0.33	+2%	0.33	0%	0.33	0%
Millway	-	0.27	**0.21**	0.26	-4%	0.17	-33%	0.17	-33%

Appendix TT

Barnstable CWMP - Climate Adaptation and Resiliency Approach

WRIGHT-PIERCE
Engineering a Better Environment

MEMORANDUM

TO:	Griffin Beaudoin – Town of Barnstable	**DATE:**	10/29/2020
FROM:	Ed Leonard; Corey Lewis	**PROJECT NO.:**	20157C
SUBJECT:	Barnstable CWMP - Climate Adaptation and Resiliency Approach		

BACKGROUND AND PURPOSE

The Town of Barnstable submitted its Comprehensive Wastewater Management Plan (CWMP) for review under the Massachusetts Environmental Policy Act (MEPA). The Executive Office of Energy and Environmental Affairs (EOEEA) issued a Certificate of the Secretary of the EOEEA on the Expanded Environmental Notification Form (EENF) dated April 3, 2020 which identified certain additional information required to complete the review. Select relevant text from the Certificate is indicated below:

- "The Town of Barnstable, Massachusetts is a participant in the Commonwealth's Municipal Vulnerability Preparedness (MVP) program. The MVP program is a community-driven process to define natural and climate-related hazards, identify existing and future vulnerabilities and strengths of infrastructure, environmental resources and vulnerable populations, and develop, prioritize and implement specific actions the Town can take to reduce risk and build resilience."
- "Components of the wastewater collection infrastructure, such as proposed pump station sites, appear to be located within coastal flood zones."
- "The Single EIR should discuss climate resiliency considerations made in designing and implementing other components of the CWMP, including the siting and construction of new sewer mains."

The Town intends to leverage the MVP program and the best available data on climate change predictions, to develop climate change scenarios that could affect wastewater infrastructure and identify potential adaptation measures as part of its CWMP.

The purpose of this technical memorandum is to outline the general approach that the Town will use in designing and implementing sewer mains, pump stations and forcemains as a part of the CWMP.

CLIMATE ADAPTATION AND RESILIENCY APPROACH

Some components of the Town's existing and proposed wastewater collection infrastructure, such as proposed pump station sites and sewer extensions, appear to be located within coastal flood zones and/or areas that may also be affected by future climate change related stressors. The following approach is suggested as a supplement to the MVP program while the Town is conducting pre-design and design activities for projects that will result from the CWMP. This approach can be applied to both new and existing infrastructure.

Participating Personnel

The first step in the wastewater infrastructure climate resiliency planning approach should include the identification of Town personnel and stakeholders that will be part of the resiliency planning process, their roles and responsibilities and level of involvement in the decision-making process. The stakeholder group should include:

- Town wastewater system administrative and operational staff members;
- Key Town decision-makers, including administrative, planning and financial staff;
- Relevant Local, State and Federal regulatory entities;
- Community stakeholders;
- Relevant consultants, as needed.

Preliminary Climate-Related Hazard and Infrastructure Reconnaissance

The Town should collect the best available data on climate change predictions and additional resources listed below to assist with evaluating and selecting the most appropriate adaptation measures for wastewater infrastructure.

- A review of readily available information on applicable climate-related hazards and wastewater infrastructure technical information:
    - Interviews with Town wastewater field personnel familiar with the Town's existing wastewater system components;
    - Historic local weather patterns, precipitation data and flooding information;
    - Existing infrastructure operational and maintenance data and procedures;
    - Town GIS maps and databases, wastewater and utility support systems record drawings, and any available conceptual or preliminary site plans and data for planned future infrastructure and land development;

  - Floodplain mapping, future climate scenario models, reports and resources including Federal Emergency Management Agency (FEMA) floodplain maps and GIS data, EEA's Climate Change Adaptation Report (September 2011), the Town's Climate Change Vulnerability Assessment (dated December, 2019) and other pertinent information available on the www.resilientMA.org website.
  - Current wastewater industry and regulatory design standards for critical and non-critical infrastructure, such as the New England Interstate Water Pollution Control Conference's *TR-16: Guides for the Design of Wastewater Treatment Works* guidance on wastewater infrastructure design and flood protection.
- Supplemental field reconnaissance such as aerial/drone site imagery, topographic survey, infrastructure elevation truthing and data gathering for critical infrastructure components.

Data and Hazard Evaluation

The Town should review the data and conduct a climate-related hazard evaluation including:

- Review of floodplain inundation using best available climate scenarios and modeling compared to existing and planned critical assets to identify and assess potential threats to infrastructure reliability as well as the ability to safely access and operate critical infrastructure during periods of inundation and utility power loss.
- Review the present and future impacts on critical infrastructure from changing precipitation patterns and storm intensity, duration and frequency.
- Review of any potential vulnerabilities in community or utility support systems that may be impacted by potential climate hazards and the consequences on the Town's system reliability. This should include a review of any known potential or planned future development and its cumulative impacts on utility support system capacity and demand.
- Review of potential impacts from wind-related hazards (e.g., falling trees, utility poles, wires) may have on existing critical infrastructure and how it may affect site planning for proposed infrastructure.
- Assessment of current and planned infrastructure redundancy and resiliency components.

Much of this work was documented for existing pump stations in the report entitled "Wastewater Pump Station Asset Management Plan" (Wright-Pierce, December 2019).

An example of climate-related hazards and their potential impacts on wastewater system reliability is included in Table 1. Potential climate-related hazards and infrastructure vulnerabilities identified during the evaluation phase should then be subjected to a hazard consequence risk assessment.

TABLE 1
POTENTIAL CLIMATE-RELATED HAZARD CONSEQUENCES

Climate Change Impact	Potential Hazards	Hazard Consequences
Sea Level Rise and Increased Flood Risk	River Flooding	• Localized flooding or ponding • Accessibility issues from temporary flooding • Soil erosion • Water leaks into enclosures, electrical equipment and conduits • Increased I/I to collection system and pump stations • SSOs from elevated groundwater or surface water intrusion exceeding system capacity
	Coastal Flooding	
	Flash Flooding	
Storm Characteristics	Increased Precipitation Intensity	• Localized flooding or ponding • Accessibility issues from temporary flooding • Soil erosion • Water leaks into enclosures, electrical equipment and conduits • Poor travel conditions • Utility power outages • Hazardous working conditions • Increased I/I to collection system and pump stations • Increased snow loading to enclosures • Accessibility issues from excess snowfall • SSOs from wet-weather flows exceeding system capacity
	Increased Precipitation Duration	
	Increased Precipitation Frequency	
	Excessive Wind Speeds	• Utility power outages • Increased wind loading to enclosures and panels • Downed trees causing equipment damage.

Hazard Risk Assessment

The hazard risk assessment leverages the available climate-related hazard and infrastructure information to assess the likelihood of climate-related hazard consequences (e.g., sewer system inundation, pump station failure, etc.) and their potential impacts on wastewater system reliability and the community at large. Potential hazard consequences and their impact on the associated assets are assessed to determine their likelihood of occurring and to help prioritize adaptation measures.

As a first step of the hazard risk assessment process, critical wastewater system components should be identified based on their importance to achieving the Town's goals of reliably serving its customers, meeting regulatory obligations, and providing a safe working environment for the Town staff. Critical wastewater components typically include the wastewater treatment facilities, pump stations, and sewer collection system main pipelines and interceptor sewers. The critical system components should then be subjected to a screening-level assessment to determine whether the asset is potentially vulnerable to the climate-related hazards, and if so, whether the asset has built-in resiliency measures that would reduce the potential hazard consequence risk. Risk is generally defined as (likelihood x impact), so the risk assessment addresses both the likelihood of the hazard occurring and the impact on the asset if it did occur. Examples of the iterative screening-level risk assessment process are depicted in the figures below and the following bulleted list.

FIGURE 1: SCREENING-LEVEL HAZARD RISK ASSESSMENT (EXAMPLE)

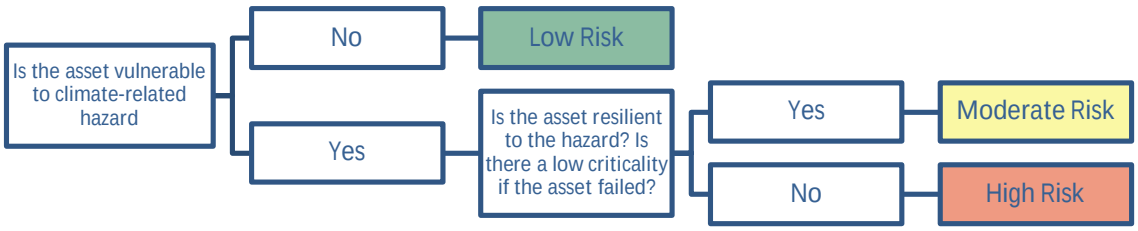


FIGURE 2: INTERCEPTOR SEWER FLOOD RISK ASSESSMENT (EXAMPLE)

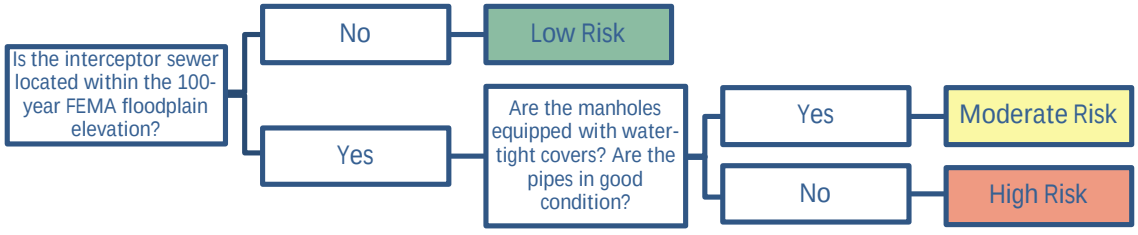
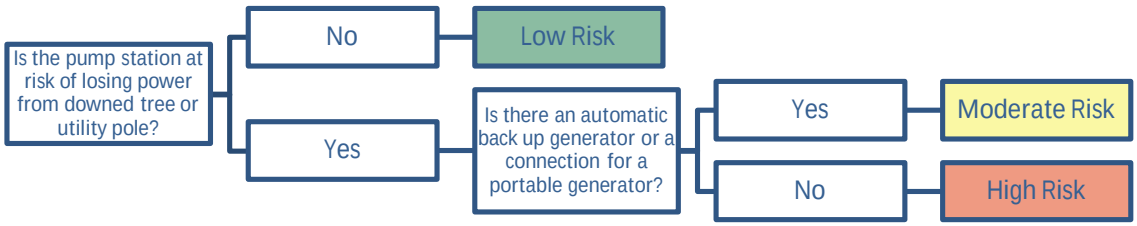


FIGURE 3: PUMP STATION UTILITY POWER OUTAGE HAZARD RISK ASSESSMENT (EXAMPLE)



The following are additional examples of iterative screening-level questions to determine risk:

- What is the significance of the asset? Stated another way, how critical would it be if the asset failed or was impacted by a potential hazard?
- When was the asset installed/constructed?
- Is the asset still performing as it was intended? (e.g., leaking/cracked pipes)
- Have there been previous historical climate-related hazards observed in the area?
- What is the accessibility of the asset? (e.g., Is it along the road, or on a cross country line without access? Is there enough room for winter snow removal?)
- Is the asset located within the 100 year or 500 year flood zone?
- Have there been new developments that might affect the historical floodplain or potential for flash flooding? (e.g., culverts, new parking lots/increased impervious areas nearby, dams, etc.)
- Is the elevation of the asset above that of the floodplain? Which components would be submerged in a flood scenario (e.g., electrical controls, electrical outlets, equipment, manhole covers, etc.)?
- Are buildings/controls/structures watertight? (e.g., manhole covers, hatches, vents, doors, louvers, electrical feeders, etc.)
- How is the asset connected to electrical utility?
- Is there a standby power source or connection for a portable generator?
- Is there another type of redundancy built into the system?
- What type of telemetry equipment is installed for remote and local alarming?
- Is there convenience lighting in the surrounding area?

- Are there trees or other structures around the asset that might be affected by high winds or heavy rain/snow?

Once the assets have been screened for high, moderate, or low risk from potential climate-related hazard consequences, adaptation or resiliency alternatives are identified and evaluated to address or mitigate the risk in the most cost-effective manner.

Adaptation Measure Evaluation

Using the available climate-related hazard information and the screening-level risk analysis, potential adaptation or resiliency alternatives should be identified that will eliminate or reduce the asset-specific vulnerability. For proposed infrastructure, preference should be given to adaptation measures that would preemptively eliminate potential vulnerability to the climate-related hazards. For example, locating structures away from floodplains, planning for stand-by power sources, including built-in process redundancy, or removing large trees that could pose a blow-down risk to future infrastructure.

If the vulnerability cannot feasibly be eliminated, the remaining adaptation alternatives should instead focus on improving the resiliency to a specific hazard. For example, if it was not technically or economically feasible to construct to relocate a pump station outside of or above the 100-year floodplain, it may be possible to construct/retrofit the existing pump station with flood barriers and elevate critical electrical components to increase flood resiliency.

Adaptation measures can generally be grouped into two major categories: operational and asset-specific measures. Operational adaptation measures are tasks or procedural changes that Town staff could undertake at minimal cost to prevent or mitigate potential hazard consequences. Asset-specific measures may include non-routine or one-time tasks, in-depth studies or evaluations, design modifications, or capital expenditures to achieve the goal of preventing or mitigating the potential hazard consequence.

The following are examples of potential operational adaptation measures to be considered:

- Perform routine inspections of exposed equipment after heavy or intense precipitation events.
- Monitor pump station flow trends during wet-weather events and snow-melt conditions.
- Exercise extreme caution and limit travel time during poor travel conditions.
- Discuss utility power restoration priorities with utility power supply company.
- Exercise caution and use proper PPE while working outdoors in wet-weather conditions.

- Evaluate I/I reduction in the collection system.
- Review wet-weather management plan to ensure it is up-to-date and make any necessary adjustments.
- Review wet-weather management plan with current operations staff and any new hires.
- Routinely remove excess snow to facilitate access to critical assets.
- Monitor large trees adjacent to utility power lines and discuss potential risks with utility power supply company.
- Monitor cross-country sewer lines for signs of ponding on manholes and embedment erosion.
- Develop an emergency pump station access plan and procedures manual with operations staff in case flooding restricts typical access routes to pump station.
- Obtain a small flat bottom boat for deployment if flood waters restrict vehicle access to the pump station site.

The following are examples of asset-specific adaptation measures to be considered:

- Locate sewer and pump station infrastructure outside of or above the flood zones.
- Consider low pressure sewers (versus conventional gravity sewers) inside of flood zones.
- Evaluate and install drainage improvements in areas with significant local flooding or ponding of water on sewer manholes.
- Upgrade pump station buildings to include removable flood barriers at the building entrances and louvers to protect the station’s critical electrical and mechanical equipment from flood damage.
- Upgrade stand-by generators and relocate them 1 to 3 feet above the 100-year flood elevation (depending on criticality) to reduce the risk of flood damage.
- Install portable generator power receptacles and manual transfer switches at pump stations to provide back-up power in the event of an extended utility power or dedicated standby power system failure.

- Install bollards to protect the station structure and equipment from potential damage due to snow removal activities and/or vehicular impacts during inclement weather conditions.
- Discuss expected utility repair crew response time for the pump station area with the local utility power supplier and keep an up-to-date contact list of sewage/septage hauling contractors in the event that bypass pumping is needed.
- If the pump station is upgraded, consider dry-pit submersible pumps that are capable of being fully submerged without damage.
- Evaluate and implement drainage improvements in areas with significant local flooding or ponding of water on sewer manholes.
- Provide adequate access routes to major interceptor sewers to facilitate frequent maintenance, inspection activities, and repairs, as needed.
- Evaluate and implement water-tight manhole covers in low-lying and flood-prone areas, as needed.
- Continue Town's private inflow source detection and removal program and enforce illicit sewer connection ordinance to reduce I/I.
- Frequent cleaning and CCTV inspection of sewer segments suspected of higher Inflow/Infiltration influence and/or clogging and targeted sewer rehabilitation to decrease influence of wet weather on collection system capacity and pumping needs.

The selected climate adaptation measures should be identified during the pre-design phase and then be carried forward through funding, design, construction and operations to maximize the resiliency and reliability of the Town's infrastructure.

Appendix UU

Barnstable CWMP – Preliminary GHG Emissions Review

WRIGHT-PIERCE
Engineering a Better Environment

MEMORANDUM

TO:	Griffin Beaudoin – Town of Barnstable	**DATE:**	10/30/2020
FROM:	Ed Leonard; George Pickard	**PROJECT NO.:**	20157A
SUBJECT:	Barnstable CWMP – Preliminary GHG Emissions Review		

BACKGROUND AND PURPOSE

The Town of Barnstable submitted its Comprehensive Wastewater Management Plan (CWMP) for review under the Massachusetts Environmental Policy Act (MEPA). The Executive Office of Energy and Environmental Affairs (EOEEA) issued a Certificate of the Secretary of the EOEEA on the Expanded Environmental Notification Form (EENF) dated April 3, 2020 which required an evaluation of greenhouse gas (GHG) emissions under the May 5, 2010 GHG Policy. The policy requires project proponents to quantify carbon dioxide emissions and identify measures to avoid, minimize or mitigate such emissions.

The Barnstable CWMP describes a Recommended Plan (significant expansion of traditional wastewater management systems supplemented by non-traditional nitrogen removal measures) and a No Action Plan (continued widespread use of septic systems without expansion of traditional wastewater management systems). The Recommended Plan and the No Action Plan will result in continued and increased long-term electrical energy and fossil fuel use related to septic systems, I/A systems, sewer system conveyance pumping, wastewater treatment, effluent disposal and sludge disposal.

A preliminary evaluation of GHG emissions has been performed for the Recommended Plan, comparing a "project baseline" and a "preferred measures" plan. Design assumptions for the "project baseline" are based on existing operations as well as general requirements for expansion of wastewater management systems according to the requirements of TR-16, *Guides for the Design of Wastewater Treatment Works,* 2016 Edition.

The purpose of this technical memorandum is to summarize the methodology utilized to estimate the "project baseline" condition, to analyze options to achieve GHG emission reductions, to develop a listing of recommended measures and to estimate the GHG emission reductions under this "preferred plan". The content of this memorandum and analysis is based on the material outlined in the CWMP and EENF filing.

DESCRIPTION OF PROJECT BASELINE

The project baseline was formulated in conjunction with the Town based on: the number of septic systems; the number of innovative/alternative (I/A) septic systems; the number of sewer connections; the number and size of sewage pump stations; and the number, size and function of wastewater treatment plants required for the CWMP. This information is summarized in Table 2 at the end of this memorandum.

The pump stations were estimated in three categories:

- Small (50 to 500 gpm, submersible pump station)
- Medium (500 to 1200 gpm, submersible pump station with small electrical building)
- Large (1200 to 7500 gpm, wetwell/drywell pump station with superstructure)

The treatment facility will generally include the following functions/features:

- Preliminary treatment/ headworks and septage receiving
- Primary treatment
- Advanced secondary treatment for nitrogen removal
- Separate stage denitrification filters
- Disinfection
- Effluent pumping and disposal
- Biosolids thickening for off-site disposal
- Standby power system
- Administrative, operations, maintenance and laboratory functions

CALCULATION APPROACH

Since this project is only in the planning phase (i.e. no detailed design information is available), we have utilized engineering judgment and "unit emission rates" for septic systems, I/A systems, pump stations and the treatment facilities based on a literature search. The parameters included and excluded from this analysis are summarized in Table 1 at the end of this memorandum.

Emissions have been categorized as direct or indirect emissions in accordance with the May 5, 2010 MEPA GHG Policy. Direct emissions include on-site stationary sources which burn fossil fuel for heat, hot water, steam and other processes. Indirect emissions result from the consumption of energy, such as electricity generated by burning of fossil fuels, and emissions from vehicles used by employees. Unit emission rates were developed using literature values for emission sources. The basis for the unit emission rates is summarized in Attachment A. These values can be better refined in the design phase.

GHG EMISSION REDUCTION ALTERNATIVES AND SELECTED MEASURES

Numerous concepts were considered to reduce GHG emissions associated with the CWMP. General and specific operating and design practices to improve energy efficiency were aggregated from a literature search. Measures were sorted by system (pump station or treatment facility) and then further organized as "previously suggested" (from 2015 Barnstable WWTP Walk-through Report), operational measures, building system energy conservation measures, system energy conservation measures, and renewable energy measures. These measures are summarized in Table 3 for the pump stations and in Table 4 for the treatment facility.

Each of the identified measures were evaluated for applicability and for the potential to reduce GHG emission for the Barnstable CWMP and were categorized as follows:

- *Preferred Measure* - These items are preferred and recommended for implementation.
- *Not Preferred Measure* - These items are not preferred and not recommended for implementation.
- *Measure to be Considered in Final Design* - These items may be preferred but the analysis requires more details to make an informed decision.
- *Not Applicable* - These items do not meet project goals, project requirements and/or relevant design standards and are not recommended for implementation.

As required by the GHG Emissions Policy, an explanation is provided for any measures that are not preferred. Where available in the literature, a range of energy savings associated with the identified measures is also identified. These values vary considerably and are highly dependent on the application.

Most of the measures provide energy savings to a select portion of the system (e.g., aeration systems, dewatering systems, heating and cooling energy, etc.) and many of the measures have overlapping benefits (e.g., perform facility energy assessment, energy education, specific process improvements, avoid throttling valves, install VFDs, etc.). Engineering judgement was used to assess cumulative energy reductions for the major process systems based on the ranges from the literature search. The direct emissions (resultant from gas burning) portion of the facility energy use was derived using the Barnstable facility's reported natural gas consumption. Estimated energy use reduction was converted to GHG emissions reduction (as CO_2-equivalent) using EPA conversion factors. This preliminary GHG emission estimate may be influenced substantially by process and operations decision made in the design phase.

SUMMARY AND CONCLUSIONS

The MEPA GHG Policy requires that the project proponent evaluate measures to reduce GHG emissions. MEPA requires that the Town commit to implementing the Preferred Measures. The estimated GHG emissions for the Baseline Scenario are 11,280,000 kg CO2-eq/year, as summarized in Table 5 at the end of this memorandum. The estimated GHG emissions for the CWMP with Preferred Measures are 9,060,000 kg CO2-eq/year, as summarized in Table 5 at the end of this memorandum.

The Preferred Measures are estimated to result in a 20% decrease in overall GHG emissions. This is the net result of a 0% change in emissions from septic systems, a 5% decrease in emissions from sewage pumping stations, and a 30% decrease in emissions from centralized wastewater treatment.

Many of the identified measures require more detailed analysis to determine if they meet process objectives in addition to reducing GHG emissions. Additional reductions could result from the "Measures to be Considered in Design"; however, it is premature for the Town to commit to these measures at this time.

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TABLE 1 - PARAMETERS OF GREENHOUSE GAS EMISSION ANALYSIS

	Included in Analysis **	**Not Included in Analysis ****
Project Phase	Operation	Construction
Greenhouse Gases	CO_2	SO_x, NO_x, PFCs, HFCs, CH_4, N_2O
Direct Emissions	On-site boiler & generator fuel combustion	Collection system WWTF with nitrogen removal Individual septic systems Effluent disposal Non-traditional nitrogen removal measures
Indirect Emissions	Electricity for I/A septic systems Septage hauling vehicles (to WWTF) Electricity for collection system Electricity for treatment system Sludge hauling vehicles (to disposal) Staff/Chemical/ (included in WWTF units)	Electricity for septic systems Electricity for effluent disposal Chemical production (e.g., methanol) Non-traditional nitrogen removal measures
Other Issues	-	Purchased offsets

NOTE: ** All "per unit" direct and indirect emissions data were obtained from a literature search. No site-specific direct or indirect emission calculations were developed for this review **

TABLE 2 - SEPTIC SYSTEMS, SEWER CONNECTIONS AND FLOWS FOR PRE-CWMP AND POST-CWMP CONDITIONS														
	PRE-CWMP (EX. CONDITIONS)					CHANGE					CWMP			
COMPONENT	Quantity		Notes			Quantity		Notes			Quantity		Notes	
Septic Systems (town-wide)	20,400	EDU	Corresp. w/Town			-10,760	EDU	Corresp. w/Town			9,640	EDU	Corresp. w/Town	
I/A Systems (town-wide)	98	EDU	Corresp. w/Town			0	EDU	Corresp. w/Town			98	EDU	Corresp. w/Town	
Sewer Connections	9,220	EDU	Corresp. w/Town			10,760	EDU	Corresp. w/Town			19,980	EDU	Corresp. w/Town	
Total Equivalent Dwelling Units	29,718	EDU				0	EDU				29,718	EDU		
Sewers	55.0	miles	CWMP			208.0	miles	CWMP			263.0	miles	CWMP	
Sewage Pumping Stations	28	ea	Corresp. w/Town			58	ea	Corresp. w/Town			86	ea	Corresp. w/Town	
Small Stations	23	ea	Corresp. w/Town			39	ea	Corresp. w/Town			62	ea	Corresp. w/Town	
Mid-Size Stations	4	ea	Corresp. w/Town			15	ea	Corresp. w/Town			19	ea	Corresp. w/Town	
Large Stations	1	ea	Corresp. w/Town			4	ea	Corresp. w/Town			5	ea	Corresp. w/Town	
Forcemains	25.5	miles				10.0	miles				35.5	miles		
Treatment Facilities														
Barnstable WCPF	1.670	mgd	CWMP			2.691	mgd	CWMP			4.361	mgd	CWMP	
Marston Mills WWTP	0.012	mgd	CWMP			-0.012	mgd	CWMP			0.000	mgd	CWMP	
Other WPCF - to be determined	0.000	mgd	CWMP			0.000	mgd	CWMP			0.000	mgd	CWMP	
Total, Treatment Facilities	1.682	mgd				2.679	mgd				4.361	mgd		

Notes:
1) Refer to CWMP, dated Januay 2020.

TABLE 3 GHG EMISSION REDUCTION MEASURES FOR PUMP STATIONS

	Measure	Small	Medium	Large	
Previously Suggested[1]	Reduce pumping lift station energy usage	P	P	P	Not quantified
Energy Conservation Measures	Install VFDs	NP	NP	P	10-40% of motor HP [a]
	Replace inefficient pumps	P	P	TBC	2-15% of motor HP
	Retrofit with premium efficiency motors	P	P	P	4-8% of motor HP
	Install improved pump controls	P	P	P	1-15% of motor HP [c]
	Evaluate demand, replace with smaller pumps	NP	NP	TBC	Application dependent, detailed design required
	Identify and reduce infiltration/inflow	TBC	TBC	TBC	Monitoring required to quantify.
	Install jockey pump	NA	NA	TBC	Application dependent, detailed design required
	Install power factor correction capacitors	NA	NA	P	5-10% of connected load
	Reduce water consumption	TBC	TBC	TBC	Application dependent, detailed design required
	Reduce pump head by increasing pipe size, decrease roughness	NA	NA	TBC	Application dependent, detailed design required
Building System Energy Conservation Measures	Install timer or motion-detecting lights	NA	P	P	15-90%[a] of lighting energy
	Install high-efficiency lighting	NA	P	P	30%[a] of lighting energy
	Install programmable thermostats	NA	P	P	10%[e] of heating and cooling energy
	Implement increased air ventilation system maintenance	NA	P	P	Application dependent, detailed design required [a]
	Install solar thermal heat system	NA	NP	TBC	Application dependent, detailed design required
	Wastewater heat recovery	NA	NA	TBC	Application dependent, detailed design required
	Use LEED Building practices as guidance with no certifications	NA	TBC	P	14-48% of building energy [a]
Operational Measures	Run at higher wet well levels	TBC	TBC	P	Application dependent, detailed design required [a]
	Set pumps at lower flow rates	NA	TBC	P	Application dependent, detailed design required [a]
	Implement enhanced maintenance program	TBC	TBC	P	May reveal inefficiencies [b]
	Install smart meter energy monitoring system and perform real time energy monitoring and control	NP	NP	P	5-20%[a] of applicable loads
	Energy Education for Facility Personnel	P	P	P	Expected outcomes not quantified
Renewable Energy	Install Solar PV	NA	TBC	TBC	Application dependent, detailed design required

P=Preferred; NP=Not preferred; TBC=Measure to be Considered in Design; NA=Not applicable.
[1] Recommended Energy Conservation measures from Demand Management Institute June 2015 Barnstable WWTP Walkthrough Report
[a] NYSERDA Water and Wastewater Energy Management Best Practices Handbook
[b] EPA Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities
[c] https://www.waterworld.com/home/article/16190476/constant-wet-well-level-control-saves-cost-and-energy

TABLE 4 GHG EMISSION REDUCTION MEASURES FOR TREATMENT FACILITIES

	Measure	Category	Expected Reduction from baseline/Rationale for Rejection
Previously Suggested[1]	Sludge blower actuator valve and controls upgrade custom retrofit	P	10,015 kWh/yr [1]
	Install new high-performance blowers	P	35-39% of blower energy [1]
	Implement a motor operated valve sequence for aeration control	P	2-5% of total aeration energy [1]
	Install individual dissolved oxygen controls in aeration tank cells	P	2% of total aeration energy [1]
	Reduce nighttime dissolved oxygen level	P	1- 1.5% of total aeration energy [1]
	Install high efficiency garage heating system	P	1,982 therms/yr [1]
	Replacement of hot water circulation pumps in Septage Building and Maintenance Garage.	P	10,046 kWh/yr [1]
	Office building lighting upgrade: T8 to LED	P	5,278 kWh/yr [1]
	Lighting controls – Daylighting	P	683 kWh/yr [1]
	Lighting controls – occupancy sensors	P	2,730 kWh/yr [1]
	Improved thermostat controls	P	2,771 kWh + 279 therms [1]
Operational Measures	Perform Facility Energy Assessment	P	10-50%[a] of total facility energy
	Install smart meter energy monitoring system and perform real time energy monitoring and control	P	5-20%[a] of applications where applied
	Energy education for facility personnel	P	Dependent on measures adopted
	Electric peak reduction	TBC	Application dependent, detailed design required
	Idle or Turn off equipment	TBC	Application dependent, detailed design required
	Use automatic control to monitor and control motors	P	Application dependent, detailed design required [a]
	Properly maintain motors	P	Dependent on equipment status[a]
	Reduce pump rates	TBC	Application dependent, detailed design required [a]
	Avoid using throttling valves	P	15-50%[a] of pumping energy where throttling used
Building System Energy Conservation Measures	Install VFD control on air compressors	TBC	Application dependent, detailed design required [a]
	Maintain and adjust boilers and furnaces, perform regular tune-ups	P	2-20%[a] of heating energy
	Upgrade to high-efficiency boilers	P	30-60%[c] of boiler energy
	Reduce air changes during cold temperatures where allowed by code	P	Application dependent, detailed design required
	Install demand-controlled ventilation with heat exchangers to recapture heat from exhaust air	P	Application dependent, detailed design required
	Implement increased air ventilation system maintenance	P	Can be a significant savings depending on existing maintenance routine[a]
	Install high-efficiency lighting	P	30%[a] of lighting energy
	Install timer or motion-detecting lights occupancy sensors	P	15-90%[a] of lighting energy
	Install programmable thermostats	P	10%[e] of heating and cooling energy
	Wastewater heat recovery	TBC	Wastewater temperature data, and existing heating infrastructure evaluation necessary.
	Install green roof(s) or white roof(s)	TBC	Application dependent, detailed design required

	Measure	Category	Expected Reduction from baseline/Rationale for Rejection
	Heat and cool with heat pumps using effluent	TBC	Application dependent, detailed design required
	Use LEED building practices as guidance with no certifications	P	14-48% of building energy
	Implement passive solar strategies by orienting new buildings with larger southern faces, use sunshades, improve building insulation	P	5%-20[d] of building heating and cooling energy dependent on site conditions
	Install High Efficiency Windows	P	9-22%[b] of heating energy depending on single or double paned windows
Energy Conservation Measures - System	Use of VFDs	P	10-40%[a] where applied
	Use of premium efficiency pumps and motors	P	4-8%[a] of pumping energy
	Reduce water consumption	TBC	Water consumption data, operations, and equipment O&M information necessary.
	Increase piping sizes to reduce friction loss	TBC	Equipment operating and existing site specific details required for evaluation.
	Aeration & biological nutrient removal process control, blower, mixer, pumping and diffuser equipment upgrades	P	30-40%[a] of aeration energy
	Sludge dewatering improvements	P	10-30% of sludge dewatering and transport energy
	Continue to process all septage and off-site sludges received as biosolids, only filtrate treated in the liquid treatment process.	P	4% of flow-based treatment energy[2]
	Select supplemental carbon chemicals with lower GHG emission	TBC	Application dependent, detailed design required
Renewable Energy	Install Solar Thermal	TBC	30%[e] of heating energy, Application dependent.
	Install Solar PV	TBC	Currently have solar PV, could expand if space permits
	Install Wind Turbine	TBC	Currently have two wind turbines, could expand if space permits
	Effluent Hydraulic Turbine	NA	Insufficient site topography
	Sludge energy recovery	TBC	Sludge and operating data required.
	Natural gas combined heat and power	TBC	Dependent on sludge energy recovery selection.

P=Preferred; NP=Not preferred; TBC= Measure to be Considered in Design; NA=Not applicable.
[1] Recommended Energy Conservation measures from Demand Management Institute June 2015 Barnstable WWTP Walkthrough Report
[2]Assumes received septage is 11% solids, for 9,640 EDU's averaging production of 180 gpd/EDU.
[a] NYSERDA Water and Wastewater Energy Management Best Practices Handbook
[b] https://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights/benefits
[c] https://www.energy.gov/energysaver/home-heating-systems/furnaces-and-boilers
[d] https://www.nrel.gov/docs/legosti/old/17252.pdf
[e] https://openscholarship.wustl.edu/cgi/viewcontent.cgi?article=1053&context=mems500

TABLE 5 - DIRECT AND INDIRECT EMISSIONS FOR CWMP PROJECT BASELINE AND CWMP PREFERRED MEASURES											
	BASELINE CWMP GHG EMISSIONS					Energy	PREFERRED CWMP GHG EMISSIONS				
	Direct	Direct	Indirect	Indirect	Combined	Reduction	Direct	Direct	Indirect	Indirect	Combined
COMPONENT	kg CO2-eq Year-Unit	kg CO2-eq Year	kg CO2-eq Year-Unit	kg CO2-eq Year	kg CO2-eq Year	% (Dir/Indir)	kg CO2-eq Year-Unit	kg CO2-eq Year	kg CO2-eq Year-Unit	kg CO2-eq Year	kg CO2-eq Year
Septic Systems (town-wide)	0	0	3	28,920	29,000	0%	0	0	3	28,920	29,000
I/A Systems (town-wide)	0	0	78	7,644	8,000	0%	0	0	78	7,644	8,000
Sewage Pumping Stations											
Small Stations	0	0	29,000	1,798,000	1,798,000	5%	0	0	27,550	1,708,100	1,708,000
Mid-Size Stations	0	0	94,000	1,786,000	1,786,000	5%	0	0	89,300	1,696,700	1,697,000
Large Stations	0	0	188,000	940,000	940,000	5%	0	0	178,600	893,000	893,000
Treatment Facilities											
Barnstable WCPF	42,200	184,034	1,450,000	6,323,450	6,507,000	75%/26%	10,550	46,009	1,073,000	4,679,353	4,725,000
Marston Mills WWTP	0	0	0	0	0	-	0	0	0	0	0
Other WPCF - to be determined	0	0	0	0	0	-	0	0	0	0	0
Sludge Hauling Vehicles	0	0	212,000	212,000	212,000	-	0	0	51,000	51,000	51,000
Total (kg CO2-eq/year) (rounded)		180,000		11,100,000	**11,280,000**			50,000		9,010,000	**9,060,000**
											-20%

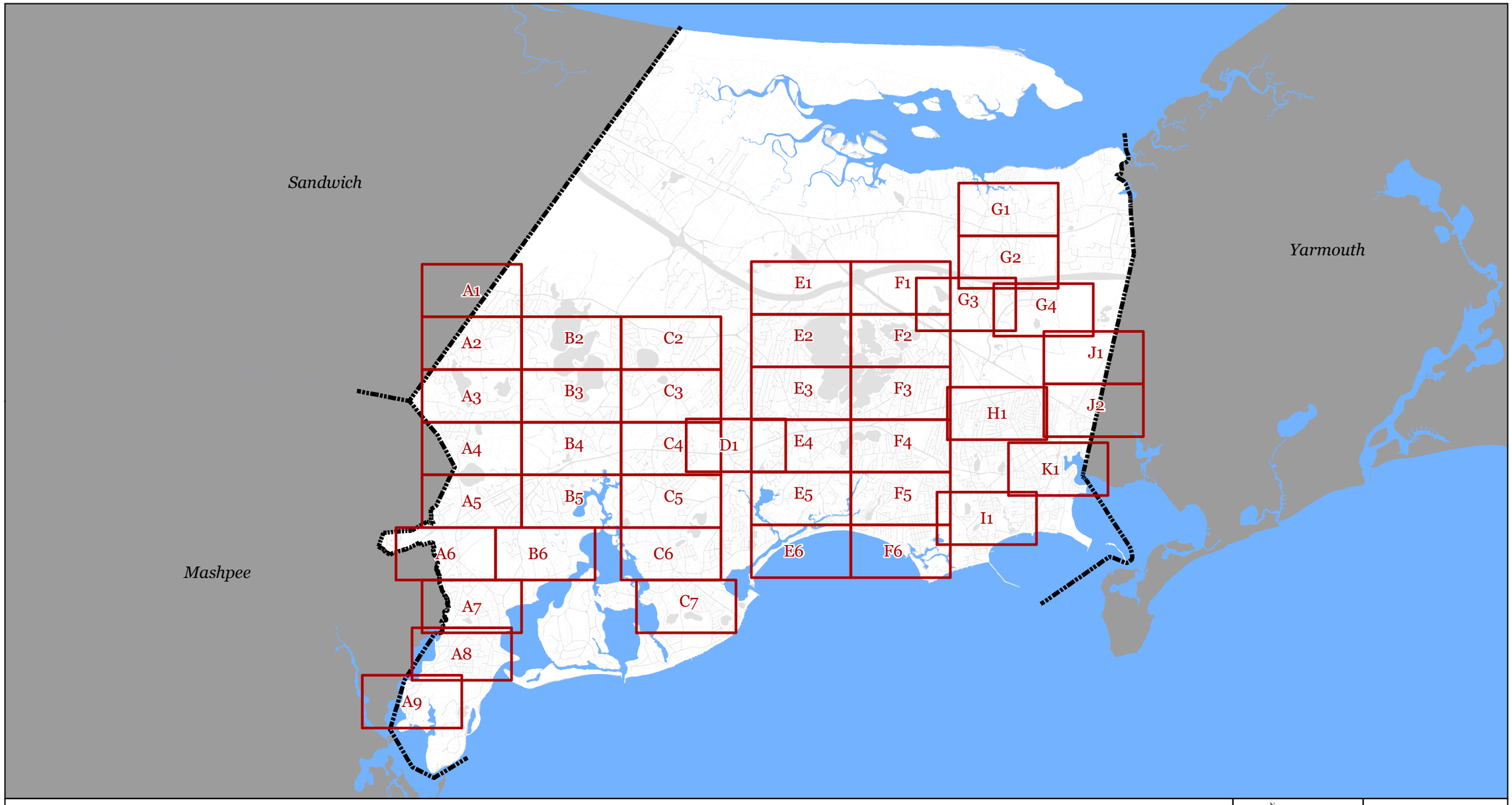
Notes:

1) Refer to CWMP, dated Januay 2020.

2) See GHG unit rates worksheet for backup information on unit rates and literature citations. Site-specific for direct/ indirect emissions were not developed for this review.

Appendix VV

Conceptual Sewer Expansion – Restricted Land Map



A1 Sheet locus

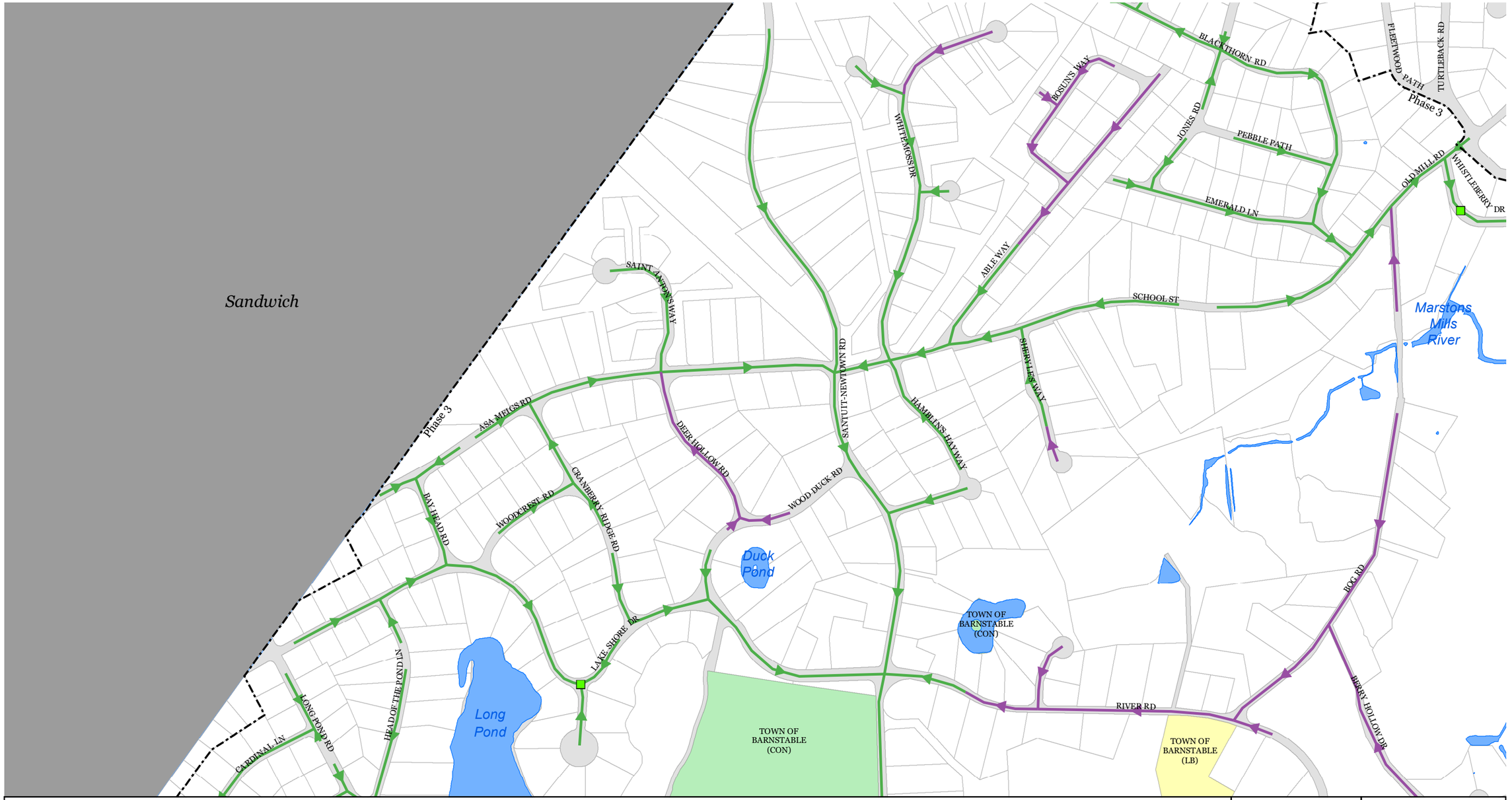
Town boundary

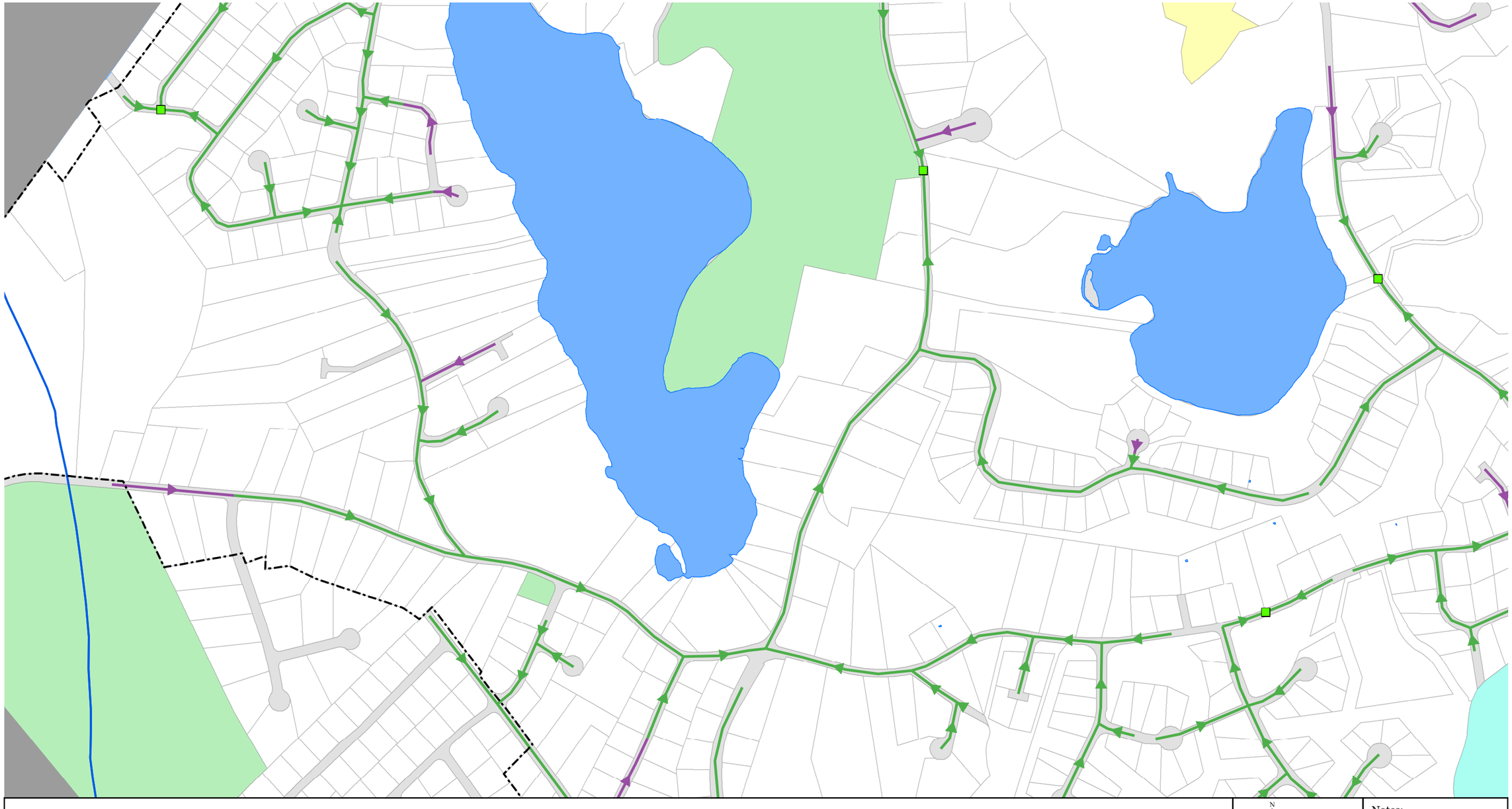
N
W E
S
feet
0 1,000 5,000
1 inch = 7,500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

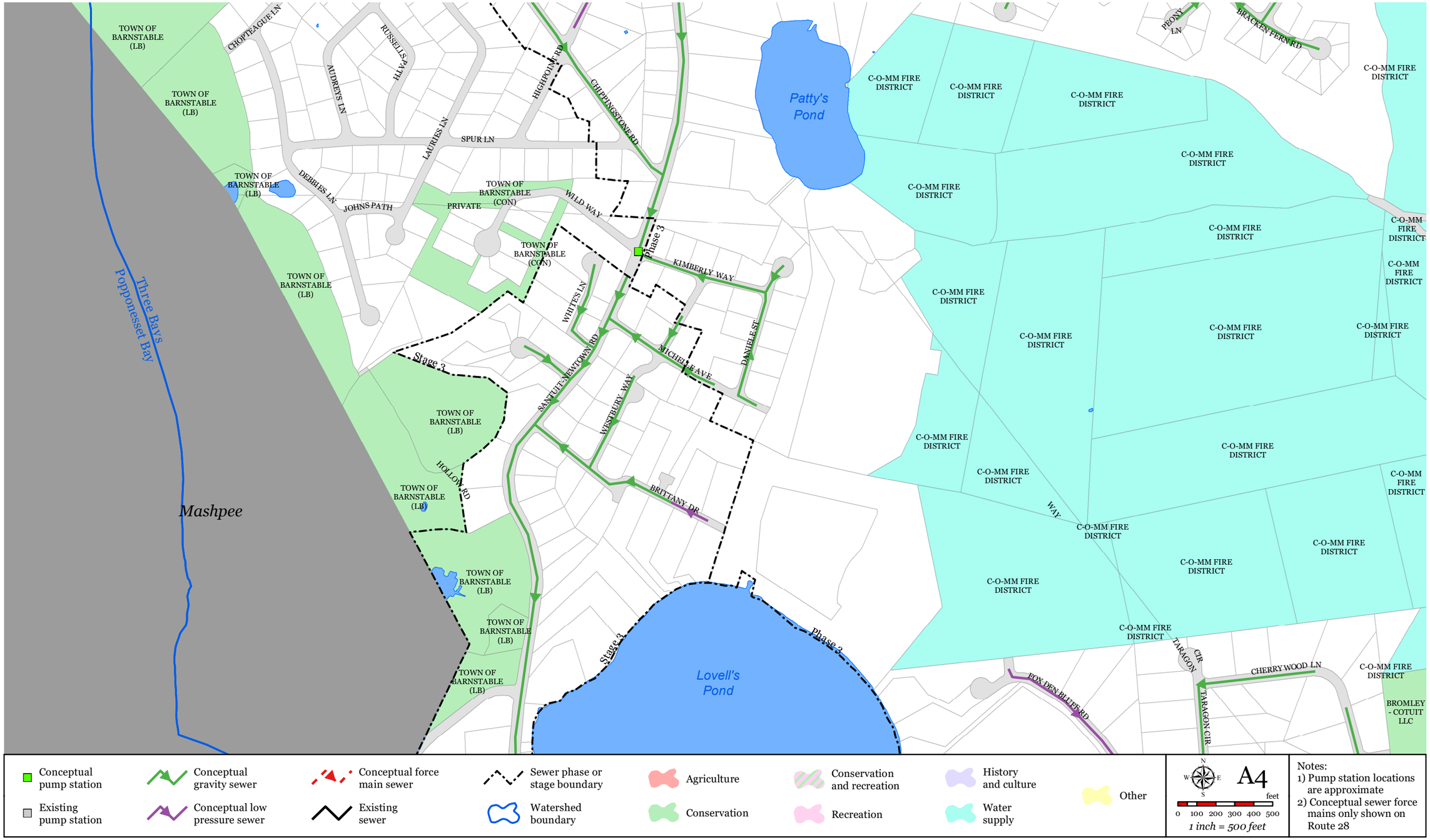


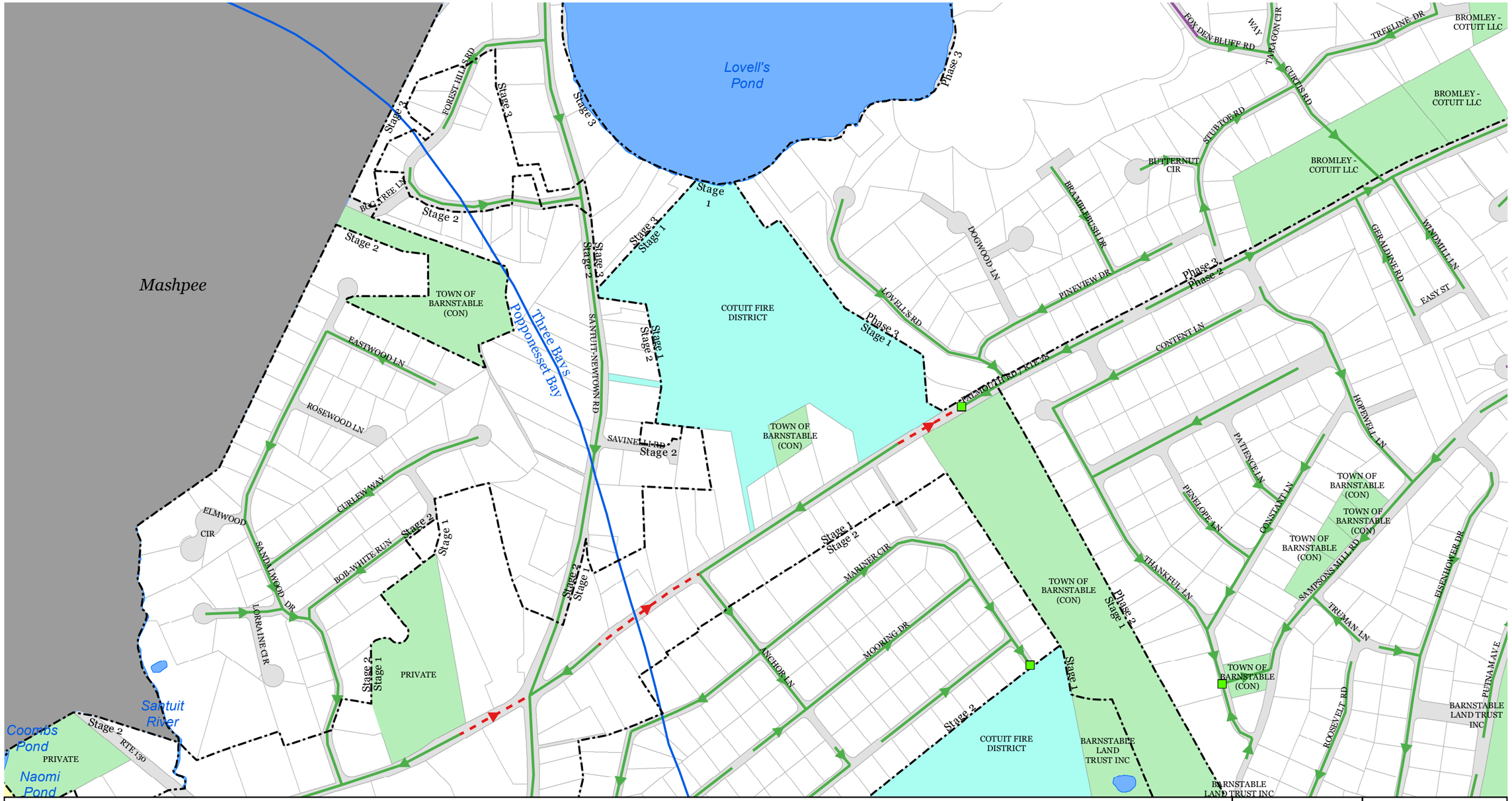
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Sandwich
Phase 3
ASA MEIGS RD
SAINT AARON'S WAY
DEER HOLLOW RD
SANTUIT-NEWTOWN RD
WHITE MOSS DR
BOSUN'S WAY
ABLE WAY
HAMBLIN'S HAYWAY
SHERRY LEE'S WAY
SCHOOL ST
BLACKTHORN RD
JONES RD
PEBBLE PATH
EMERALD LN
FLEETWOOD PATH
TURTLEBACK RD
Phase 3
OLD MILL RD
WHISTLEBERRY DR
Marstons Mills River
WOODCREST RD
CRANBERRY RIDGE RD
BAY HEAD RD
WOOD DUCK RD
Duck Pond
LAKE SHORE DR
HEAD OF THE POND LN
LONG POND RD
CARDINAL LN
Long Pond
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (LB)
RIVER RD
ROG RD
BERRY HOLLOW DR
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
A2
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


TOWN OF BARNSTABLE (LB)
CHOPTEAGUE LN
AUDREYS LN
RUSSELLS PATH
LAURIES LN
SPUR LN
HIGHPOINT RD
CHIPPINGSTONE RD
Patty's Pond
PEONY LN
BRACKEN FERN RD
C-O-MM FIRE DISTRICT
DEBBIES LN
JOHNS PATH
PRIVATE
WILD WAY
Phase 3
KIMBERLY WAY
WHITES LN
MICHELLE AVE
DANIELLE ST
SANTUIT-NEWTOWN RD
WESTBURY WAY
BRITTANY DR
Stage 3
Three Bays
Popponesset Bay
Mashpee
HOLLOW RD
Lovell's Pond
Phase 2
FOX DEN BLUFF RD
TARAGON CIR
CHERRY WOOD LN
BROMLEY - COTUIT LLC
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
A4
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



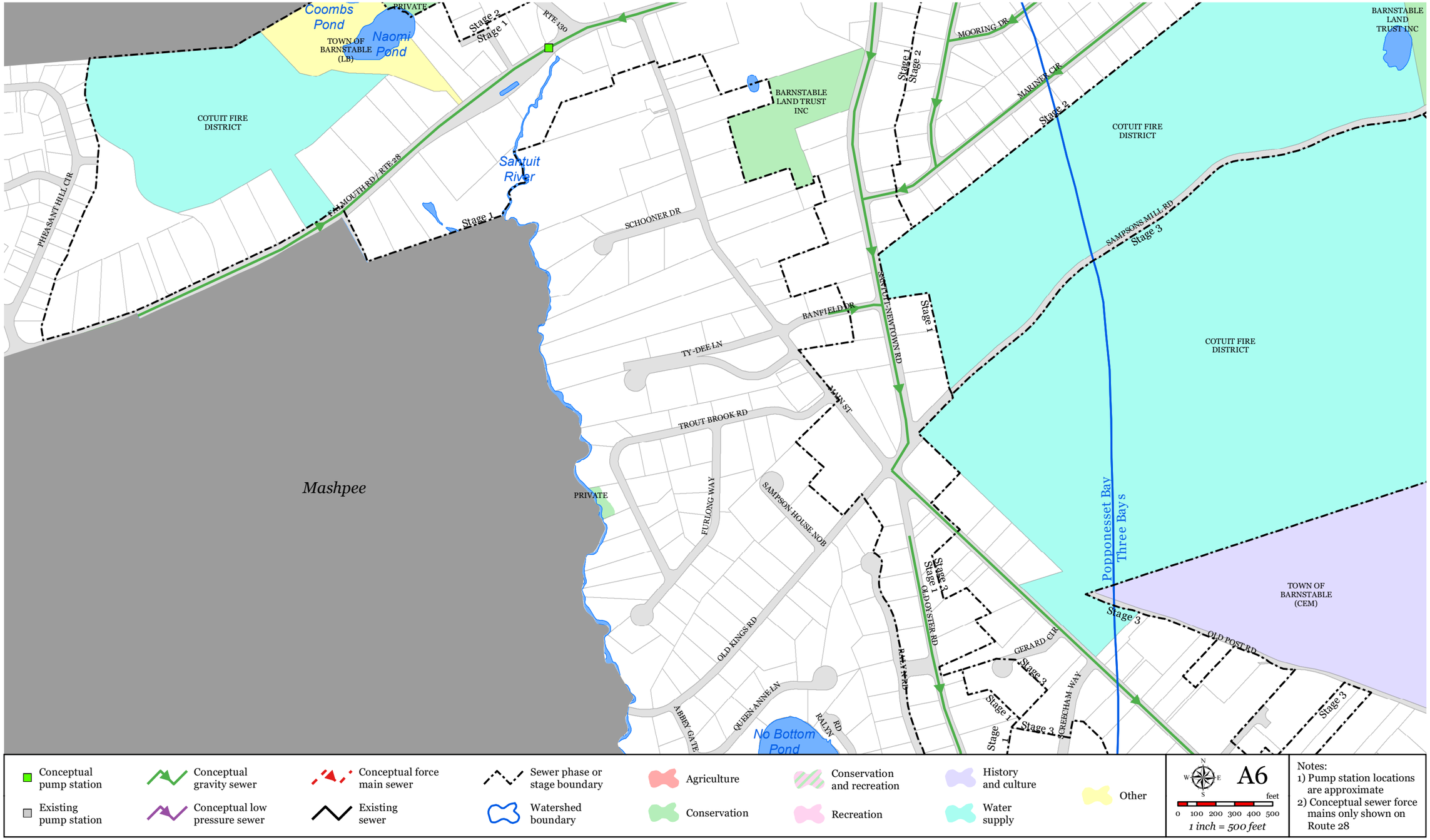
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

A5

0 100 200 300 400 500 feet

1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



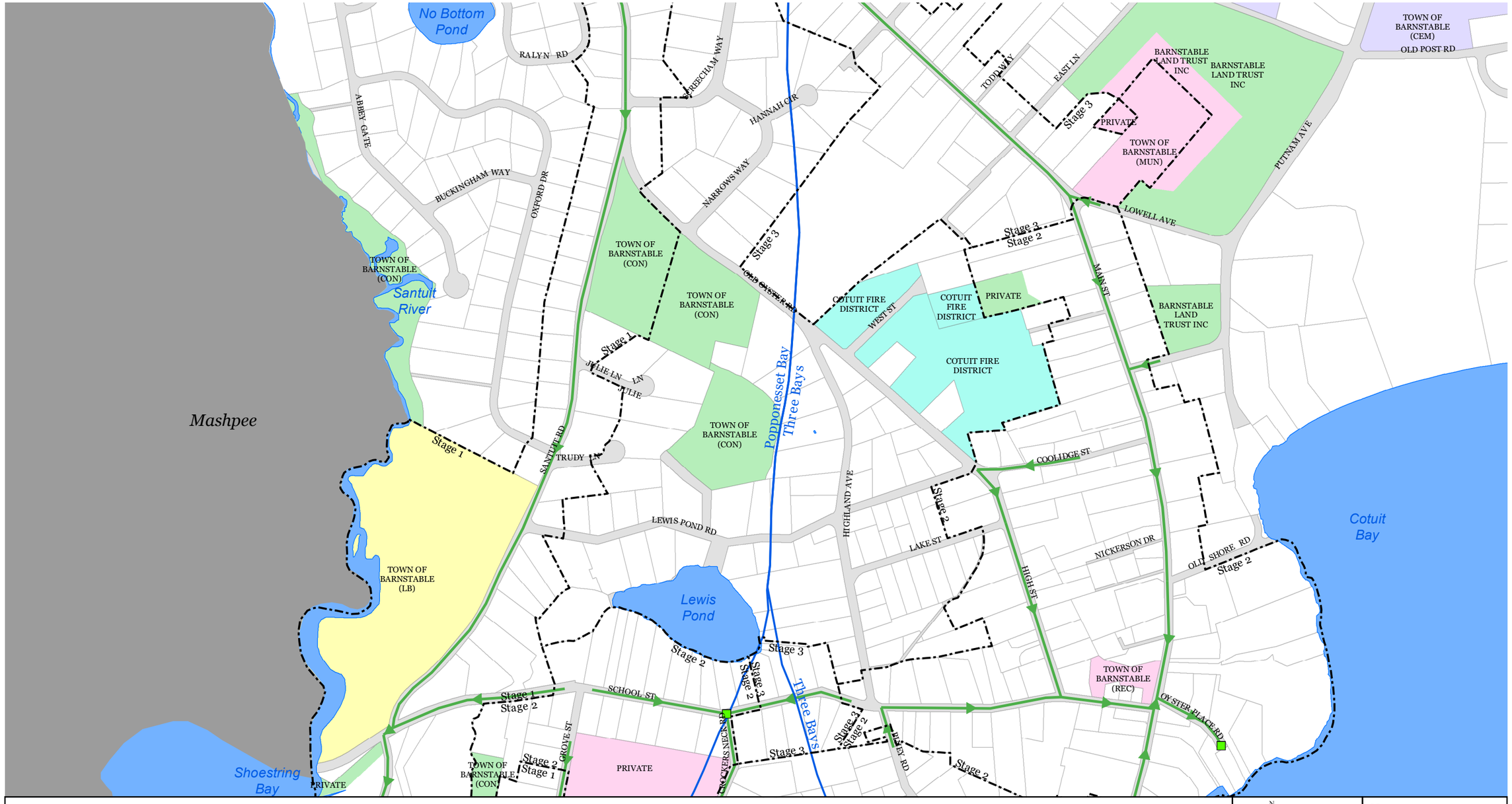
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

A6

0 100 200 300 400 500 feet

1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

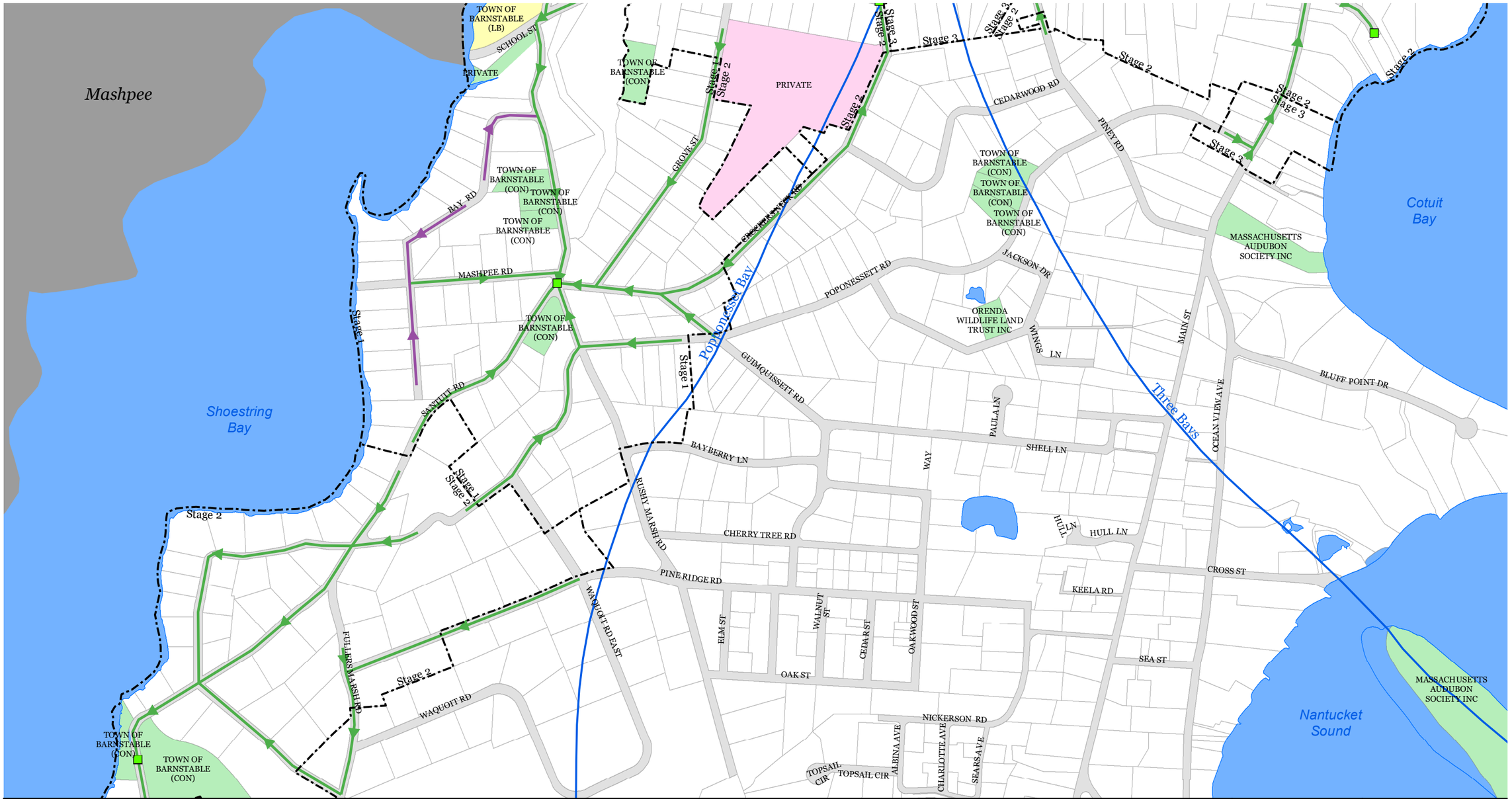


Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

A7

feet
0 100 200 300 400 500
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



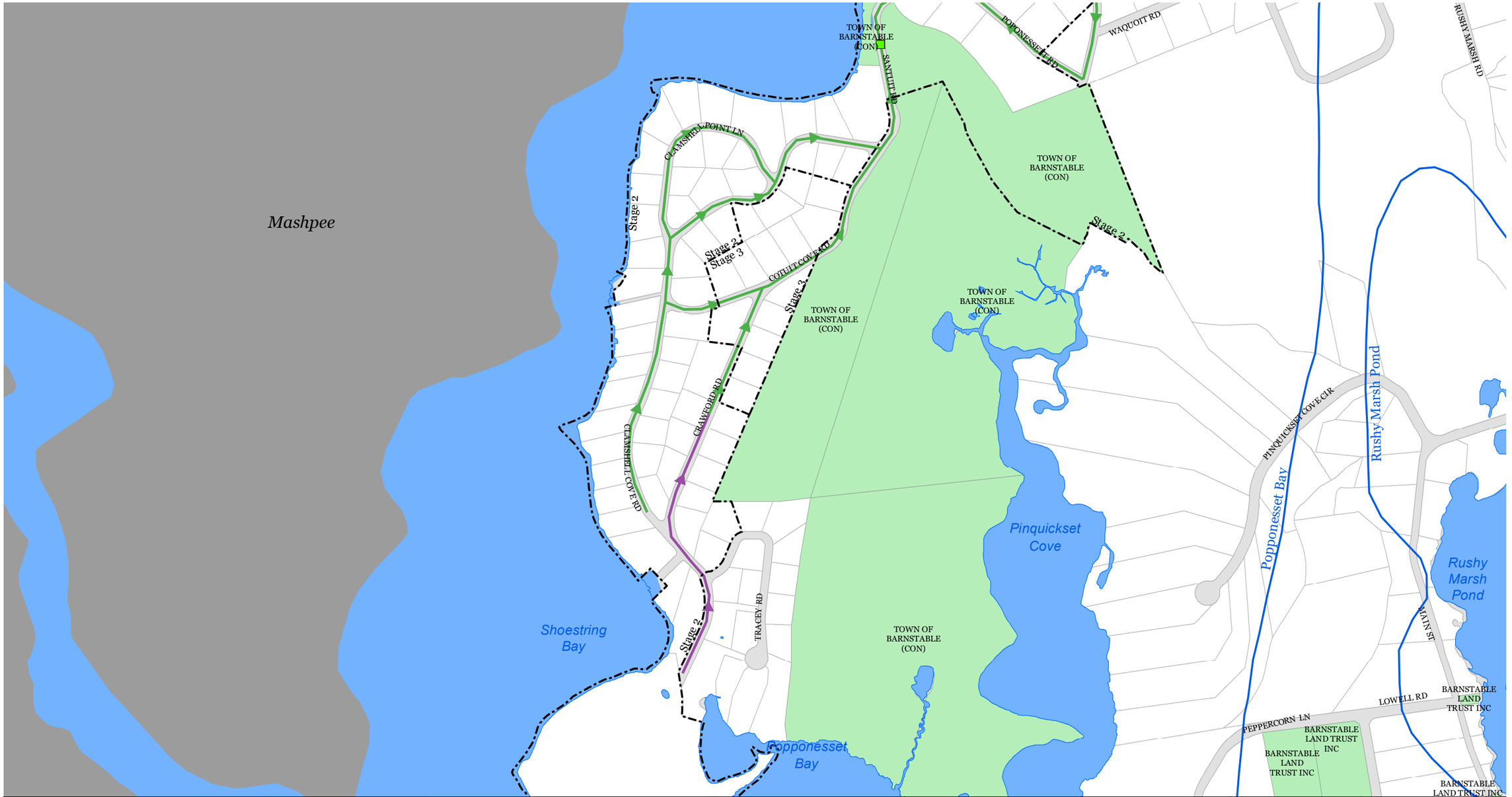
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

A8

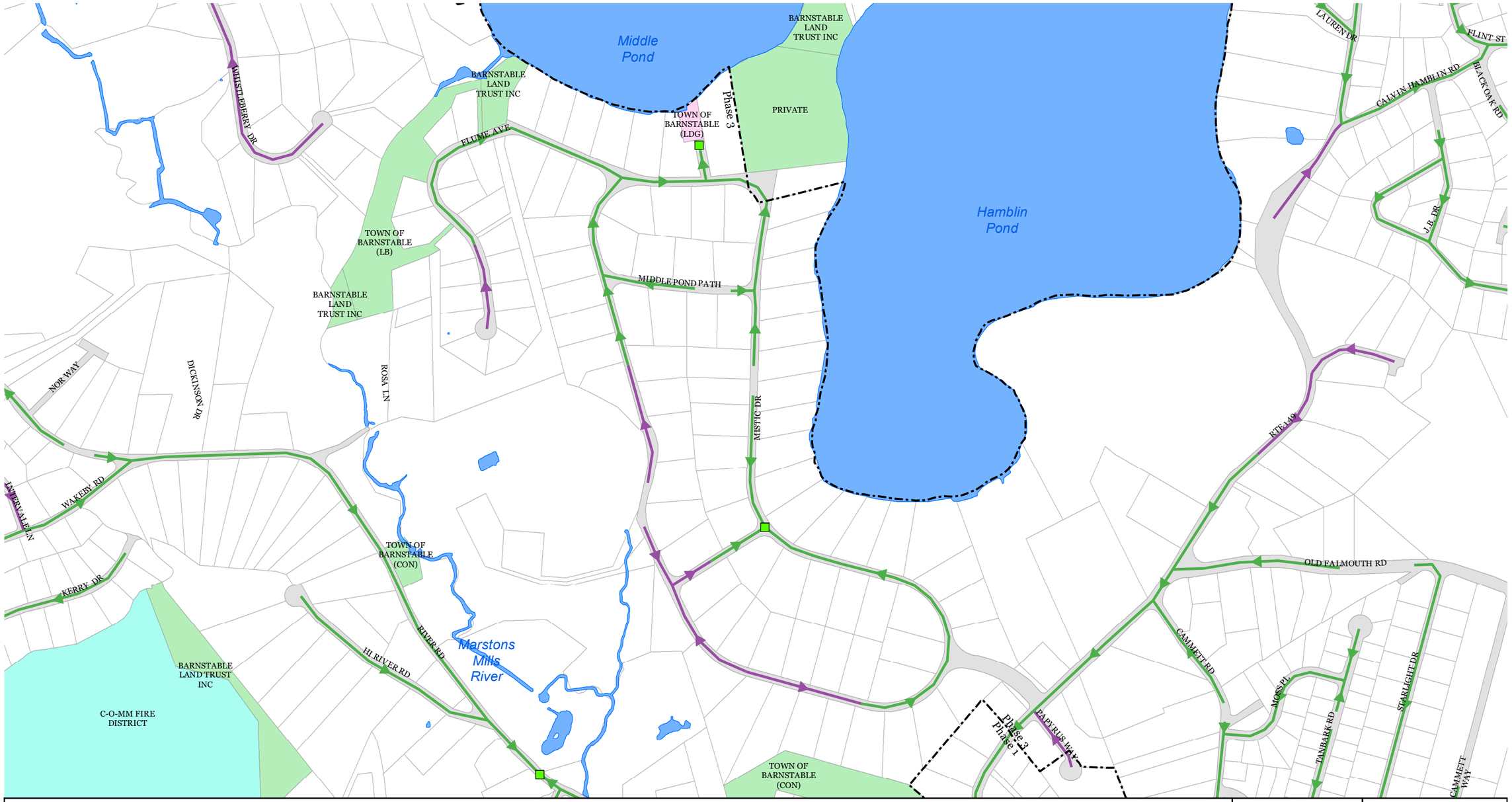
0 100 200 300 400 500 feet

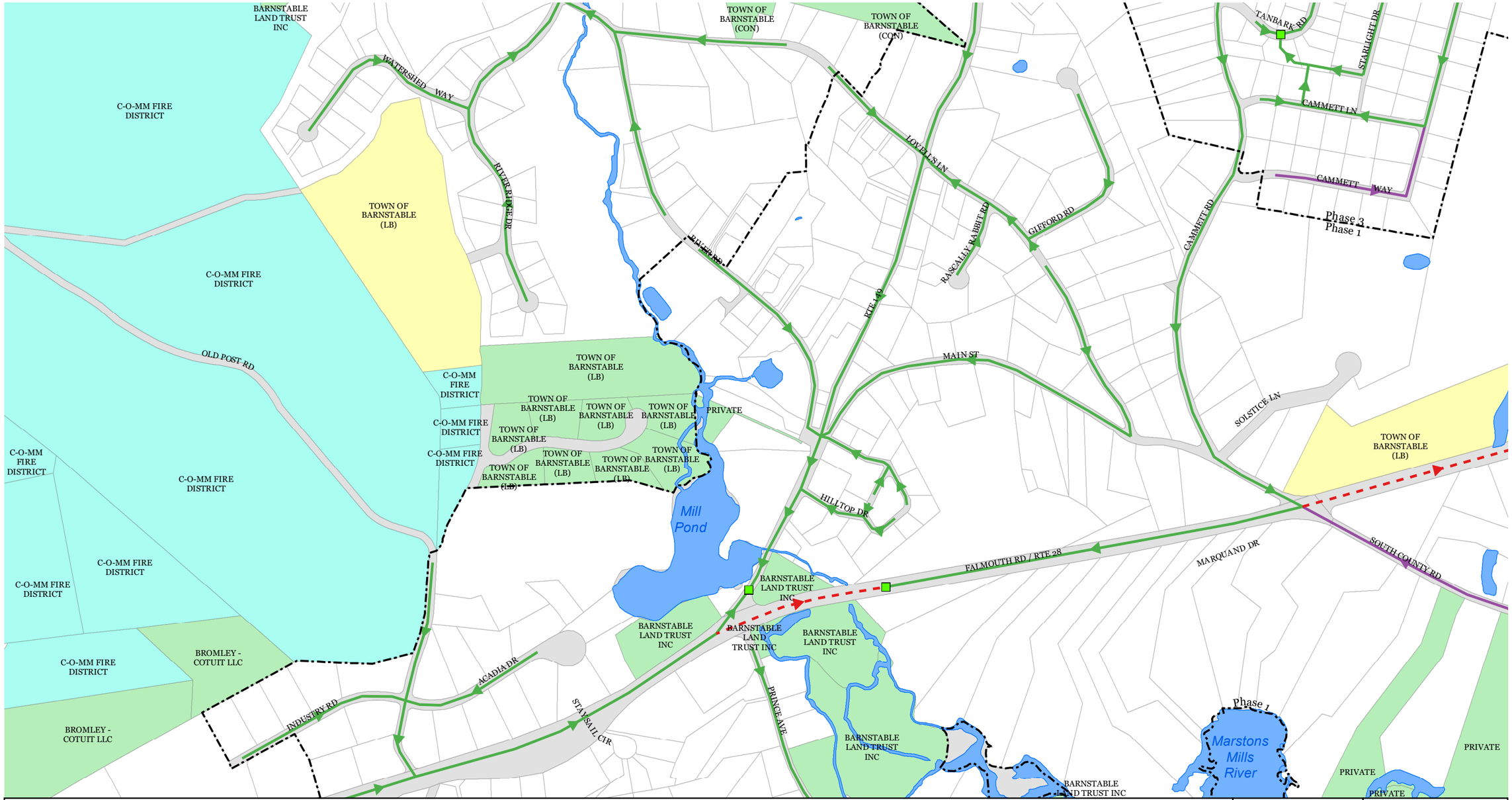
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

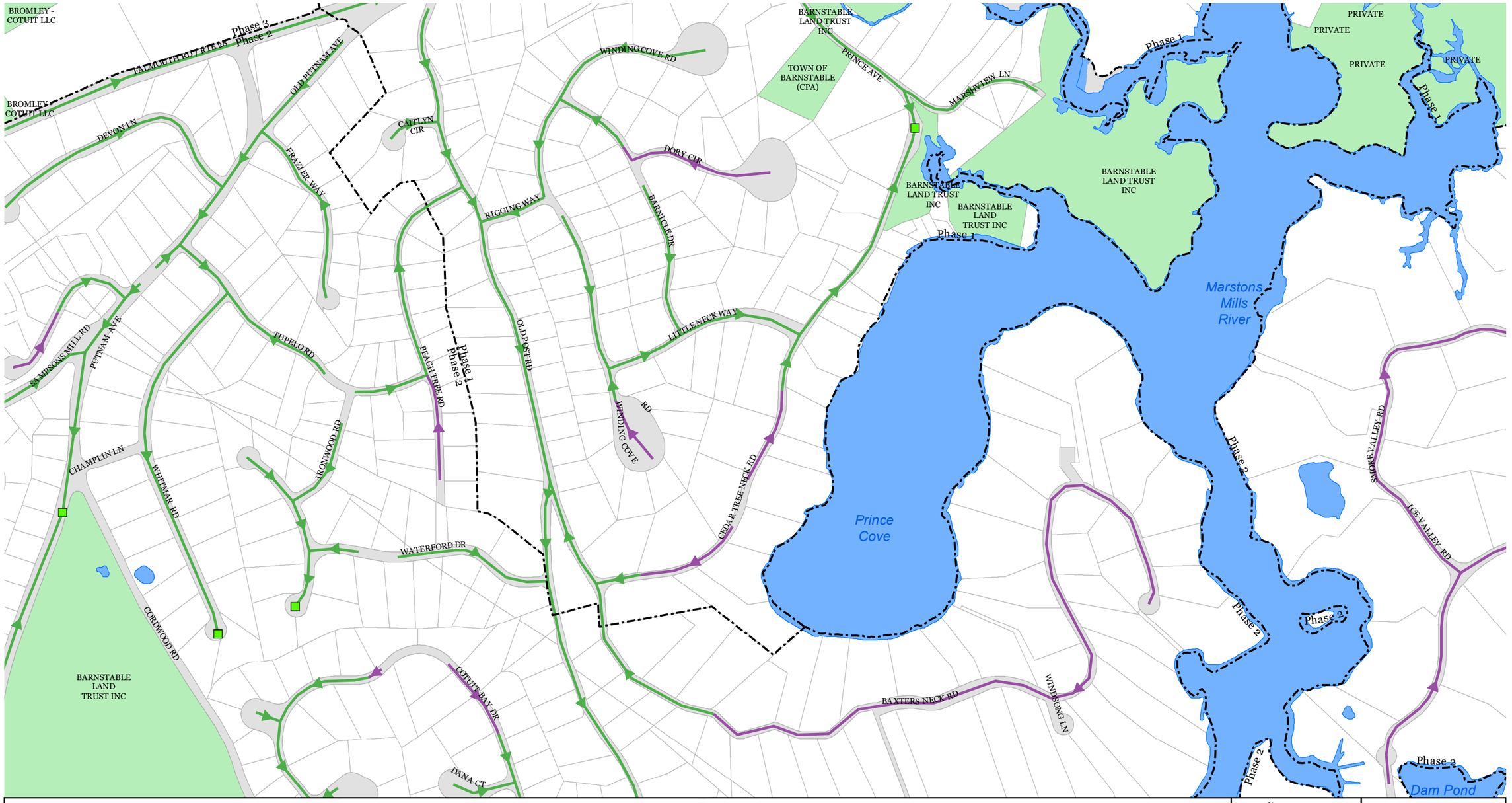

Mashpee
TOWN OF BARNSTABLE (CON)
SANDY LN
POPONESSET RD
WAQUOIT RD
RUSHY MARSH RD
CLAMSHELL POINT LN
Stage 2
Stage 2
Stage 3
COTUIT COVE RD
Stage 2
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
Stage 2
CRAWFORD RD
CLAMSHELL COVE RD
Pinquickset Cove
PINQUICKSET COVE CIR
Popponesset Bay
Rushy Marsh Pond
Shoestring Bay
Stage 2
TRACEY RD
TOWN OF BARNSTABLE (CON)
MAIN ST
LOWELL RD
BARNSTABLE LAND TRUST INC
PEPPERCORN LN
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
Popponesset Bay
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
A9
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


OLD MILL RD
REGENCY DR
HEATH ROW
HAZEL PATH
MILL POND RD
BRAMBLE PATH
TURTLEBACK RD
SAWMILL RD
Mystic Lake
TOWN OF BARNSTABLE (LB)
BURNS LN
WHEELER RD
NEW LONDON AVE
E. CONN. RD
NORWICH RD
COLUMBIA AVE
WILLIMANTIC DR
Three Bays Centerville River
BARNSTABLE LAND TRUST INC
ROSELAND TER
KNOWLTON LN
Phase 3
ALPINE WAY
Marstons Mills River
WHISTLEBERRY DR
Phase 3
LAKESIDE DR
RASPBERRY LN
RTE 149
BARNSTABLE LAND TRUST INC
HOLLIDGE HILL LN
GOOSEBERRY LN
PLANT ST
Middle Pond
Hamblin Pond
WATERS EDGE
BARNSTABLE LAND TRUST INC
LAUREN DR
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
B2
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Middle Pond
BARNSTABLE LAND TRUST INC
PRIVATE
Phase 3
TOWN OF BARNSTABLE (LDG)
WHISTLEBERRY DR
FLUME AVE
TOWN OF BARNSTABLE (LB)
BARNSTABLE LAND TRUST INC
MIDDLE POND PATH
Hamblin Pond
LAUREN DR
FLINT ST
CALVIN HAMBLIN RD
BLACK OAK RD
J.T.B. DR
NOR WAY
DICKINSON DR
ROSA LN
MISTIC DR
RTE 149
WAKEBY RD
INTERVALE LN
KERRY DR
TOWN OF BARNSTABLE (CON)
RIVER RD
HI RIVER RD
Marstons Mills River
BARNSTABLE LAND TRUST INC
C-O-MM FIRE DISTRICT
OLD FALMOUTH RD
CAMMETT RD
MOSS PL
TANBARK RD
STARLIGHT DR
CAMMETT WAY
Phase 2
Phase 1
PAPYRUS WAY
TOWN OF BARNSTABLE (CON)
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
B3
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



BARNSTABLE LAND TRUST INC
C-O-MM FIRE DISTRICT
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (CON)
WATERSHED WAY
RIVER RIDGE DR
LOVELLS LN
RIVER RD
RASCALLY RABBIT RD
GIFFORD RD
RTE 149
TANBARK RD
STARLIGHT DR
CAMMETT LN
CAMMETT WAY
CAMMETT RD
Phase 3
Phase 1
OLD POST RD
MAIN ST
SOLSTICE LN
PRIVATE
HILLTOP DR
Mill Pond
FALMOUTH RD / RTE 28
MARQUAND DR
SOUTH COUNTY RD
BARNSTABLE LAND TRUST INC
BROMLEY - COTUIT LLC
ACADIA DR
INDUSTRY RD
STAYSAIL CIR
PRINCE AVE
Marstons Mills River
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
B4
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



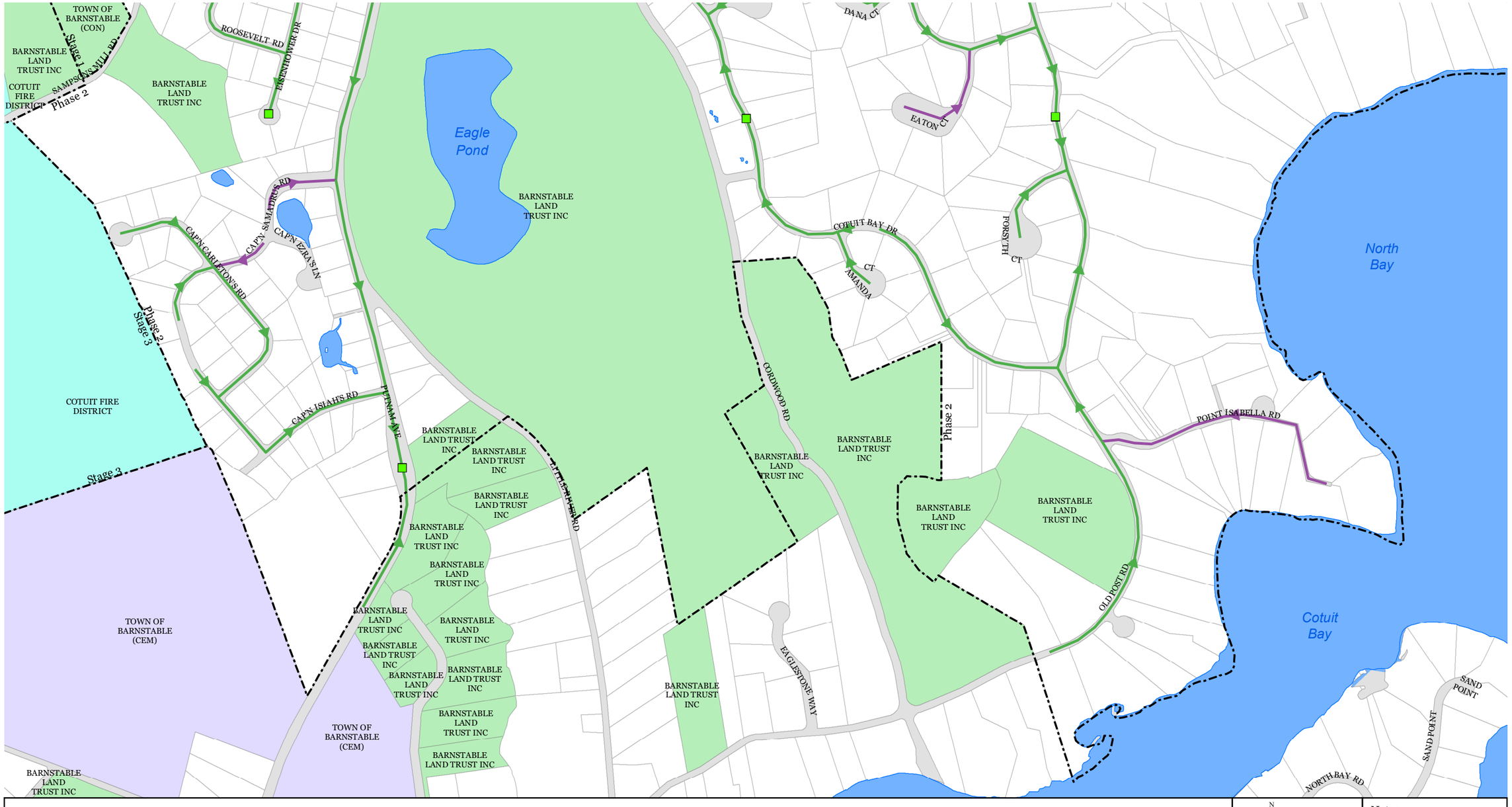
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

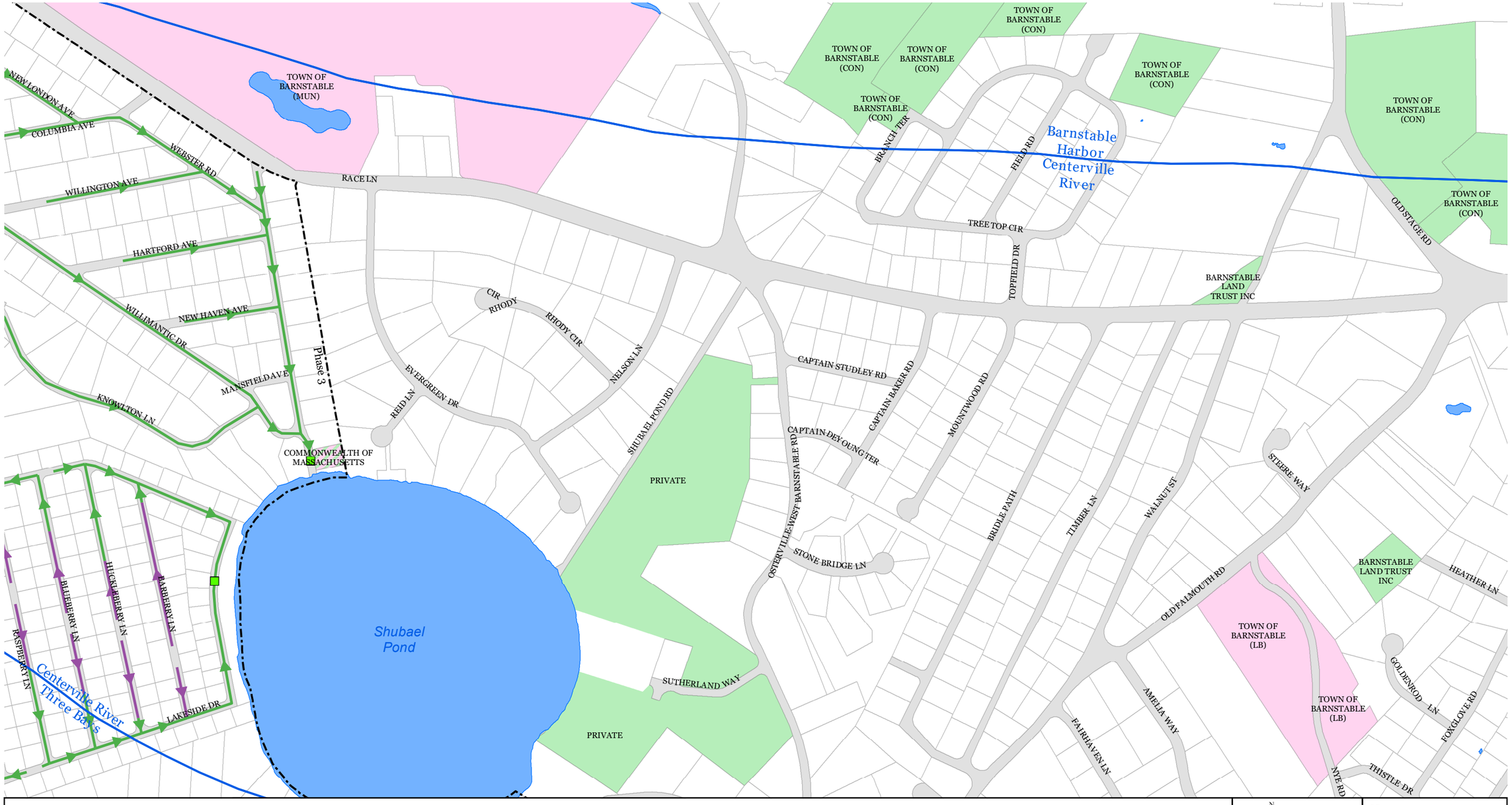
B5

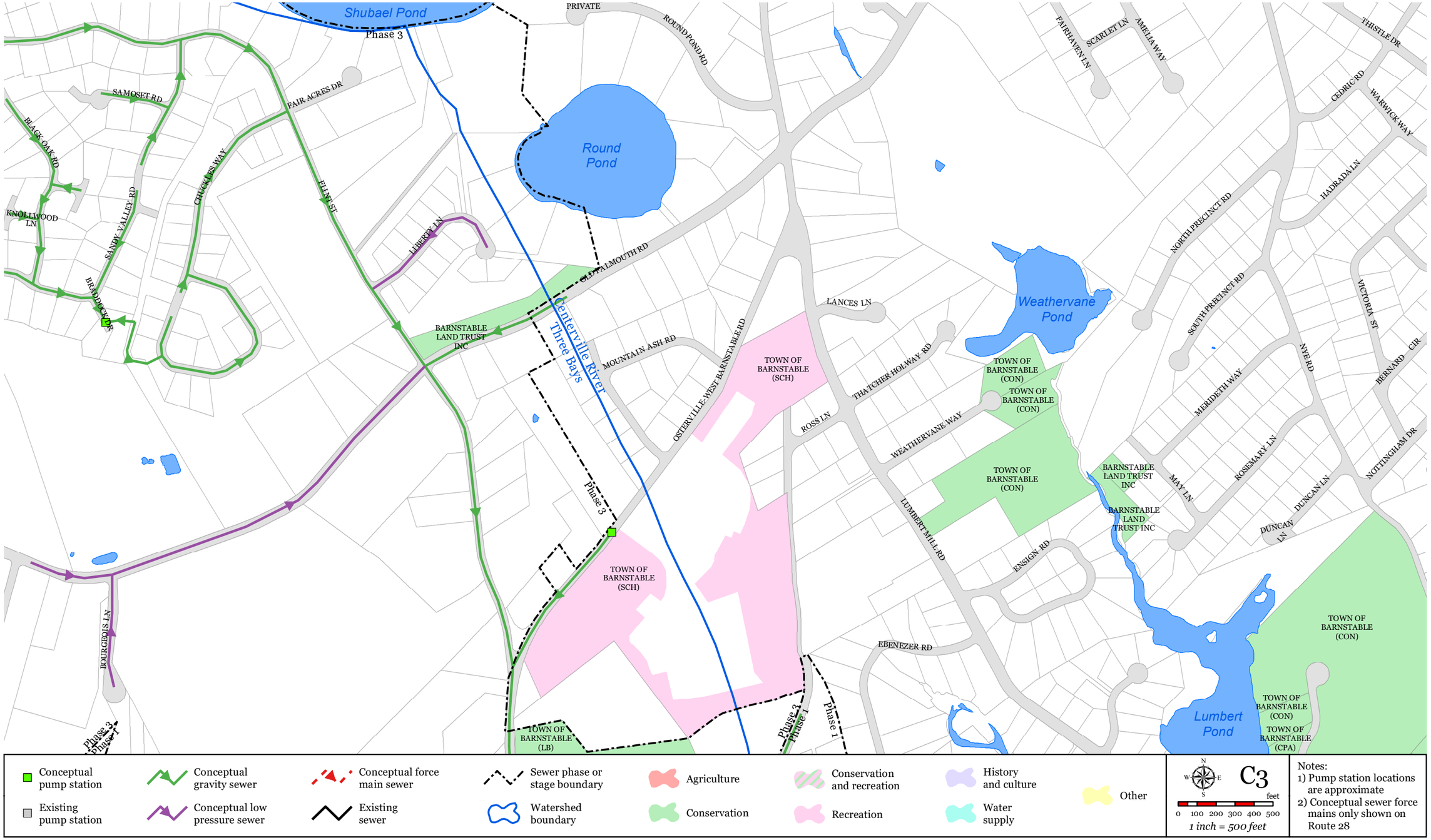
0 100 200 300 400 500 feet

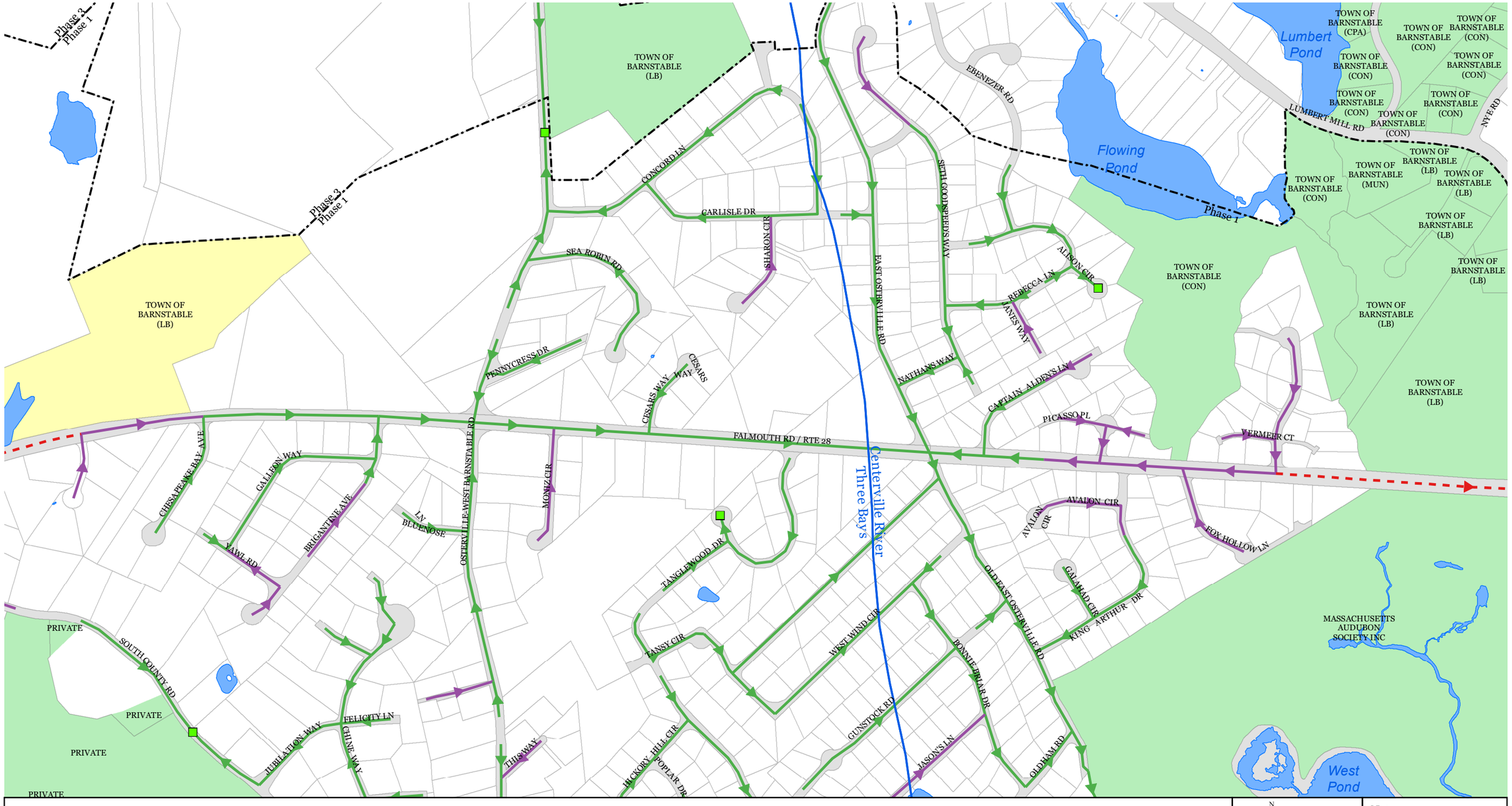
1 inch = 500 feet

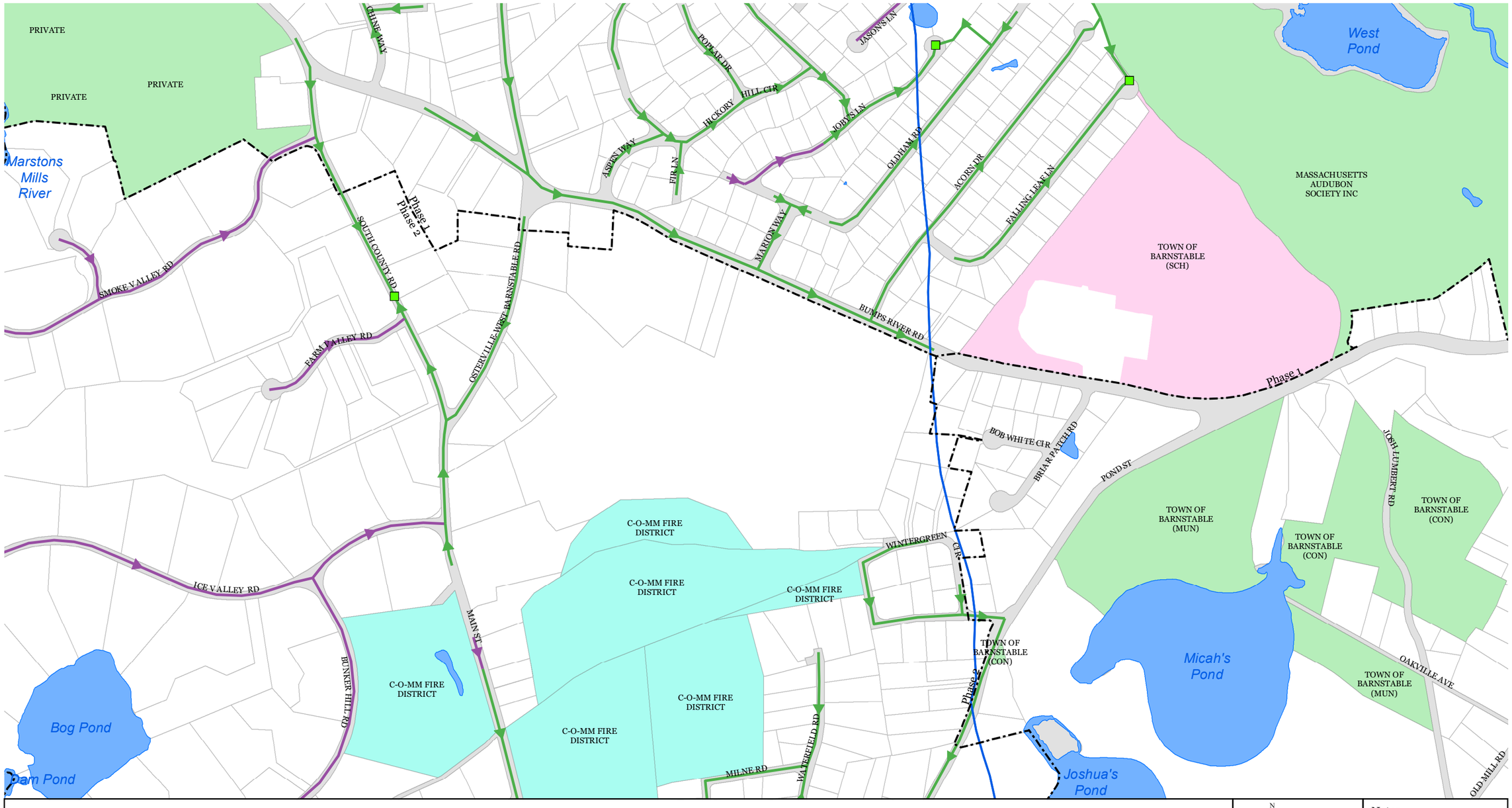
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

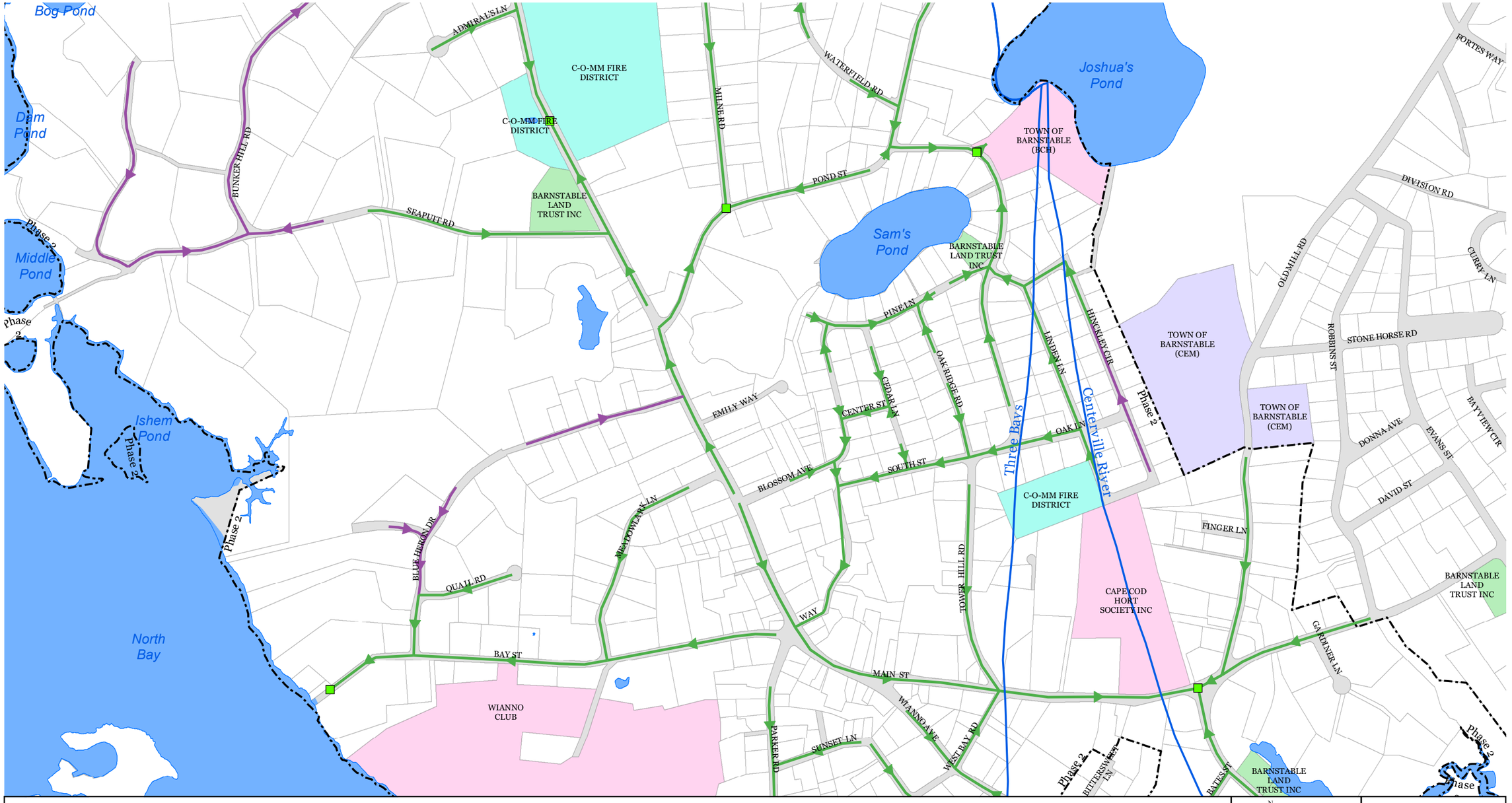

TOWN OF BARNSTABLE (CON)
Stage 1
SAMPSONS MILL RD
BARNSTABLE LAND TRUST INC
COTUIT FIRE DISTRICT
Phase 2
BARNSTABLE LAND TRUST INC
ROOSEVELT RD
EISENHOWER DR
Eagle Pond
BARNSTABLE LAND TRUST INC
CAPN SAMATRUS RD
CAPN CARLETON'S RD
CAPN EZRA'S LN
Phase 2 Stage 3
COTUIT FIRE DISTRICT
CAPN ISAIAHS RD
PUTNAM AVE
Stage 3
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CEM)
TOWN OF BARNSTABLE (CEM)
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
DANA CT
EATON CT
COTUIT BAY DR
CT AMANDA
TOWSITH CT
CORDWOOD RD
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
Phase 2
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
OLD POST RD
EAGLESTONE WAY
BARNSTABLE LAND TRUST INC
North Bay
POINT ISABELLA RD
Cotuit Bay
SAND POINT
SAND POINT
NORTH BAY RD
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
B6
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


TOWN OF BARNSTABLE (MUN)
NEW LONDON AVE
COLUMBIA AVE
WEBSTER RD
WILLINGTON AVE
HARTFORD AVE
WILLIMANTIC DR
NEW HAVEN AVE
MANSFIELD AVE
KNOWLTON LN
RACE LN
Phase 3
COMMONWEALTH OF MASSACHUSETTS
Shubael Pond
BLUEBERRY LN
HUCKLEBERRY LN
BARBERRY LN
RASPBERRY LN
LAKESIDE DR
Centerville River
Three Bays
REID LN
EVERGREEN DR
CIR
RHODY
RHODY CIR
NELSON LN
SHUBAEL POND RD
PRIVATE
SUTHERLAND WAY
PRIVATE
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
BRANCH TER
FIELD RD
Barnstable Harbor
Centerville River
TREE TOP CIR
TOPFIELD DR
OLD STAGE RD
BARNSTABLE LAND TRUST INC
CAPTAIN STUDLEY RD
CAPTAIN BAKER RD
CAPTAIN DEYOUNG TER
MOUNTWOOD RD
STABLE RD
OSTERVILLE-WEST BARNSTABLE RD
STONE BRIDGE LN
BRIDLE PATH
TIMBER LN
WALNUT ST
STEERE WAY
OLD FALMOUTH RD
BARNSTABLE LAND TRUST INC
HEATHER LN
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
GOLDENROD LN
FOXGLOVE RD
FAIRHAVEN LN
AMELIA WAY
NYE RD
THISTLE DR
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
C2
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Shubael Pond
Phase 3
PRIVATE
ROUND POND RD
Round Pond
FAIRHAVEN LN
SCARLET LN
AMELIA WAY
THISTLE DR
CEDRIC RD
WARWICK WAY
HADRADA LN
NORTH PRECINCT RD
SOUTH PRECINCT RD
VICTORIA ST
BERNARD CIR
NYE RD
MERIDETH WAY
SAMOSET RD
FAIR ACRES DR
BLACK OAK RD
KNOLLWOOD LN
SANDY VALLEY RD
CHUCKLES WAY
BRADDOCK DR
FLINT ST
LIBERTY LN
OLD FALMOUTH RD
Centerville River
Three Bays
BARNSTABLE LAND TRUST INC
MOUNTAIN ASH RD
OSTERVILLE-WEST BARNSTABLE RD
TOWN OF BARNSTABLE (SCH)
LANCES LN
THATCHER HOLWAY RD
ROSS LN
WEATHERVANE WAY
Weathervane Pond
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
MAY LN
ROSEMARY LN
DUNCAN LN
DUNCAN LN
NOTTINGHAM DR
LUMBERT MILL RD
ENSIGN RD
EBENEZER RD
Lumbert Pond
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CPA)
BOURGEOIS LN
Phase 3
Phase 1
Phase 3
Phase 1
Phase 1
TOWN OF BARNSTABLE (LB)
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
C3
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Phase 3
Phase 1
TOWN OF BARNSTABLE (LB)
CONCORD LN
CARLISLE DR
SHARON CIR
SEA ROBIN RD
PENNYCRESS DR
CESARS WAY
CESARS WAY
EBENEZER RD
SETH GOODSPEED WAY
EAST OSTERVILLE RD
NATHANS WAY
ALISON CIR
REBECCA LN
JANES WAY
CAPTAIN ALDEN'S LN
PICASSO PL
VERMEER CT
AVALON CIR
AVALON CIR
FOX HOLLOW LN
FALMOUTH RD / RTE 28
Centerville River
Three Bays
Lumbert Pond
Flowing Pond
Phase 1
TOWN OF BARNSTABLE (CPA)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (MUN)
TOWN OF BARNSTABLE (LB)
LUMBERT MILL RD
NYE RD
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (MUN)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (LB)
CHESAPEAKE BAY AVE
GALLEON WAY
YAWL RD
BRIGANTINE AVE
LN
BLUENOSE
OSTERVILLE-WEST BARNSTABLE RD
MONIZ CIR
TANGLEWOOD DR
TANSY CIR
WEST WIND CIR
JASON'S LN
BONNIE BRIAR DR
OLD EAST OSTERVILLE RD
GUNSTOCK RD
OLDHAM RD
GALAHAD CIR
KING ARTHUR DR
THIS WAY
HICKORY HILL CIR
POPLAR DR
PRIVATE
SOUTH COUNTY RD
PRIVATE
PRIVATE
PRIVATE
JUBILATION WAY
FELICITY LN
CHENE WAY
MASSACHUSETTS AUDUBON SOCIETY INC
West Pond
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
C4
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


PRIVATE
PRIVATE
PRIVATE
PRIVATE
Marstons Mills River
CHIAVE WAY
POPLAR DR
HICKORY HILL CIR
JASON'S LN
JOBY'S LN
OLDHAM RD
ACORN DR
FALLING LEAF LN
ASPEN WAY
FIR LN
MARION WAY
West Pond
MASSACHUSETTS AUDUBON SOCIETY INC
TOWN OF BARNSTABLE (SCH)
Phase 1
Phase 2
SOUTH COUNTY RD
OSTERVILLE-WEST BARNSTABLE RD
SMOKE VALLEY RD
FARM VALLEY RD
BUMPS RIVER RD
BOB WHITE CIR
BRIAR PATCH RD
POND ST
JOSH LUMBERT RD
TOWN OF BARNSTABLE (MUN)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (MUN)
C-O-MM FIRE DISTRICT
C-O-MM FIRE DISTRICT
C-O-MM FIRE DISTRICT
C-O-MM FIRE DISTRICT
C-O-MM FIRE DISTRICT
WINTERGREEN CIR
MAIN ST
ICE VALLEY RD
BUNKER HILL RD
MILNE RD
WATERFIELD RD
Micah's Pond
Joshua's Pond
Bog Pond
OAKVILLE AVE
OLD MILL RD
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
C5
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



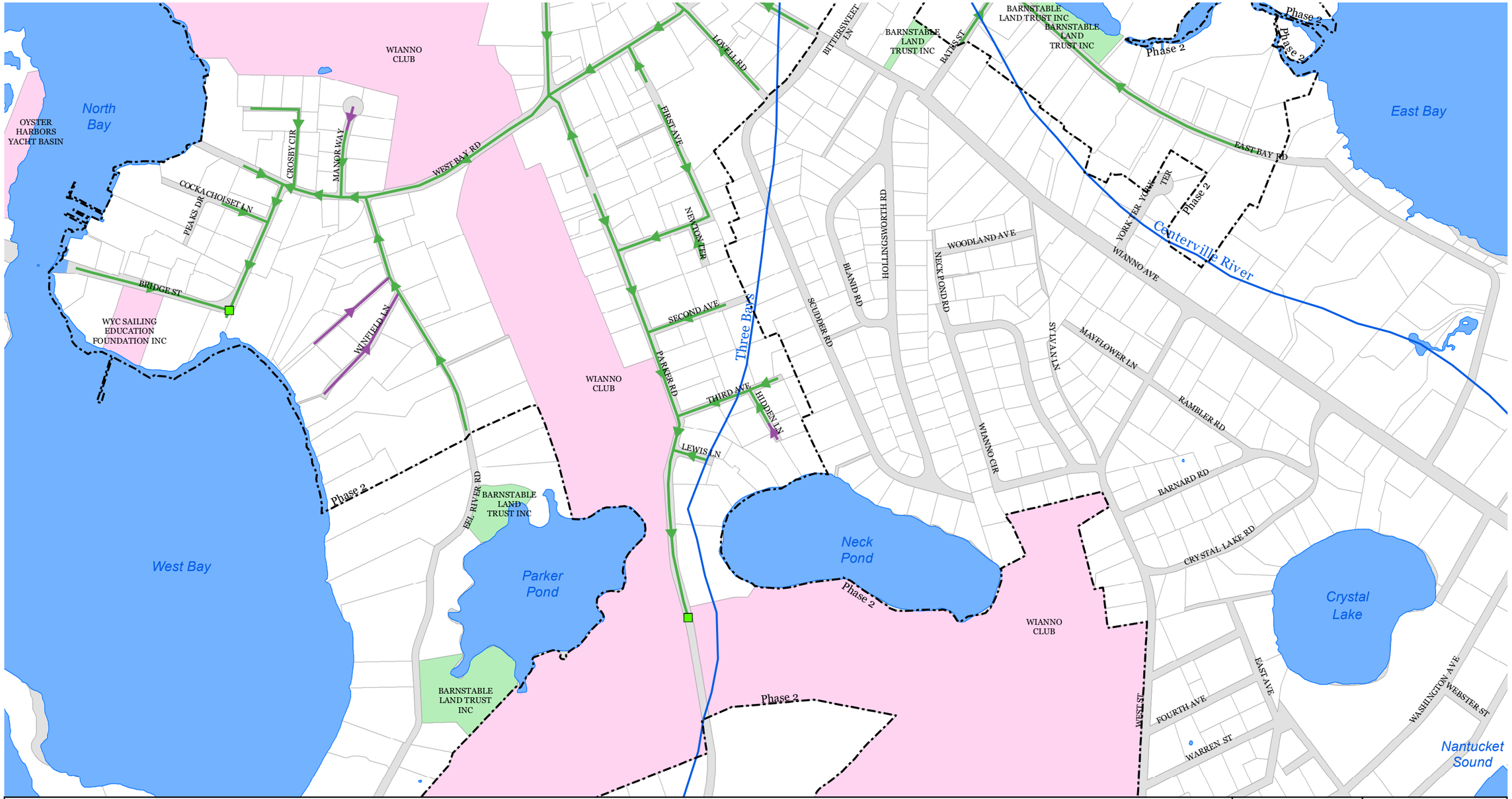
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

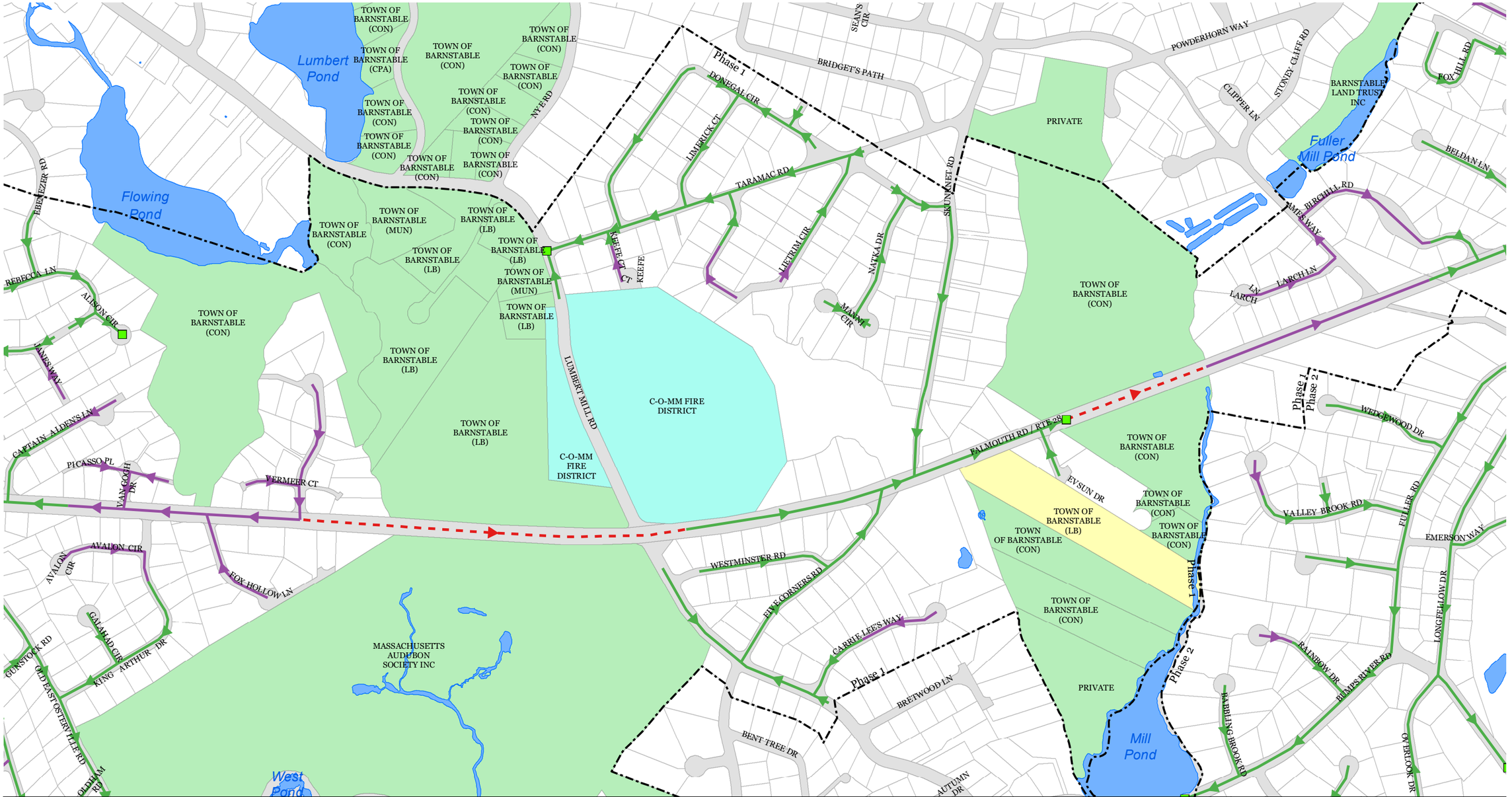
N W E S

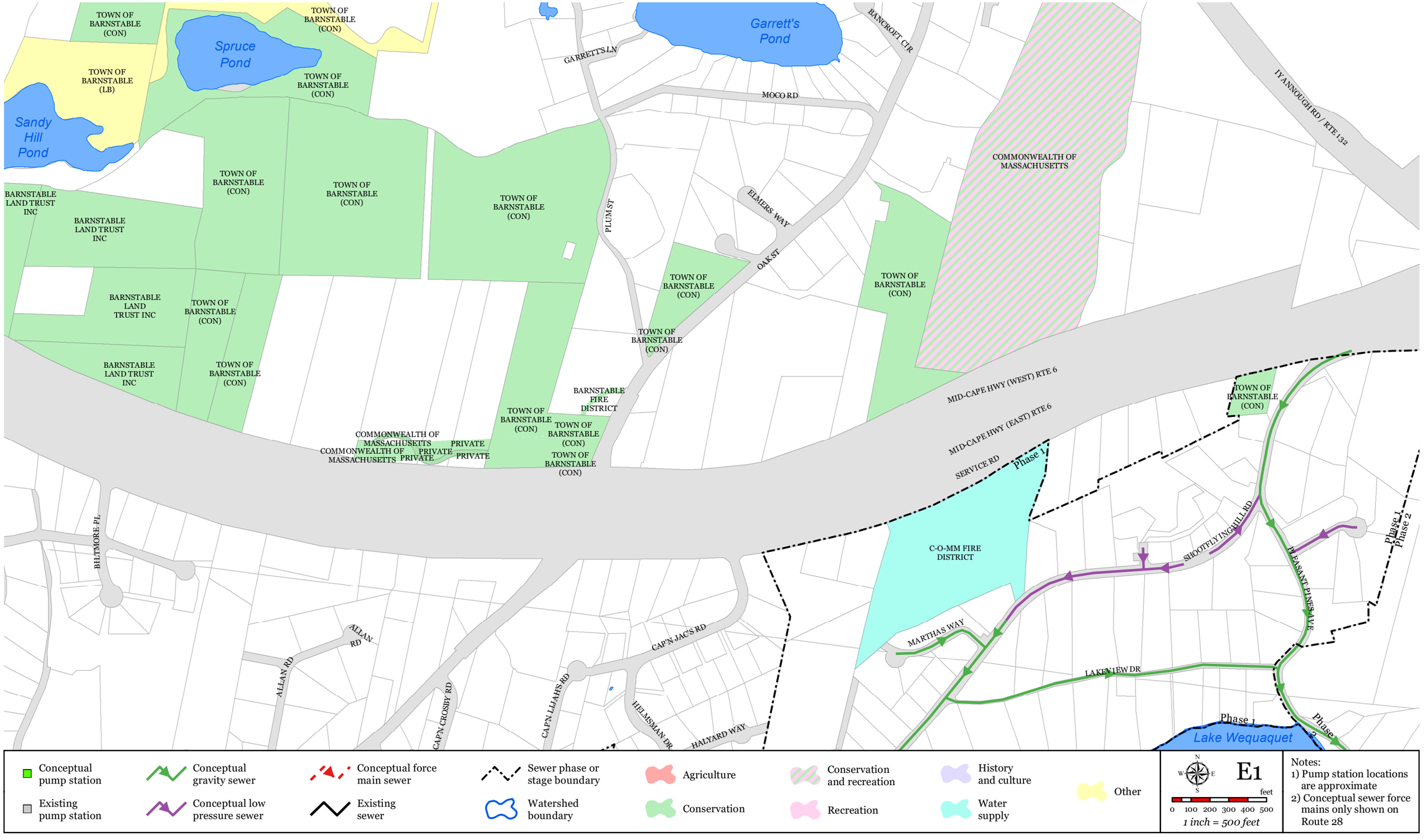
C6

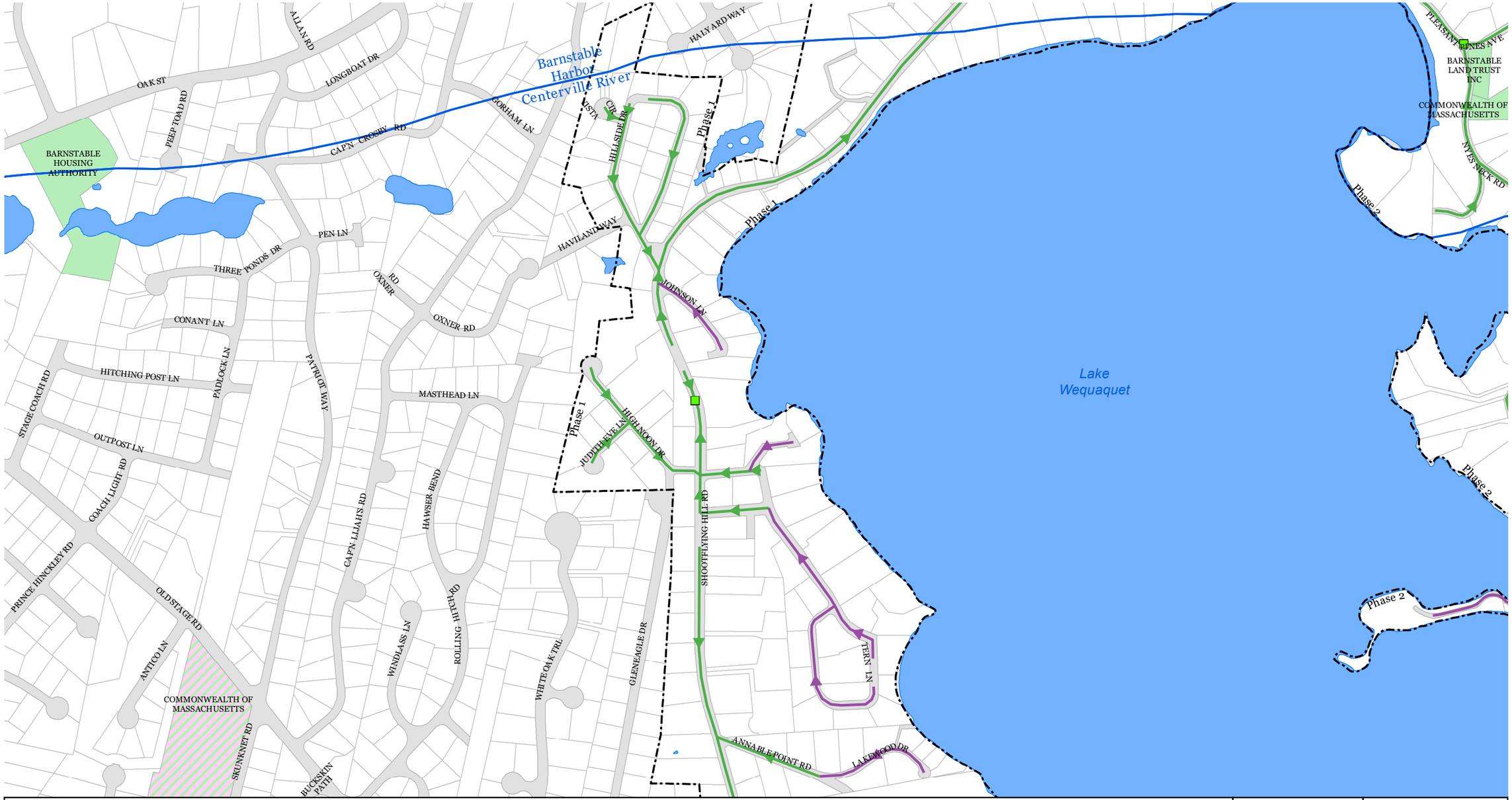
feet
0 100 200 300 400 500
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


North Bay
OYSTER HARBORS YACHT BASIN
WIANNO CLUB
WEST BAY RD
CROSBY CIR
MANOR WAY
COCKACHOISET LN
PEAKS DR
BRIDGE ST
WYC SAILING EDUCATION FOUNDATION INC
WINFIELD LN
West Bay
Phase 2
EEL RIVER RD
BARNSTABLE LAND TRUST INC
Parker Pond
BARNSTABLE LAND TRUST INC
WIANNO CLUB
LOVELL RD
FIRST AVE
NEWTON TER
SECOND AVE
PARKER RD
THIRD AVE
HIDDEN LN
LEWIS LN
Three Bays
Phase 2
Neck Pond
WIANNO CLUB
BITTERSWEET LN
BARNSTABLE LAND TRUST INC
BATES ST
HOLLINGSWORTH RD
BLAND RD
SCUDDER RD
NECK POND RD
WOODLAND AVE
WIANNO CIR
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
Phase 2
Phase 2
Phase 2
EAST BAY RD
East Bay
YORKSHIRE TER
Phase 2
Centerville River
WIANNO AVE
SYLVAN LN
MAYFLOWER LN
RAMBLER RD
BARNARD RD
CRYSTAL LAKE RD
Crystal Lake
EAST AVE
FOURTH AVE
WARREN ST
WEST ST
WASHINGTON AVE
WEBSTER ST
Nantucket Sound
Phase 2
Phase 2
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
C7
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Lumbert Pond
Flowing Pond
Fuller Mill Pond
West Pond
Mill Pond
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CPA)
TOWN OF BARNSTABLE (MUN)
TOWN OF BARNSTABLE (LB)
C-O-MM FIRE DISTRICT
PRIVATE
BARNSTABLE LAND TRUST INC
MASSACHUSETTS AUDUBON SOCIETY INC
Phase 1
Phase 2
BRIDGET'S PATH
SEAN'S CIR
POWDERHORN WAY
CLIPPER LN
STONEY CLIFF RD
FOX HILL RD
BELDAN LN
BIRCHILL RD
JAMES WAY
LARCH LN
DONEGAL CIR
LIMERICK CT
TARAMAC RD
LIFFEY RUN CIR
NATICK DR
MANAMET CIR
SKUNNET RD
KEEFE CT
KEEFE
NYE RD
EBENEZER CIR
REBECCA LN
ALISON CIR
JAMES WAY
CAPTAIN ALDEN'S LN
PICASSO PL
VAN GOGH DR
VERMEER CT
AVALON CIR
FOX HOLLOW LN
GALAHAD CIR
KING ARTHUR DR
GUNSTOCK RD
OLD EASTOSTERVILLE RD
OLDHAM RD
LUMBERT MILL RD
FALMOUTH RD / RTE 28
EVSUN DR
WESTMINSTER RD
FIVE CORNERS RD
CARRIE LEE'S WAY
BRETWOOD LN
BENT TREE DR
AUTUMN DR
BABBLING BROOK RD
WEDGEWOOD DR
VALLEY BROOK RD
FULLER RD
EMERSON WAY
LONGFELLOW DR
RAINBOW DR
BUMPS RIVER RD
OVERLOOK DR
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
D1
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Spruce Pond
Sandy Hill Pond
Garrett's Pond
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (LB)
BARNSTABLE LAND TRUST INC
GARRETT'S LN
BANCROFT CIR
MOCO RD
PLUM ST
ELMERS WAY
OAK ST
IYANNOUGH RD / RTE 132
COMMONWEALTH OF MASSACHUSETTS
MID-CAPE HWY (WEST) RTE 6
MID-CAPE HWY (EAST) RTE 6
SERVICE RD
BARNSTABLE FIRE DISTRICT
COMMONWEALTH OF MASSACHUSETTS PRIVATE
C-O-MM FIRE DISTRICT
Phase 1
Phase 2
SHOOTFLYINGHILL RD
PLEASANT PINES AVE
MARTHAS WAY
LAKEVIEW DR
Lake Wequaquet
BILTMORE PL
ALLAN RD
CAP'N JAC'S RD
CAP'N CROSBY RD
CAP'N LUAHS RD
HELMSMAN DR
HALYARD WAY
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
E1
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



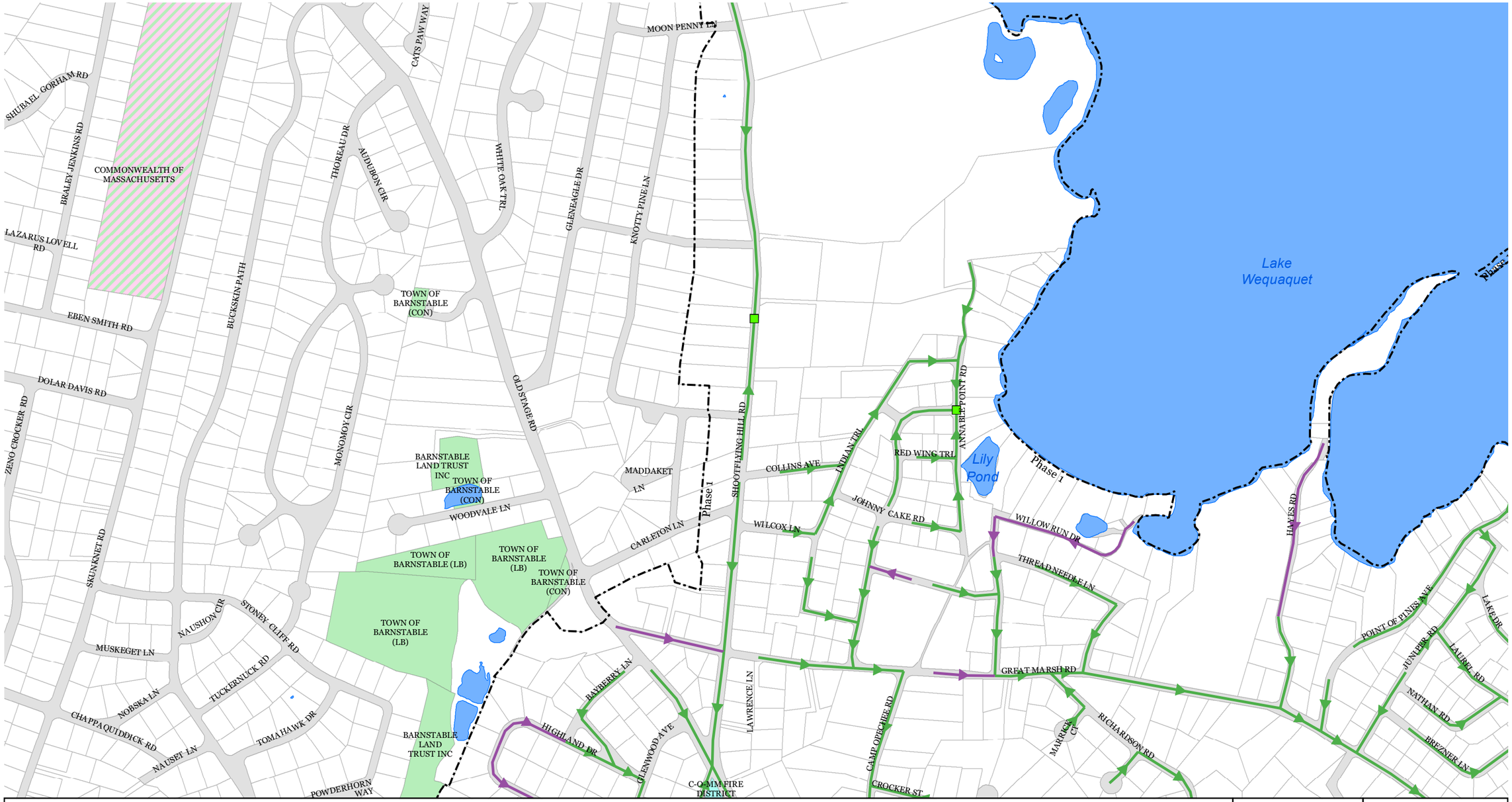
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

N W E S

E2

feet
0 100 200 300 400 500
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

E3

0 100 200 300 400 500 feet

1 inch = 500 feet

Notes:
1) Pump station locations are approximate
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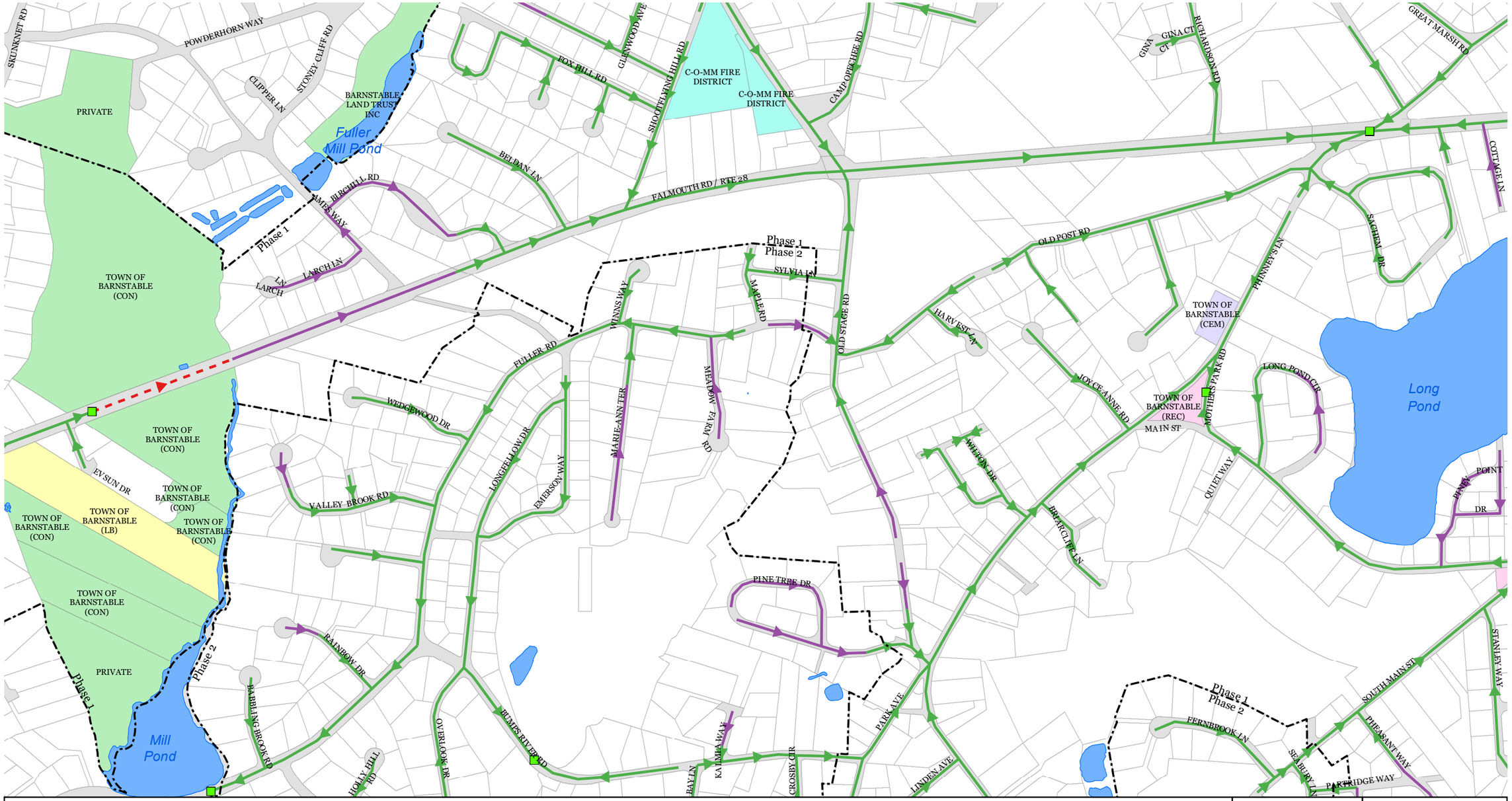

Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

E4

0 100 200 300 400 500 feet

1 inch = 500 feet

Notes:
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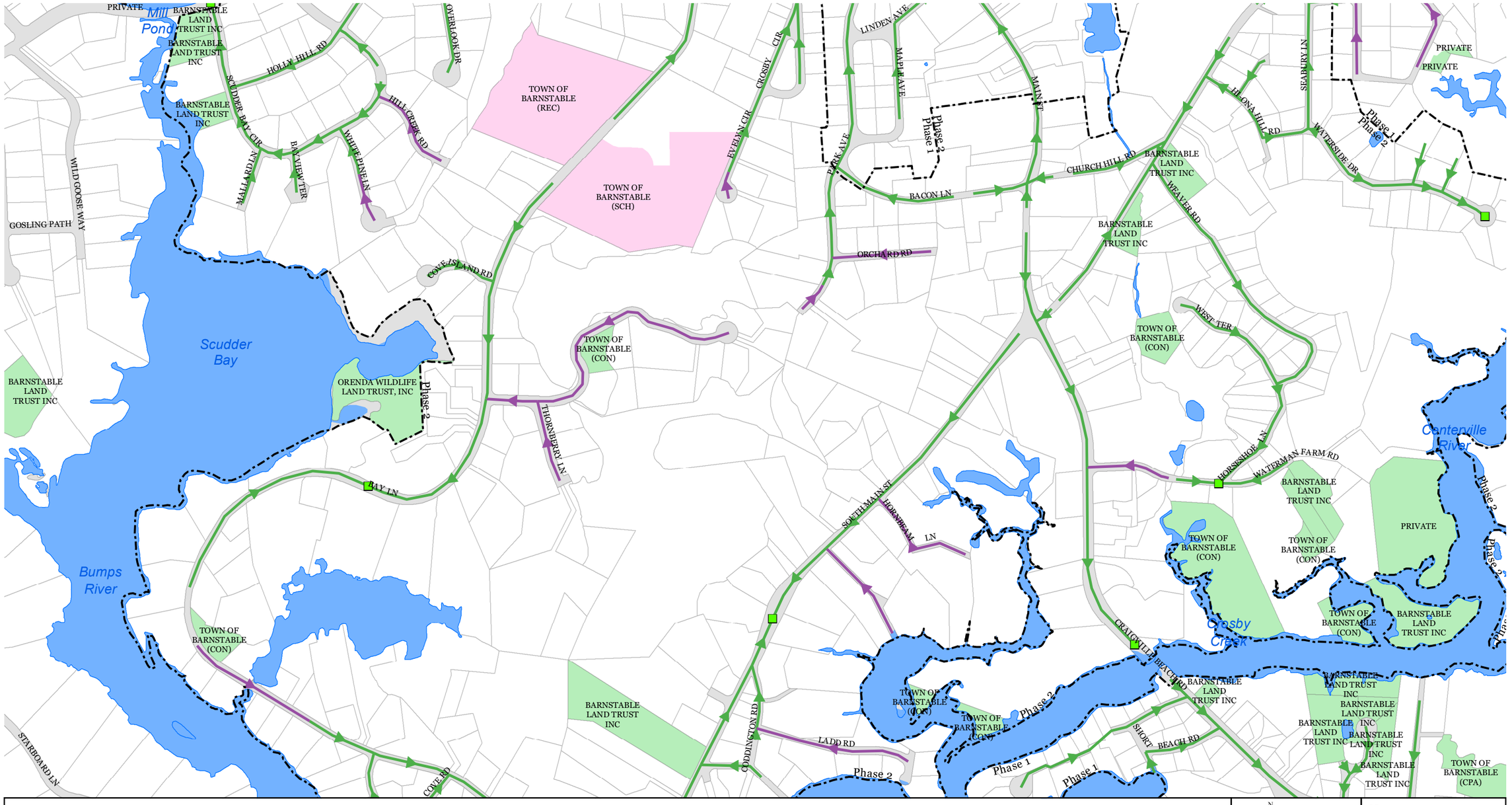
2) Conceptual sewer force mains only shown on Route 28


PRIVATE
Mill Pond
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
HOLLY HILL RD
SCUDDER BAY CIR
MALLARD LN
BAY VIEW TER
WHITE PINE LN
HILL CREEK RD
OVERLOOK DR
WILD GOOSE WAY
GOSLING PATH
TOWN OF BARNSTABLE (REC)
TOWN OF BARNSTABLE (SCH)
EVELYN CIR
CROSBY CTR
LINDEN AVE
MAPLE AVE
PARK AVE
Phase 2
Phase 1
MAIN ST
BACON LN
CHURCH HILL RD
ORCHARD RD
COVE ISLAND RD
TOWN OF BARNSTABLE (CON)
THORNBERRY LN
Scudder Bay
BARNSTABLE LAND TRUST INC
ORENDA WILDLIFE LAND TRUST, INC
Phase 2
BAY LN
Bumps River
TOWN OF BARNSTABLE (CON)
BARNSTABLE LAND TRUST INC
STARBOARD LN
COVE RD
SOUTH MAIN ST
HORNBEAM LN
CODDINGTON RD
LADD RD
Phase 2
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
Phase 2
Phase 1
Phase 1
CRAIGVILLE BEACH RD
BARNSTABLE LAND TRUST INC
SHORT BEACH RD
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CPA)
Crosby Creek
BARNSTABLE LAND TRUST INC
WEAVER RD
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CON)
WEST TER
HORSESHOE LN
WATTERMAN FARM RD
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
PRIVATE
Canterville River
Phase 2
Phase 2
HLONA HILL RD
SEABURY LN
WATERSIDE DR
Phase 2
Phase 1
PRIVATE
PRIVATE
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
E5
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

N W E S

E6

feet
0 100 200 300 400 500
1 inch = 500 feet

Notes:
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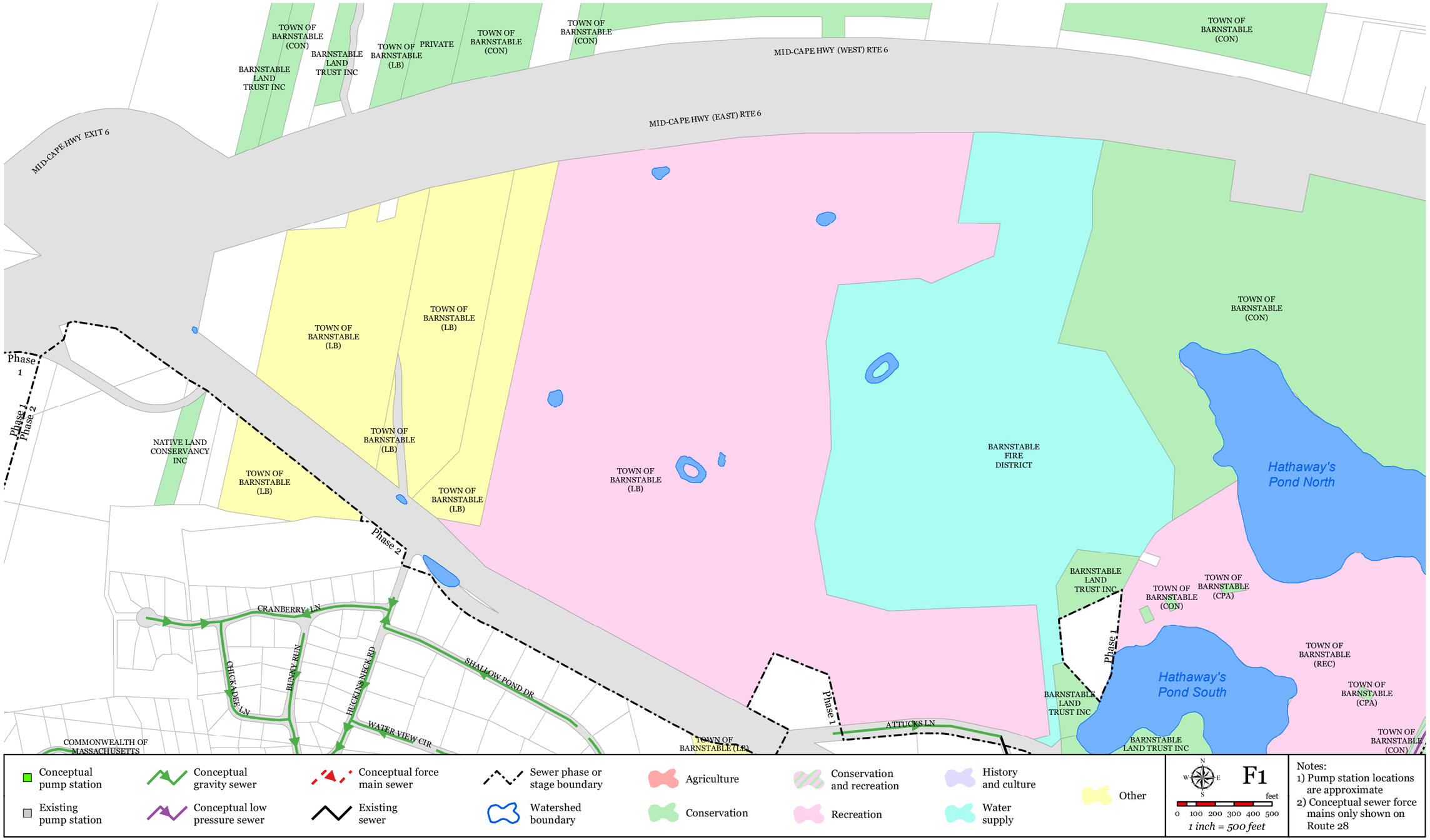
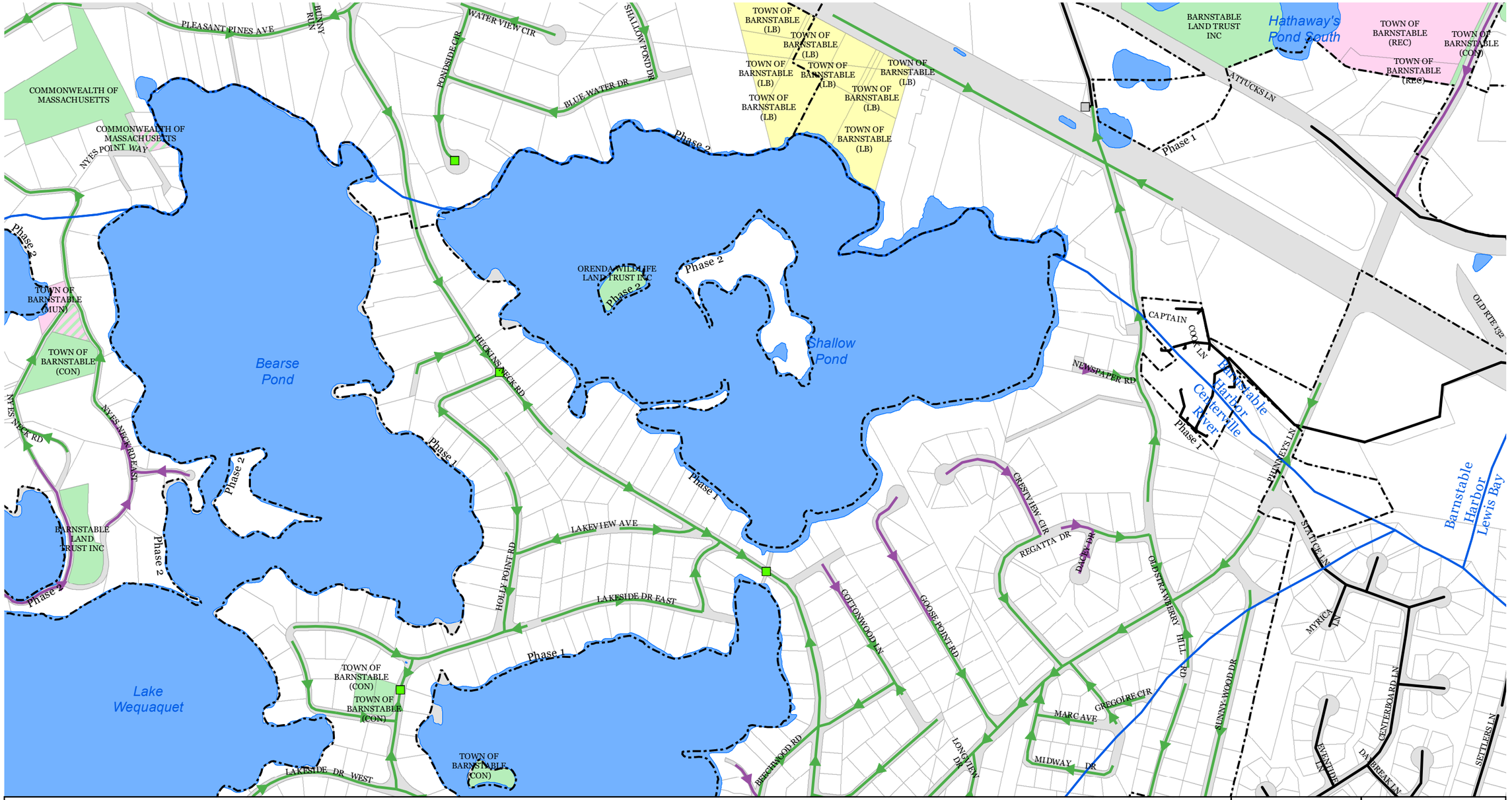
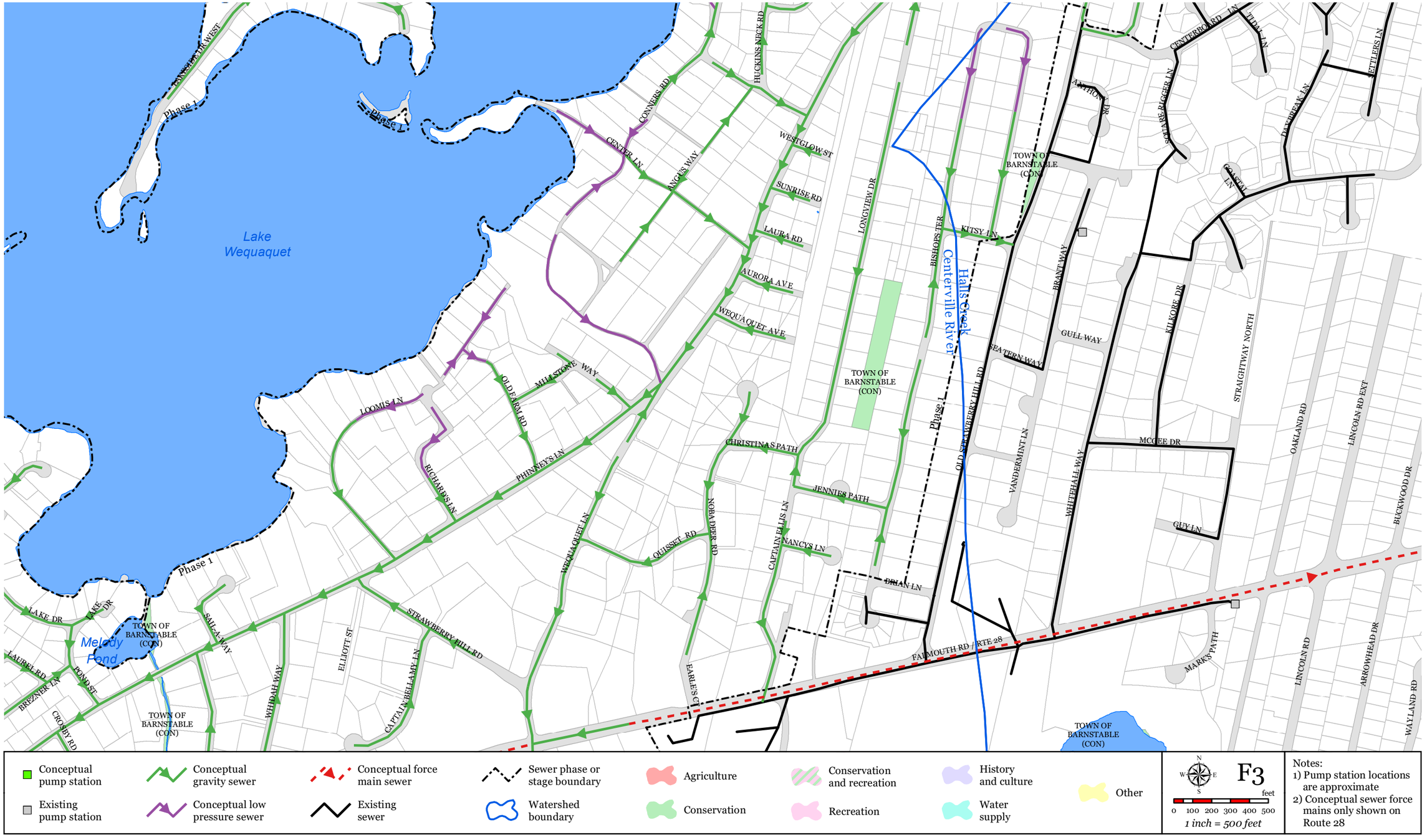
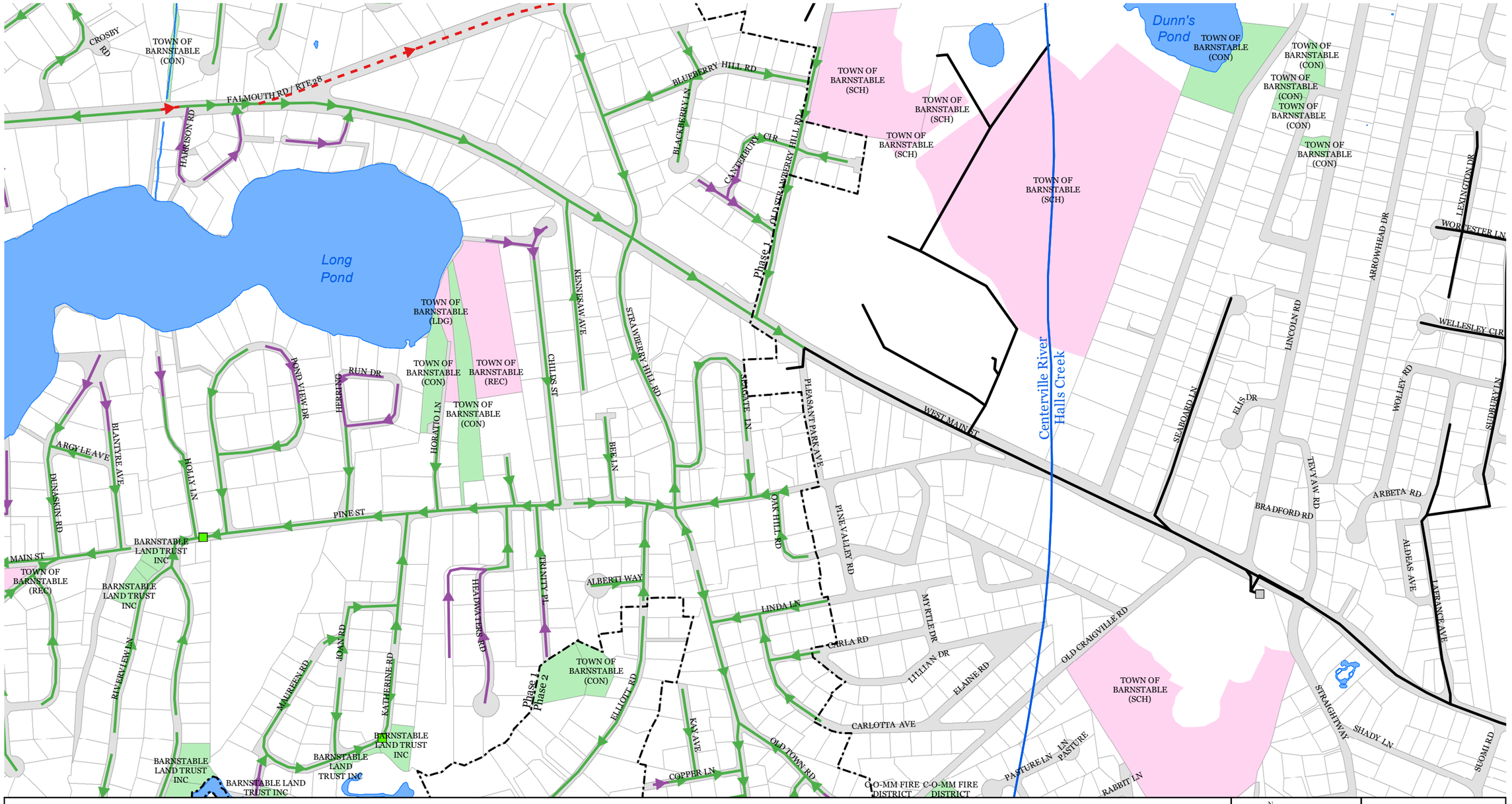
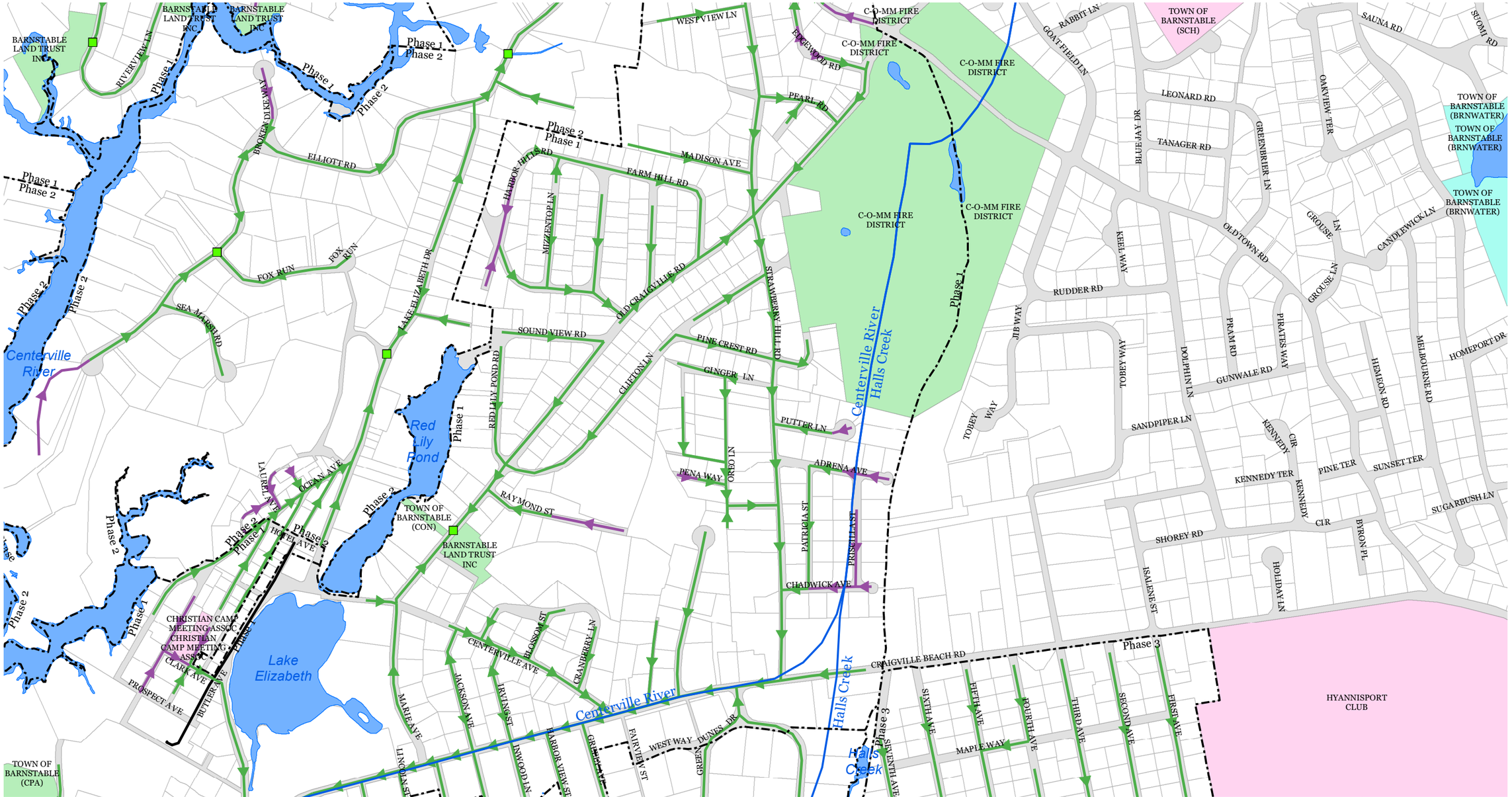

MID-CAPE HWY EXIT 6
MID-CAPE HWY (EAST) RTE 6
MID-CAPE HWY (WEST) RTE 6
TOWN OF BARNSTABLE (CON)
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (LB)
PRIVATE
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
NATIVE LAND CONSERVANCY INC
BARNSTABLE FIRE DISTRICT
TOWN OF BARNSTABLE (CON)
Hathaway's Pond North
Hathaway's Pond South
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CPA)
TOWN OF BARNSTABLE (REC)
TOWN OF BARNSTABLE (CPA)
TOWN OF BARNSTABLE (CON)
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
Phase 1
Phase 2
Phase 1
Phase 2
Phase 1
CRANBERRY LN
CHICKADEE LN
BUNNY RUN
HUCKINS NECK RD
SHALLOW POND DR
WATER VIEW CIR
ATTUCKS LN
COMMONWEALTH OF MASSACHUSETTS
TOWN OF BARNSTABLE (LB)
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
F1
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


PLEASANT PINES AVE
BELLEVUE RUN
WATER VIEW CIR
BONDSIDE CIR
SHALLOW POND DR
BLUE WATER DR
COMMONWEALTH OF MASSACHUSETTS
COMMONWEALTH OF MASSACHUSETTS
NYES POINT WAY
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
BARNSTABLE LAND TRUST INC
Hathaway's Pond South
TOWN OF BARNSTABLE (REC)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (REC)
ATTUCKS LN
Phase 1
Phase 2
Phase 2
ORENDA WILDLIFE LAND TRUST INC
Phase 2
Phase 2
Shallow Pond
TOWN OF BARNSTABLE (MUN)
TOWN OF BARNSTABLE (CON)
Bearse Pond
HUCKINS NECK RD
CAPTAIN COOK LN
OLD RTE 132
NEWSPAPER RD
Barnstable Harbor
Centerville River
Phase 1
NYES NECK RD
NYES NECK RD EAST
Phase 2
Phase 1
Phase 1
PHINNEYS LN
Barnstable Harbor
Lewis Bay
BARNSTABLE LAND TRUST INC
Phase 2
Phase 2
HOLLY POINT RD
LAKEVIEW AVE
LAKESIDE DR EAST
CRESTVIEW CIR
REGATTA DR
DAISY DR
OLD STAGE WAY
HILL RD
STATE BEACH
MYRICA LN
Phase 1
COTTONWOOD LN
GOOSE POINT RD
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
Lake Wequaquet
LAKESIDE DR WEST
TOWN OF BARNSTABLE (CON)
BEECHWOOD RD
LONGVIEW DR
GREGOIRE CIR
MARC AVE
MIDWAY DR
SUNNYWOOD DR
CENTERBOARD LN
DAYBREAK LN
EVENTIDE LN
SETTLERS LN
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
F2
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Lake Wequaquet
Phase 1
Phase 1
Phase 1
Phase 1
Phase 1
Centerville River
Halls Creek
Melody Pond
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)


Long Pond
Dunn's Pond
Centerville River
Halls Creek
Phase 1
Phase 2
CROSBY RD
FALMOUTH RD / RTE 28
HARRISON RD
BLUEBERRY HILL RD
BLACKBERRY LN
CANTERBURY CIR
STRAWBERRY HILL RD
KENNEDAW AVE
CHILTON ST
STRAWBERRY HILL RD
HORATIO LN
BEE LN
SPRAGUE LN
PLEASANT PARK AVE
WEST MAIN ST
OAK HILL RD
PINE VALLEY RD
LINDA LN
CARLA RD
MYRTLE DR
LILLIAN DR
ELAINE RD
CARLOTTA AVE
OLD TOWN RD
COPPER LN
KAY AVE
ELLIOTT RD
OLD CRAGVILLE RD
PASTURE LN
RABBIT LN
STRAIGHTWAY
SHADY LN
SUOMI RD
LAFRANCE AVE
ALDEAS AVE
ARBETA RD
BRADFORD RD
TEVYAW RD
ARROWHEAD DR
LINCOLN RD
ELLIS DR
SEABOARD LN
WOLLEY RD
SUDBURY LN
WELLESLEY CIR
WORCESTER LN
LEXINGTON DR
POND VIEW DR
RUN DR
HERRING
DUNASKIN RD
ARGYLE AVE
BLAINTYRE AVE
HOLLY LN
PINE ST
MAIN ST
RIVERVIEW LN
MAUREEN RD
JOAN RD
KATHERINE RD
HEADWATERS RD
TRINITY PL
ALBERTI WAY
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (SCH)
TOWN OF BARNSTABLE (LDG)
TOWN OF BARNSTABLE (REC)
TOWN OF BARNSTABLE (CON)
C-O-MM FIRE DISTRICT
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
F4
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



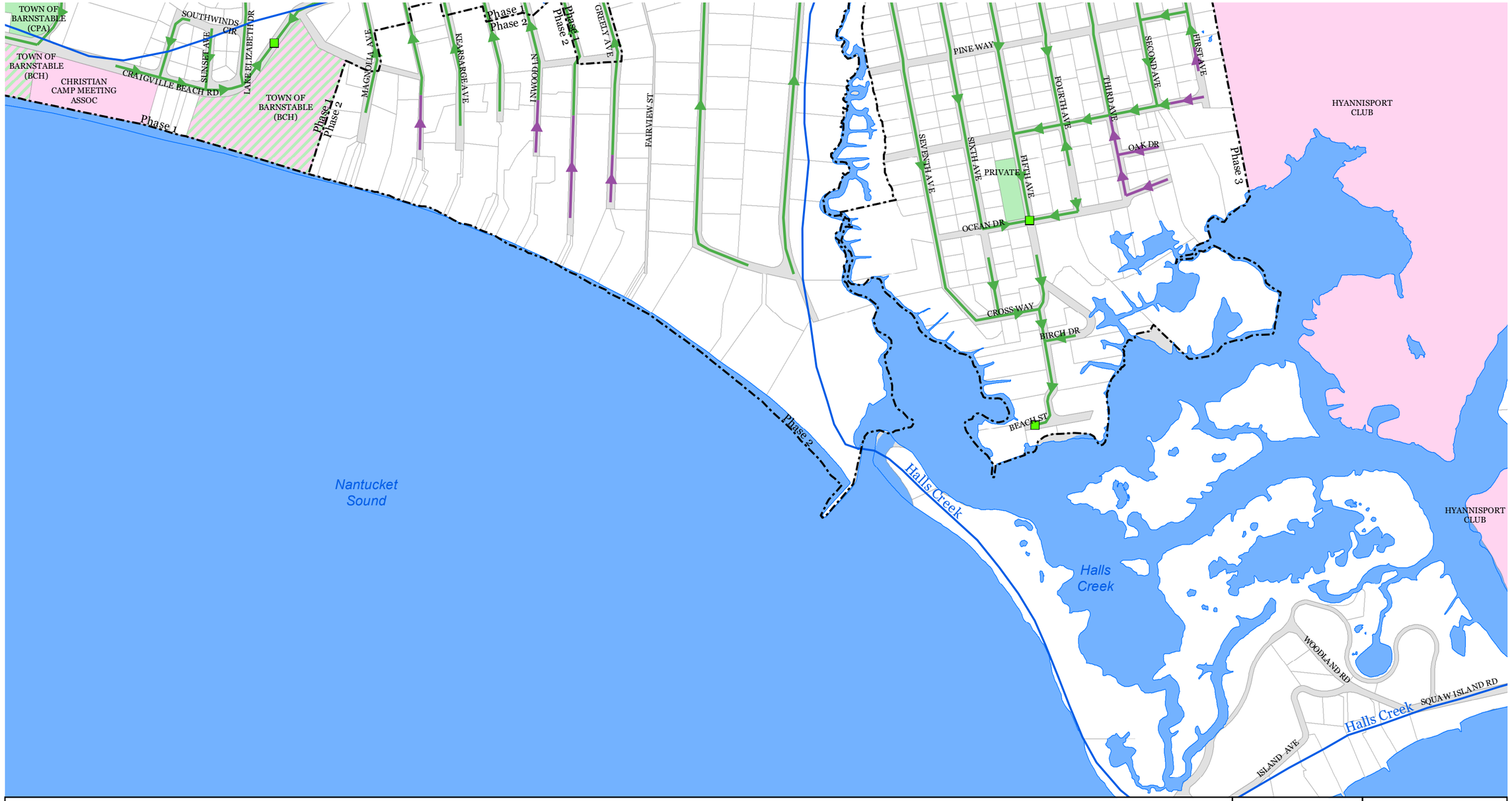
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

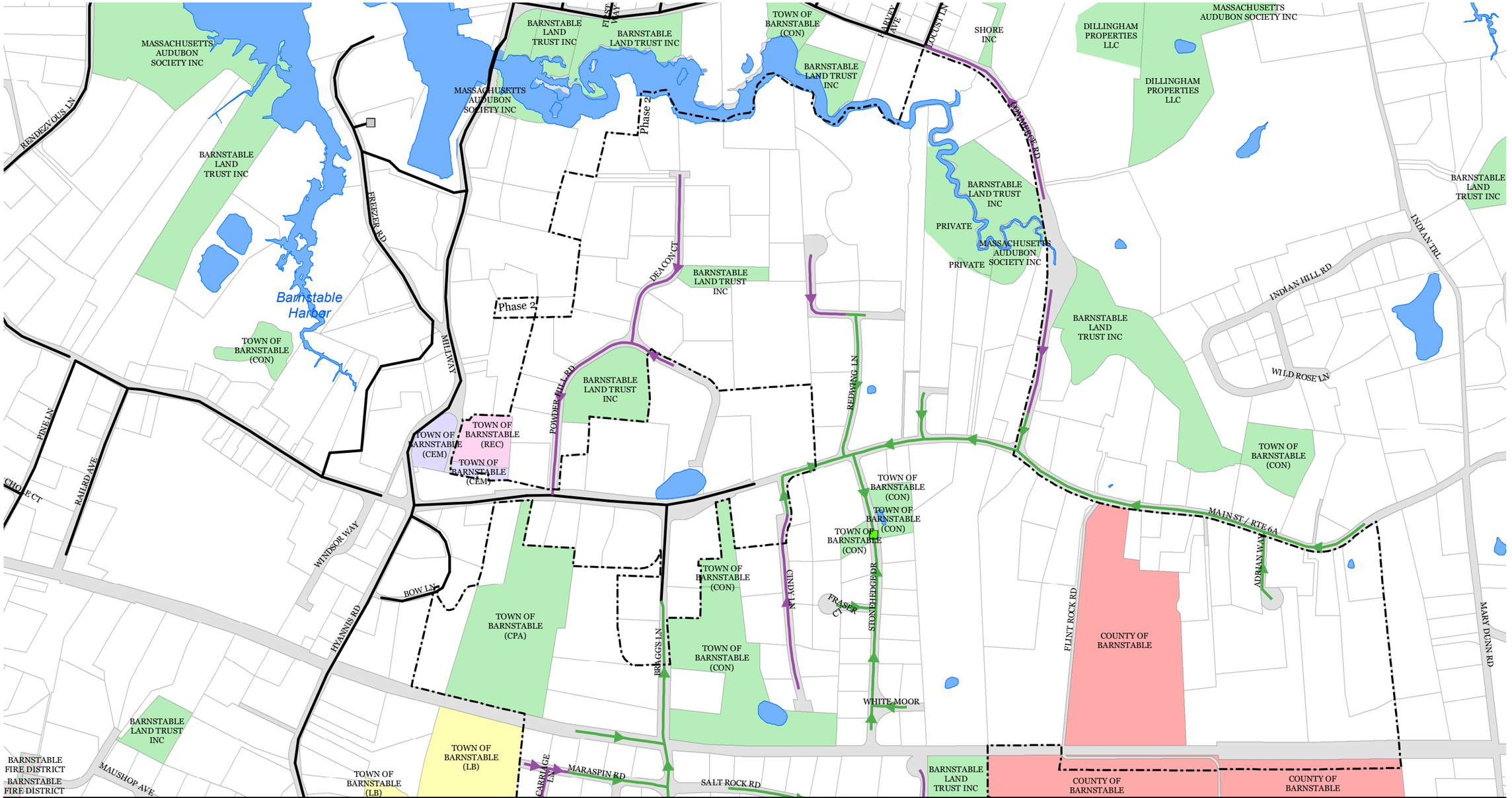
N W E S

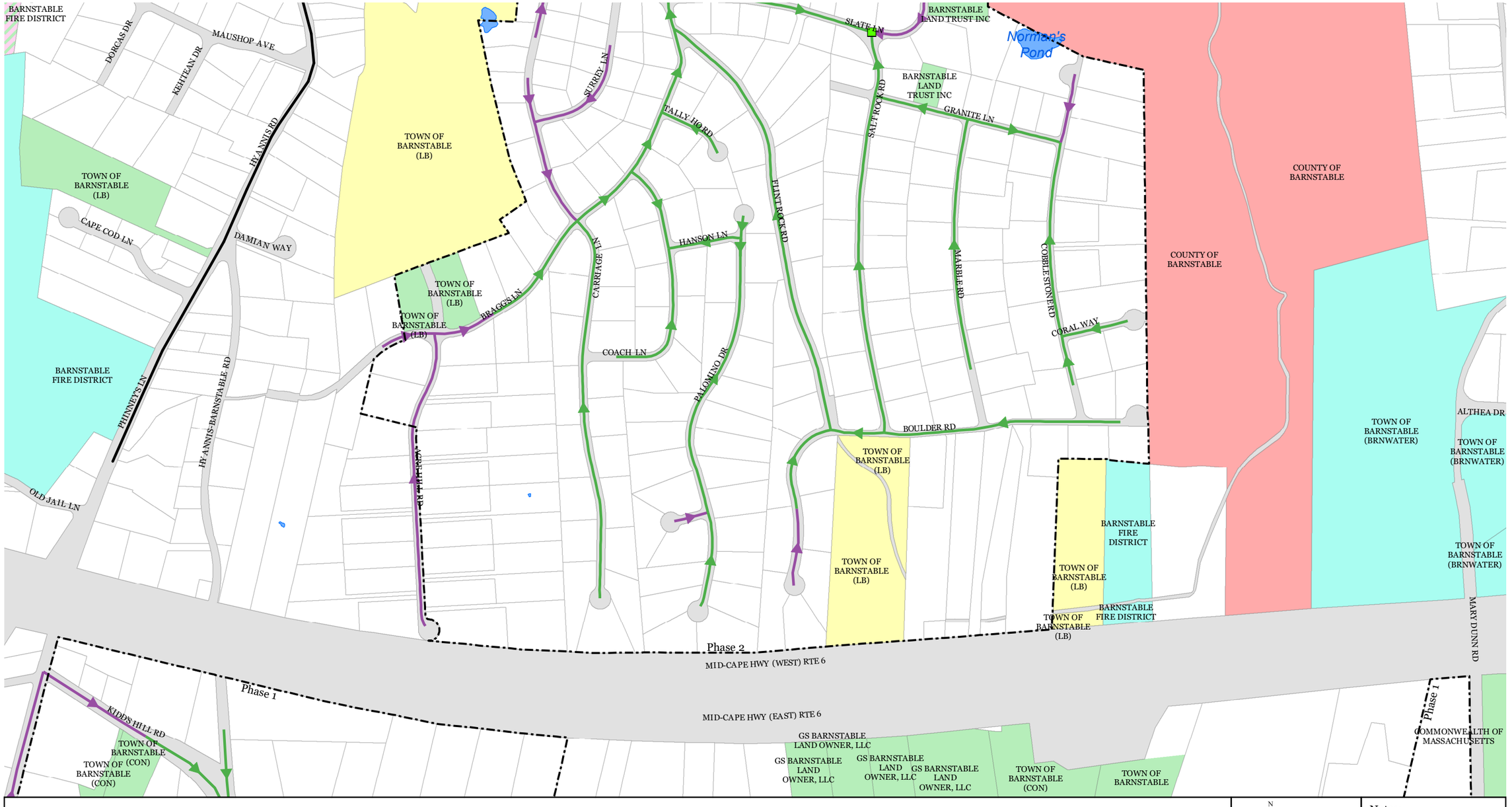
F5

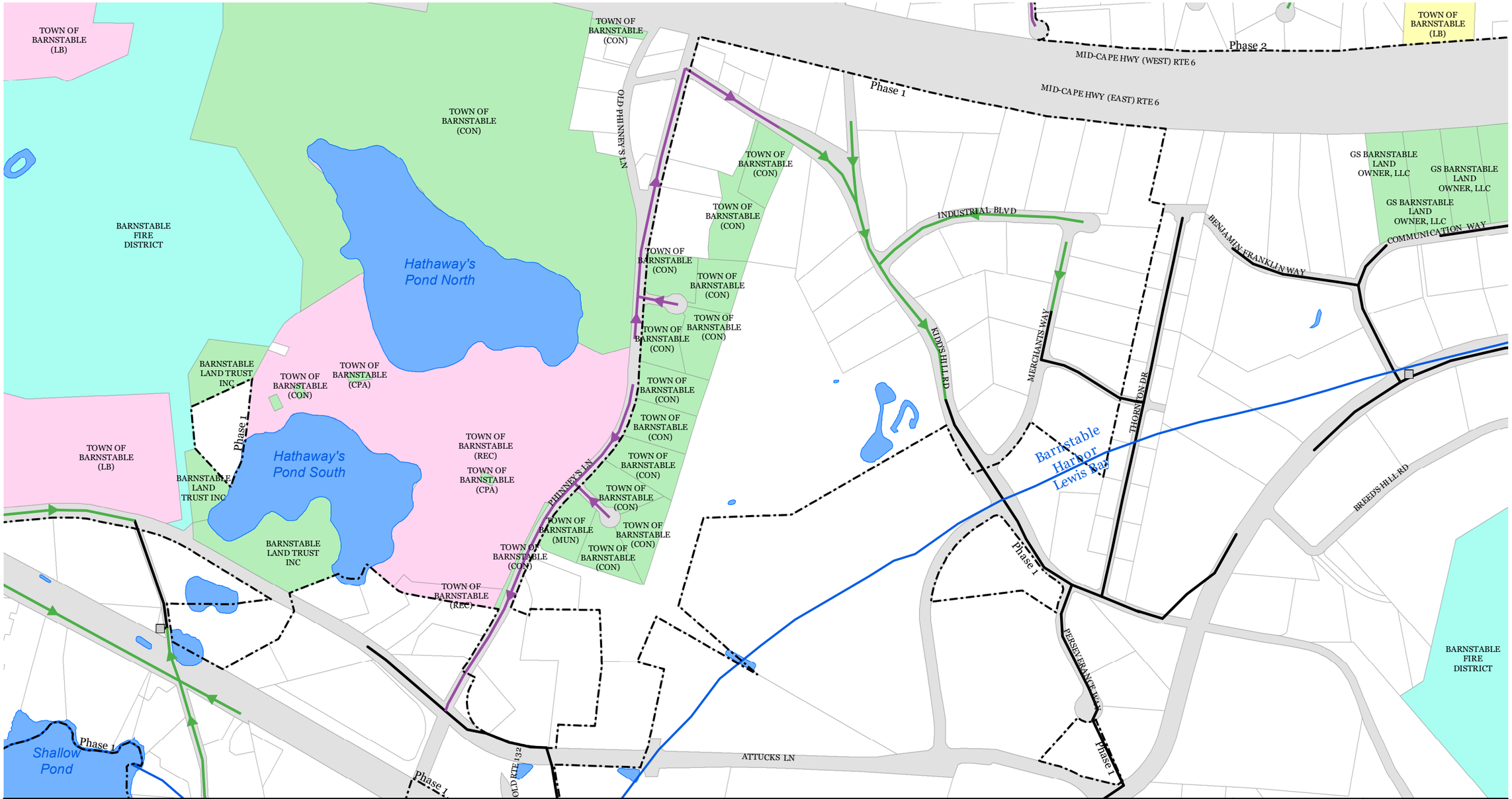
feet
0 100 200 300 400 500
1 inch = 500 feet

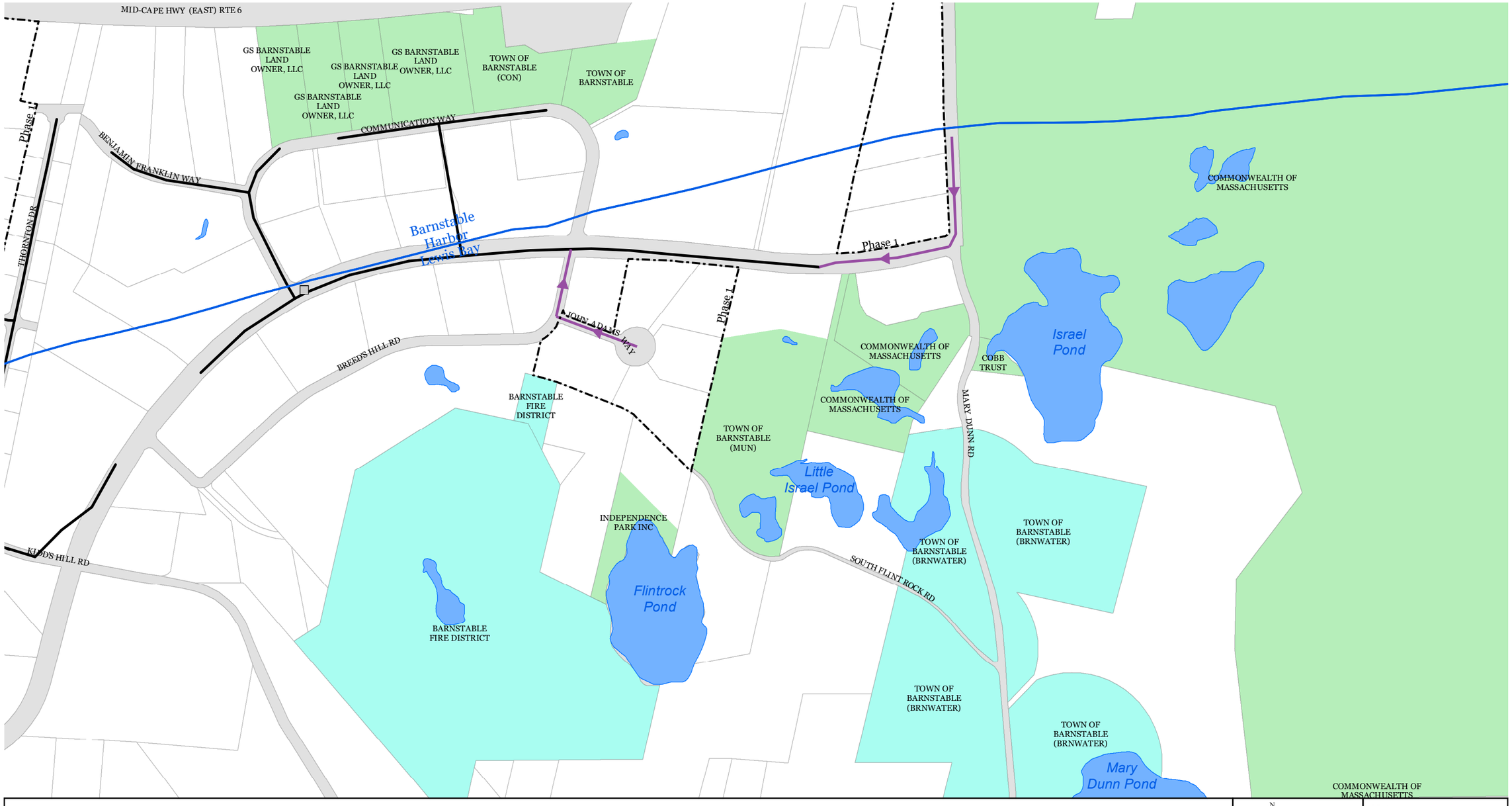
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

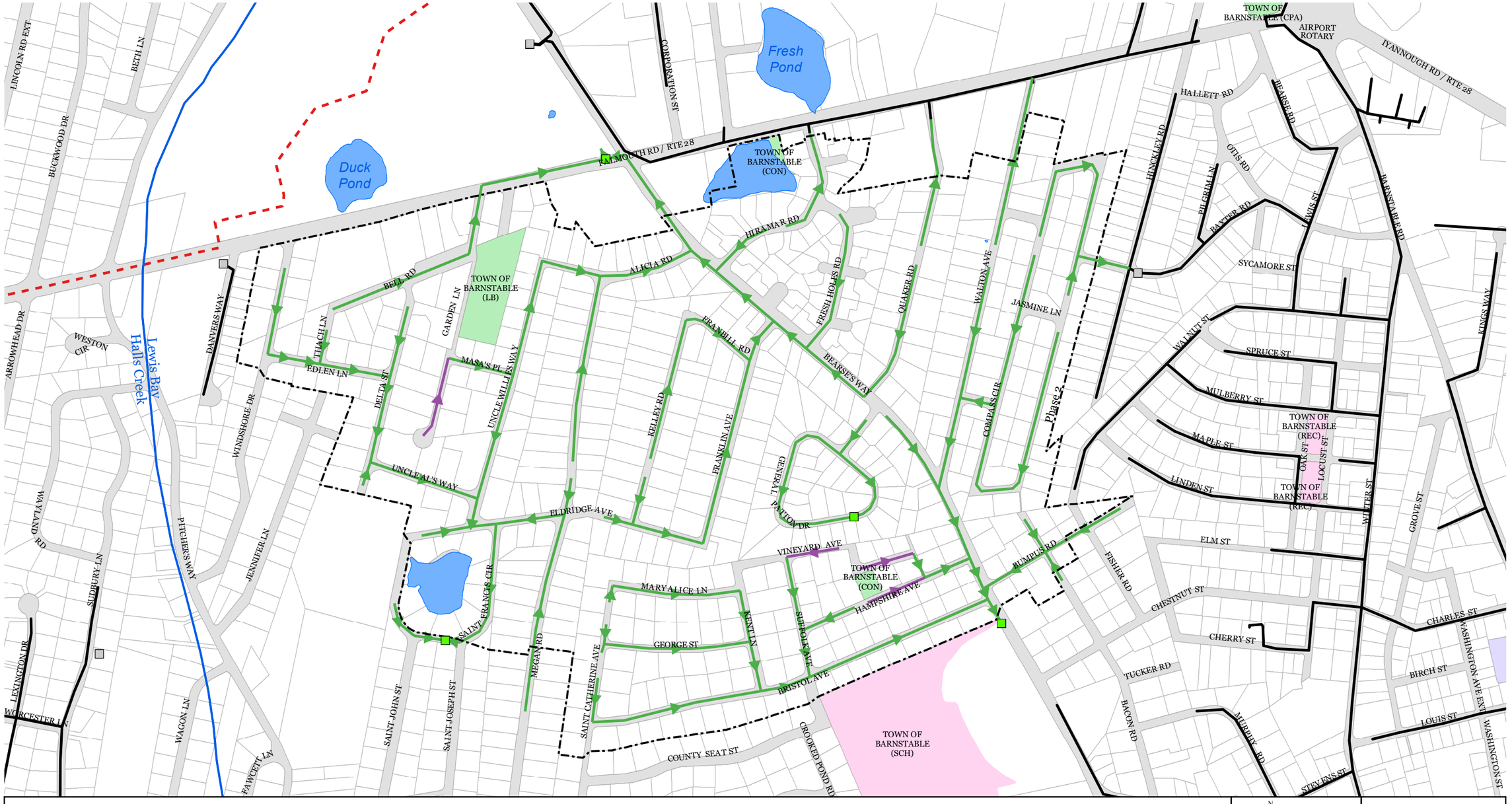

TOWN OF BARNSTABLE (CPA)
TOWN OF BARNSTABLE (BCH)
CHRISTIAN CAMP MEETING ASSOC
TOWN OF BARNSTABLE (BCH)
SOUTHWINDS CIR
SUNSET AVE
LAKE ELIZABETH DR
CRAIGVILLE BEACH RD
MAGNOLIA AVE
KEARSARGE AVE
NTOOMNI
GREELY AVE
FAIRVIEW ST
Phase 1
Phase 2
Phase 3
PINE WAY
SEVENTH AVE
SIXTH AVE
PRIVATE
FIFTH AVE
FOURTH AVE
THIRD AVE
SECOND AVE
FIRST AVE
OAK DR
OCEAN DR
CROSS WAY
BIRCH DR
BEACH ST
HYANNISPORT CLUB
Nantucket Sound
Halls Creek
WOODLAND RD
SQUAW ISLAND RD
ISLAND AVE
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
F6
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


MASSACHUSETTS AUDUBON SOCIETY INC
RENDEZVOUS LN
BARNSTABLE LAND TRUST INC
FERRIER RD
Barnstable Harbor
TOWN OF BARNSTABLE (CON)
MILLWAY
PINE LN
CHOATE CT
RAILROAD AVE
WINDSOR WAY
BOW LN
IYANNOUGH RD
BARNSTABLE LAND TRUST INC
BARNSTABLE FIRE DISTRICT
MAUSHOP AVE
TOWN OF BARNSTABLE (CEM)
TOWN OF BARNSTABLE (REC)
TOWN OF BARNSTABLE (CEM)
POWDER HILL RD
Phase 2
Phase 2
DEACON CT
BARNSTABLE LAND TRUST INC
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CPA)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
CARRIAGE LN
MARASPIN RD
BRAGGS LN
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
CINDY LN
FRASER CT
STONEHEDGE DR
WHITE MOOR
SALT ROCK RD
BARNSTABLE LAND TRUST INC
FELLSMERE RD
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CON)
HARVEY AVE
LOCUST LN
SHORE INC
BARNSTABLE LAND TRUST INC
COMMERCE RD
BARNSTABLE LAND TRUST INC
PRIVATE
PRIVATE
MASSACHUSETTS AUDUBON SOCIETY INC
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
REDWING LN
TOWN OF BARNSTABLE (CON)
COUNTY OF BARNSTABLE
COUNTY OF BARNSTABLE
COUNTY OF BARNSTABLE
FLINT ROCK RD
MAIN ST / RTE 6A
ADRIAN WAY
MARY DUNN RD
MASSACHUSETTS AUDUBON SOCIETY INC
DILLINGHAM PROPERTIES LLC
DILLINGHAM PROPERTIES LLC
BARNSTABLE LAND TRUST INC
INDIAN TRL
INDIAN HILL RD
WILD ROSE LN
TOWN OF BARNSTABLE (CON)
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
G1
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


BARNSTABLE FIRE DISTRICT
DORCAS DR
KEHTEAN DR
MAUSHOP AVE
HYANNIS RD
TOWN OF BARNSTABLE (LB)
CAPE COD LN
DAMIAN WAY
BARNSTABLE FIRE DISTRICT
PHINNEY'S LN
HYANNIS-BARNSTABLE RD
OLD JAIL LN
TOWN OF BARNSTABLE (LB)
SURREY LN
TALLY HO RD
CARRIAGE LN
HANSON LN
FLINTROCK RD
BRAGG'S LN
TOWN OF BARNSTABLE (LB)
COACH LN
PALOMINO DR
TOWN OF BARNSTABLE (LB)
SLATE LN
BARNSTABLE LAND TRUST INC
Norman's Pond
BARNSTABLE LAND TRUST INC
SALT ROCK RD
GRANITE LN
MARBLE RD
COBBLESTONE RD
CORAL WAY
COUNTY OF BARNSTABLE
COUNTY OF BARNSTABLE
BOULDER RD
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (LB)
BARNSTABLE FIRE DISTRICT
TOWN OF BARNSTABLE (LB)
BARNSTABLE FIRE DISTRICT
TOWN OF BARNSTABLE (BRNWATER)
ALTHEA DR
TOWN OF BARNSTABLE (BRNWATER)
MARY DUNN RD
Phase 2
MID-CAPE HWY (WEST) RTE 6
Phase 1
MID-CAPE HWY (EAST) RTE 6
Phase 1
KIDDS HILL RD
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
GS BARNSTABLE LAND OWNER, LLC
GS BARNSTABLE LAND OWNER, LLC
GS BARNSTABLE LAND OWNER, LLC
GS BARNSTABLE LAND OWNER, LLC
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE
COMMONWEALTH OF MASSACHUSETTS
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
G2
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (LB)
MID-CAPE HWY (WEST) RTE 6
MID-CAPE HWY (EAST) RTE 6
Phase 2
Phase 1
OLD KENNEDY'S LN
TOWN OF BARNSTABLE (CON)
BARNSTABLE FIRE DISTRICT
Hathaway's Pond North
INDUSTRIAL BLVD
GS BARNSTABLE LAND OWNER, LLC
GS BARNSTABLE LAND OWNER, LLC
GS BARNSTABLE LAND OWNER, LLC
COMMUNICATION WAY
BENJAMIN FRANKLIN WAY
KIDDS HILL RD
MERCHANTS WAY
THORNTON DR
BARNSTABLE LAND TRUST INC
TOWN OF BARNSTABLE (CPA)
TOWN OF BARNSTABLE (REC)
TOWN OF BARNSTABLE (MUN)
Hathaway's Pond South
PHINNEY'S LN
Barnstable Harbor
Lewis Bay
BREEDS HILL RD
Shallow Pond
ATTUCKS LN
OLD RTE 132
PERSEVERANCE WAY
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
G3
feet
0 100 200 300 400 500
1 inch = 546.5 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


MID-CAPE HWY (EAST) RTE 6
GS BARNSTABLE LAND OWNER, LLC
GS BARNSTABLE LAND OWNER, LLC
GS BARNSTABLE LAND OWNER, LLC
GS BARNSTABLE LAND OWNER, LLC
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE
Phase 1
COMMUNICATION WAY
BENJAMIN FRANKLIN WAY
THORNTON DR
Barnstable Harbor
Lewis Bay
Phase 1
JOHN A DAMS WAY
Phase 1
BREED'S HILL RD
COMMONWEALTH OF MASSACHUSETTS
Israel Pond
COBB TRUST
COMMONWEALTH OF MASSACHUSETTS
COMMONWEALTH OF MASSACHUSETTS
MARY DUNN RD
BARNSTABLE FIRE DISTRICT
TOWN OF BARNSTABLE (MUN)
Little Israel Pond
INDEPENDENCE PARK INC
TOWN OF BARNSTABLE (BRNWATER)
TOWN OF BARNSTABLE (BRNWATER)
KUDS HILL RD
SOUTH FLINT ROCK RD
Flintrock Pond
BARNSTABLE FIRE DISTRICT
TOWN OF BARNSTABLE (BRNWATER)
TOWN OF BARNSTABLE (BRNWATER)
Mary Dunn Pond
COMMONWEALTH OF MASSACHUSETTS
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
G4
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Fresh Pond
Duck Pond
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (LB)
TOWN OF BARNSTABLE (CPA)
TOWN OF BARNSTABLE (REC)
TOWN OF BARNSTABLE (REC)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (SCH)
Lewis Bay
Halls Creek
Phase 2
MAIN ST / RTE 28
CORPORATION ST
AIRPORT ROTARY
IYANNOUGH RD / RTE 28
HALLETT RD
BEARSE RD
HINCKLEY RD
OTIS RD
PILGRIM LN
BAXTER RD
LEWIS ST
BARNSTABLE RD
SYCAMORE ST
WALNUT ST
SPRUCE ST
MULBERRY ST
MAPLE ST
OAK ST
LOCUST ST
LINDEN ST
ELM ST
CHESTNUT ST
CHERRY ST
BIRCH ST
CHARLES ST
KINGS WAY
WASHINGTON AVE EXT
WASHINGTON ST
WHITER ST
GROVE ST
LOUIS ST
STEVENS ST
MERRIHEW RD
TUCKER RD
BACON RD
FISHER RD
RUMFUS RD
JASMINE LN
WALTON AVE
QUAKER RD
FRESH HOPES RD
HIRAM A R RD
ALICIA RD
BELL RD
GARDEN LN
THATCH LN
EDLEN LN
DELTA ST
MASA'S PL
UNCLE WILLIE'S WAY
UNCLE AL'S WAY
KELLEY RD
FRANKLIN AVE
FRANKLIN HILL RD
BEARSE'S WAY
GENERAL PATTON DR
COMPASS CIR
ELDRIDGE AVE
VINEYARD AVE
HAMPSHIRE AVE
SUFFOLK AVE
KENT LN
MARY ALICE LN
GEORGE ST
BRISTOL AVE
SAINT CATHERINE AVE
MEGAN RD
SAINT FRANCIS CIR
SAINT JOHN ST
SAINT JOSEPH ST
COUNTY SEAT ST
CROOKED POND RD
DANVERS WAY
ARROWHEAD DR
WESTON CIR
WINDSHORE DR
PITCHERS WAY
JENNIFER LN
WAYLAND RD
SUDBURY LN
LEXINGTON DR
WORCESTER LN
WAGON LN
FAWCETT LN
LINCOLN RD EXT
BUCKWOOD DR
BETH LN
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
H1
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
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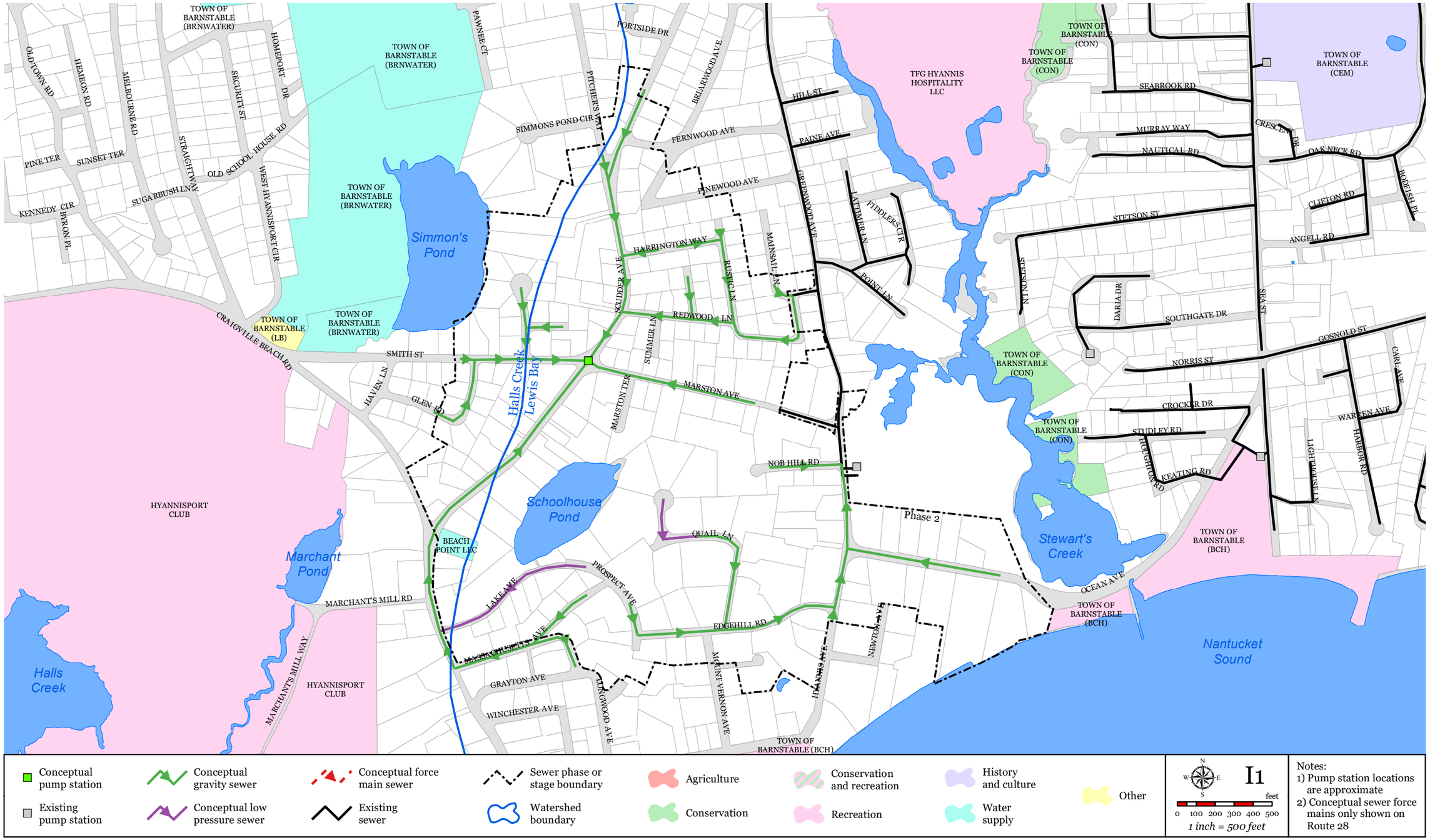
2) Conceptual sewer force mains only shown on Route 28



Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

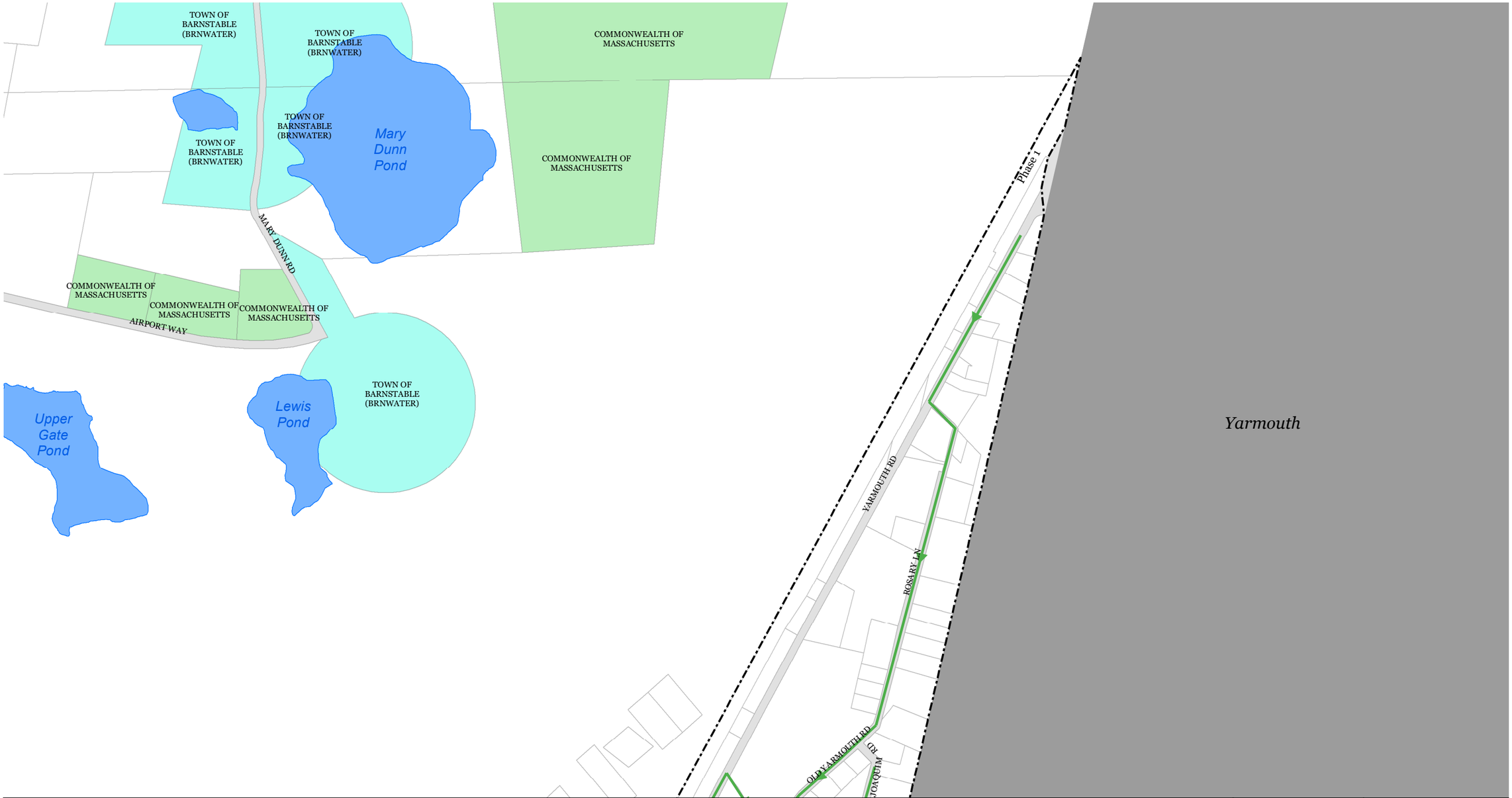
N W E S

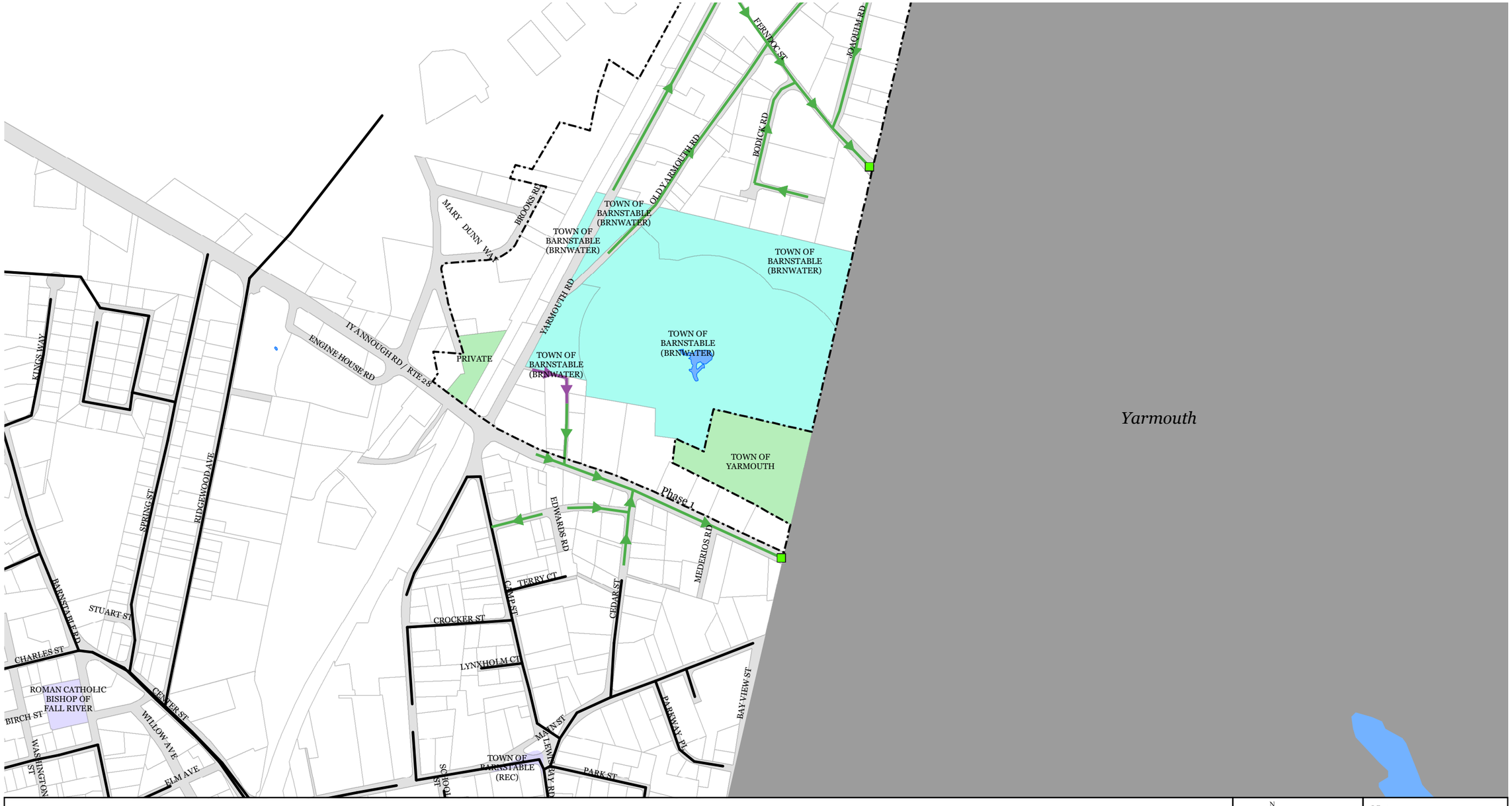
I1

0 100 200 300 400 500 feet

1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


TOWN OF BARNSTABLE (BRNWATER)
TOWN OF BARNSTABLE (BRNWATER)
TOWN OF BARNSTABLE (BRNWATER)
TOWN OF BARNSTABLE (BRNWATER)
Mary Dunn Pond
COMMONWEALTH OF MASSACHUSETTS
COMMONWEALTH OF MASSACHUSETTS
MARY DUNN RD
COMMONWEALTH OF MASSACHUSETTS
COMMONWEALTH OF MASSACHUSETTS
COMMONWEALTH OF MASSACHUSETTS
AIRPORT WAY
TOWN OF BARNSTABLE (BRNWATER)
Lewis Pond
Upper Gate Pond
Phase I
Yarmouth
YARMOUTH RD
ROSARY LN
OLD YARMOUTH RD
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
J1
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



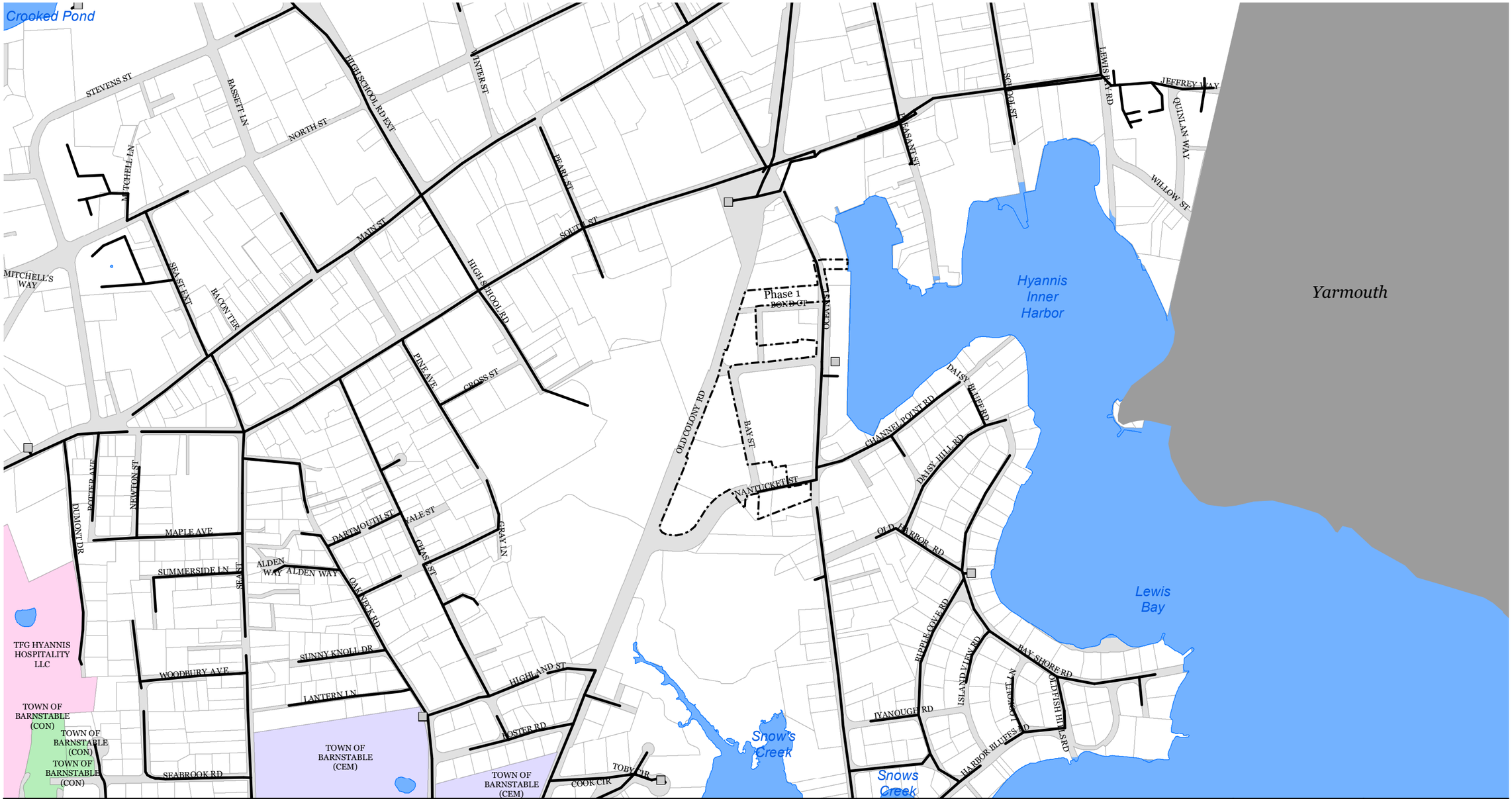
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other

J2

0 100 200 300 400 500 feet

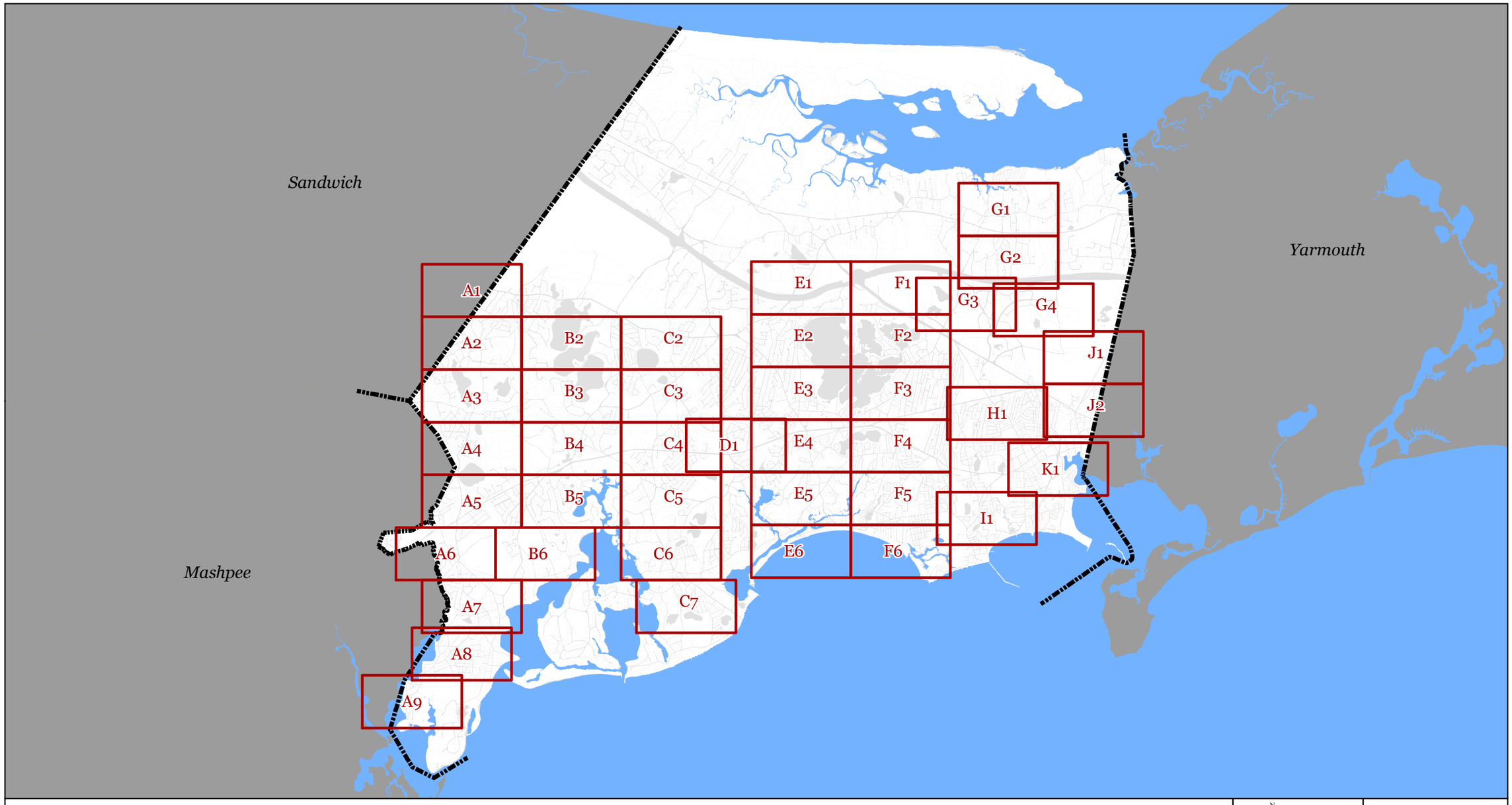
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Crooked Pond
STEVENS ST
BASSETT LN
NORTH ST
HIGH SCHOOL RD EXT
WINTER ST
MITCHELL LN
PEARL ST
MAIN ST
SOUTH ST
MITCHELL'S WAY
SEA ST EXT
BACON TER
HIGH SCHOOL RD
PINE AVE
CROSS ST
Phase 1
BOND CT
QUEEN ST
OLD COLONY RD
BAY ST
NANTUCKET ST
PHEASANT ST
SCHOOL ST
LEWIS BAY RD
JEFFREY WAY
QUINLAN WAY
WILLOW ST
Hyannis Inner Harbor
Yarmouth
CHANNEL POINT RD
DAISY HILL RD
OLD HARBOR RD
RIPPLE COVE RD
ISLAND VIEW RD
BAY SHORE RD
ODDFISH HILL RD
IVANOUGH RD
HARBOR BLUFFS RD
Lewis Bay
Snow's Creek
Snows Creek
DUMONT DR
DEERFIELD AVE
NEWTON ST
MAPLE AVE
SUMMERSIDE LN
SEA ST
ALDEN WAY
ALDEN WAY
OAK NECK RD
DARTMOUTH ST
GALE ST
CHASE ST
GRAY LN
SUNNY KNOLL DR
WOODBURY AVE
LANTERN LN
HIGHLAND ST
FOSTER RD
TOBY CIR
COOK CIR
SEABROOK RD
TFG HYANNIS HOSPITALITY LLC
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CON)
TOWN OF BARNSTABLE (CEM)
TOWN OF BARNSTABLE (CEM)
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or stage boundary
Watershed boundary
Agriculture
Conservation
Conservation and recreation
Recreation
History and culture
Water supply
Other
N
W
E
S
K1
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

Appendix WW

Conceptual Sewer Expansion - Regulatory Overlays



A1 Sheet locus

Town boundary

N
W E
S
feet
0 1,000 5,000
1 inch = 7,500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



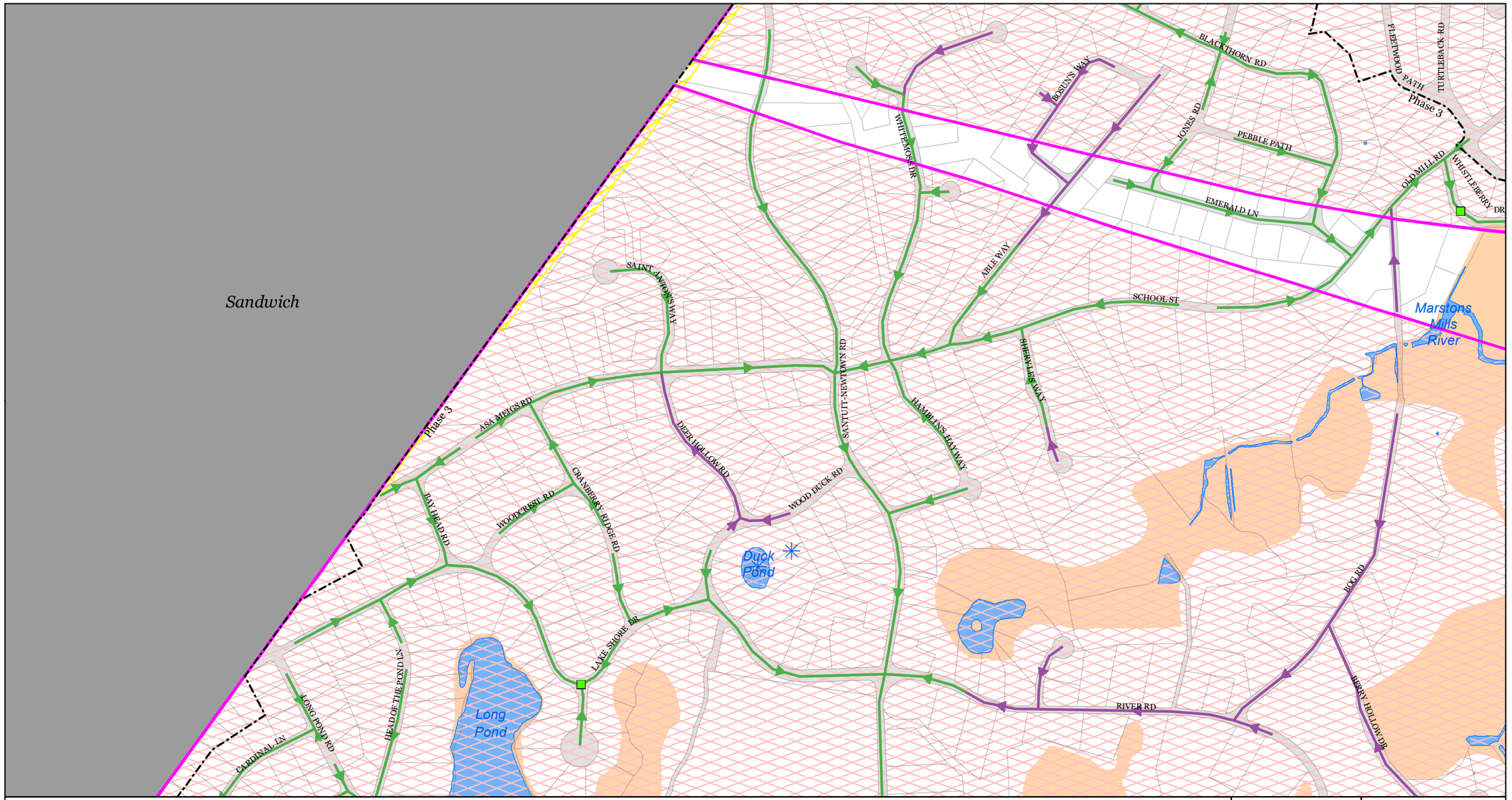
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)

N W E S

A1

feet
0 100 200 300 400 500
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



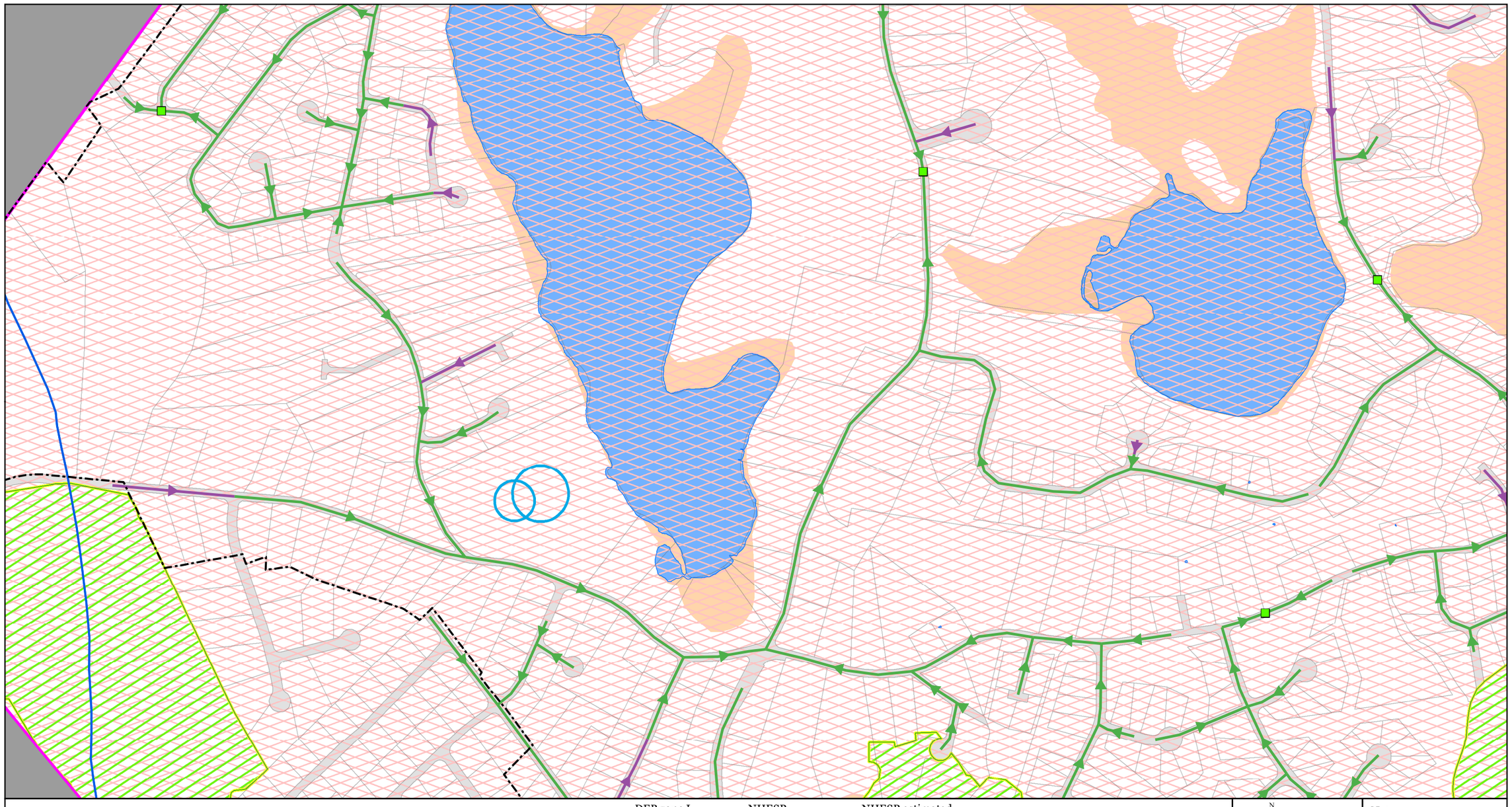
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)

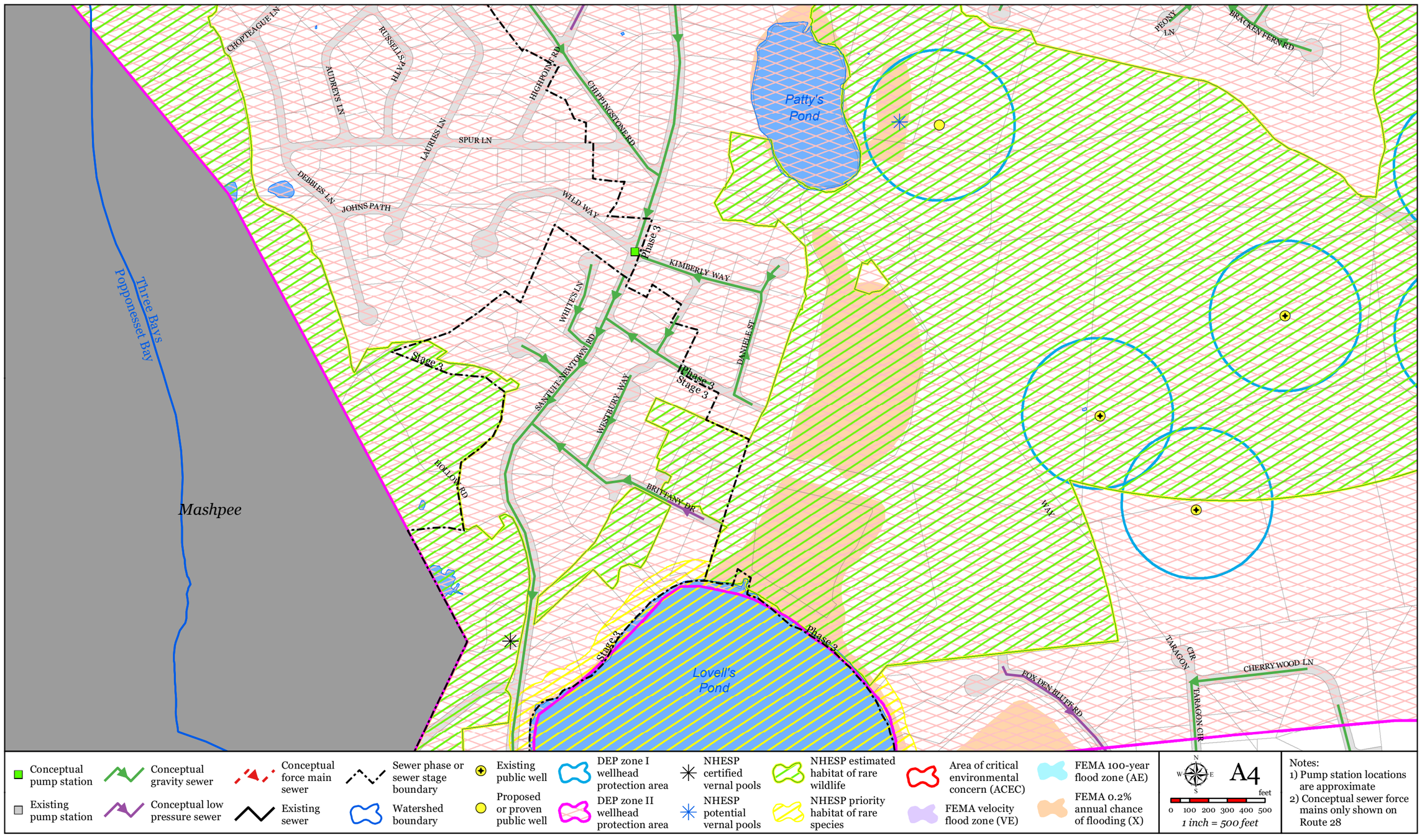
A2

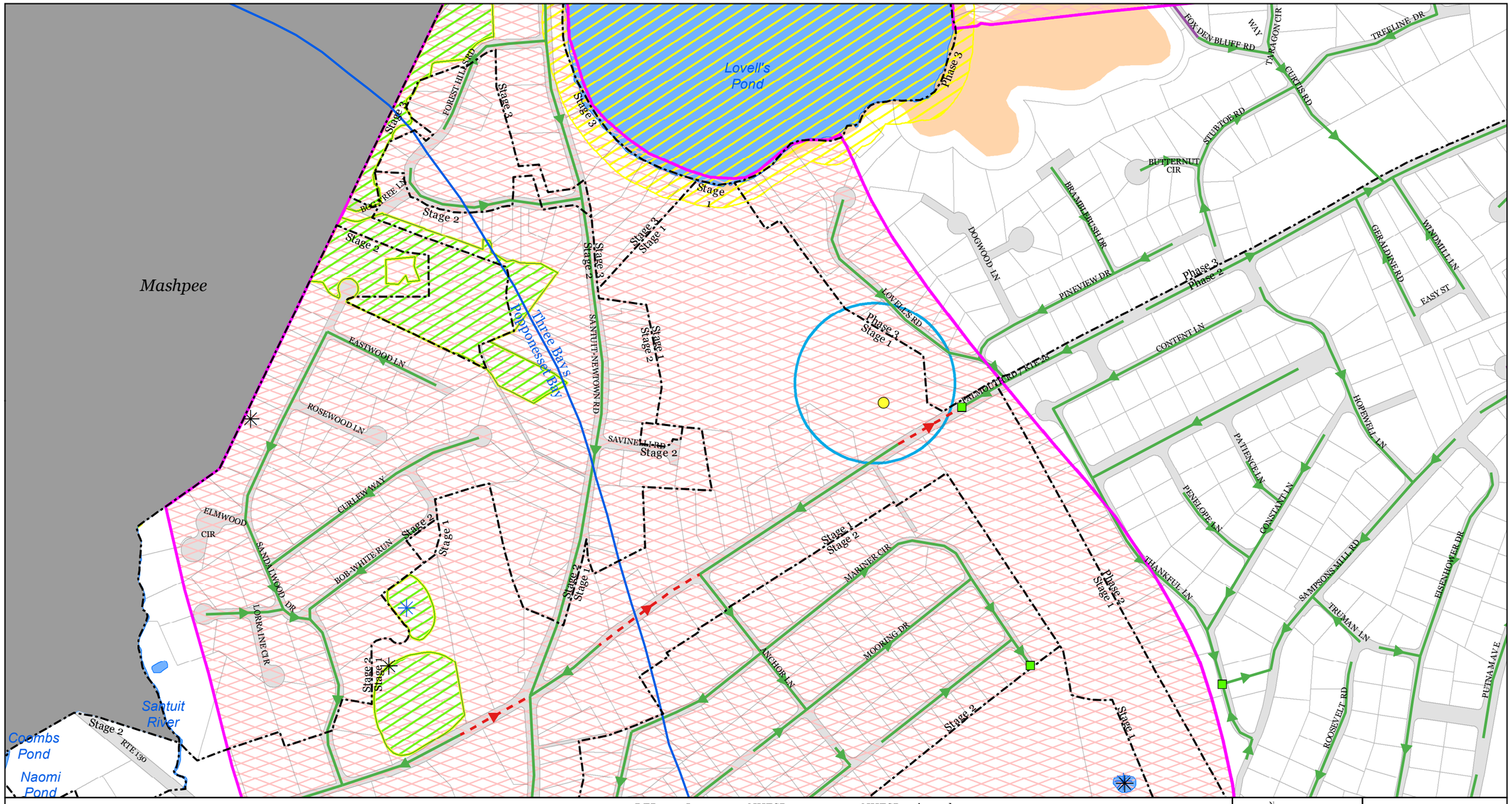
0 100 200 300 400 500 feet

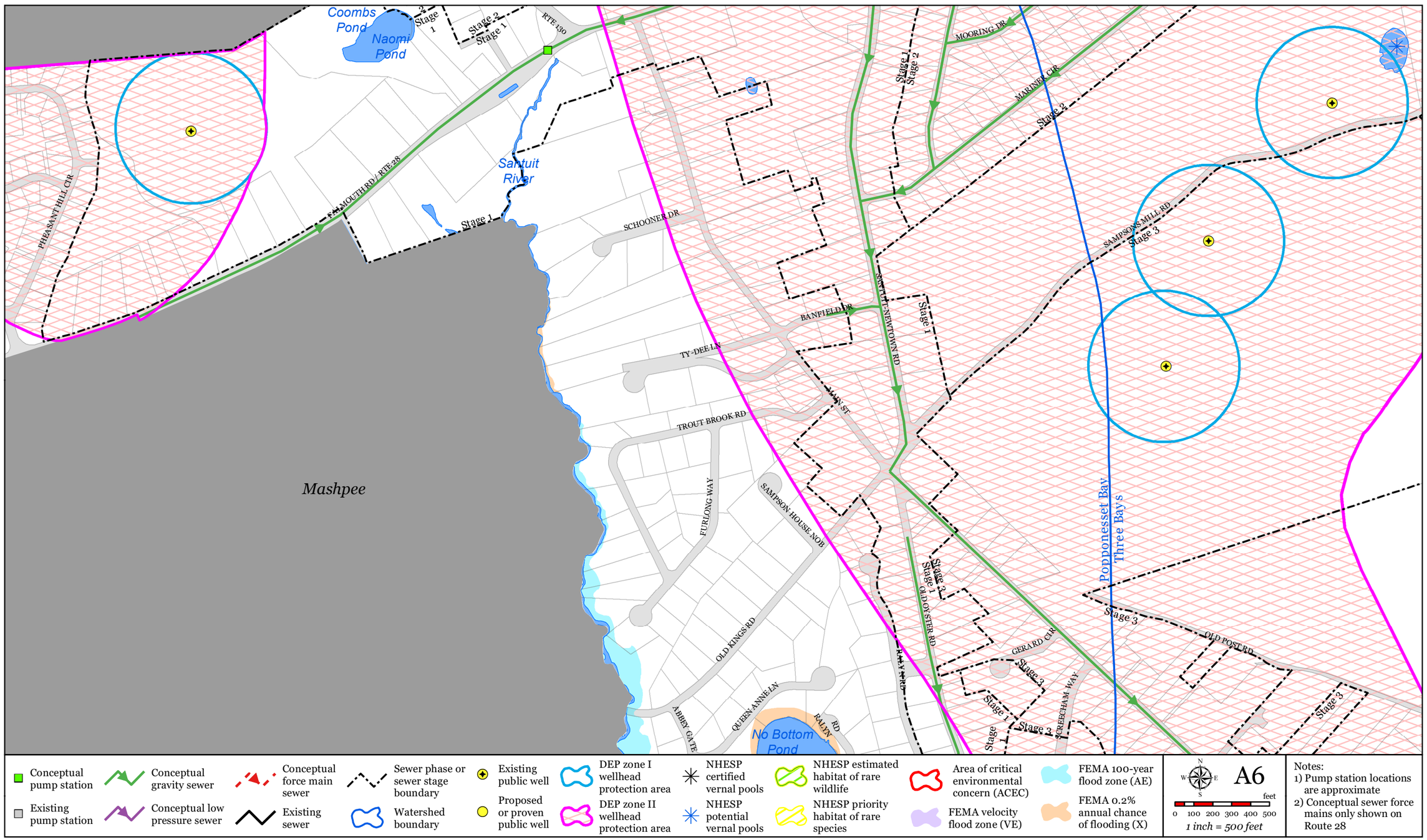
1 inch = 500 feet

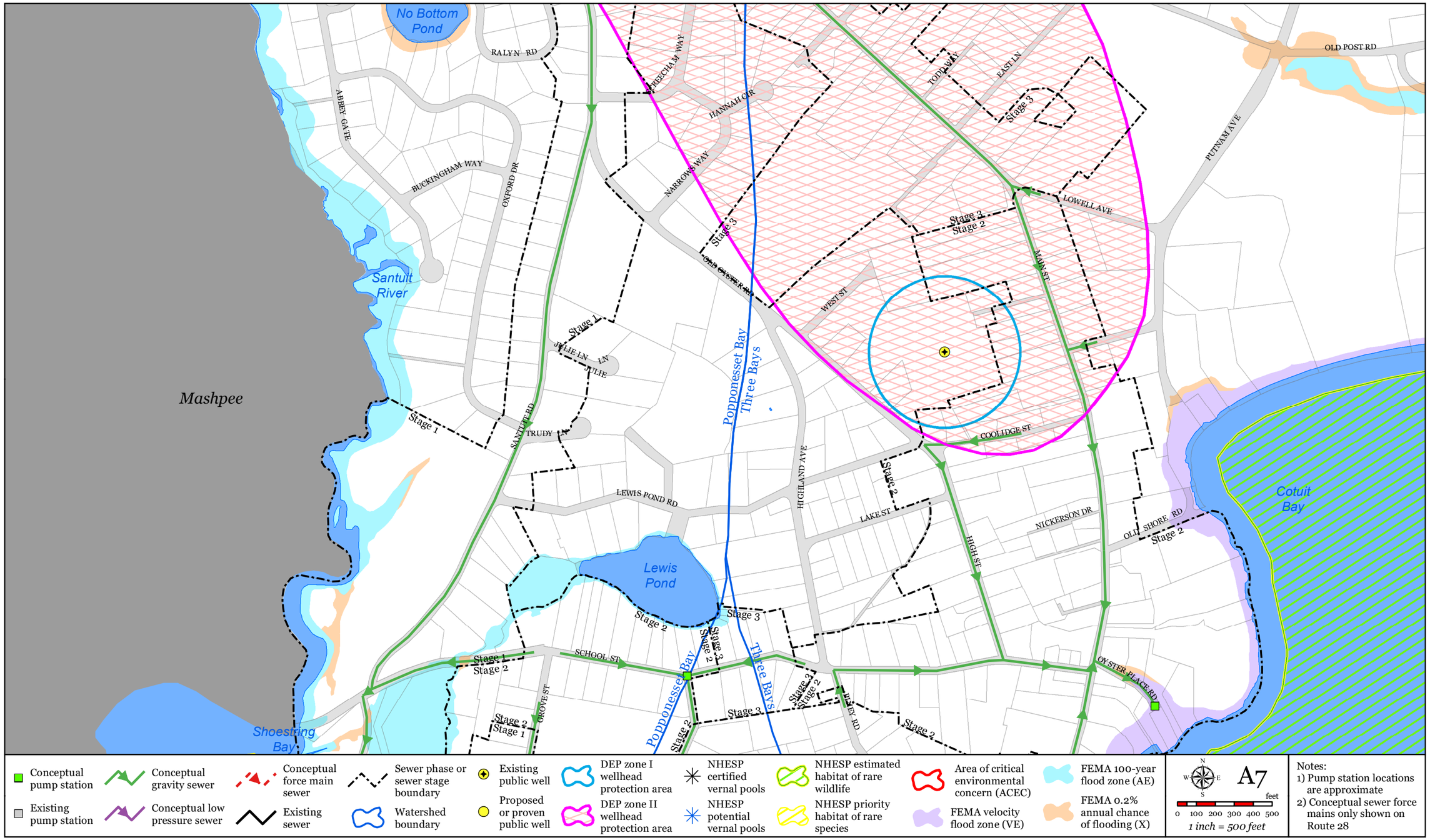
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

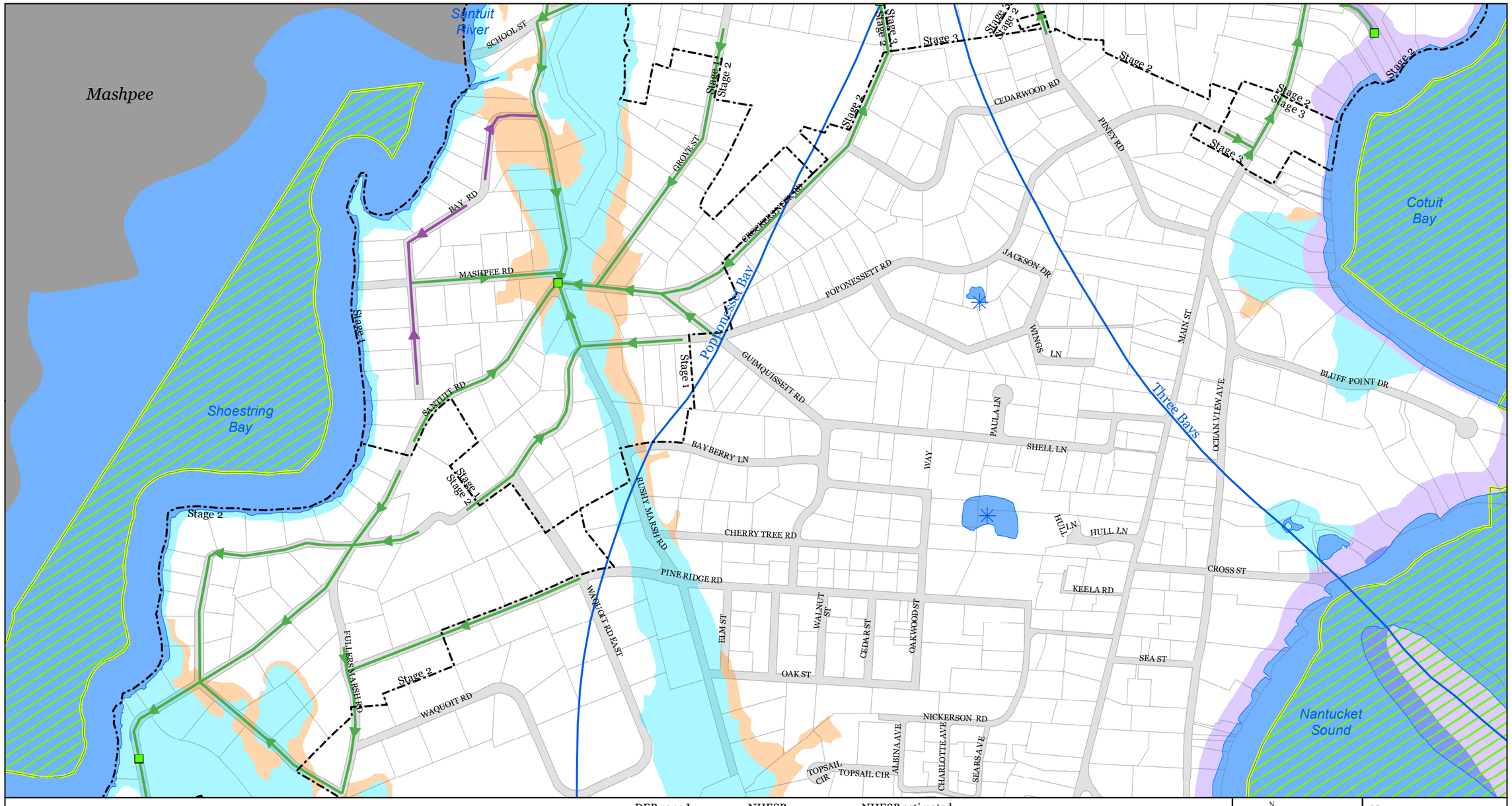

Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
A3
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Three Bays
Popponesset Bay
Mashpee
Patty's Pond
Lovell's Pond
CHOPTEAGUE LN
RUSSELLS PATH
AUDREYS LN
LAURIES LN
SPUR LN
HIGHPOINT RD
CHIPPINGSTONE RD
DEBBIES LN
JOHNS PATH
WILD WAY
Phase 3
KIMBERLY WAY
WHITTIES LN
SANTUIT-NEWTOWN RD
WESTBURY WAY
DANIELLE ST
Stage 3
Phase 3
Stage 3
HOLLOW RD
BRITTANY DR
Stage 3
Phase 3
PEONY LN
BRACKEN FERN RD
WAY
FOX DEN BLUFF RD
TARAGON CIR
CHERRY WOOD LN
TARAGON CIR
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
A4
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

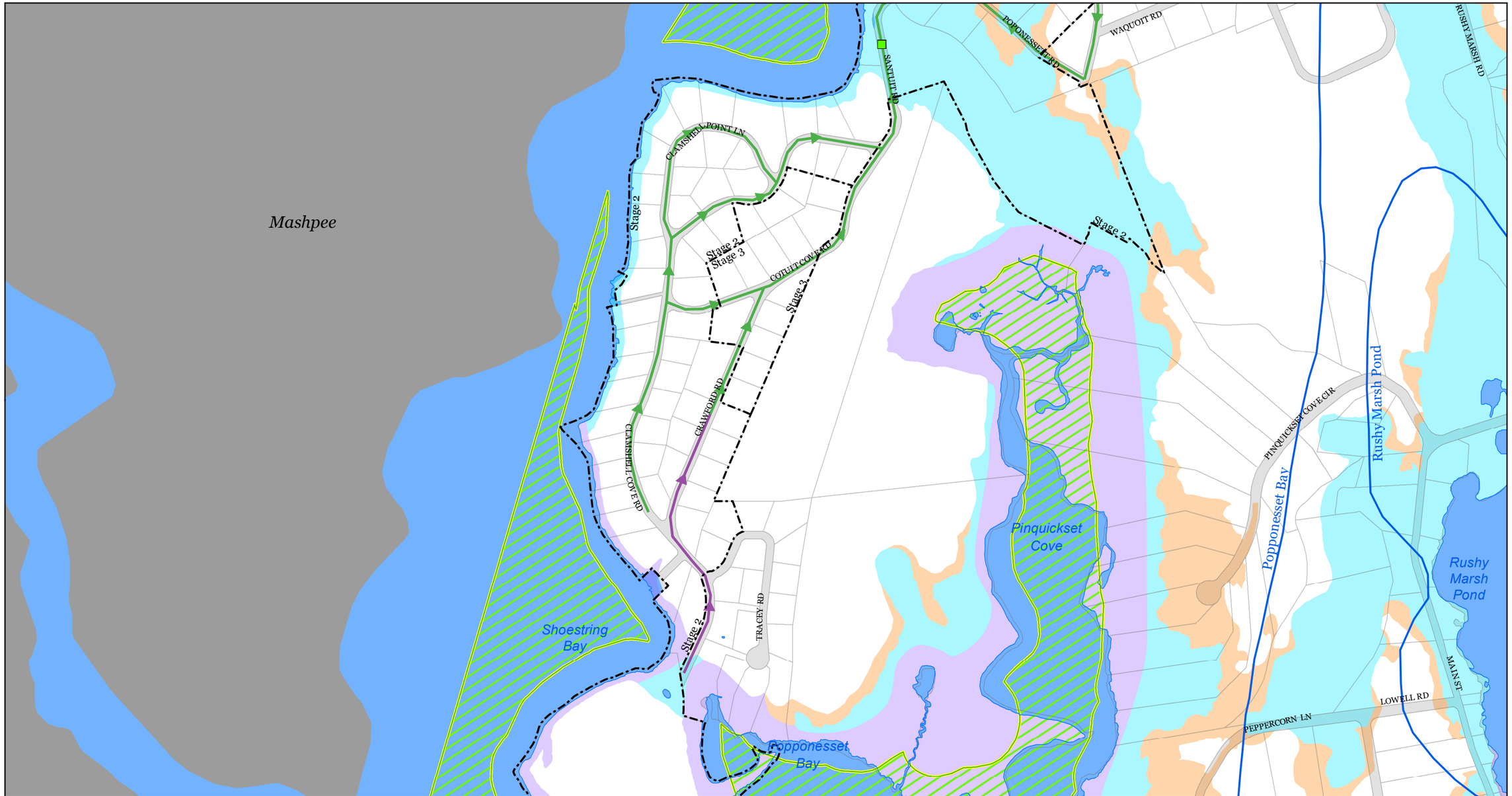

Mashpee
Lovell's Pond
Three Bays
Popponesset Bay
Coombs Pond
Naomi Pond
Santuit River
SANTUIT-NEWTOWN RD
FOREST HILL RD
BOB-O-LINK LN
EASTWOOD LN
ROSEWOOD LN
CURLEW WAY
ELMWOOD CIR
SANDALWOOD DR
LORRAINE CIR
BOB-WHITE RUN
SAVINELL RD
LOVELL'S RD
TRAMOUTH RD
RTE 28
RTE 130
FOX DEN BLUFF RD
TAKAGON CIR
WAY
TREELINE DR
CURTIS RD
STUBTOE RD
BUTTERNUT CIR
BRAMBLEBUSH DR
DOGWOOD LN
PINEVIEW DR
GERALDINE RD
WINDMILL LN
EASY ST
CONTENT LN
HOPEWELL LN
PATIENCE LN
CONSTANT LN
PENELOPE LN
THANKFUL LN
SAMPSONS MILL RD
TRUMAN LN
EISENHOWER DR
PUTNAM AVE
ROOSEVELT RD
MARINER CIR
MOORING DR
ANCHOR LN
Phase 1
Phase 2
Phase 3
Stage 1
Stage 2
Stage 3
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
A5
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28

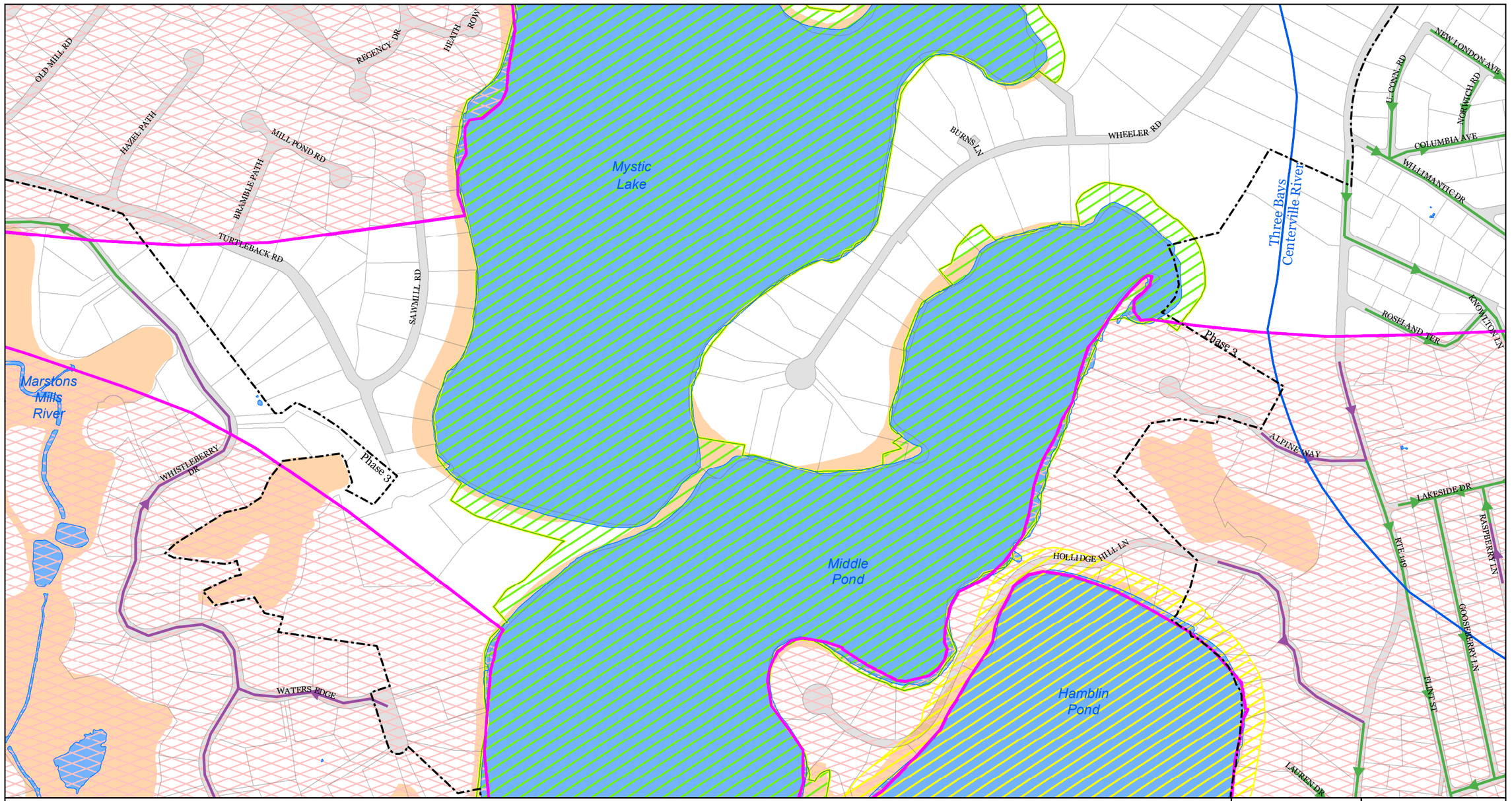

Coombs Pond
Naomi Pond
Stage 2
Stage 1
Stage 2
Stage 1
RTE 130
Santuit River
Stage 1
FALMOUTH RD / RTE 28
PHEASANT HILL CIR
SCHOONER DR
MOORING DR
MARINER CIR
Stage 1
Stage 2
Stage 2
SAMPSONS MILL RD
Stage 3
SMITH NEWTOWN RD
Stage 1
BANFIELD DR
TY-DEE LN
MAIN ST
TROUT BROOK RD
FURLONG WAY
SAMPSON HOUSE NOB
Mashpee
Popponesset Bay
Three Bays
Stage 3
Stage 1
OLD OYSTER RD
Stage 3
OLD KINGS RD
GERARD CIR
Stage 3
OLD POST RD
Stage 3
Stage 1
Stage 2
CREECHAM WAY
ABBEY GATE
QUEEN ANNE LN
No Bottom Pond
RALYN RD
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
A6
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


No Bottom Pond
RALYN RD
ABBEY GATE
BUCKINGHAM WAY
OXFORD DR
REBECHAM WAY
HANNAH CIR
NARROWS WAY
TODD WAY
EAST LN
Stage 3
OLD POST RD
PUTNAM AVE
LOWELL AVE
Stage 3
Stage 2
Stage 3
OLD OYSTER RD
MAIN ST
WEST ST
Santuit River
Mashpee
Stage 1
JULIE LN
LN
JULIE
Stage 1
SANTUIT RD
TRUDY LN
Poppones Bay
Three Bays
COOLIDGE ST
HIGHLAND AVE
Stage 2
LEWIS POND RD
LAKE ST
NICKERSON DR
OLD SHORE RD
Stage 2
HIGH ST
Cotuit Bay
Lewis Pond
Stage 2
Stage 3
Stage 2
Stage 3
SCHOOL ST
Stage 1
Stage 2
GROVE ST
Poppones Bay
Three Bays
Stage 3
Stage 2
Stage 3
Stage 2
OYSTER PLACE RD
Stage 2
Stage 2
Stage 1
Shoestring Bay
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
A7
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Mashpee
CLAMSHELL POINT LN
SANTUIT RD
POPONESSET RD
WAQUOIT RD
RUSHY MARSH RD
Stage 2
Stage 2
Stage 3
COTUIT COVE RD
Stage 2
Stage 2
CRAWFORD RD
CLAMSHELL COVE RD
TRACEY RD
Shoestring Bay
Pinquickset Cove
Popponesset Bay
PINQUICKSET COVE CIR
Popponesset Bay
Rushy Marsh Pond
MAIN ST
LOWELL RD
PEPPERCORN LN
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
A9
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



- Conceptual pump station
- Existing pump station
- Conceptual gravity sewer
- Conceptual low pressure sewer
- Conceptual force main sewer
- Existing sewer
- Sewer phase or sewer stage boundary
- Watershed boundary
- Existing public well
- Proposed or proven public well
- DEP zone I wellhead protection area
- DEP zone II wellhead protection area
- NHESP certified vernal pools
- NHESP potential vernal pools
- NHESP estimated habitat of rare wildlife
- NHESP priority habitat of rare species
- Area of critical environmental concern (ACEC)
- FEMA velocity flood zone (VE)
- FEMA 100-year flood zone (AE)
- FEMA 0.2% annual chance of flooding (X)

N W E S

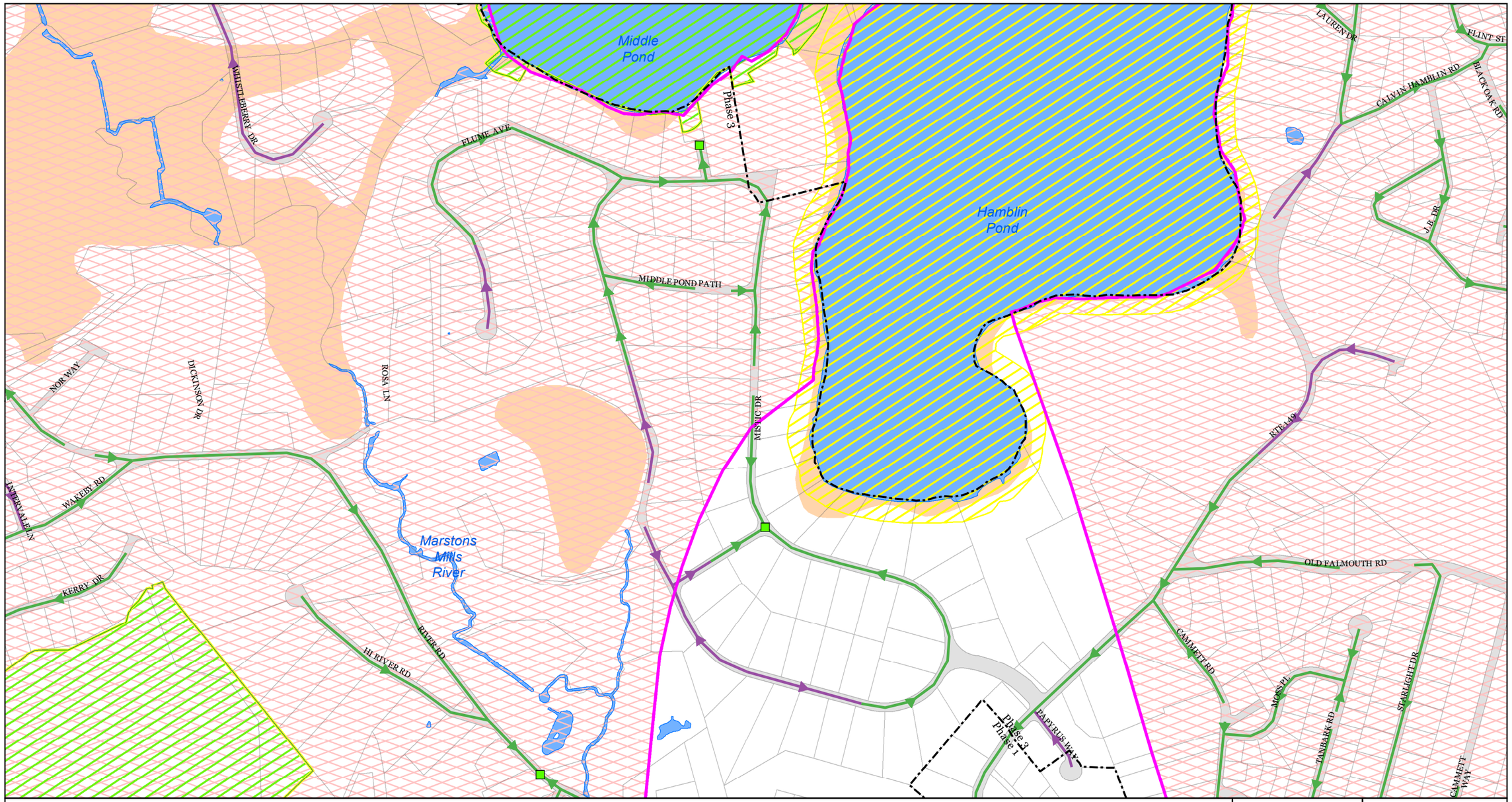
B2

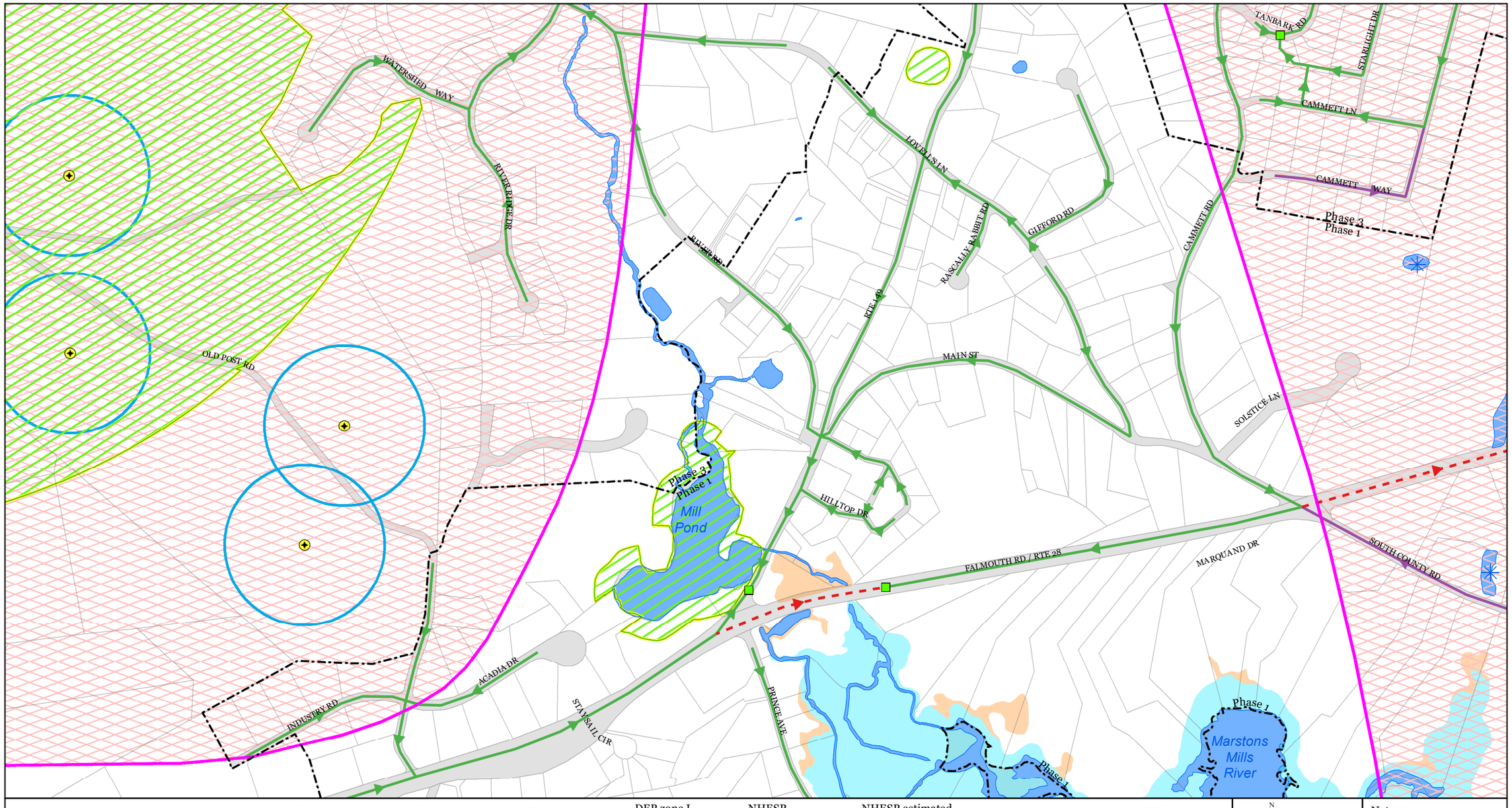
feet

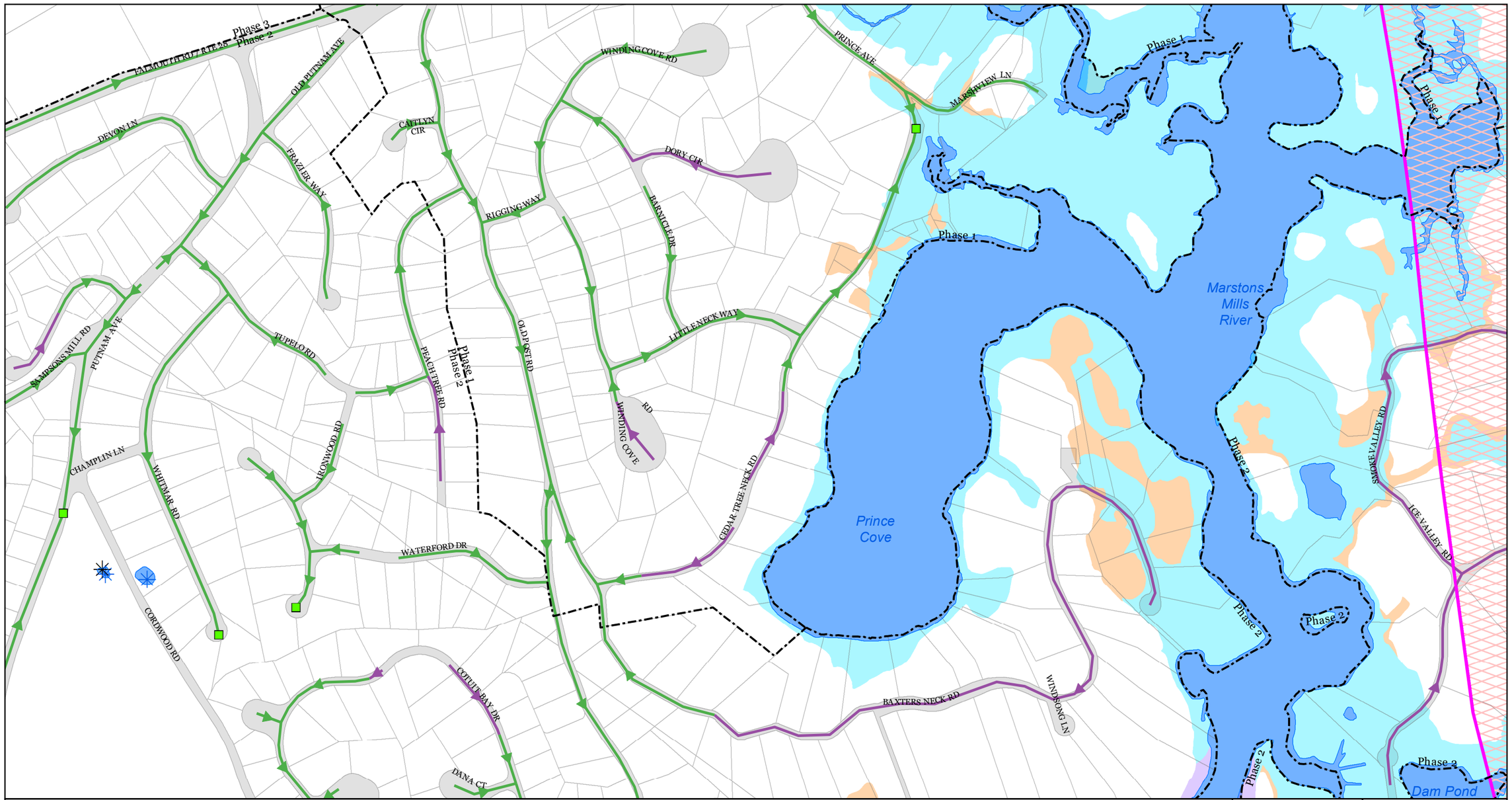
0 100 200 300 400 500

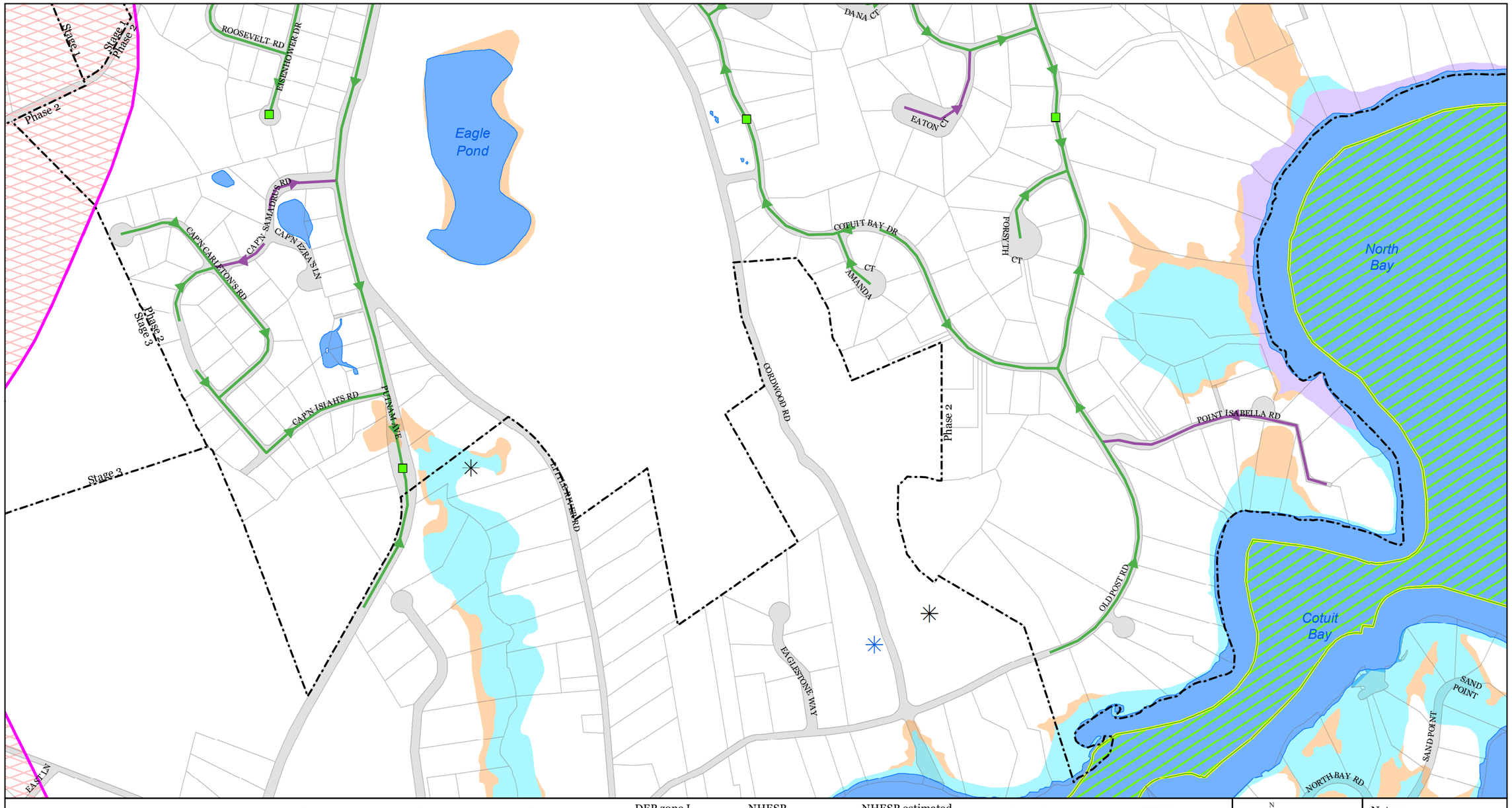
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Middle Pond
Hamblin Pond
Marstons Mills River
Phase 3
Phase 2
Phase 1
WHISTLEBERRY DR
FLUME AVE
MIDDLE POND PATH
MISTIC DR
ROSA LN
DICKINSON DR
NOR WAY
WAKEBY RD
INTERVALE LN
KERRY DR
HI RIVER RD
RIVER RD
PAPYRUS WAY
LAUREN DR
FLINT ST
CALVIN HAMBLIN RD
BLACK OAK RD
J B DR
RTE 149
OLD FALMOUTH RD
CAMMETT RD
MORS PL
TANBARK RD
STARLIGHT DR
CAMMETT WAY
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
B3
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


WATERSHED WAY
RIVER RIDGE DR
OLD POST RD
INDUSTRY RD
ACADIA DR
STAYSAIL CIR
PRINCE AVE
FALMOUTH RD / RTE 28
HILLTOP DR
RTE 149
MAIN ST
RASCALLY RABBIT RD
GIFFORD RD
LOVELL'S LN
CAMMETT RD
TANBARK RD
STARLIGHT DR
CAMMETT LN
CAMMETT WAY
MARQUAND DR
SOLSTICE LN
SOUTH COUNTY RD
Phase 3
Phase 1
Mill Pond
Marstons Mills River
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
B4
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Phase 3
Phase 2
FALMOUTH RT 7 RTE 28
DEVON LN
OLD PUTNAM AVE
FRAZIER WAY
CAITLYN CIR
WINDING COVE RD
DORY CIR
RIGGING WAY
BARNICLE DR
PRINCE AVE
MARSHVIEW LN
Phase 1
Phase 1
Phase 1
Marstons Mills River
SIMPSONS MILL RD
PUTNAM AVE
TUPELO RD
PEACHTREE RD
Phase 1
Phase 2
OLD POST RD
LITTLENECK WAY
WINDING COVE RD
CHAMPLIN LN
WHITMAR RD
IRONWOOD RD
CEDAR TREE NECK RD
Phase 2
SMOKE VALLEY RD
ICE VALLEY RD
WATERFORD DR
Prince Cove
CORDWOOD RD
COTUIT BAY DR
DANA CT
BAXTERS NECK RD
WINDSONG LN
Phase 2
Phase 2
Phase 2
Phase 2
Dam Pond
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
B5
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



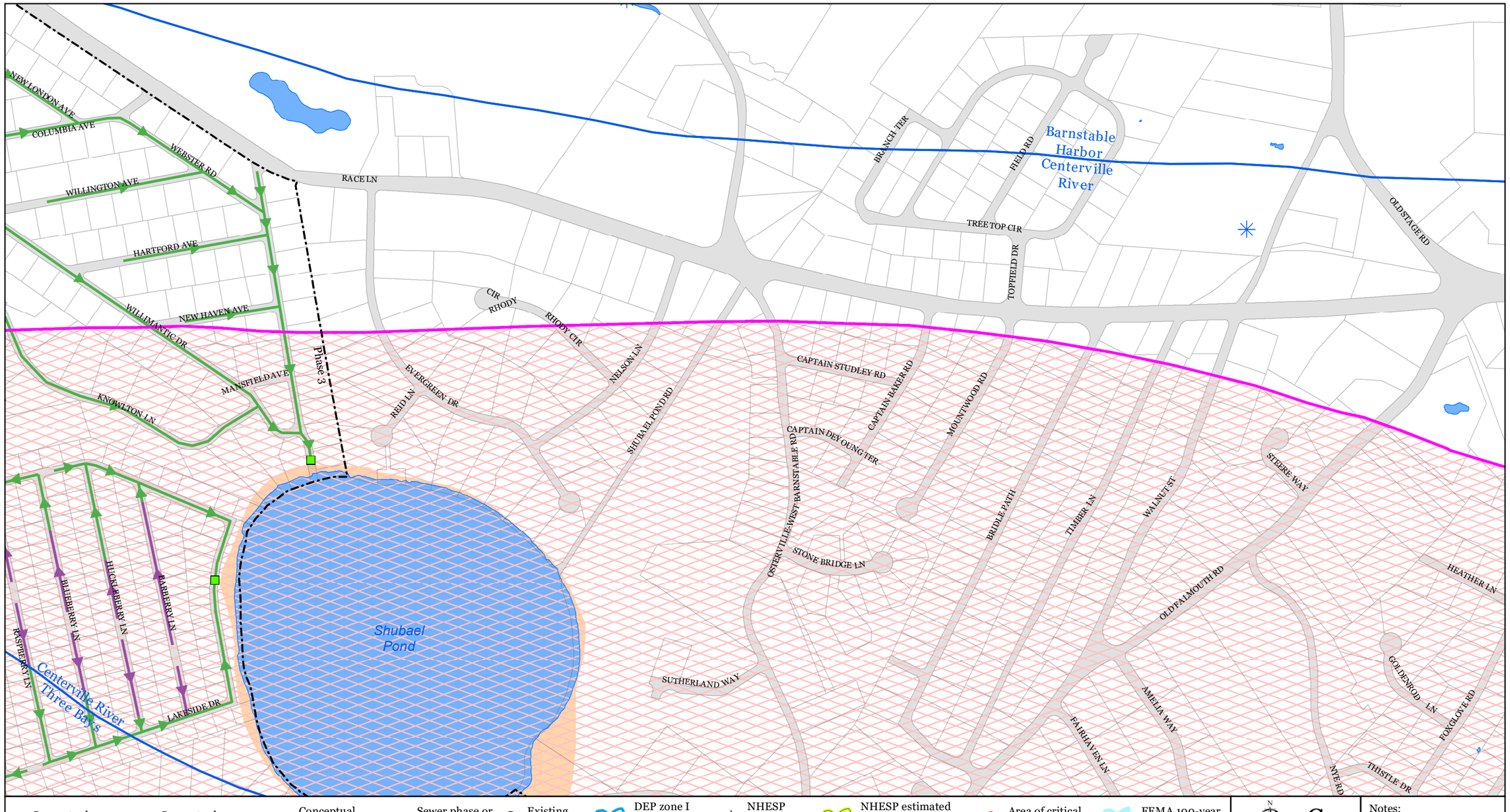
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)

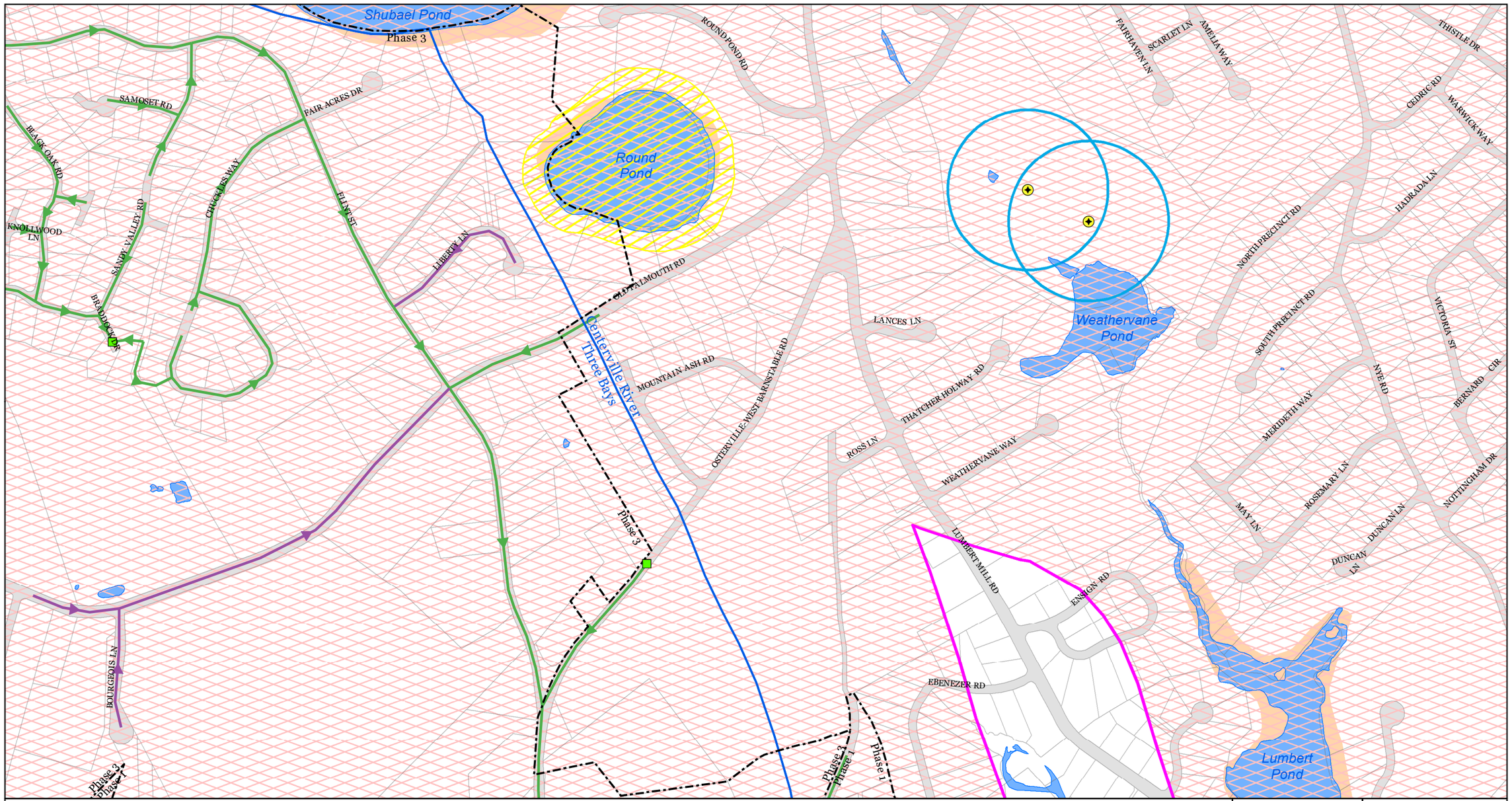
N
W E
S

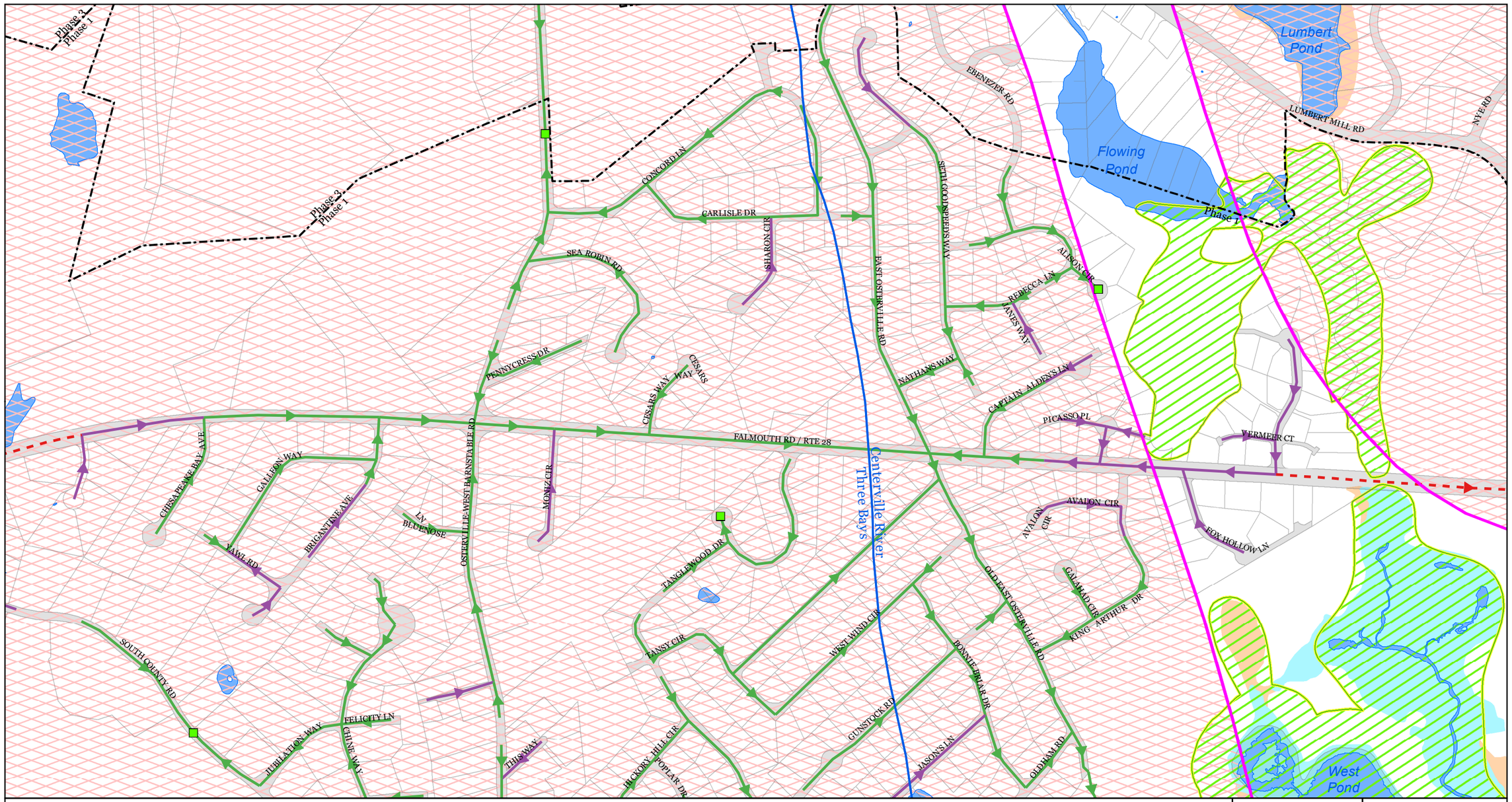
B6

feet
0 100 200 300 400 500
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


NEW LONDON AVE
COLUMBIA AVE
WEBSTER RD
WILLINGTON AVE
HARTFORD AVE
NEW HAVEN AVE
WILLIMANTIC DR
MANSFIELD AVE
KNOWLTON LN
RACE LN
Phase 3
RHODY CIR
CIR
RHODY
NELSON LN
EVERGREEN DR
REID LN
SHUBAEL POND RD
CAPTAIN STUDLEY RD
CAPTAIN BAKER RD
CAPTAIN DEYOUNG TER
CAPTAIN DEYOUNG TABLE RD
MOUNTWOOD RD
BRANCH TER
FIELD RD
TREE TOP CIR
TOPFIELD DR
Barnstable Harbor
Centerville River
OLD STAGE RD
STEERE WAY
BRIDLE PATH
TIMBER LN
WALNUT ST
OSTERVILLE-WEST BARNSTABLE RD
STONE BRIDGE LN
OLD FALMOUTH RD
HEATHER LN
GOLDENROD LN
FOXGLOVE RD
AMELIA WAY
FAIRHAVEN LN
NYE RD
THISTLE DR
SUTHERLAND WAY
Shubael Pond
BLUEBERRY LN
HUCKLEBERRY LN
BARBERRY LN
RASPBERRY LN
LAKESIDE DR
Centerville River
Three Bays
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
C2
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Shubael Pond
Phase 3
ROUND POND RD
Round Pond
FAIRHAVEN LN
SCARLET LN
AMELIA WAY
THISTLE DR
CEDRIC RD
WARWICK WAY
SAMOSET RD
FAIR ACRES DR
BLACK OAK RD
CHUCKLES WAY
ELLIS ST
KNOLLWOOD LN
SANDY VALLEY RD
BRADDOCK DR
LIBERTY LN
OLD FALMOUTH RD
Centerville River
Three Bays
MOUNTAIN ASH RD
OSTERVILLE-WEST BARNSTABLE RD
LANCES LN
THATCHER HOLWAY RD
ROSS LN
WEATHERVANE WAY
Weathervane Pond
NORTH PRECINCT RD
HADRADA LN
SOUTH PRECINCT RD
VICTORIA ST
BERNARD CIR
MERIDETH WAY
NYE RD
ROSEMARY LN
MAY LN
DUNCAN LN
NOTTINGHAM DR
LUMBERT MILL RD
ENSIGN RD
EBENEZER RD
Lumbert Pond
BOURGEOIS LN
Phase 3
Phase 1
Phase 3
Phase 1
Phase 3
Phase 1
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
C3
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Phase 3
Phase 1
Phase 3
Phase 1
Lumbert Pond
Flowing Pond
Phase 1
EBENEZER RD
LUMBERT MILL RD
NYE RD
CONCORD LN
CARLISLE DR
SHARON CIR
SEA ROBIN RD
PENNYCRESS DR
SETH GOODSPEEDS WAY
EAST OSTERVILLE RD
ALISON CIR
REBECCA LN
JANES WAY
NATHANS WAY
CAPTAIN ALDEN'S LN
PICASSO PL
VERMEER CT
CESARS WAY
CESARS WAY
FALMOUTH RD / RTE 28
Centerville River
Three Bays
FOX HOLLOW LN
AVALON CIR
AVALON CIR
GALAHAD CIR
KING ARTHUR DR
OLD EAST OSTERVILLE RD
BONNIE BRIAR DR
OLDHAM RD
JASON'S LN
GUNSTOCK RD
WEST WIND CIR
TANGLEWOOD DR
TANSY CIR
HICKORY HILL CIR
POPLAR DR
CHESAPEAKE BAY AVE
GALLEON WAY
BRIGANTINE AVE
YAWL RD
LN
BLUENOSE
OSTERVILLE-WEST BARNSTABLE RD
MONTZ CIR
THISTLE WAY
SOUTH COUNTY RD
JUBILATION WAY
FELICITY LN
CHINE WAY
West Pond
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
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FEMA 100-year flood zone (AE)
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N
W
E
S
C4
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
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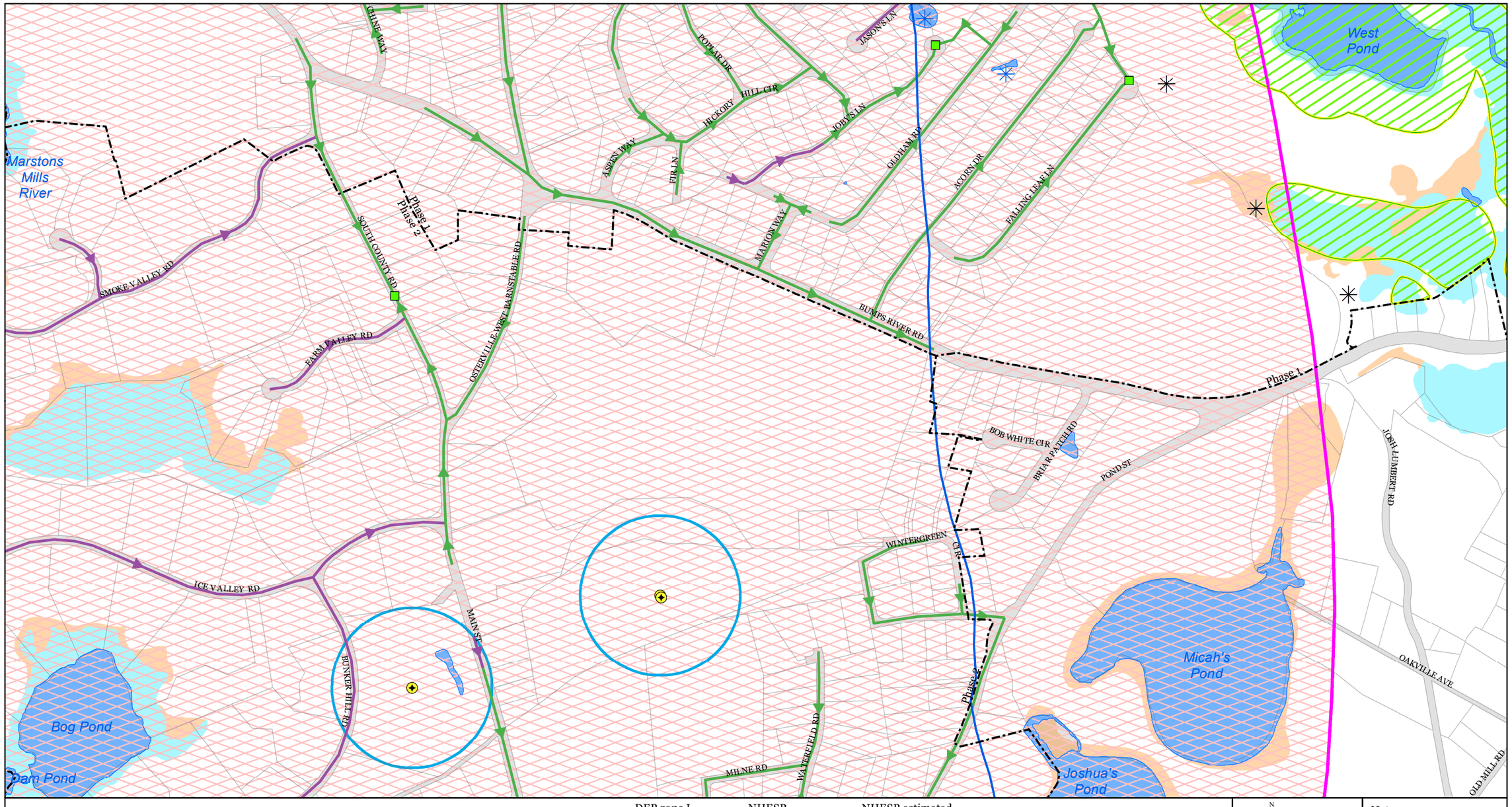

- Conceptual pump station
- Existing pump station
- Conceptual gravity sewer
- Conceptual low pressure sewer
- Conceptual force main sewer
- Existing sewer
- Sewer phase or sewer stage boundary
- Watershed boundary
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- NHESP priority habitat of rare species
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- FEMA 100-year flood zone (AE)
- FEMA 0.2% annual chance of flooding (X)

N W E S

C5

feet

0 100 200 300 400 500

1 inch = 500 feet

Notes:
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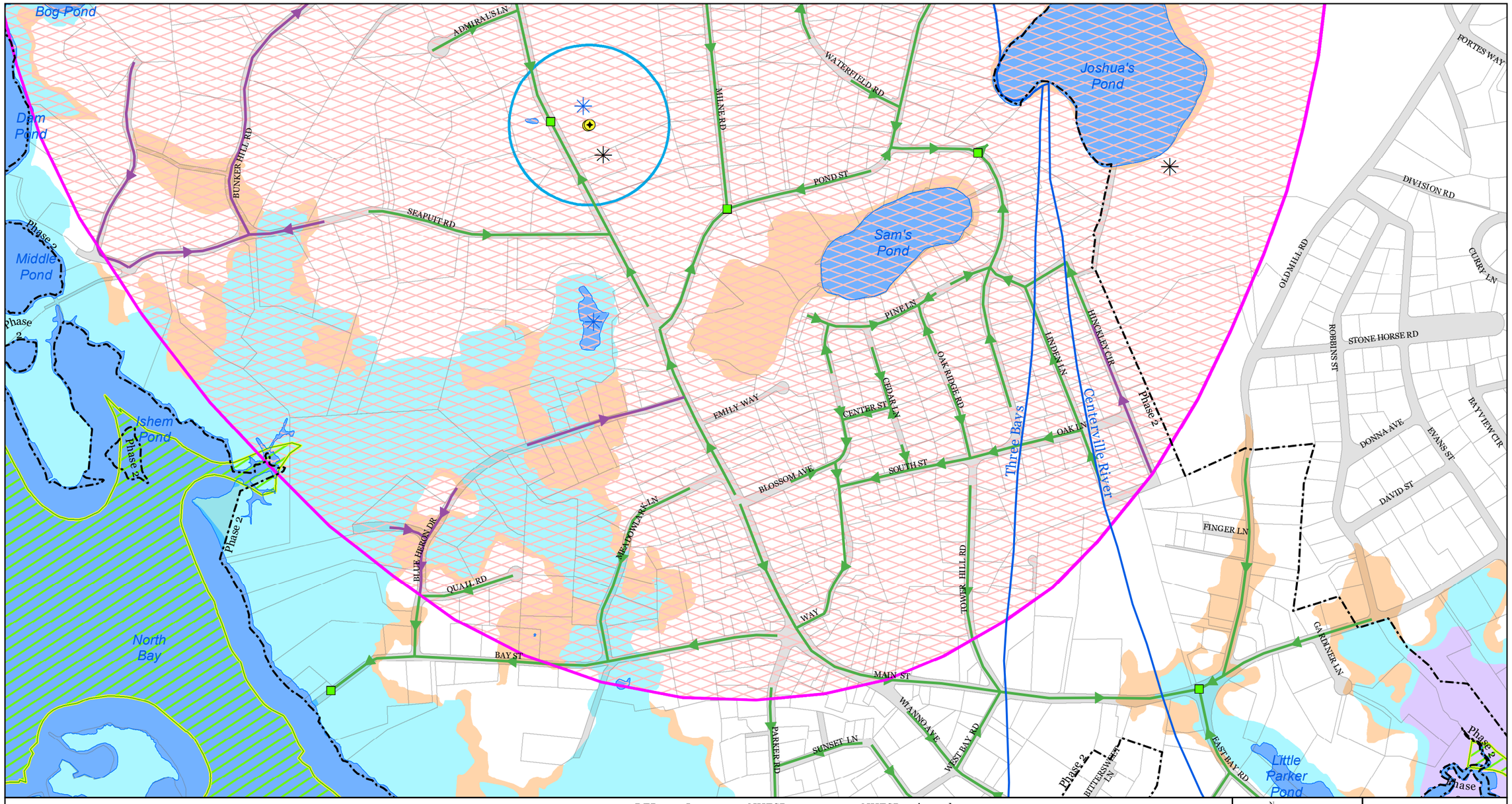

Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
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Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
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FEMA 0.2% annual chance of flooding (X)

N W E S

C6

feet
0 100 200 300 400 500
1 inch = 500 feet

Notes:
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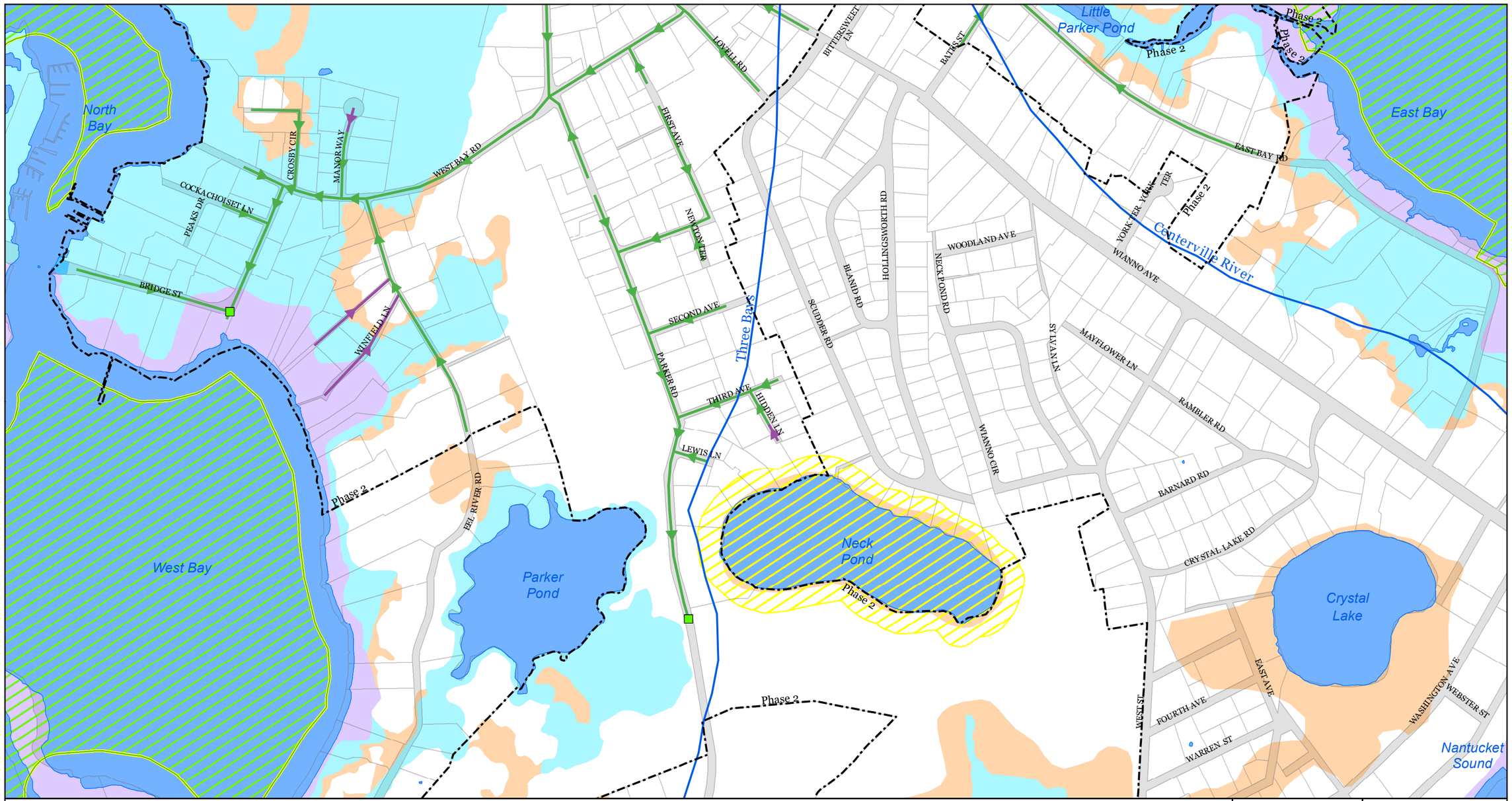

Notes:
1) Pump station locations are approximate
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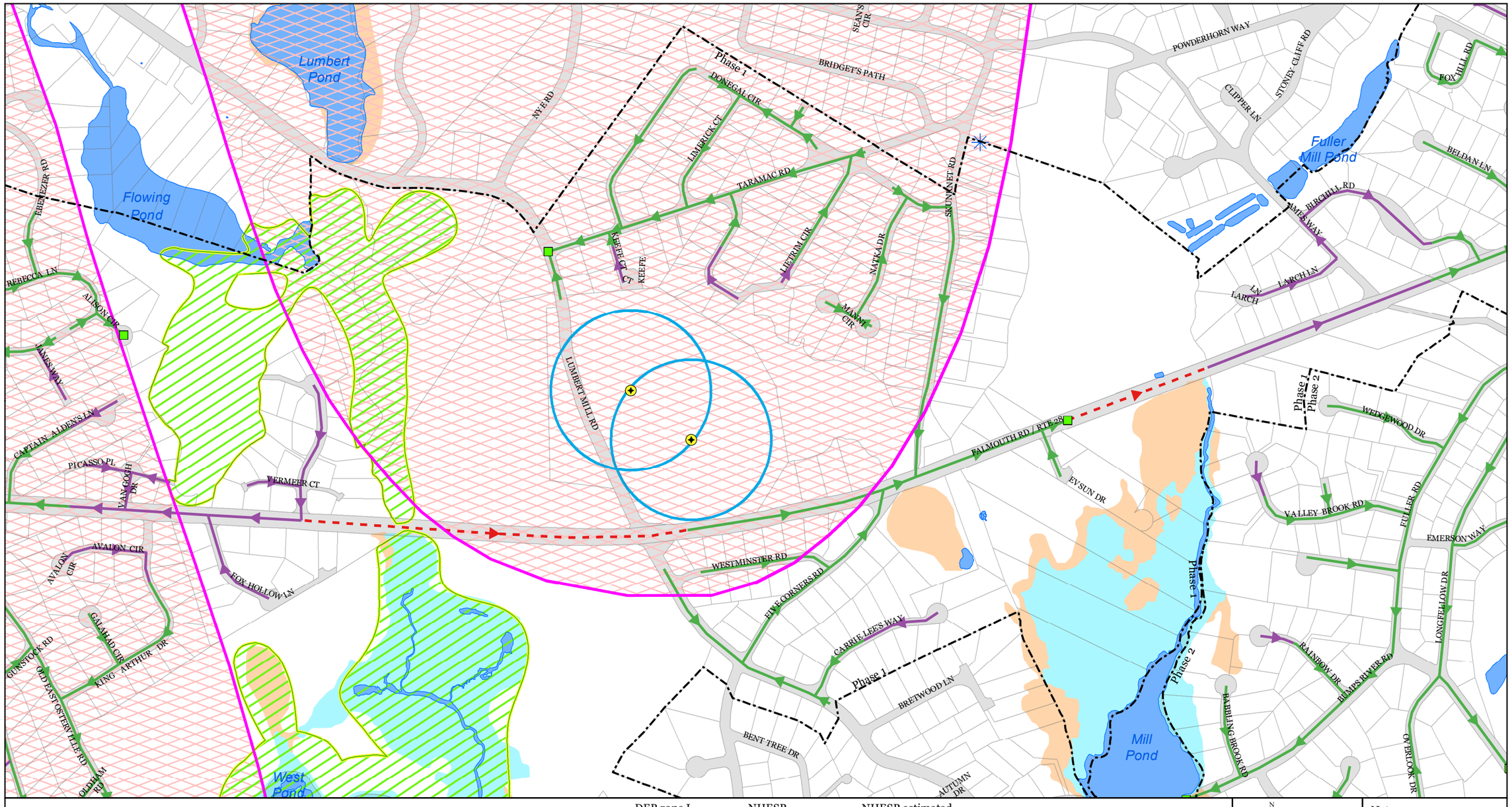
Lumbert Pond
Flowing Pond
West Pond
Fuller Mill Pond
Mill Pond
Phase 1
Phase 2
Phase 1
Phase 2
Phase 1
EBENEZER RD
REBECCA LN
ALISON CIR
JAMES WAY
CAPTAIN ALDEN'S LN
PICASSO PL
VAN GOGH DR
VERMEER CT
AVALON CIR
AVALON CIR
FOX HOLLOW LN
GALAHAD CIR
KING ARTHUR DR
GUNSTOCK RD
OLD EAST OSTERVILLE RD
OLDHAM RD
NYE RD
BRIDGET'S PATH
SEAN'S CIR
DONEGAL CIR
LIMERICK CT
TARAMAC RD
KEEFE CT CT
KEEFE
LIFFEY M CIR
NATICK DR
MANNY CIR
SKUNNET RD
LUMBERT MILL RD
POWDERHORN WAY
CLIPPER LN
STONEY CLIFF RD
FOX HILL RD
BELDAN LN
BIRCHILL RD
AMES WAY
LARCH LN
LARCH LN
FALMOUTH RD / RTE 28
EVSUN DR
WEDGEWOOD DR
VALLEY BROOK RD
FULLER RD
EMERSON WAY
LONGFELLOW DR
OVERLOOK DR
WESTMINSTER RD
FIVE CORNERS RD
CARRIE LEE'S WAY
BRETWOOD LN
BENT TREE DR
AUTUMN DR
RAINBOW DR
BIMPS RIVER RD
BARBLING BROOK RD
Conceptual pump station
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Conceptual low pressure sewer
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NHESP potential vernal pools
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NHESP priority habitat of rare species
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FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
N
W
E
S
D1
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
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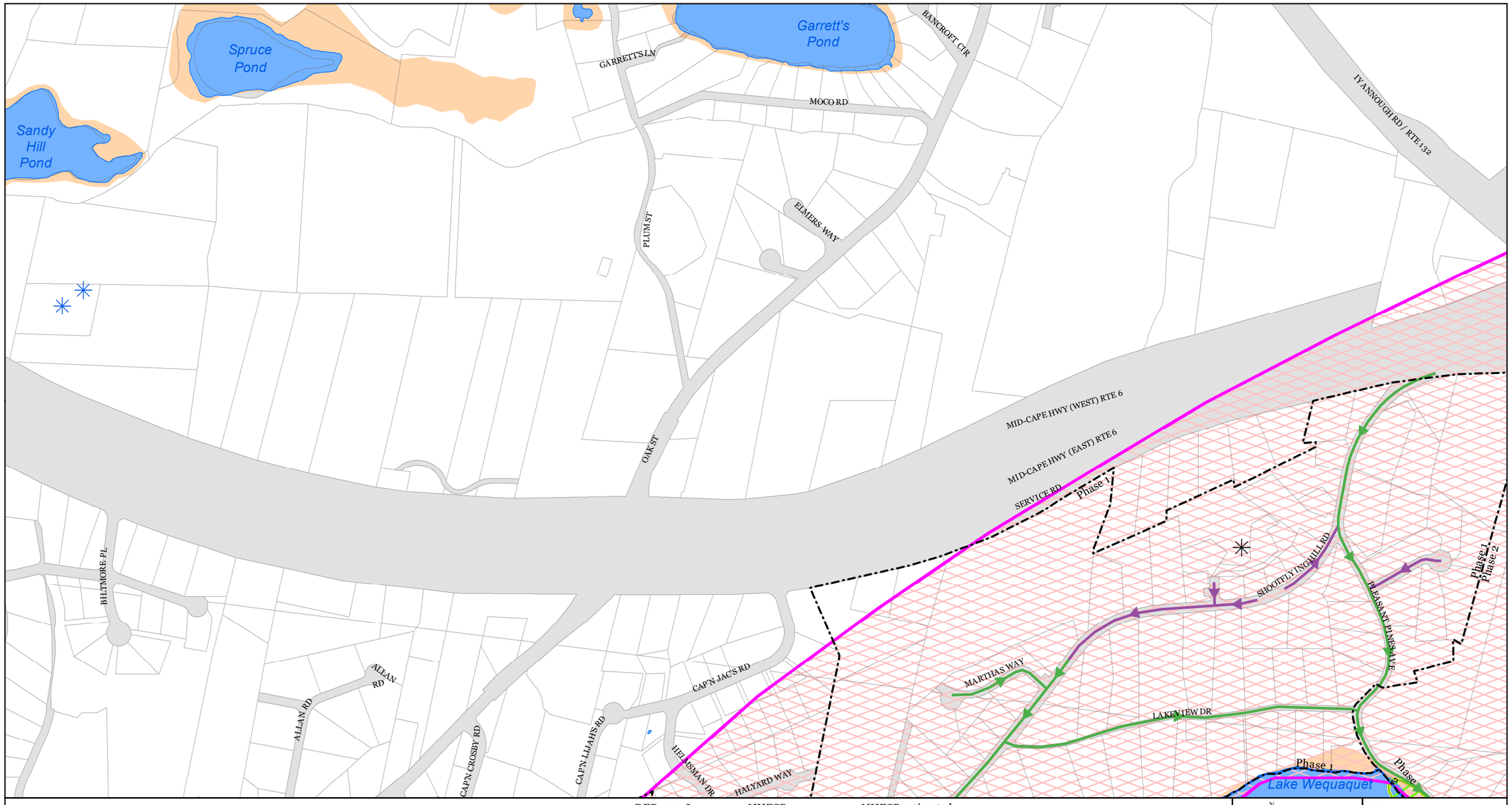
Spruce Pond
Sandy Hill Pond
Garrett's Pond
GARRETT'S LN
BANCROFT CIR
MOCO RD
IYANNOUGH RD / RTE 132
PLUM ST
ELMERS WAY
OAK ST
MID-CAPE HWY (WEST) RTE 6
MID-CAPE HWY (EAST) RTE 6
SERVICE RD
Phase 1
Phase 2
SHOOTFLY HILL RD
PLEASANT PINES AVE
MARTHAS WAY
LAKEVIEW DR
Lake Wequaquet
BILTMORE PL
ALLAN RD
CAP'N JAC'S RD
CAP'N LIJAHS RD
CAP'N CROSBY RD
HELMSMAN DR
HALYARD WAY
Conceptual pump station
Existing pump station
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N
W
E
S
E1
feet
0 100 200 300 400 500
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Notes:
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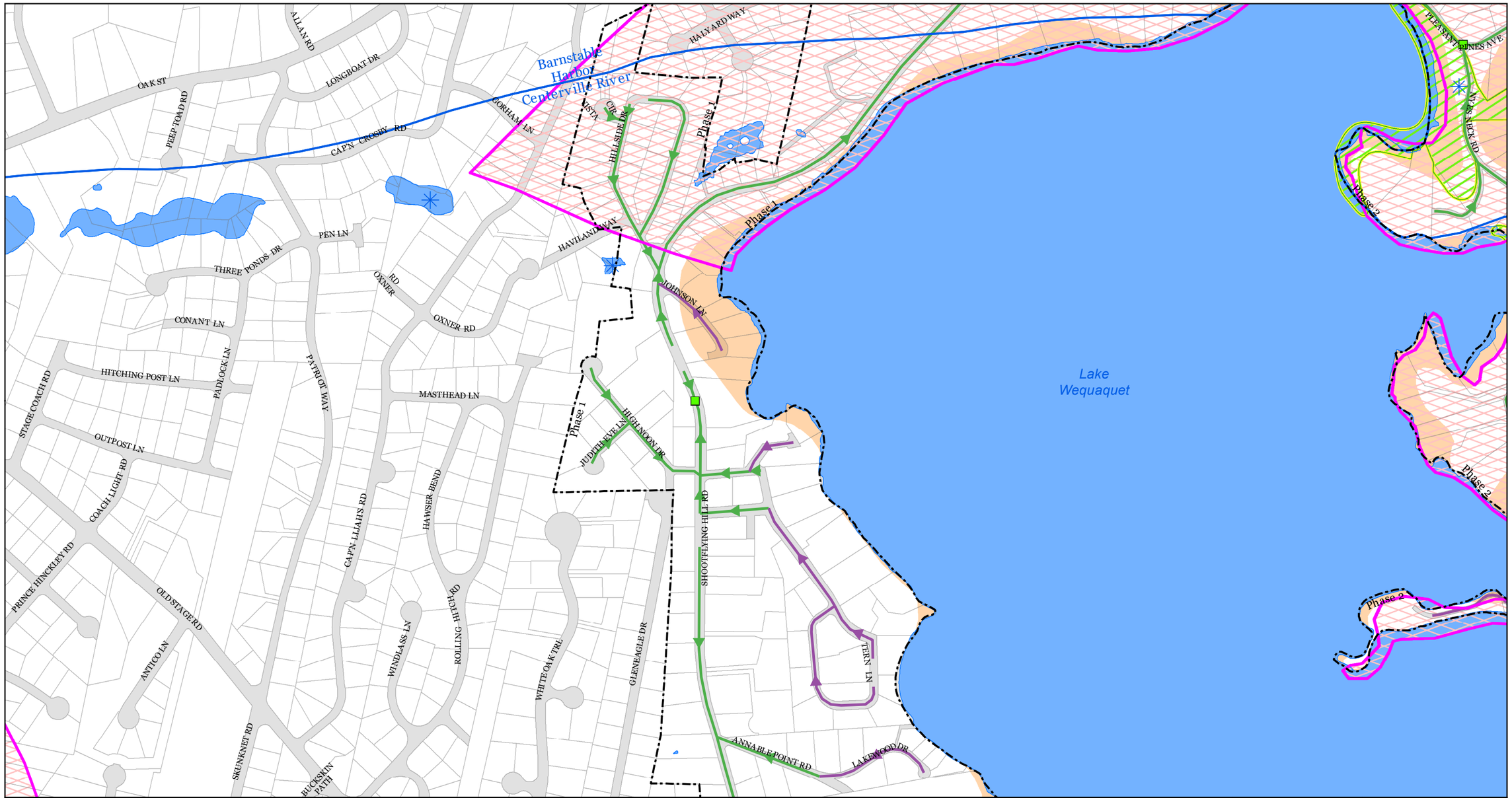
Barnstable Harbor
Centerville River
Lake Wequaquet
ALLAN RD
LONGBOAT DR
OAK ST
PEEP TOAD RD
CAPN CROSBY RD
GORHAM LN
VISTA CIR
HILLSIDE DR
HALYARD WAY
Phase 1
HAVILAND WAY
PEN LN
THREE PONDS DR
OXNER RD
CONANT LN
PADLOCK LN
PATRIOT WAY
HITCHING POST LN
MASTHEAD LN
STAGECOACH RD
OUTPOST LN
COACH LIGHT RD
PRINCE HINCKLEY RD
OLD STAGE RD
ANTICO LN
SKUNKNET RD
BUCKSKIN PATH
CAPN LLIAHS RD
HAWSER BEND
WINDLASS LN
ROLLING HITCH RD
WHITE OAK TRL
GLENEAGLE DR
JOHNSON LN
JUDITH EVE LN
HIGH NOON DR
SHOOTFLYING HILL RD
TERN LN
ANNABLE POINT RD
LAKEWOOD DR
PLEASANT PINES AVE
MAYS NECK RD
Phase 2
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
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N
W
E
S
E2
feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
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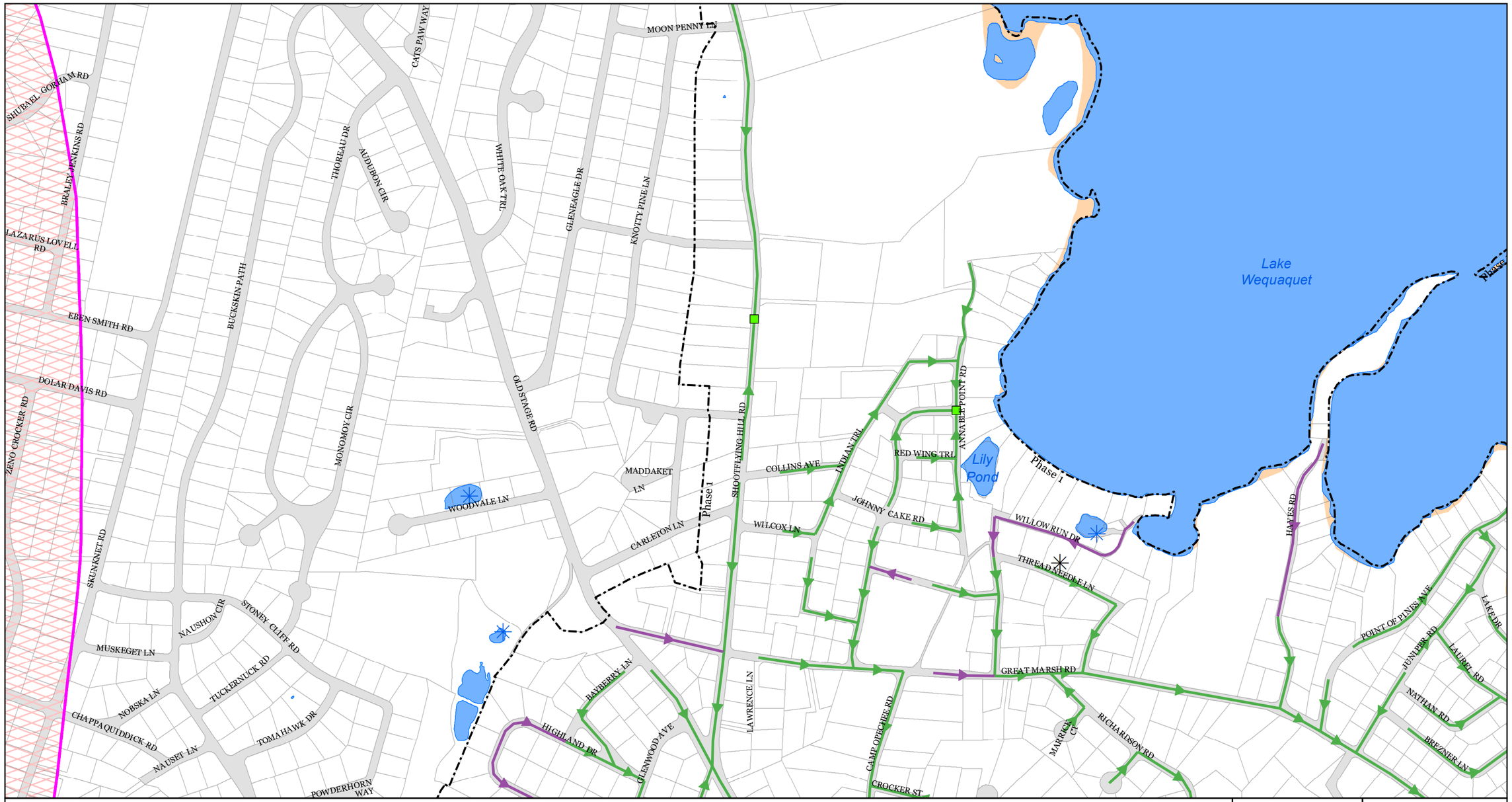

Conceptual pump station
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N W E S

E3

feet

0 100 200 300 400 500

1 inch = 500 feet

Notes:
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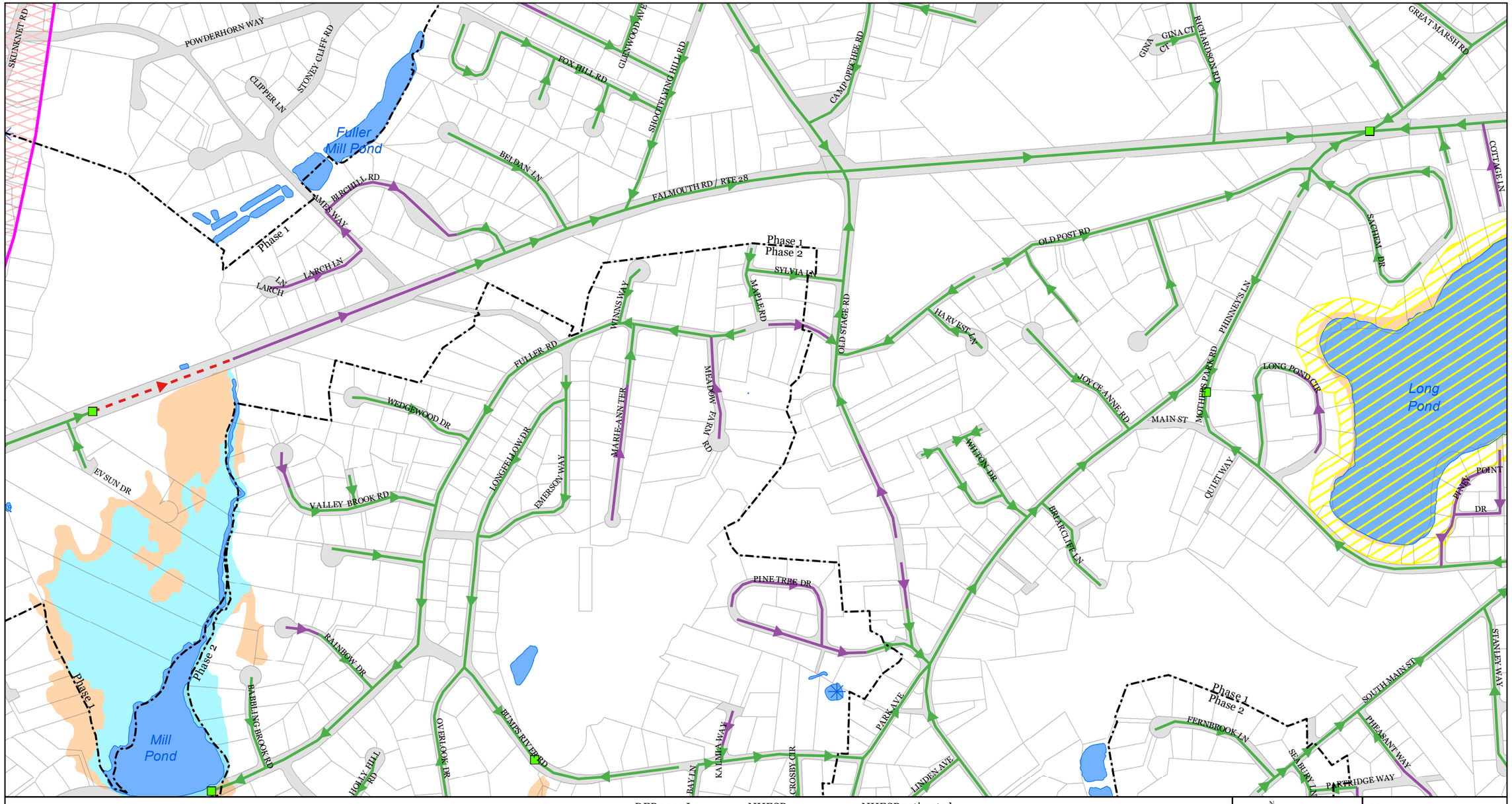

Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
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Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)

N
W E
S

E4

feet
0 100 200 300 400 500
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
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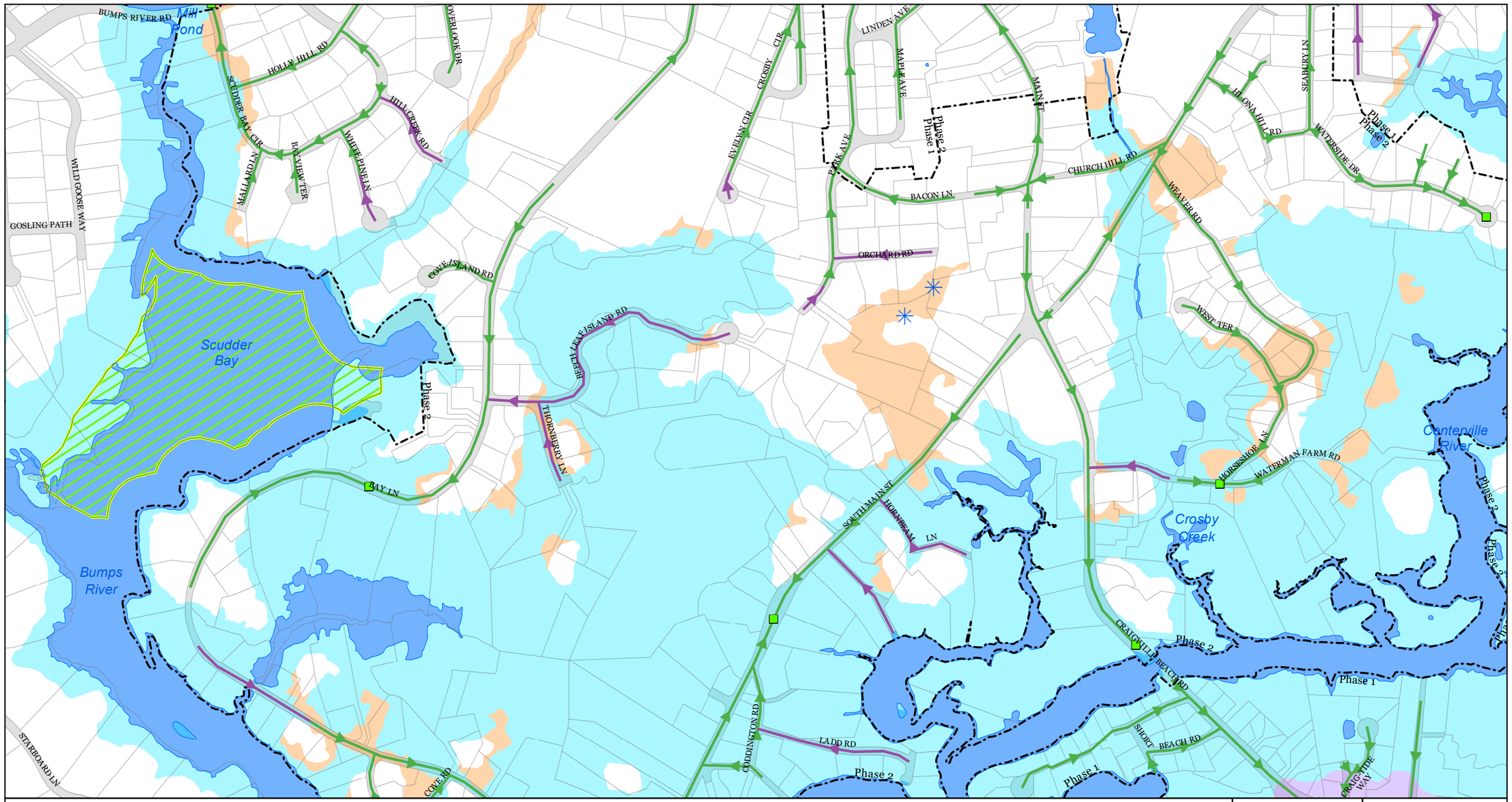

- Conceptual pump station
- Existing pump station
- Conceptual gravity sewer
- Conceptual low pressure sewer
- Conceptual force main sewer
- Existing sewer
- Sewer phase or sewer stage boundary
- Watershed boundary
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- NHESP priority habitat of rare species
- Area of critical environmental concern (ACEC)
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N W E S

E5

feet

0 100 200 300 400 500

1 inch = 500 feet

Notes:
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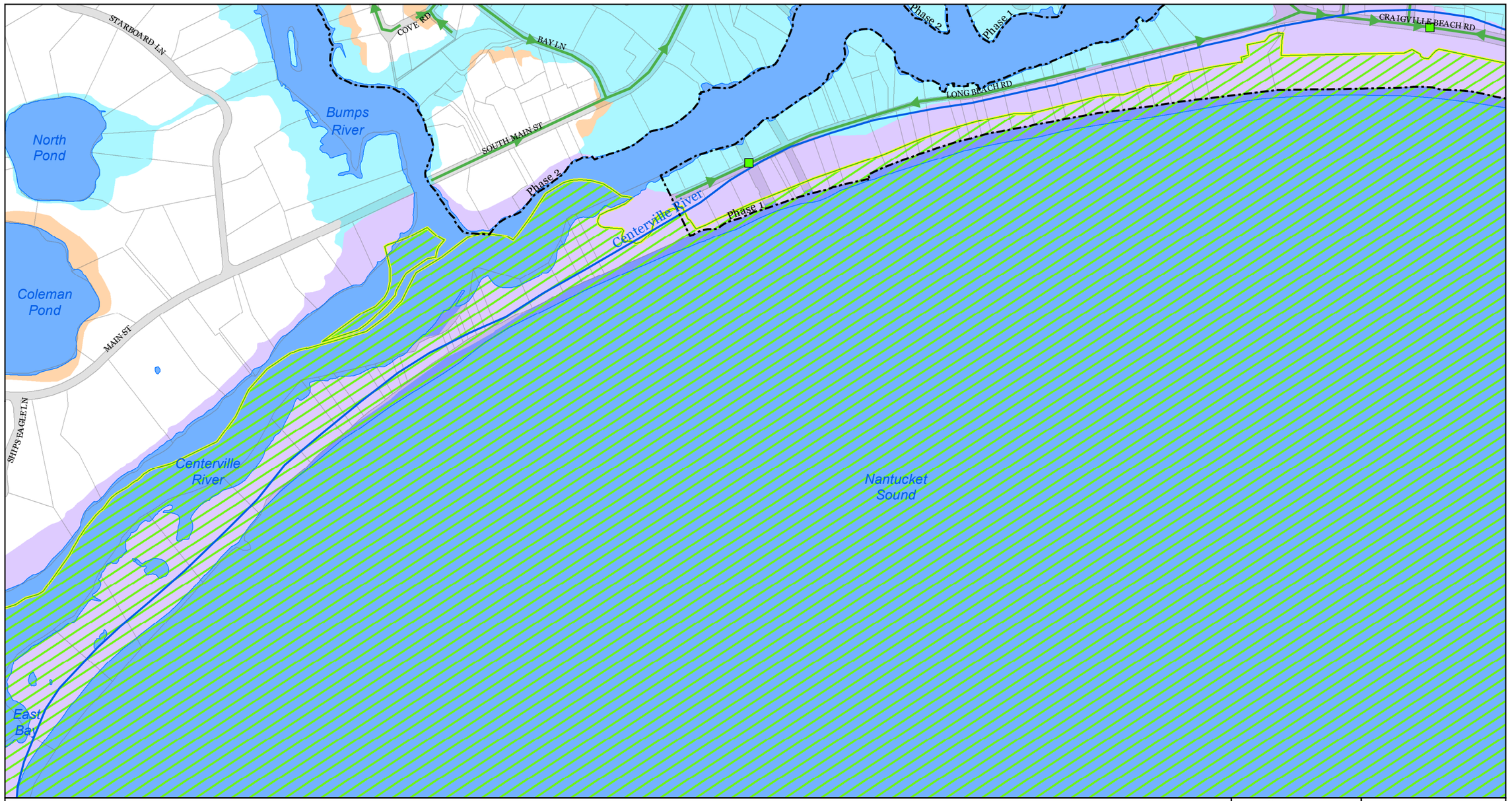

- Conceptual pump station
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- Existing sewer
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N W E S

E6

feet

0 100 200 300 400 500

1 inch = 500 feet

Notes:
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MID-CAPE HWY EXIT 6

MID-CAPE HWY (WEST) RTE 6

MID-CAPE HWY (EAST) RTE 6

Phase 1

Phase 2

Phase 2

Phase 1

Phase 1

CRANBERRY LN

CHICKADEE LN

BUNNY RUN

HUCKINS NECK RD

SHALLOW POND DR

WATER VIEW CIR

PLEASANT PINES AVE

ATTUCKS LN

Hathaway's Pond North

Hathaway's Pond South

- Conceptual pump station
- Existing pump station
- Conceptual gravity sewer
- Conceptual low pressure sewer
- Conceptual force main sewer
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N W E S

F1

feet

0 100 200 300 400 500

1 inch = 500 feet

Notes:
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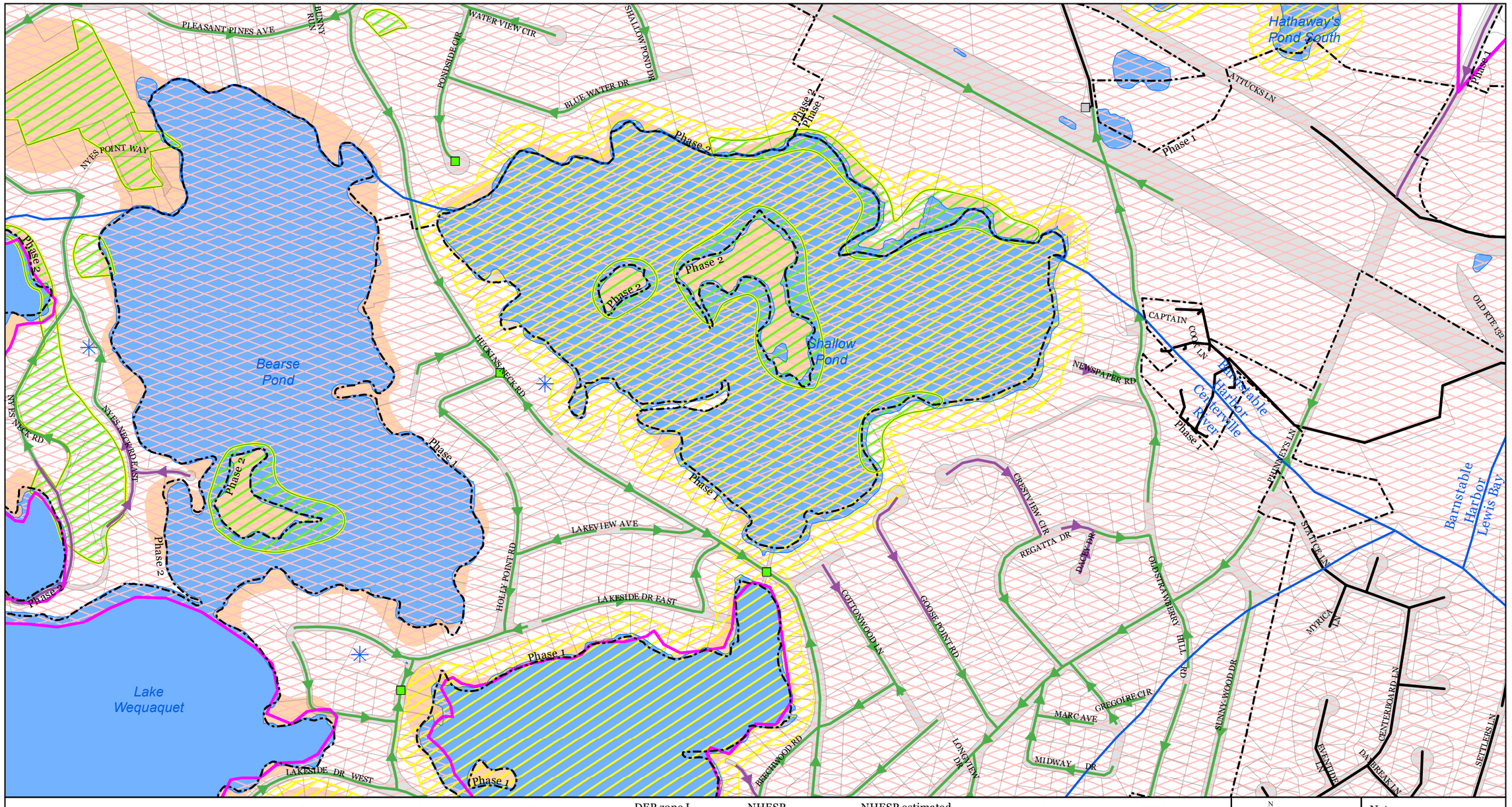

- Conceptual pump station
- Existing pump station
- Conceptual gravity sewer
- Conceptual low pressure sewer
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- Existing sewer
- Sewer phase or sewer stage boundary
- Watershed boundary
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N W E S

F2

feet

0 100 200 300 400 500

1 inch = 500 feet

Notes:
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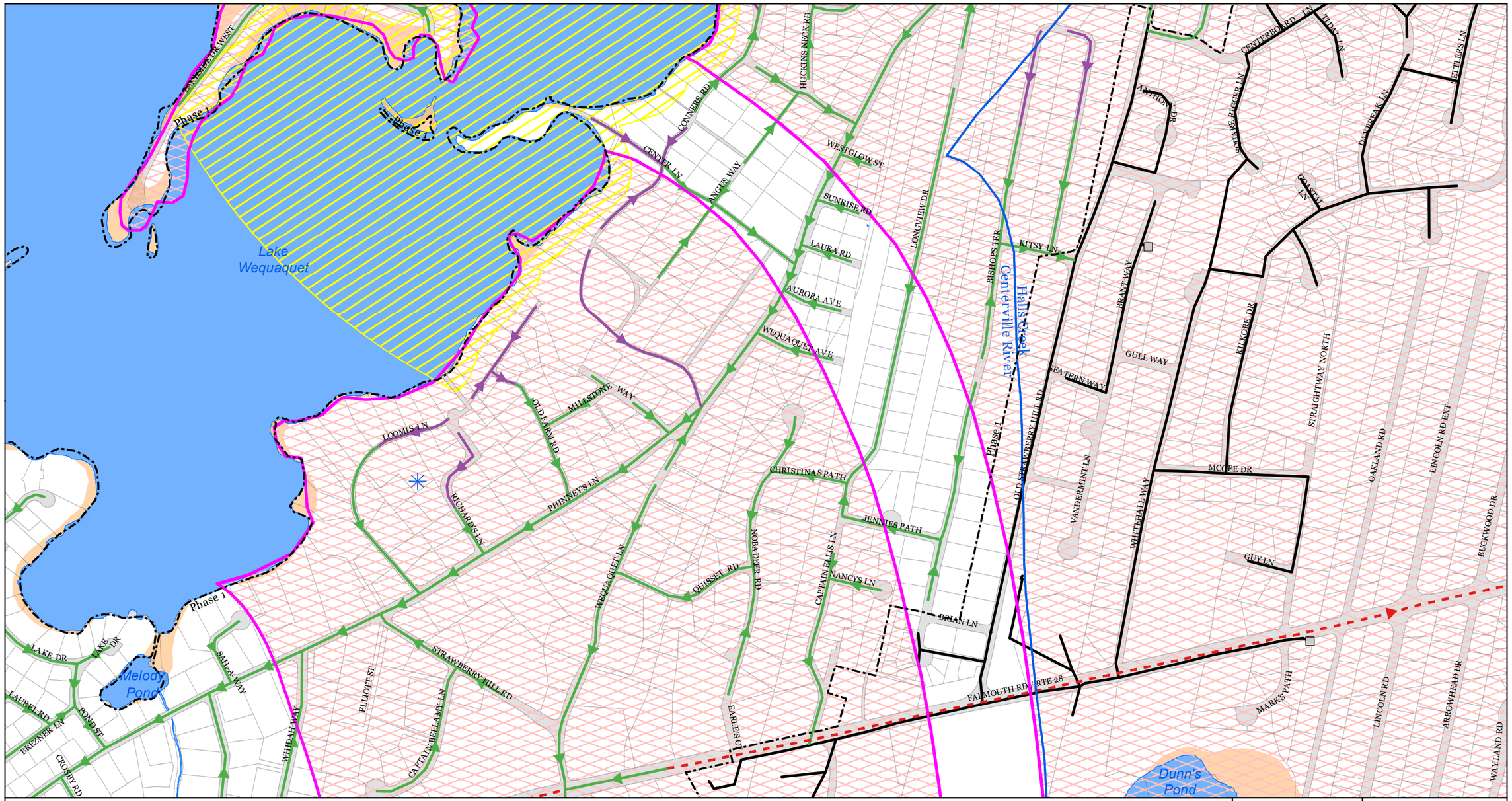

Conceptual pump station	Conceptual gravity sewer	Conceptual force main sewer	Sewer phase or sewer stage boundary	Existing public well	DEP zone I wellhead protection area	NHESP certified vernal pools	NHESP estimated habitat of rare wildlife	Area of critical environmental concern (ACEC)	FEMA 100-year flood zone (AE)
Existing pump station	Conceptual low pressure sewer	Existing sewer	Watershed boundary	Proposed or proven public well	DEP zone II wellhead protection area	NHESP potential vernal pools	NHESP priority habitat of rare species	FEMA velocity flood zone (VE)	FEMA 0.2% annual chance of flooding (X)

N W E S

F3

0 100 200 300 400 500 feet

1 inch = 500 feet

Notes:
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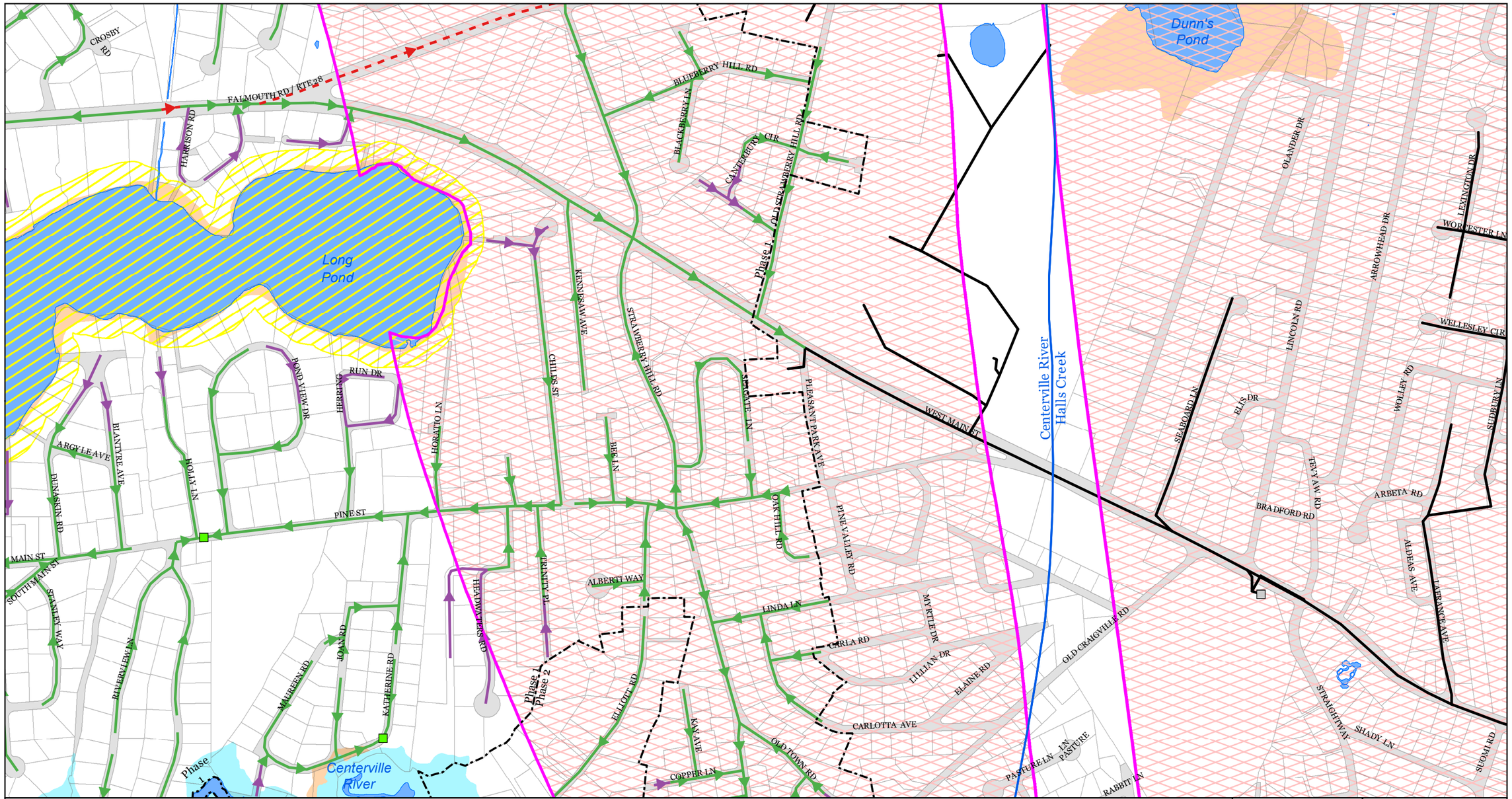

Conceptual pump station
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N W E S

F4

feet
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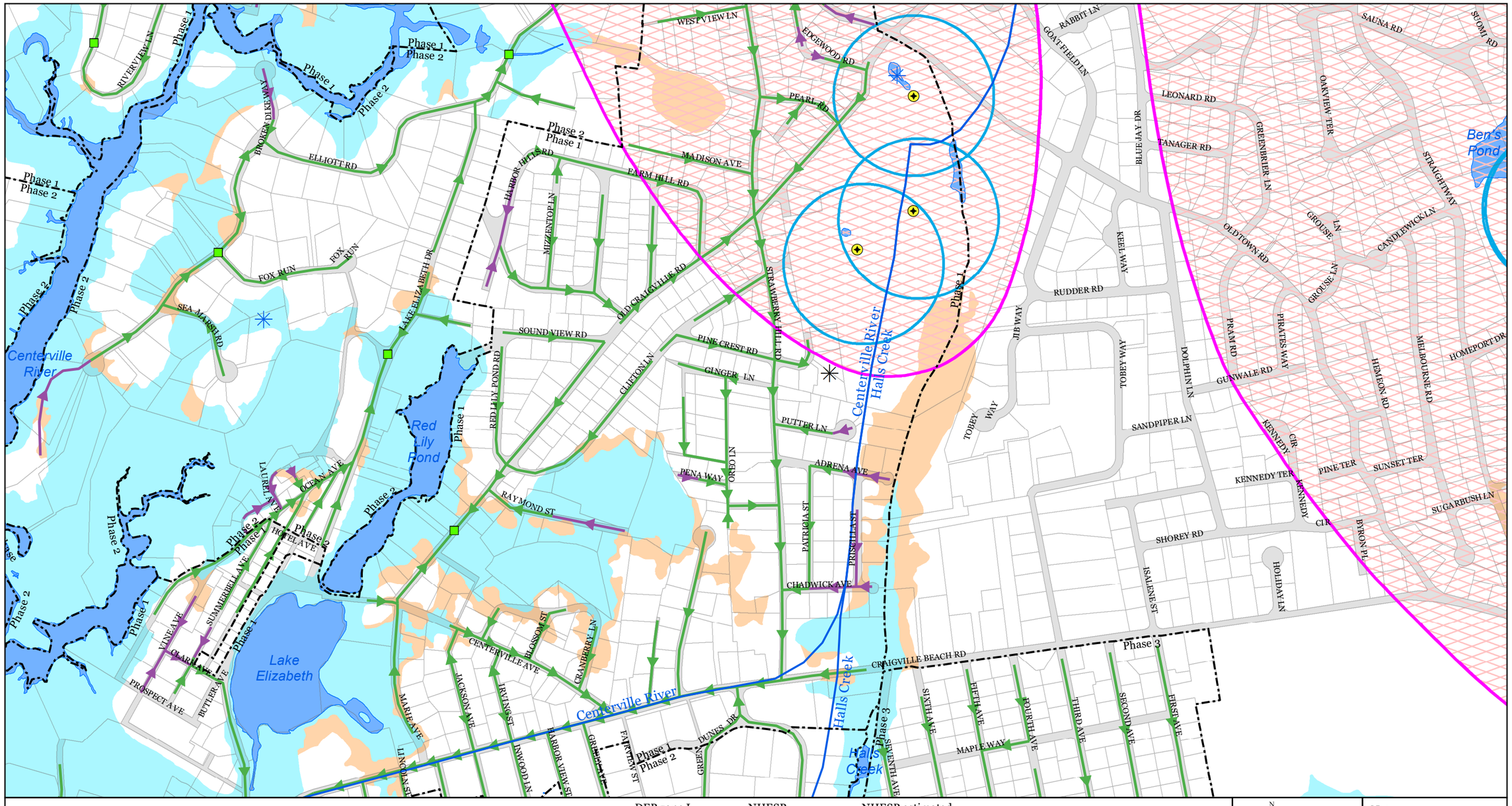
Centerville River
Red Lily Pond
Lake Elizabeth
Halls Creek
Ben's Pond
Phase 1
Phase 2
Phase 3
RIVERVIEW LN
BROKEN OAR WAY
ELLIOTT RD
FOX RUN
SEA MARSH RD
LAKE ELIZABETH DR
HARBOR HILLS RD
MIZZENTOP LN
WEST VIEW LN
EDGEWOOD RD
PEARL RD
MADISON AVE
FARM HILL RD
OLD CRAIGVILLE RD
STRAWBERRY HILL RD
SOUND VIEW RD
RED LILY POND RD
CLIFTON LN
PINE CREST RD
GINGER LN
PUTTER LN
PENA WAY
OREO LN
ADRENA AVE
PATRICIA ST
PRISCILLA ST
CHADWICK AVE
RAYMOND ST
LAUREL AVE
OCEAN AVE
HOTEL AVE
SUMMERBELL AVE
VINE AVE
CLARA AVE
PROSPECT AVE
BUTLER AVE
CENTERVILLE AVE
BLOSSOM ST
CRANBERRY LN
MARIE AVE
JACKSON AVE
IRVING ST
INWOOD LN
HARBOR VIEW ST
GREEN ST
FAIRVIEW ST
DUNES DR
LINCOLN ST
CRAIGVILLE BEACH RD
SIXTH AVE
FIFTH AVE
FOURTH AVE
THIRD AVE
SECOND AVE
FIRST AVE
SEVENTH AVE
MAPLE WAY
RABBIT LN
GOAT FIELD LN
BLUE JAY DR
LEONARD RD
TANAGER RD
KEEL WAY
RUDDER RD
JIB WAY
TOBEY WAY
TOBEY WAY
SANDPIPER LN
DOLPHIN LN
GUNWALE RD
PRAM RD
PIRATES WAY
KENNEDY CIR
KENNEDY TER
KENNEDY CIR
SHOREY RD
ISALENE ST
HOLIDAY LN
BYRON PL
PINE TER
SUNSET TER
SUGARBUSH LN
GREENBRIER LN
OAKVIEW TER
OLDTOWN RD
GROUSE LN
GROUSE LN
CANDLEWICK LN
STRAIGHTWAY
HOMEPORT DR
MELBOURNE RD
HEMLON RD
SAUNA RD
SUOMI RD
Conceptual pump station
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N
W
E
S
F5
feet
0 100 200 300 400 500
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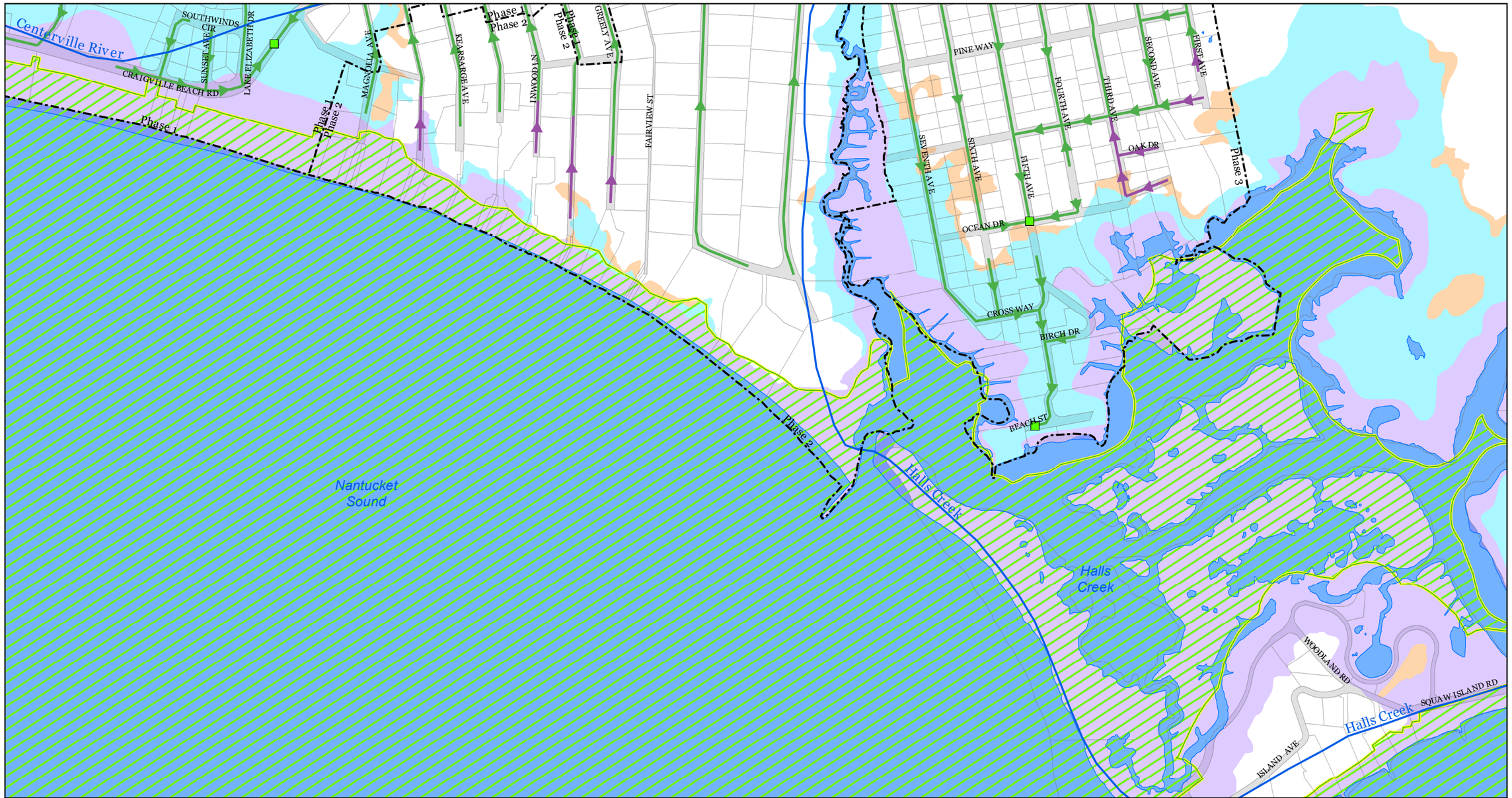
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28



- Conceptual pump station
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- Conceptual gravity sewer
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- Existing sewer
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- Watershed boundary
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- Proposed or proven public well
- DEP zone I wellhead protection area
- DEP zone II wellhead protection area
- NHESP certified vernal pools
- NHESP potential vernal pools
- NHESP estimated habitat of rare wildlife
- NHESP priority habitat of rare species
- Area of critical environmental concern (ACEC)
- FEMA velocity flood zone (VE)
- FEMA 100-year flood zone (AE)
- FEMA 0.2% annual chance of flooding (X)

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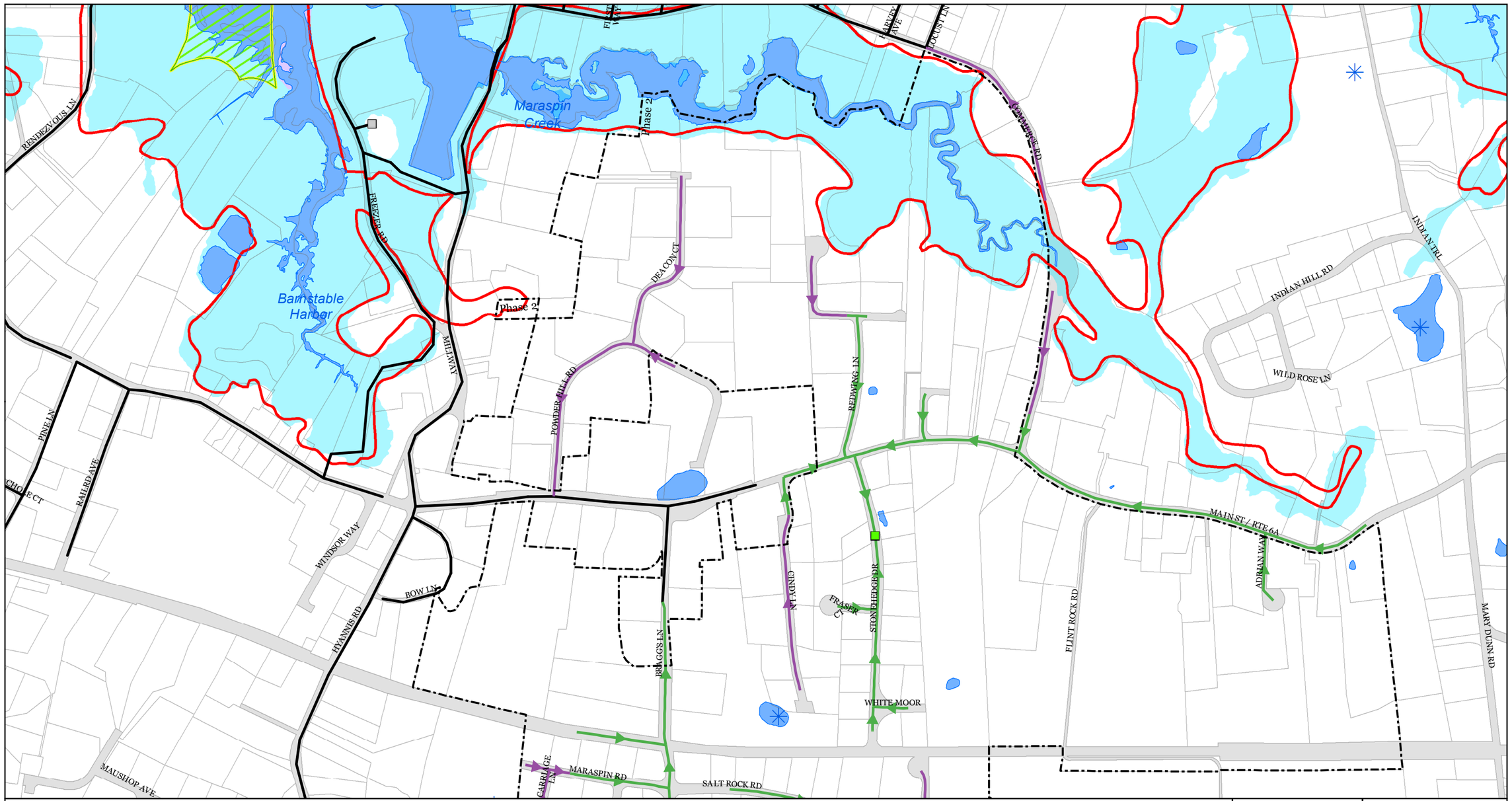
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


Maraspin Creek
Barnstable Harbor
Phase 2
Phase 2
RENDEZVOUS LN
FERNFIELD RD
MILLWAY
DEACON CT
POWDER HILL RD
REDWING LN
COMMERCE RD
LOCUST LN
HARVEY AVE
INDIAN TRL
INDIAN HILL RD
WILD ROSE LN
PINE LN
CHOATE CT
RAILROAD AVE
WINDSOR WAY
BOW LN
IYANNOUGH RD
BRAGGS LN
CINDY LN
FRASER CT
STONEHEDGE DR
WHITE MOOR
FLINT ROCK RD
ADRIAN WAY
MAIN ST / RTE 6A
MARY DUNN RD
CARRIAGE LN
MARASPIN RD
SALT ROCK RD
MAUSHOP AVE
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
DEP zone II wellhead protection area
NHESP certified vernal pools
NHESP potential vernal pools
NHESP estimated habitat of rare wildlife
NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
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1 inch = 500 feet
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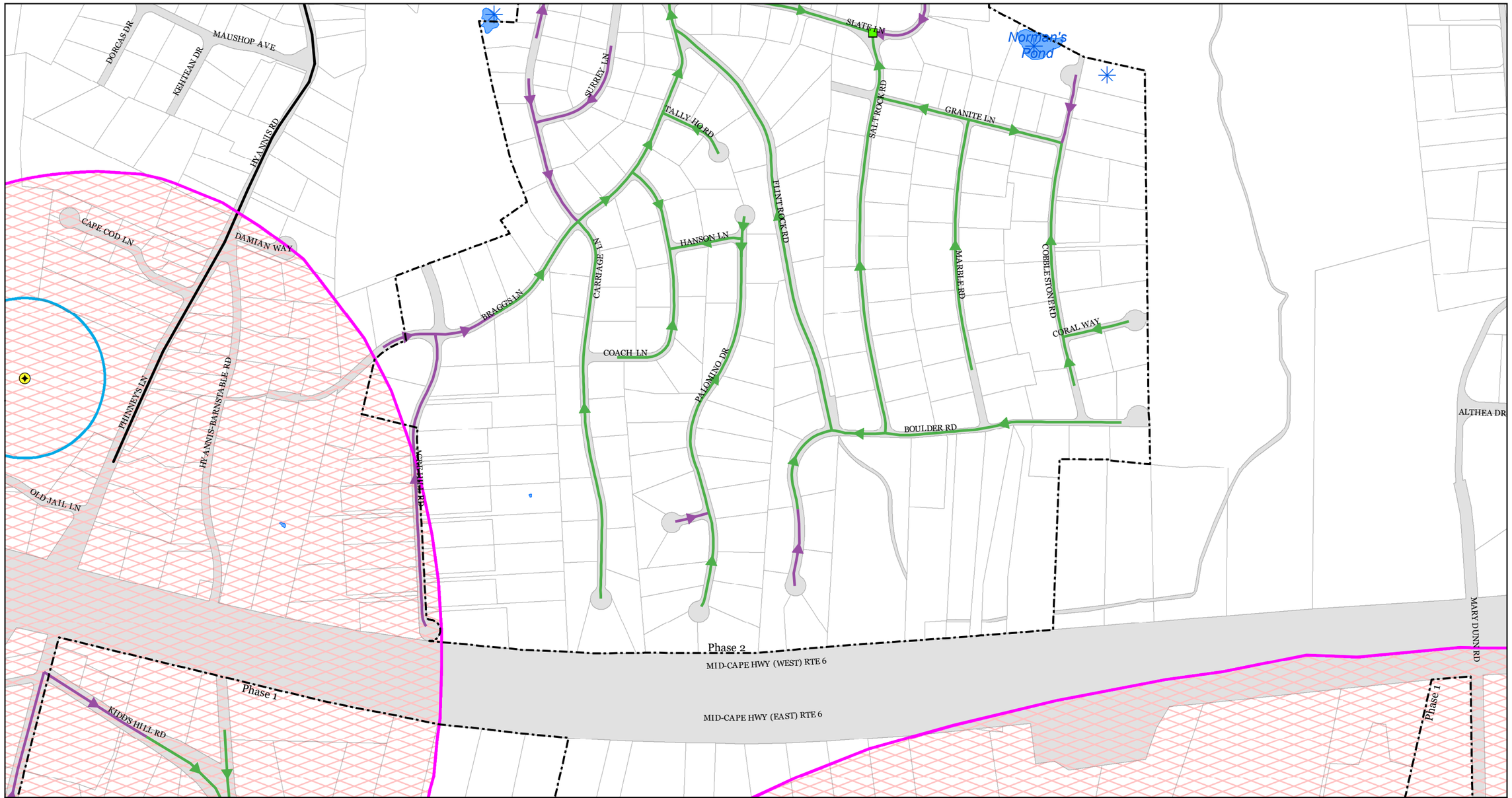
2) Conceptual sewer force mains only shown on Route 28



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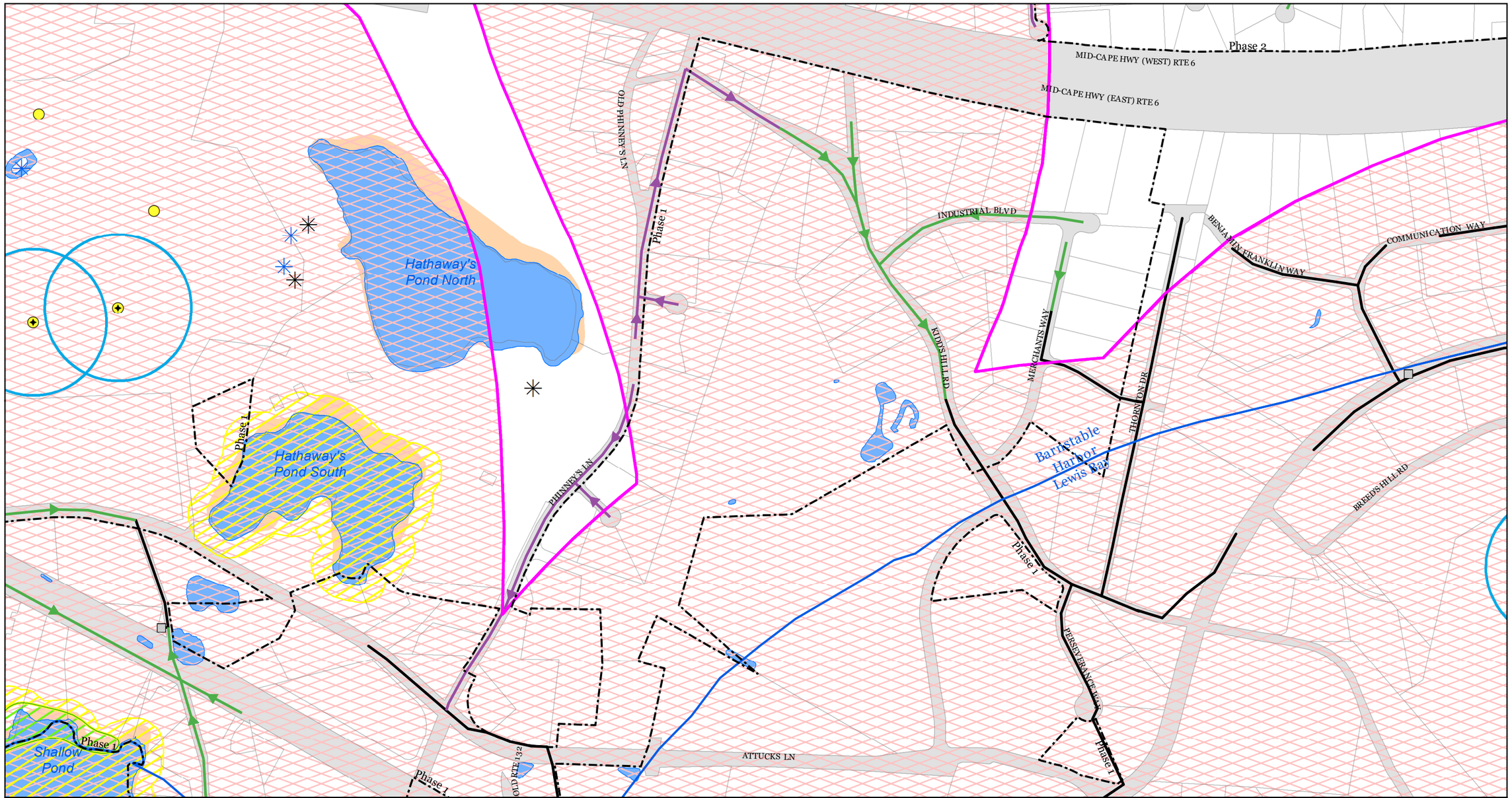
1 inch = 500 feet

Notes:
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28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MID-CAPE HWY (EAST) RTE 6
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Phase 1
INDUSTRIAL BLVD
KIDDS HILL RD
MERCHANTS WAY
BENJAMIN FRANKLIN WAY
COMMUNICATION WAY
THORNTON DR
Hathaway's Pond North
Hathaway's Pond South
Barnstable Harbor
Lewis Bay
PHINNEY'S LN
BREEDS HILL RD
PERSEVERANCE WAY
ATTUCKS LN
OLD RTE 132
Shallow Pond
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
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Sewer phase or sewer stage boundary
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NHESP potential vernal pools
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NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
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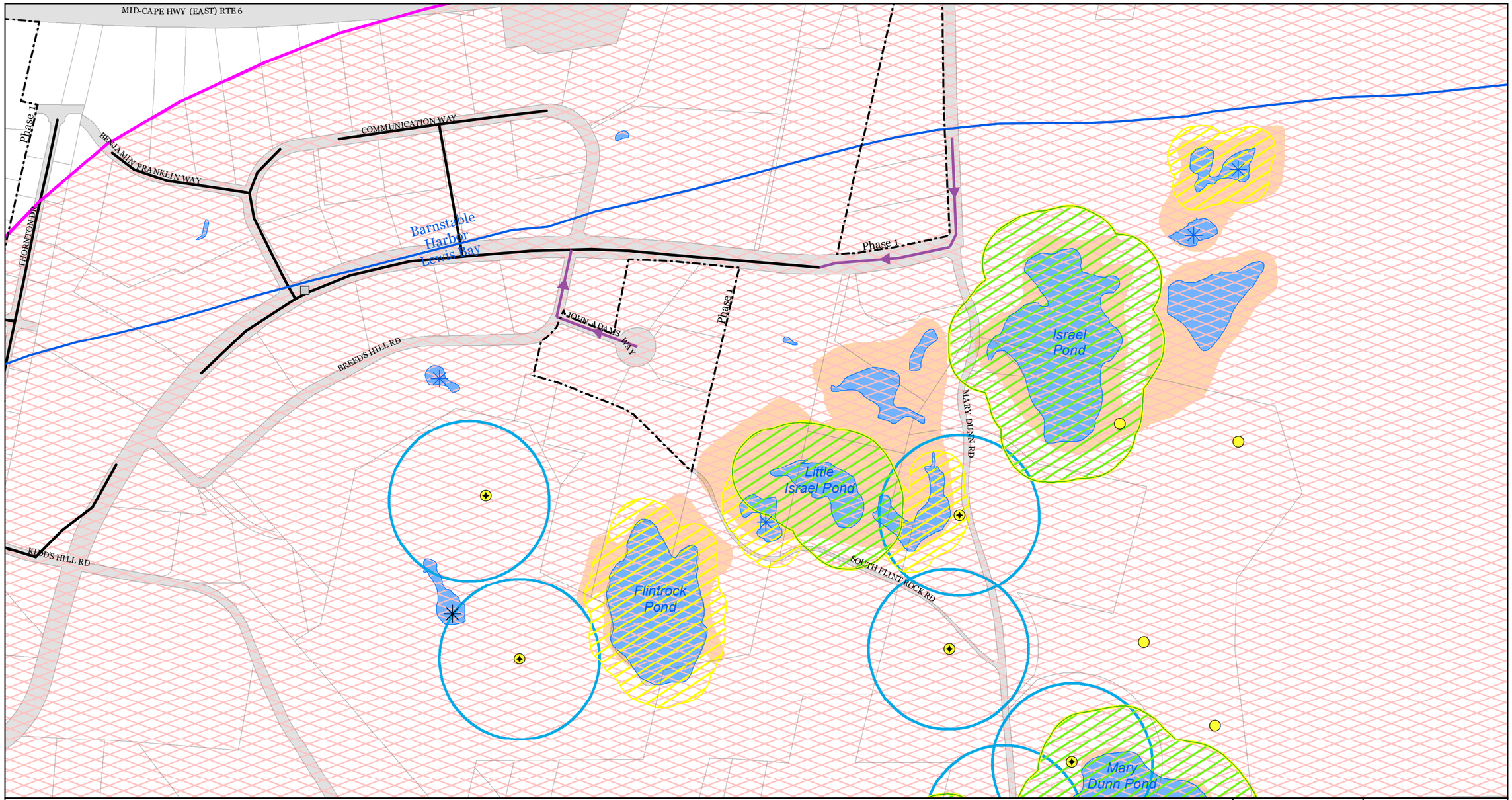
1) Pump station locations are approximate
2) Conceptual sewer force mains only shown on Route 28


MID-CAPE HWY (EAST) RTE 6
Phase 1
BENJAMIN FRANKLIN WAY
COMMUNICATION WAY
THORNTON DR
Barnstable Harbor
Lewis Bay
Phase 1
JOHN ADAMS WAY
BREED'S HILL RD
Phase 1
MARY DUNN RD
Israel Pond
Little Israel Pond
SOUTH FLINT ROCK RD
KIDDS HILL RD
Flintrock Pond
Mary Dunn Pond
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
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Area of critical environmental concern (ACEC)
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FEMA 0.2% annual chance of flooding (X)
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1 inch = 500 feet
Notes:
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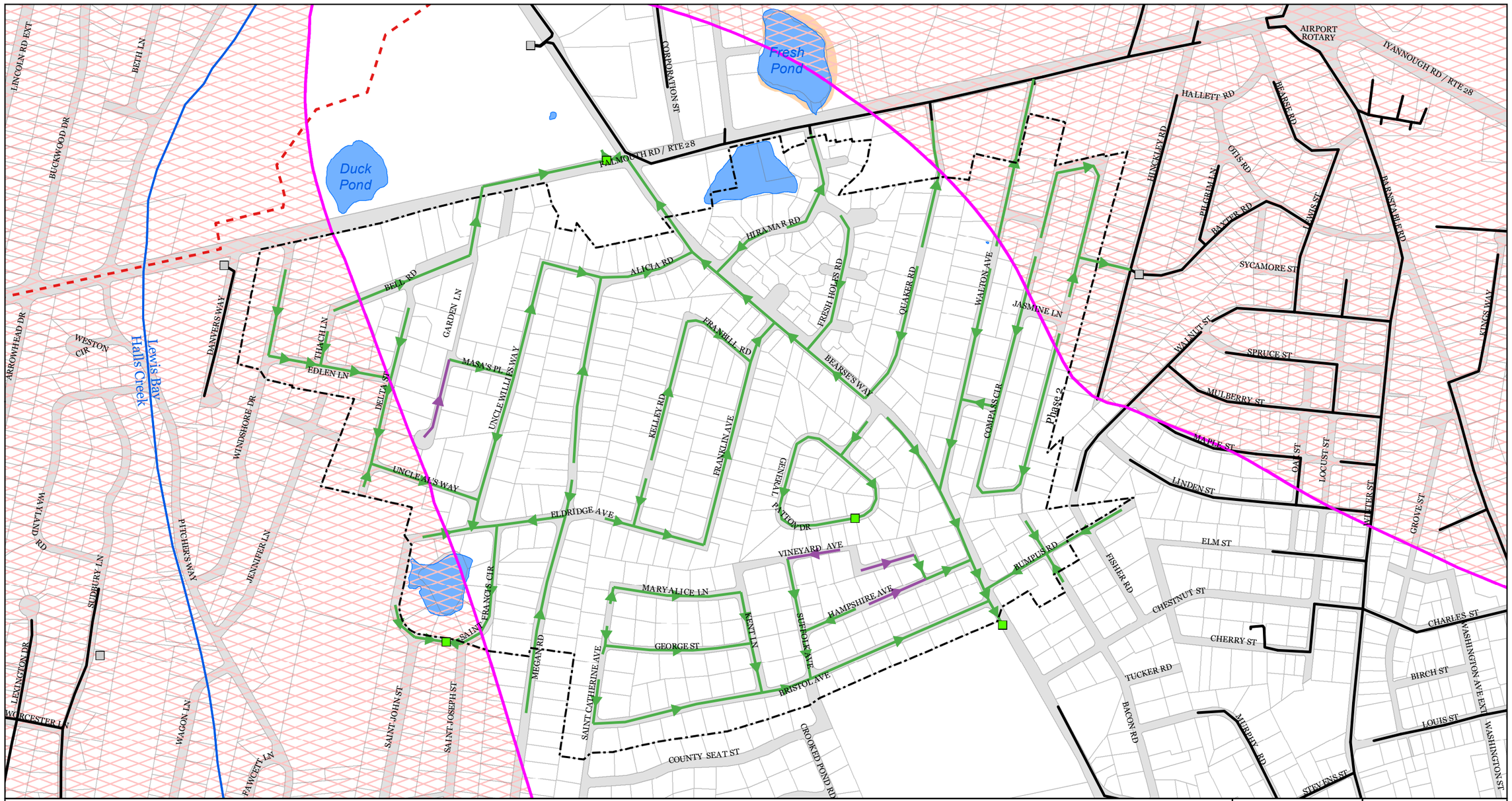

Fresh Pond
Duck Pond
Lewis Bay
Halls Creek
Phase 2
FALMOUTH RD / RTE 28
AIRPORT ROTARY
IYANNOUGH RD / RTE 28
CORPORATION ST
LINCOLN RD EXT
BETH LN
BUCKWOOD DR
ARROWHEAD DR
WESTON CIR
DANVERS WAY
WINDSHORE DR
WAYLAND RD
SUDBURY LN
LEXINGTON DR
WORCESTER LN
PITCHER'S WAY
JENNIFER LN
WAGON LN
FAWCETT LN
SAINT JOHN ST
SAINT JOSEPH ST
SAINT FRANCIS CIR
MEGAN RD
SAINT CATHERINE AVE
BELL RD
THACH LN
EDLEN LN
DELTA ST
GARDEN LN
MASA'S PL
UNCLE WILLIES WAY
UNCLE AL'S WAY
ELDRIDGE AVE
ALICIA RD
HIRAMAR RD
KELLEY RD
FRANKLIN AVE
FRANBILL RD
FRESH HOLES RD
QUAKER RD
WALTON AVE
JASMINE LN
BEARSE'S WAY
COMPASS CIR
GENERAL PATTON DR
VINEYARD AVE
MARY ALICE LN
GEORGE ST
KENT LN
SUFFOLK AVE
HAMPSHIRE AVE
BRISTOL AVE
COUNTY SEAT ST
CROOKED POND RD
BUMPUS RD
FISHER RD
HALLETT RD
HINCKLEY RD
PILGRIM LN
OTIS RD
BEARSE RD
BAXTER RD
LEWIS ST
BARNSTABLE RD
SYCAMORE ST
WALNUT ST
SPRUCE ST
MULBERRY ST
MAPLE ST
OAK ST
LOCUST ST
LINDEN ST
WINTER ST
GROVE ST
KINGS WAY
ELM ST
CHESTNUT ST
CHERRY ST
CHARLES ST
BIRCH ST
LOUIS ST
WASHINGTON AVE EXT
WASHINGTON ST
TUCKER RD
BACON RD
MURPHY RD
STEVENS ST
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
Existing public well
Proposed or proven public well
DEP zone I wellhead protection area
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NHESP priority habitat of rare species
Area of critical environmental concern (ACEC)
FEMA velocity flood zone (VE)
FEMA 100-year flood zone (AE)
FEMA 0.2% annual chance of flooding (X)
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1 inch = 500 feet
Notes:
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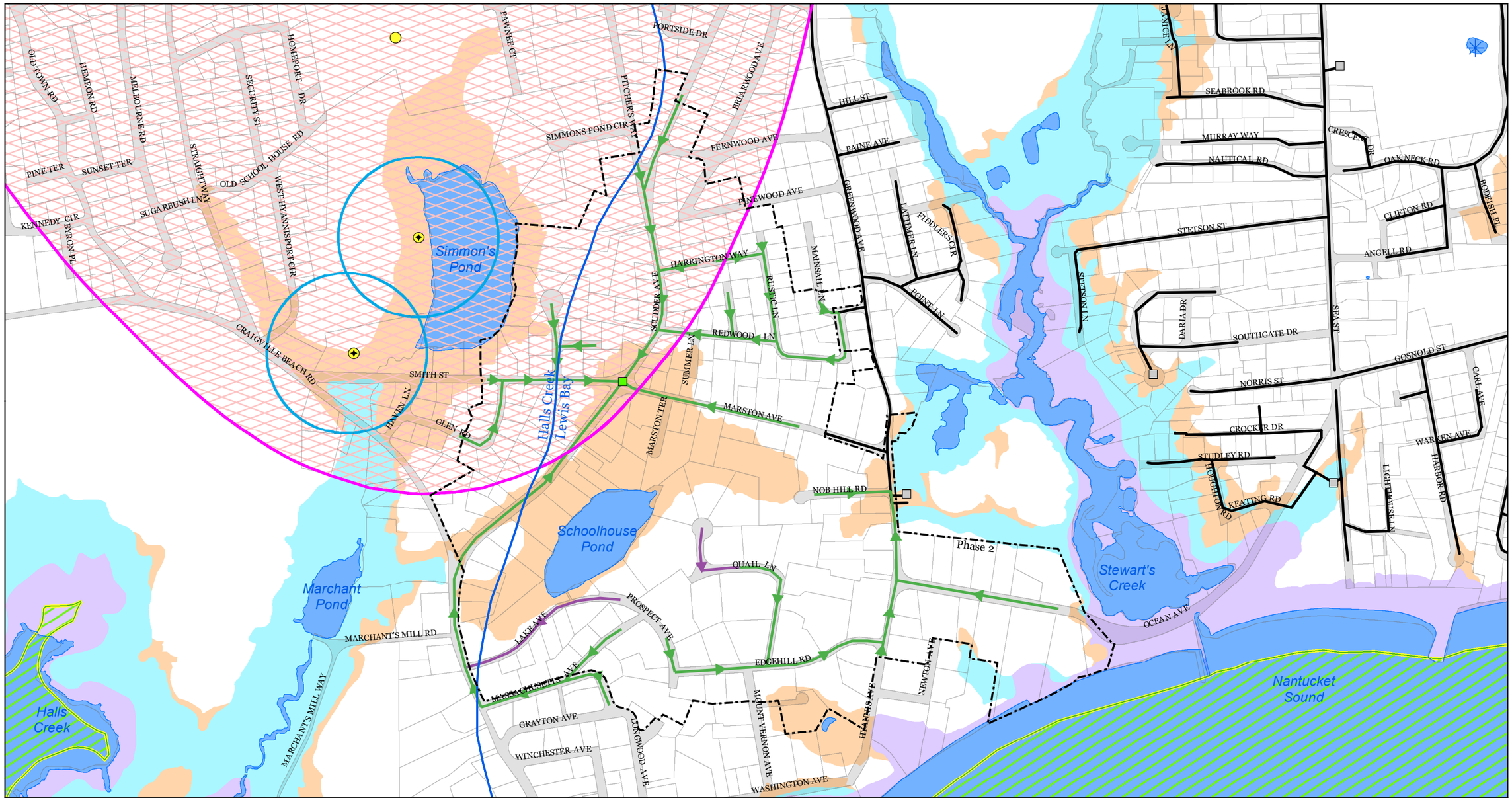
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HEMLOCK RD
MELBOURNE RD
HOMEPORT DR
SECURITY ST
PAWNEE CT
PORTSIDE DR
BRIARWOOD AVE
PINE TER
SUNSET TER
STRAIGHTWAY
OLD SCHOOL HOUSE RD
WEST HYANNISPORT CIR
SIMMONS POND CIR
PITCHER'S WAY
FERNWOOD AVE
KENNEDY CIR
BYRON PL
SUGARBUSH LN
PINEWOOD AVE
Simmon's Pond
HARRINGTON WAY
SCUDDER AVE
RUSTIC LN
MAINSAIL LN
REDWOOD LN
SUMMER LN
CRAIGVILLE BEACH RD
SMITH ST
HAVEN LN
GLEN RD
MARSTON TER
MARSTON AVE
Halls Creek
Lewis Bay
NOB HILL RD
Schoolhouse Pond
QUAIL LN
Phase 2
Marchant Pond
LAKE AVE
PROSPECT AVE
MARCHANT'S MILL RD
EDGEHILL RD
NEWTON AVE
MARCHANTS MILL WAY
MASSACHUSETTS AVE
GRAYTON AVE
WINCHESTER AVE
LONGWOOD AVE
MOUNT VERNON AVE
HYANNIS AVE
WASHINGTON AVE
Halls Creek
Stewart's Creek
OCEAN AVE
Nantucket Sound
JANICE LN
SEABROOK RD
MURRAY WAY
CRESCENT DR
NAUTICAL RD
OAK NECK RD
HODDISH PL
CLIFTON RD
STETSON ST
ANGELL RD
STETSON LN
DARIA DR
SOUTHGATE DR
SEA ST
GOSNOLD ST
NORRIS ST
CARL AVE
CROCKER DR
WARREN AVE
STUDLEY RD
HOUGHTON RD
KEATING RD
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HARBOR RD
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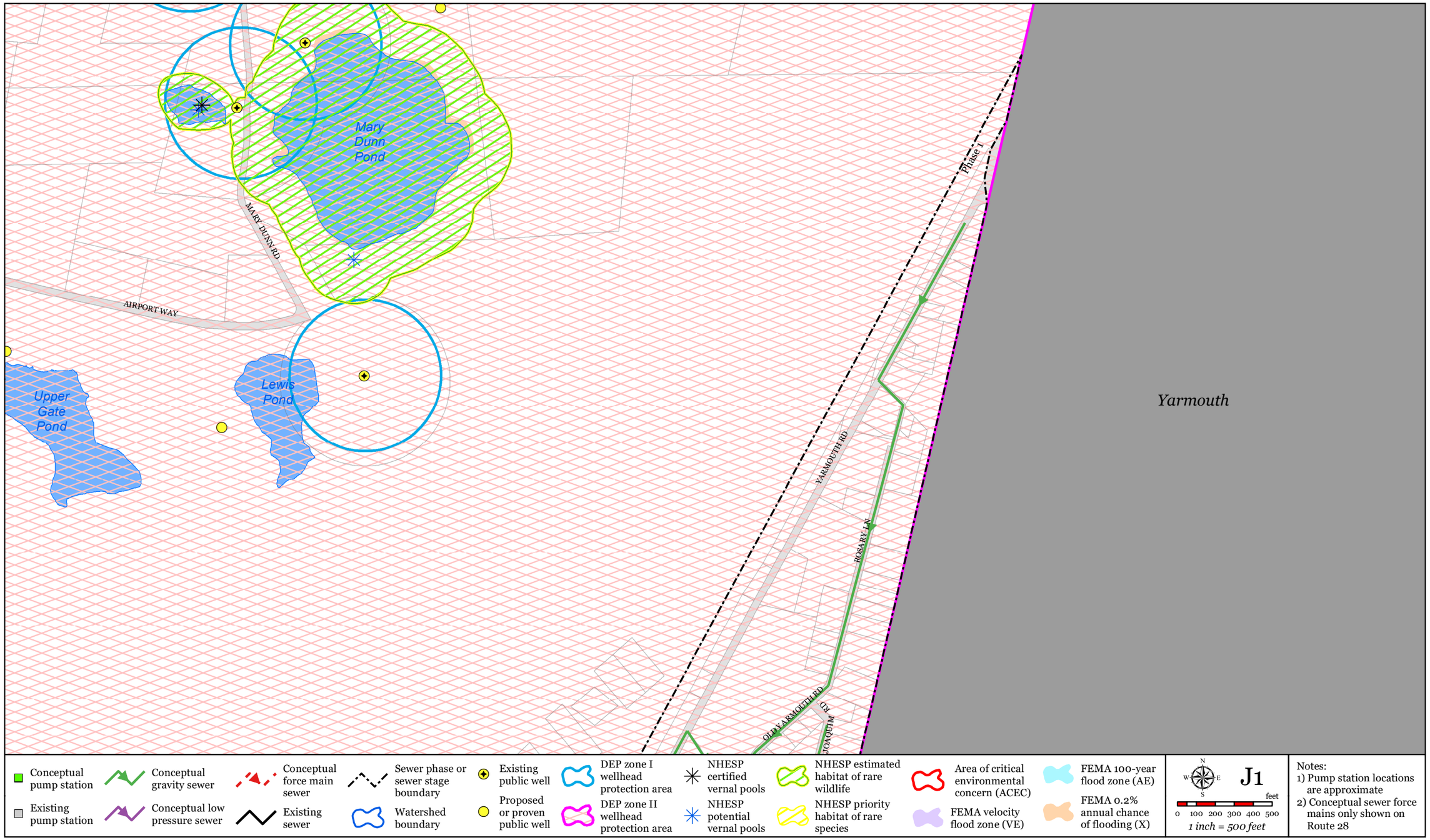
Mary Dunn Pond
Lewis Pond
Upper Gate Pond
MARY DUNN RD
AIRPORT WAY
Phase I
YARMOUTH RD
ROSARY LN
OLD YARMOUTH RD
Yarmouth
Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
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Proposed or proven public well
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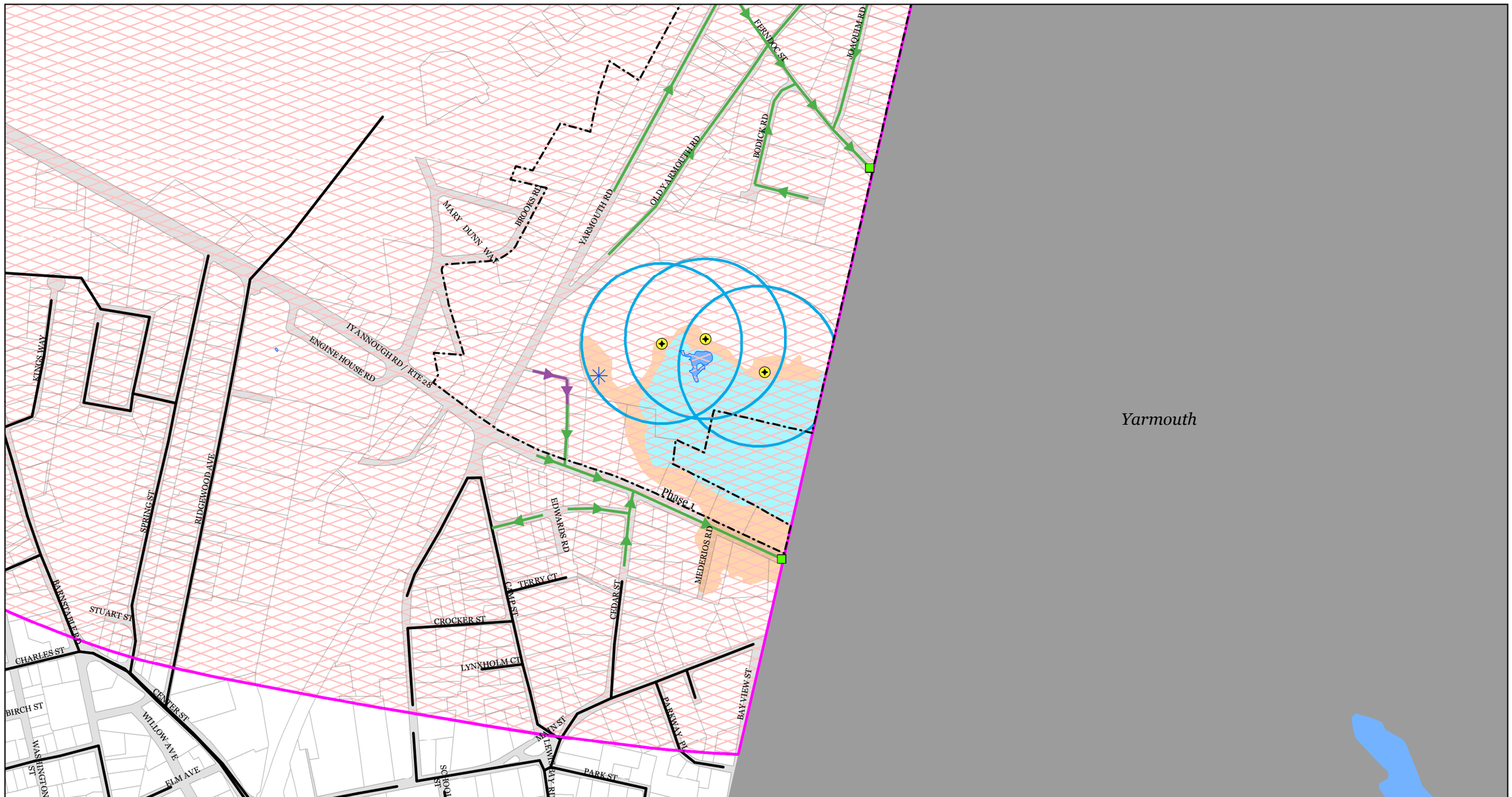

Conceptual pump station
Existing pump station
Conceptual gravity sewer
Conceptual low pressure sewer
Conceptual force main sewer
Existing sewer
Sewer phase or sewer stage boundary
Watershed boundary
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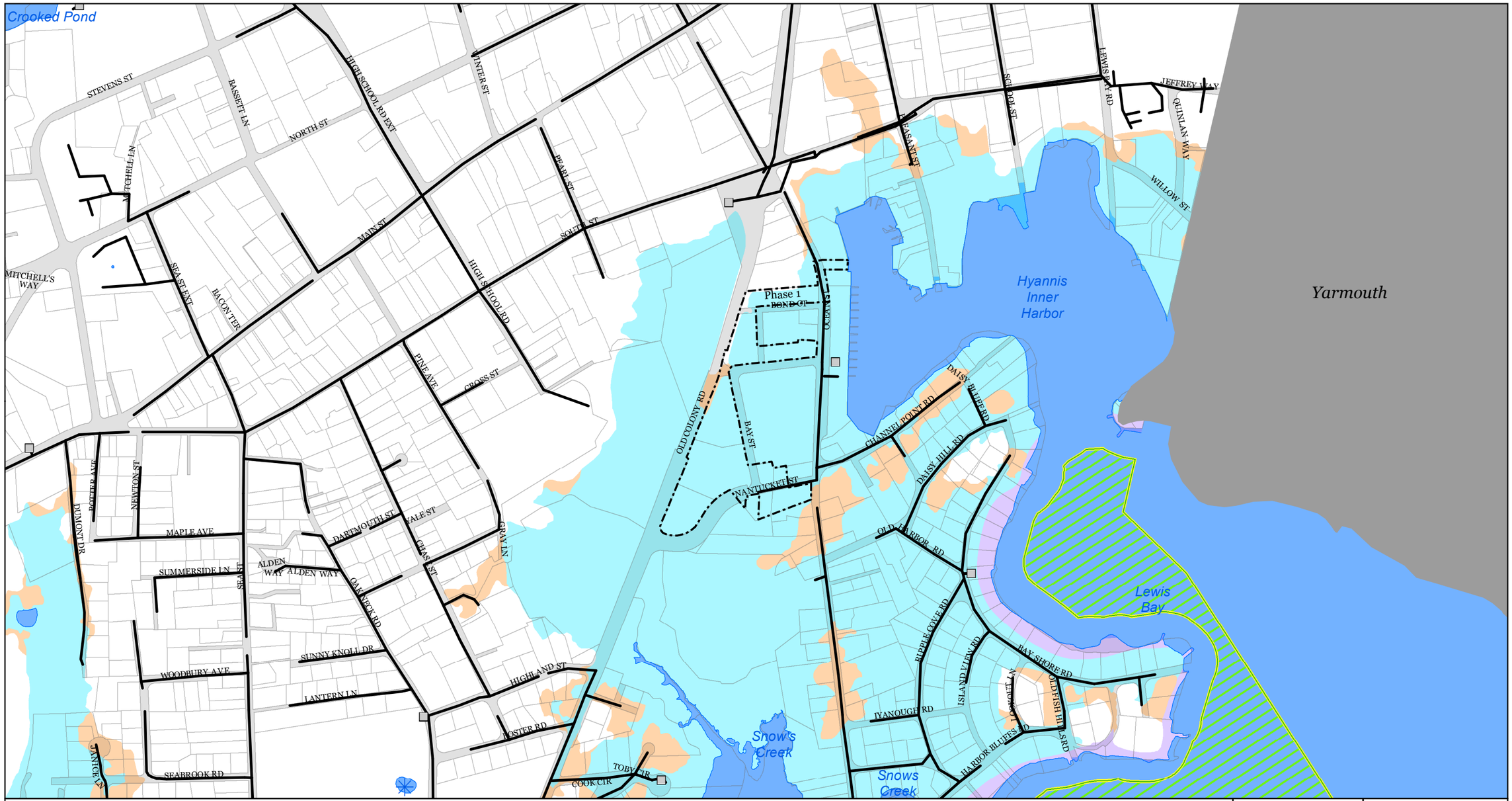
Crooked Pond
STEVENS ST
BASSETT LN
NORTH ST
HIGH SCHOOL RD EXT
WINTER ST
PEARL ST
SCHOOL ST
LEWIS BAY RD
JEFFREY WAY
QUINLAN WAY
WILLOW ST
PHEASANT ST
MITCHELL LN
MAIN ST
SOUTH ST
MITCHELL'S WAY
SEA ST EXT
BACON TER
HIGH SCHOOL RD
Phase 1
BOND CT
QUEEN ST
Hyannis Inner Harbor
Yarmouth
OLD COLONY RD
BAY ST
NANTUCKET ST
CHANNEL POINT RD
DAISY BLUFF RD
DAISY HILL RD
OLD HARBOR RD
RIPPLE COVE RD
ISLAND VIEW RD
BAY SHORE RD
ODDFISH HILL RD
HARBOR BLUFFS RD
IVANOUGH RD
Lewis Bay
Snow's Creek
Snows Creek
TOBY CIR
COOK CIR
FOSTER RD
HIGHLAND ST
LANTERN LN
SEABROOK RD
JANICE LN
WOODBURY AVE
SUNNY KNOLL DR
OAK NECK RD
ALDEN WAY
SUMMERSIDE LN
SEA ST
DUMONT DR
MAPLE AVE
NEWTON ST
DARTMOUTH ST
GALE ST
CHASE ST
GRAY LN
PINE AVE
CROSS ST
Conceptual pump station
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feet
0 100 200 300 400 500
1 inch = 500 feet
Notes:
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2) Conceptual sewer force mains only shown on Route 28

Appendix XX

CDM Smith Effluent Disposal Capacity Study

Barnstable Effluent Discharge Study

May 2020



CDM Smith

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Executive Summary

Recharge capacity at the Barnstable Water Pollution Control Facility (BWPCF) is currently limited due to concerns about flooding downgradient of the infiltration beds at low-lying areas, particularly beneath houses adjacent to existing ponds. The current groundwater discharge permit maximum day discharge is 2.7 million gallons per day (MGD). The average monthly discharge ranges from 1.4 MGD to 1.9 MGD based on 2014 through 2018 BWPCF records with an annual average discharge of 1.6 MGD for that period. The Town of Barnstable plans to expand the existing sanitary collection system and treatment plant as part of the Comprehensive Wastewater Management Plan (CWMP). This study includes additional fieldwork to identify the depth and extent of clay beneath the BWPCF, the development of steady-state and transient groundwater models which include this clay and the simulation of five scenarios.

The five scenarios include a transient simulation to identify the seasonal site capacity at the BWPCF based on impacts to off-site groundwater levels (Scenario 1), simulations of travel times to public water supply wells under both transient (Scenario 2) and steady-state conditions (Scenario 3), steady-state simulation of the feasibility of groundwater withdrawals in order to increase the BWPCF site capacity while protecting downgradient areas (Scenarios 4A/4B), and steady-state simulation of the impacts from potential sea level rise (Scenarios 5A/5B).

Findings

The geophysical survey and borings advanced as part of the 2019 site investigation at the BWPCF and the 2019 geophysical survey identified an extensive clay and silt layer under the site. The observed head difference of 6 feet (ft) and lack of response to changes in observed water levels during focused loading at the well beneath the clay/silt indicates that this clay layer limits the vertical flow of groundwater. The depth of the clay/silt layer is variable from 55 to 107 feet below ground surface (ft bgs). Borings outside the BWPCF site suggest the clay is laterally extensive and generally at an elevation of approximately 0 to -40 ft NGVD29.

Effluent recharge capacity is limited primarily by depth to water at low lying areas, particularly near St. Francis Circle. The site effluent recharge capacity varies depending on the amount of recharge from precipitation over the preceding three months. The estimated average annual site effluent recharge capacity is 2 MGD. (Scenario 1) The effluent recharge rate for the BWPCF is currently at or near the simulated effluent recharge capacity during the months of March through June. Figure ES-1 shows the average reported monthly flows and estimated monthly site recharge capacity. The error bars show the range of flows and simulated monthly capacity for the period from 2014 through 2018.

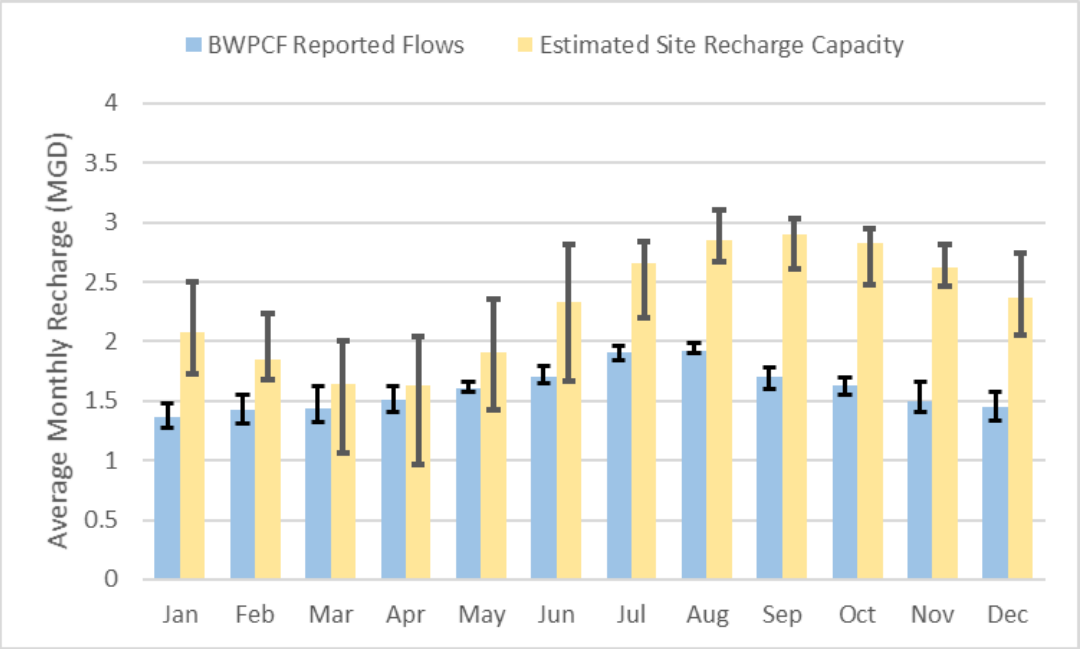


Figure ES-1: BWPCF Reported Flows and Simulated Monthly Capacity from 2014 through 2018

Impacts to public water supply wells are greater than 5 years time of travel both in the transient conditions, based on the last five years of pumping and recharge, and steady-state conditions, with the higher seasonal capacity and permitted pumping rates at nearby wells. (Scenarios 2 and 3)

Withdrawal of water can reduce groundwater levels to acceptable levels off-site, however, nearly all water above the site capacity needs to be withdrawn. The feasibility of focused groundwater withdrawals was simulated using steady-state scenarios and should be reviewed in a transient simulation due to the 3-month lag in the water table in response to changes in recharge. The simulation assumes that any water withdrawals will be discharged to the aquifer far enough from the site to prevent impacts to the water table. (Scenarios 4A and 4B)

In addition to coastal inundation, a sea level rise of 2-ft will increase the baseline groundwater elevations at the site by approximately 0.8 ft (USGS 2016). The simulations of sea level rise assumed increased pumping at public water supply wells at nearly four times the current pumping rates. Because of this increased pumping, steady-state simulations based on the estimated site recharge capacity of 2 MGD did not show increases in the water table beneath structures. (Scenario 5A). The steady-state simulation of build-out conditions with a recharge rate of 6 MGD (Scenario 5B) showed areas with groundwater depth of less than 8 feet near St. Francis Circle, Barnstable High School, Enterprise Road/Cape Cod Mall and near Fawcetts Pond.

Recommendations

Based on the findings of this study, the following recommendations are being made:

- Use focused loading data and detailed depth to clay information to fine tune the model beneath the site and optimize bed loading. The elevation of the layer beneath beds 40 to 48 is high and it may be possible to take these beds off-line to allow for treatment plant expansion, if needed.
- Collect water level data at St. Francis Circle to evaluate the response to site loading rates, precipitation and background groundwater levels. An off-site sentinel well which is not impacted by the BWPCF should be monitored to provide information on aquifer response to recharge from precipitation.
- Develop a predictive tool based on water levels in sentinel and downgradient wells, recorded precipitation and climate data (temperature) to estimate the actual recharge in the prior 3 months and predict monthly site capacity.
- Optimize placement and pumping rates for focused feasibility withdrawals with steady-state and transient modeling. Determine the seasonal impacts to pumping withdrawals using the transient model and simulate the impacts from recharge of withdrawn water.
- Identify secondary loading sites for potential wastewater recharge. Evaluate the impact of recharge at the secondary loading sites including the additive impacts from the mounding due to the BWPCF recharge beds.
- Verify well depths and conduct downhole geophysics to identify clay layers at selected locations where data was unclear.
- Improve the simulation of lakes and ponds, particularly Wequaquet Lake, in the groundwater model using the Lake Package in MODFLOW. This will allow for simulation of the resistance of lake bed sediments to flow and simulation of water levels based on lake and pond bathymetry.
- The risks of increased effluent discharge at the BWPCF should be quantified.
- The groundwater flow model should be utilized to determine impacts to groundwater of potential effluent recharge sites.

Section 1
Introduction

Recharge capacity at the Barnstable Water Pollution Control Facility (BWPCF), shown on **Figure 1,** is currently limited due to concerns about flooding downgradient of the infiltration beds at low-lying areas, particularly existing ponds. The current groundwater discharge permit maximum day flow capacity is 2.7 MGD. The average monthly discharge flow ranges from 1.4 MGD to 1.9 MGD based on 2014 through 2018 BWPCF records with an annual average discharge flow of 1.6 MGD for that period. The Town of Barnstable plans to expand the existing sanitary collection system and treatment plant as part of their Comprehensive Wastewater Management Plan (CWMP) program. This study includes additional fieldwork to identify the depth and extent of clay beneath the BWPCF, development and calibration of steady-state and transient groundwater models which include this clay and simulations of five scenarios.

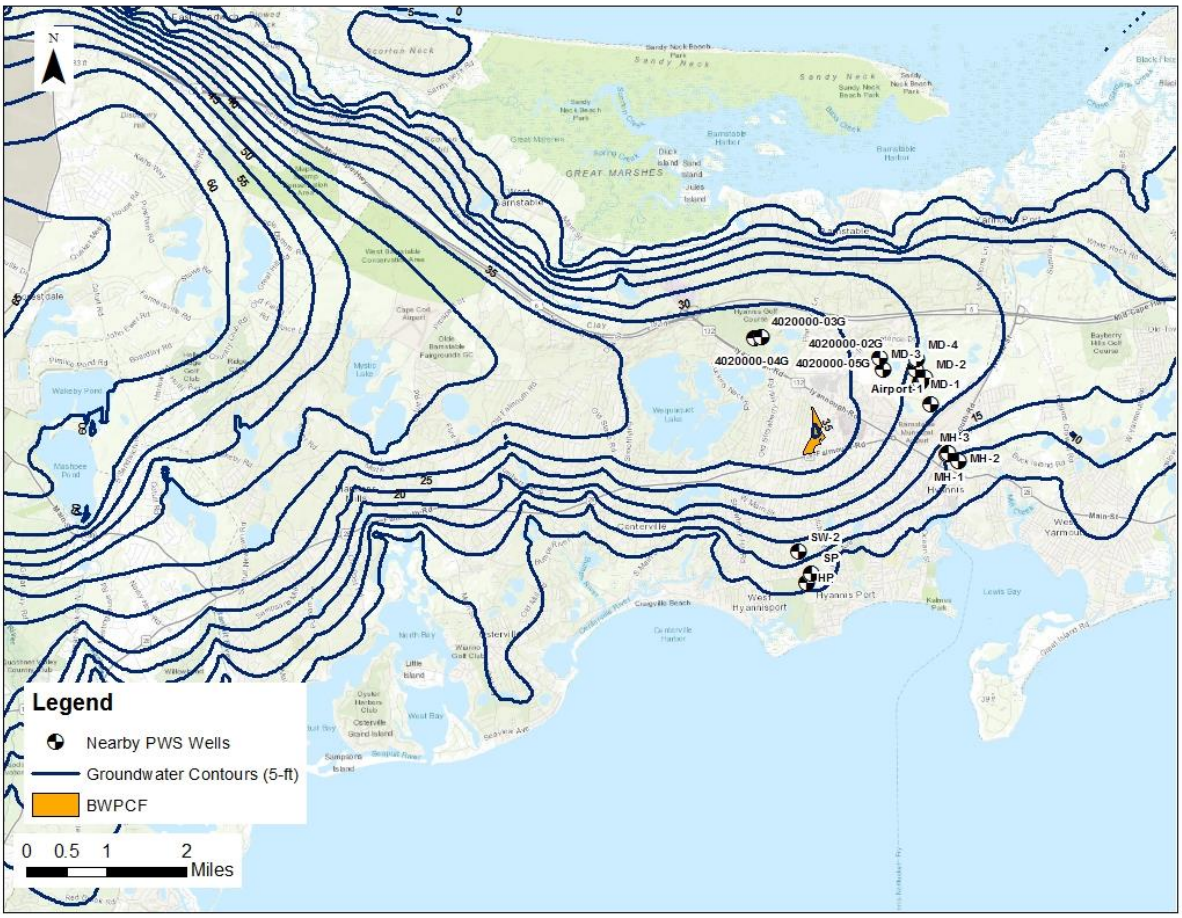


Figure 1: BWPCF Location and Regional Groundwater Contours

The five scenarios include a transient simulation to identify the seasonal site capacity at the BWPCF based on impacts to off-site groundwater levels (Scenario 1), travel times to public water supply wells under both transient (Scenario 2) and steady-state conditions (Scenario 3), the feasibility of withdrawals in order to increase the BWPCF site capacity while protecting downgradient areas (Scenarios 4A/4B), and the impacts from potential sea level rise (Scenarios 5A/5B).

Groundwater levels in Barnstable fluctuate several feet during a year due to changes in monthly recharge from precipitation and septic and wastewater return flows. Recharge is highest in the winter and spring and lowest in the summer and fall. Average groundwater levels also fluctuate several feet from year to year. Depth to groundwater measurements taken between 1976 and 2019 at Well MA-A1W 306, located at the Barnstable High School, have a range of almost 8 feet from 20.8 feet below ground surface (ft bgs) in 1998 to 28.5 ft bgs in 2002. Water levels are highest in late spring (April, May and June).

Due to the seasonal population in Barnstable, wastewater flows are highest during the summer and lowest during the winter. The BWPCF currently has issues with discharge capacity during high water periods in late spring and during extended wet periods, such as in the summer of 2018. The transient groundwater model developed for this study allows for estimation of the seasonal capacity of the BWPCF using the period from 2014 through 2018 which includes both wet and dry periods.

Section 2
Field Work

The hydrogeology of the BWPCF site has been extensively studied (Maravell et al., 1984; Cambareri, 1986; Geraghty and Miller, 1995; Stearns and Wheler, 2003; Stearns and Wheler, 2005; Stearns and Wheler, 2011; Watershed Hydrologic, Inc., 2014; GHD, 2017). Existing data was reviewed to identify data gaps. Based on the data review, a field program was developed and implemented that included boring and well installation, geophysical surveys, slug testing and focused loading at the recharge beds. The information gathered as part of the field work investigation, as well as an evaluation of prior reports, were used to refine the site conceptual model and update the numerical groundwater flow model.

2.1 Existing Data

Several sources of existing data were utilized to help refine and calibrate the model near the BWPCF. These sources included publicly available well and water level data from the Massachusetts Department of Environmental Protection (MassDEP) and the United States Geological Survey (USGS), as well as site-specific data from previous studies conducted near BWPCF. Existing data was imported along with the new data collected from the field program to a three-dimensional visualization and analysis (3DVA) model in Leapfrog Works. The 3DVA model was used to estimate the depth and lateral extent of clay beneath the site based on existing boring logs and cross-sections from previous studies.

2.1.1 DEP Well database

MassDEP maintains a web-based database of groundwater wells in Massachusetts for use by the well drilling industry, local, state, and Federal governments, and the general public. Groundwater well information including location, completion date, well type, total depth, and measured water level was downloaded from the Energy and Environmental Affairs (EEA) Data Portal for all documented wells located in Barnstable (EEA 2019). Well drilling logs were also downloaded for wells located near BWPCF, if available. A total of 1,777 wells were identified in Barnstable through the EEA Data Portal **(Figure 2**)**.** Not all wells in the database have boring logs accessible online and the quality of the boring log information varies. Of the wells near the site, a total of 127 well logs were considered suitable for the study and were included in the 3DVA model. The remaining wells were not included in the model due to missing or poor quality data.

The USGS also maintains a web-based database of groundwater wells through the National Water Information System (NWIS 2019). A total of 170 wells were identified in NWIS near BWPCF, 119 of which had lithology logs available. Lithology logs were downloaded, digitized, and reviewed, with a focus on the presence or absence of a clay lens.

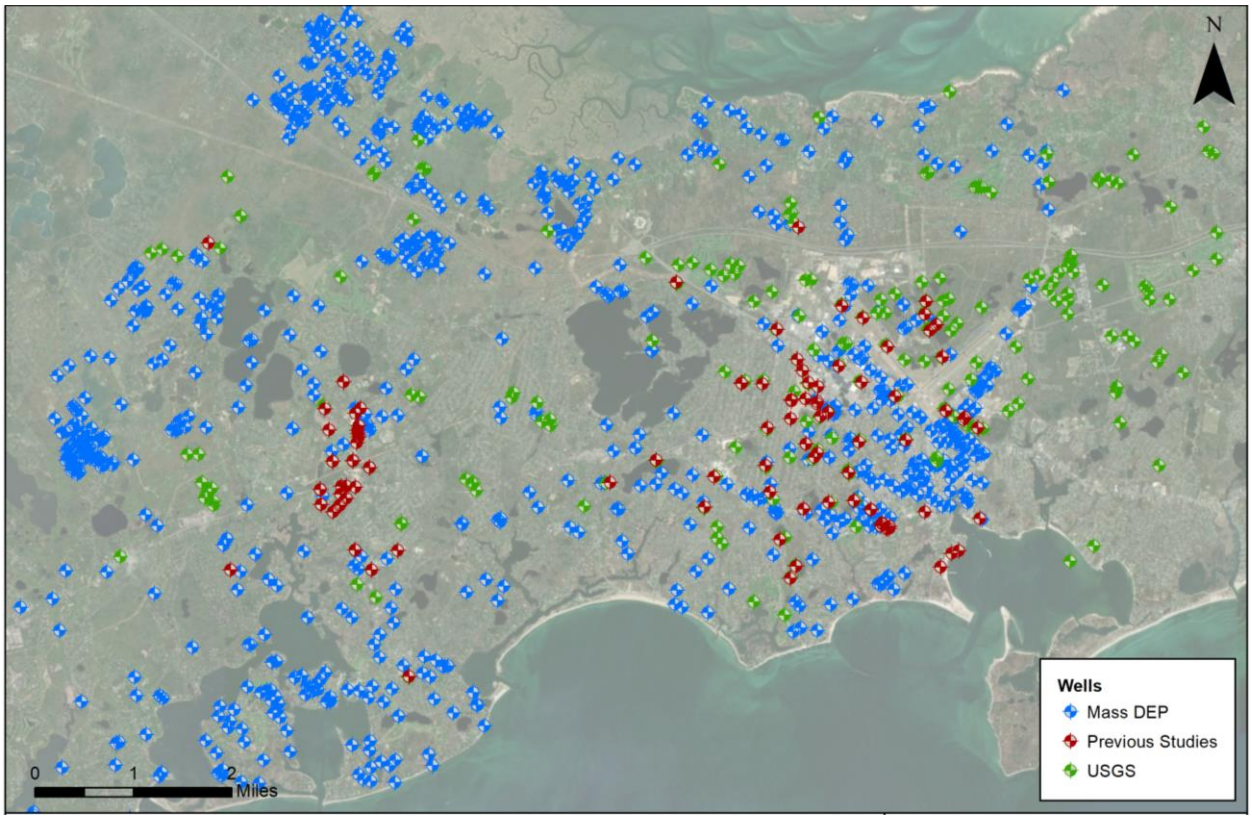


Figure 2: Existing Well Locations – Barnstable

2.1.2 Previous Studies

Extensive work has been conducted by the USGS on the hydrogeology of Cape Cod. This includes development and application of regional numerical groundwater flow models documented in multiple USGS reports including the most recent reports Walter and Whealan 2004, Carlson et al 2015 and Walter et al 2016. In particular, USGS regional cross-sections D-D' and I-I' from Masterson and Barlow 1997, shown on **Figure 3** in green, provided regional interpretations of the geology for the area, which were used in the development of the numerical groundwater model. These cross-sections are provided in Appendix G as part of the 3d visualization.

Previous locally-focused studies and investigations near BWPCF were also reviewed to refine the conceptual model near the site. Wherever possible, cross sections and well data including lithologic logs, well screen intervals, and water level measurements were digitized and imported to the 3DVA model. The following reports were reviewed in this regard:

- Maravell, W., Cambareri, T., Lambert, F., & Campo, J. (1984). *Evaluation of Monitoring Well Data for the Town of Barnstable, Mass Wastewater Treatment Facility.*
- Cambareri, T. C. (1986, September). *Hydrogeology and Hydrogeochemistry of a Sewage Effluent Plume in the Barnstable Outwash of the Cape Cod Aquifer Hyannis, Massachusetts* (Master's thesis). University of Massachusetts, Department of Geology and Geography.

- Geraghty and Miller (1995). *Modeling Analysis to Evaluate Capacity of Groundwater System at WPCF to Accept Treated Wastewater Discharge.*
- Stearns and Wheler (2003). *Effluent Mitigation Investigation Project Task 2 - Groundwater Elevation Monitoring Program.*
- Stearns and Wheler (2005). *Effluent Mitigation Investigation Project Task 3 - Benchmark Evaluation.*
- Stearns and Wheler (2011). *Final Needs Assessment Report Volume 1 – Comprehensive Wastewater Management Planning Project for the Town of Barnstable.*
- Watershed Hydrogeologic, Inc. (2014). *Technical Memorandum No. 1 Town of Barnstable Groundwater Model Development – A watershed hydrogeologic groundwater model.*
- GHD (2017). *Nutrient Management Plan and Additional Services Hyannis WPCF Groundwater Modeling Results Town of Barnstable, MA.*

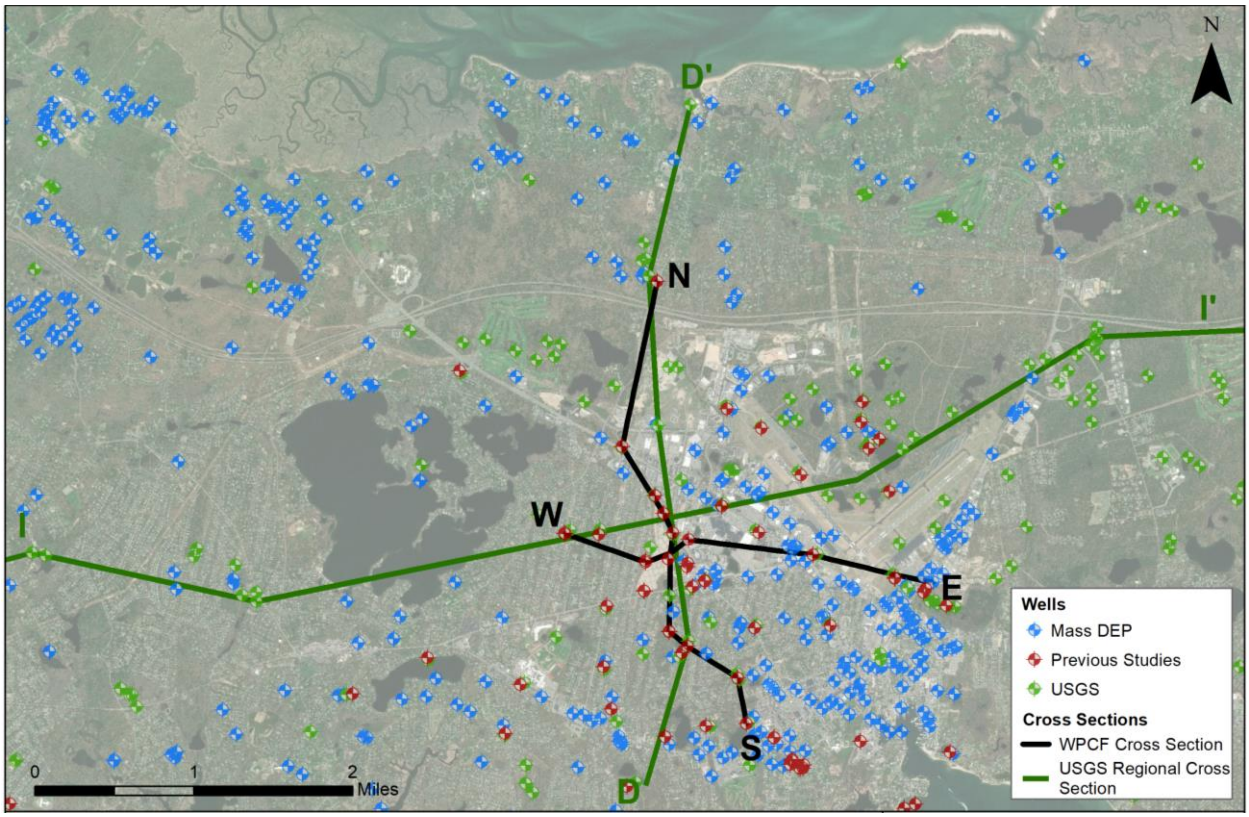


Figure 3: Cross Section Locations from Previous Studies near BWPCF

2.1.3 Site Water Levels

Groundwater levels are routinely monitored at 17 wells by the BWPCF. Water level records at these wells date as early as 1987, and monthly data is available at most wells starting in 2000. Water level data for from the past five and a half years (January 2014 to August 2019) was used to calibrate the model. A map of well locations can be found on **Figure 4** and a summary of well data can be found in **Table 1.**



Figure 4: BWPCF Site Wells

Table 1: Site Wells, Period of Record and Water Level Elevation Ranges

Well	Well Depth (ft bgs)	Start of Record	End of Record	Count	Ground Surface Elevation (ft NGVD29)	Minimum Water Level (ft NGVD29)	Maximum Water Level (ft NGVD29)	Average Water Level (ft NGVD29)	Water Level Range (ft)
92-16	Unknown	5/1/1995	2/5/2019	303	46.6	29.5	38.5	33.6	9.0
92-4	41	11/20/1996	2/5/2019	289	64.3	29.7	41.3	35.0	11.7
BA-1	80	12/1/1990	2/5/2019	296	38.2	16.4	32.2	26.4	15.8
BB-1	67	12/1/1990	2/5/2019	297	31.7	14.6	19.6	17.1	5.0
BC-1	68	12/1/1990	2/5/2019	299	43.7	28.2	38.7	32.7	10.5
BD	50	12/1/1990	2/5/2019	293	29.8	11.2	19.5	16.6	8.3
BE	50	12/1/1990	2/5/2019	297	51.2	12.6	31.9	20.7	19.3
C-2	40	5/1/1987	2/5/2019	322	36.8	20.2	30.8	24.6	10.6
C-3	200	12/1/1990	2/5/2019	292	39.2	17.9	23.8	20.8	5.9
C-4	80	12/1/1990	2/5/2019	238	43.9	12.6	28.0	23.6	15.4
PT300-SE	Unknown	3/25/2004	2/5/2019	159	59.2	29.9	36.0	32.9	6.2
S-11	75	5/27/1998	2/5/2019	256	50.1	30.5	41.1	34.7	10.6
S-15	73	3/9/2001	2/5/2019	202	66.3	22.7	31.9	26.8	9.2
S-4	76	8/7/2001	2/5/2019	199	61.7	29.9	37.2	33.5	7.3
S-7	75	5/27/1998	12/17/1998	20	46.1	31.9	36.0	34.7	4.1
W-1	Unknown	5/1/1987	2/5/2019	273	27.1	22.9	33.6	28.5	10.7
W-4	15	5/1/1987	2/5/2019	283	64.3	16.5	24.1	19.7	7.6
W-7	45	7/1/1994	2/5/2019	195	46.6	30.2	40.3	35.2	10.1

2.1.4 USGS water levels

Water level data from the USGS was used to help calibrate both the steady-state and transient models. A total of 570 wells and 31 surface water monitoring locations across Cape Cod were referenced for the steady state model calibration. For the transient model, water level measurements at MA-A1W 306, located southwest of the BWPCF near the Barnstable High School were used in addition to the historical data collected at and near the site by the BWPCF. The water level data recorded during the past five years at MA-A1W 306 are shown in **Figure 5.** Water levels vary between 3 and 5 feet in a year and were high in 2017 and 2018 compared to previous years.

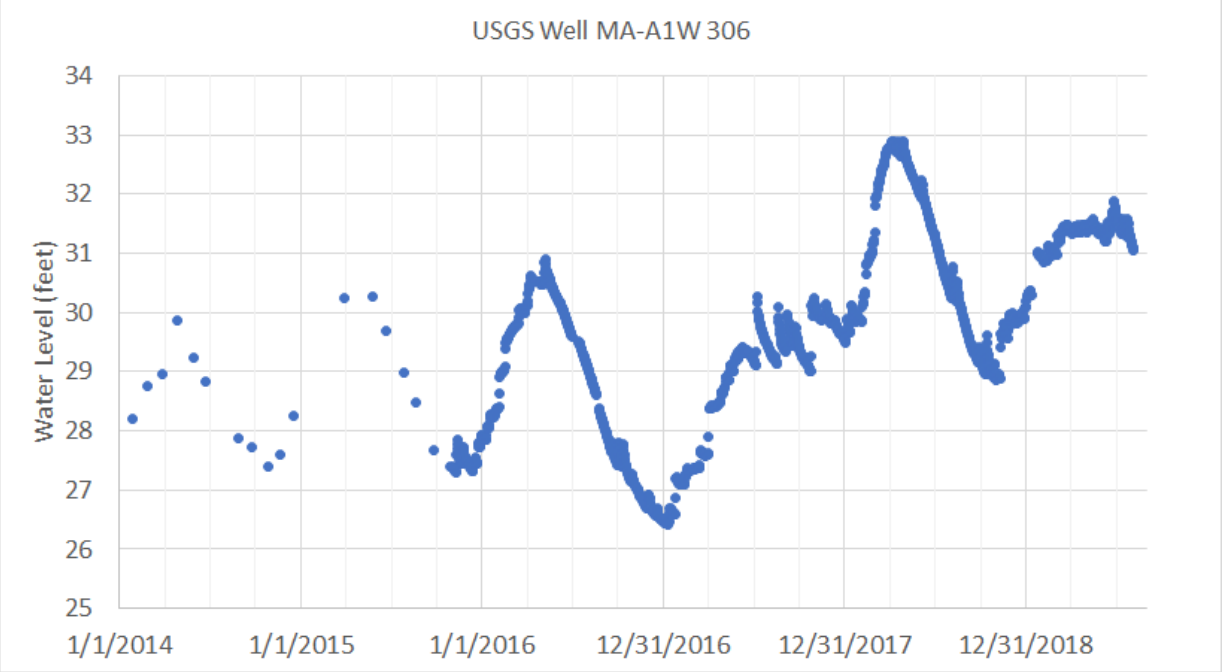


Figure 5: Water Levels at USGS Well MA-A1W 306

2.1.5 BWPCF Bed Loading

Treated effluent at BWPCF is discharged at 49 sand beds where it infiltrates and recharges the groundwater. A schematic diagram of the bed locations is shown in **Figure 6**. Beds 41 and 43 have been removed and beds 2 through 10 are no longer operational due to the installation of solar panels. Beds 33 and 34 are no longer operational due to installation of wind turbines. BWPCF keeps a daily record of which bed(s) receive effluent for infiltration. Influent BWPCF flow and bed use data from BWPCF was used to calculate a timeseries of discharge to each bed for the model period from 2014 through 2019. The monthly average, minimum, and maximum flow for all beds for this period is shown in **Figure 7.** Monthly flows are highest in July and August and lowest in the winter months. The average annual discharge to the beds over the last 5 years was 1.6 MGD, ranging from a minimum daily flow of 0.9 MGD on 1/24/2015 to a maximum daily flow of 2.5 MGD on 7/7/2017.

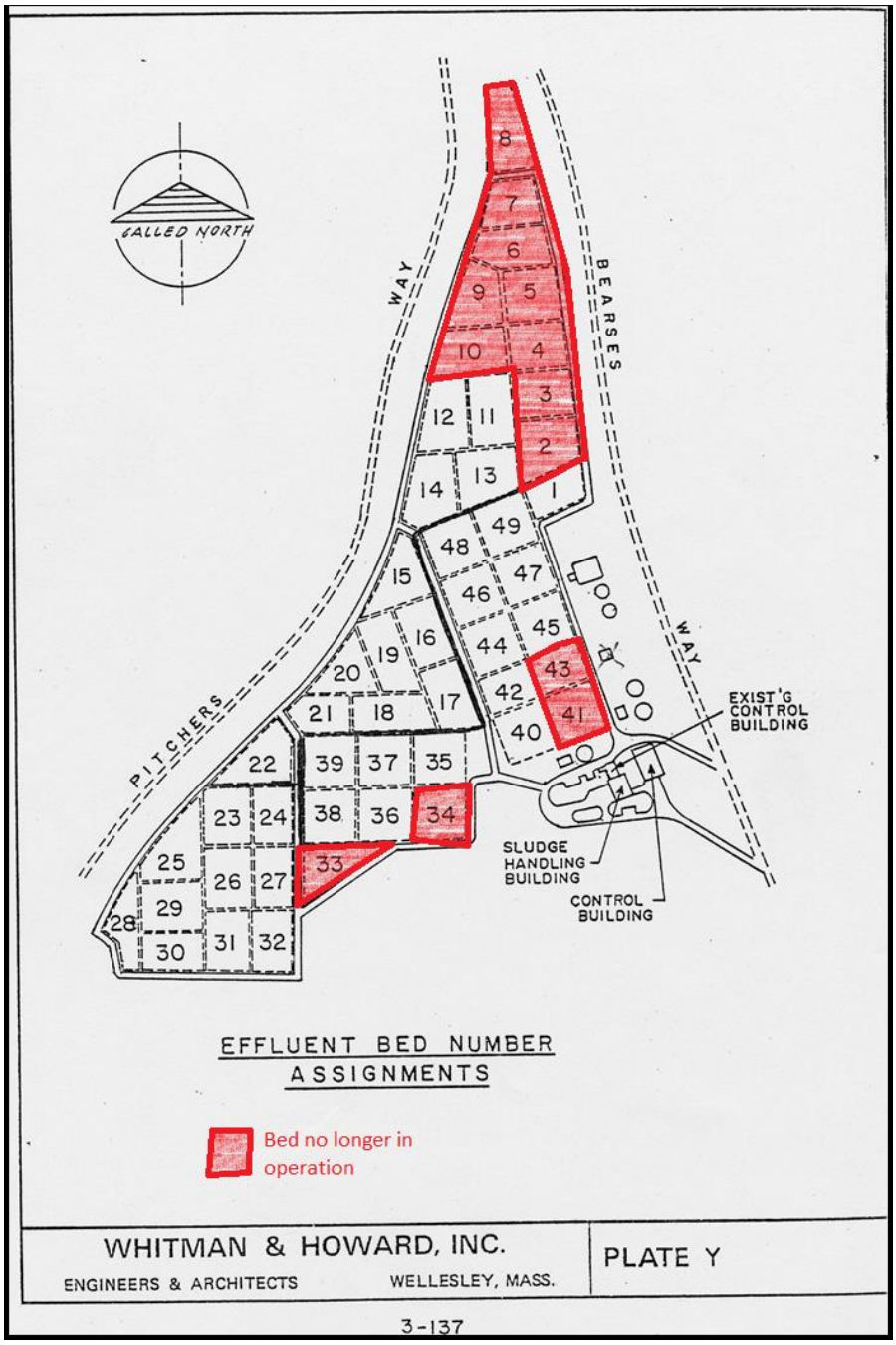


Figure 6: BWPCF Bed Locations and Numbers

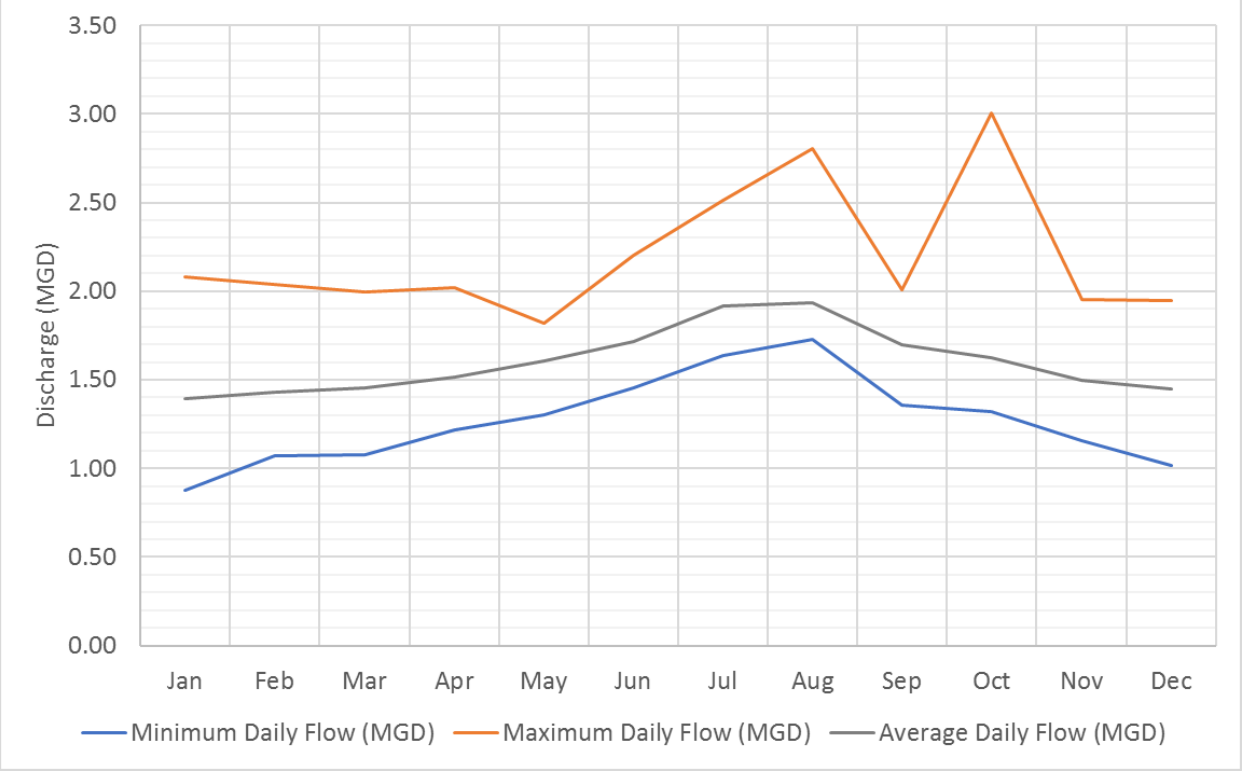


Figure 7: Average, Minimum, and Maximum Daily Discharge at BWPCF (January 2014 – August 2019)

2.2 Boring and Well Installation

Two soil borings were advanced at the site to provide reference data for the geophysics survey, to identify the depth to the clay/silt layer, and to assess the clay/silt layer thickness. Wells were installed at one location (19-01) above and below the clay/silt layer to provide information on the vertical gradient across the clay/silt layer and the thickness of that unit. **Figure 8** shows the location of the borings, wells and geophysics transects.

The location of boring 19-01 was planned in the southwest corner of the recharge beds to provide information on the clay/silt layer. The boring was advanced to a depth of 100 ft bgs (elevation -36 ft NGVD29) in order to determine the top, bottom and thickness of the clay. Boring 19-02 was located in the southeast corner near an existing pond and parking lot. This parking lot regularly floods during wet periods and water levels rise when recharge is applied to beds 40 through 49. Boring 19-02 was selected to investigate the shallow subsurface in this location and identify the possible presence of shallow clay or silt layers and was advanced to a depth of 65 ft bgs (elevation -27 ft NGVD29).

The location and ground surface elevation were surveyed for each of the boring locations and the top of the PVC casing for new wells. Boring logs, well installation reports, and particle size distribution reports for selected soil intervals are included in **Appendix A.** Survey data and a map of surveyed locations are included in **Appendix B.**

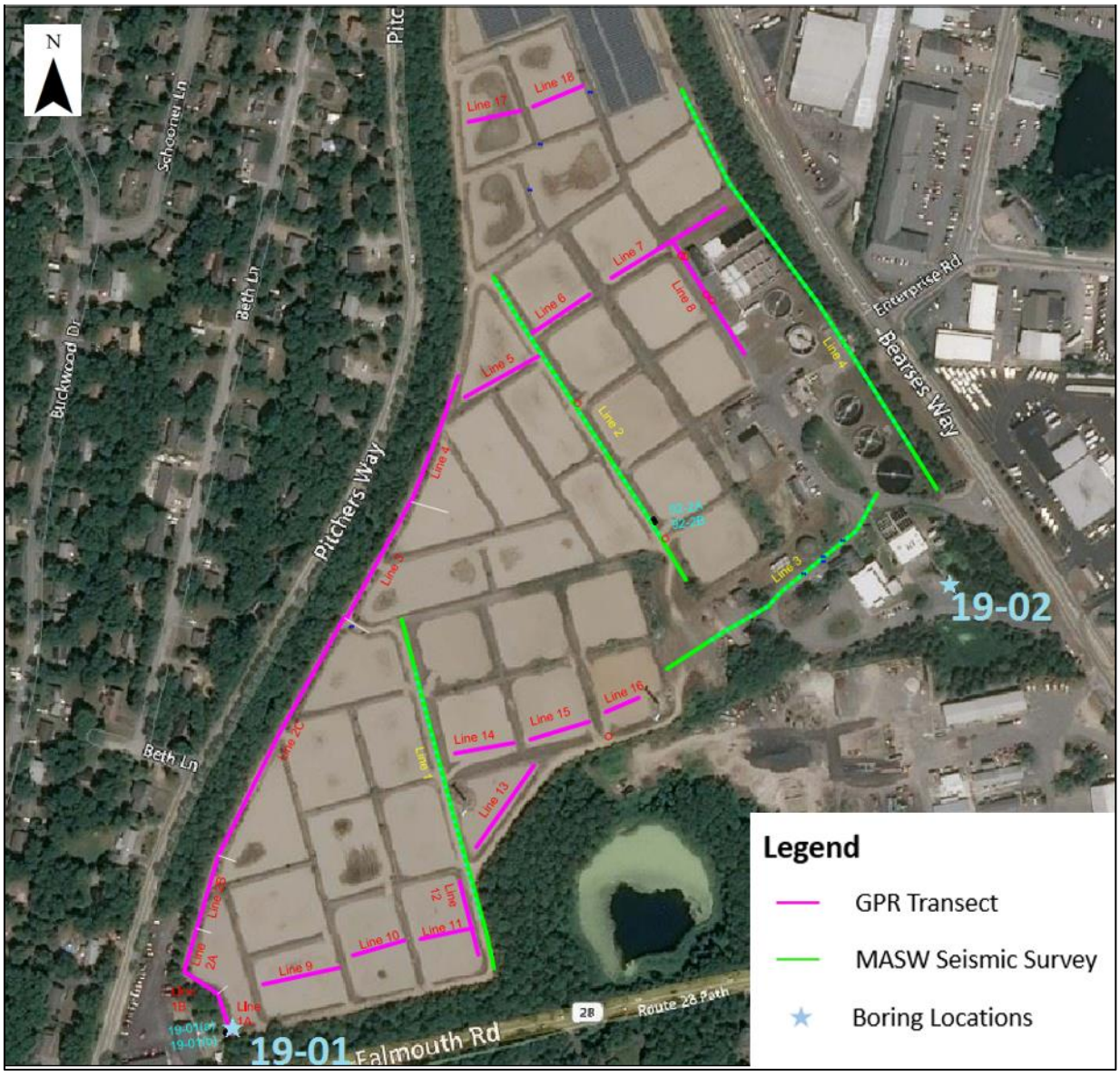


Figure 8: Boring and New Well Locations, Geophysics Transects

The boring at 19-01 was advanced to 101 ft bgs with split spoon sampling every 5 ft and continuous sampling within and below the clay. The geologic deposits encountered consisted of the following:

- light brown, coarse-fine SAND with some-little gravel down to 60 ft bgs
- light brown, medium-fine SAND from 60-78 ft bgs
- light grey, CLAY and SILT from 78-88 ft bgs
- light grey, fine SAND and SILT from 88-89 ft bgs
- light grey-light brown, medium-fine SAND from 89-100 ft bgs

Figure 9 shows photographs of two intervals from boring 19-01. The first shows the coarse-fine sand from 38 to 40 ft bgs. This sand was present in the top 60 feet at the boring. The second photograph shows a 2-foot sample of the clay/silt layer from 78 to 80 ft bgs. This clay/silt layer is 10 feet thick at the boring location.

Two wells were installed at the 19-01, one above and one below the clay/silt layer. A shallow well, 19-01A, was screened from 35 to 45 ft bgs in the coarse-fine sand and a deep well, 19-01B, was screened below the clay/silt layer from 91 to 101 ft bgs. The initial depth to water was 36.8 ft bgs in well screen 19-01A and 30.75 ft bgs in well screen 19-01B. The initial head difference between the two well screens was 6.05 ft, indicating that the clay is a barrier to flow.



Figure 9: Coarse-fine Sand from 38 to 40 ft bgs and Clay/Silt from 78 to 80 ft bgs in Boring 19-01

The boring at 19-02 was advanced to 65 ft bgs with split spoon sampling every 5 feet. The initial depth to water was approximately 3 feet. A well screen was not installed at this location. The geologic deposits encountered consisted of the following;

- light brown, coarse-fine SAND with little-trace fine gravel down to 43 ft bgs
- light brown, medium-fine SAND from 44-53 ft bgs
- light grey, fine SAND, some silt from 53-63 ft bgs
- light grey, fine SAND, SILT, CLAY from 63-65 ft bgs

Grain size analysis was conducted on samples from 3 intervals collected from boring 19-01, shown in **Table 2**. Particle size distribution reports for all three intervals are provided in **Appendix A.** The grain size data from the sample from 35 to 45 feet was used to estimate hydraulic K using three methods, Hazen, Beyer and Wang et al. (AQTESOLV, 2019). The hydraulic conductivity (K) for the coarse sand based on the three estimation methods varies from 126 feet per day (ft/day) to 488 ft/day.

Table 2: Grain Size Analyses for Selected Intervals

Sample		19-01 35-45 ft bgs	19-01 78-85 ft bgs	19-01 91-100 ft bgs
Description	-	light brown poorly graded sand with gravel	gray lean clay	gray-brown silty sand
Grain size, D10	mm	0.2677	< 0.0013	0.0414
Grain size, D60	mm	0.9906	0.0092	0.2189
Grain size, D90	mm	9.6910	0.0280	0.5022
Estimation Method*		**Estimated Hydraulic K**		
Hazen	ft/day	203	not calculated*	not calculated*
Beyer	ft/day	488	not calculated*	not calculated*
Wang et al.	ft/day	126	not calculated*	not calculated*

AQTESOLV 2019

*Hydraulic conductivity was not calculated for deeper intervals at 19-01 because the estimation methods are not valid for the range of particle sizes measured.

2.3 Slug Testing

Falling head and rising head slug tests were performed to provide the basis for estimating horizontal hydraulic conductivity. The tests were conducted using a 2-inch mechanical slug at eight wells throughout the BWPCF property and nearby areas, shown on **Figure 10**. The change in water levels resulting from the insertion and removal of the mechanical slug during the tests was measured using submerged pressure transducers. An example of the change in water levels during slug testing in monitoring well 92-2B is shown in **Figure 11**.



Figure 10: 2019 Slug Testing Locations

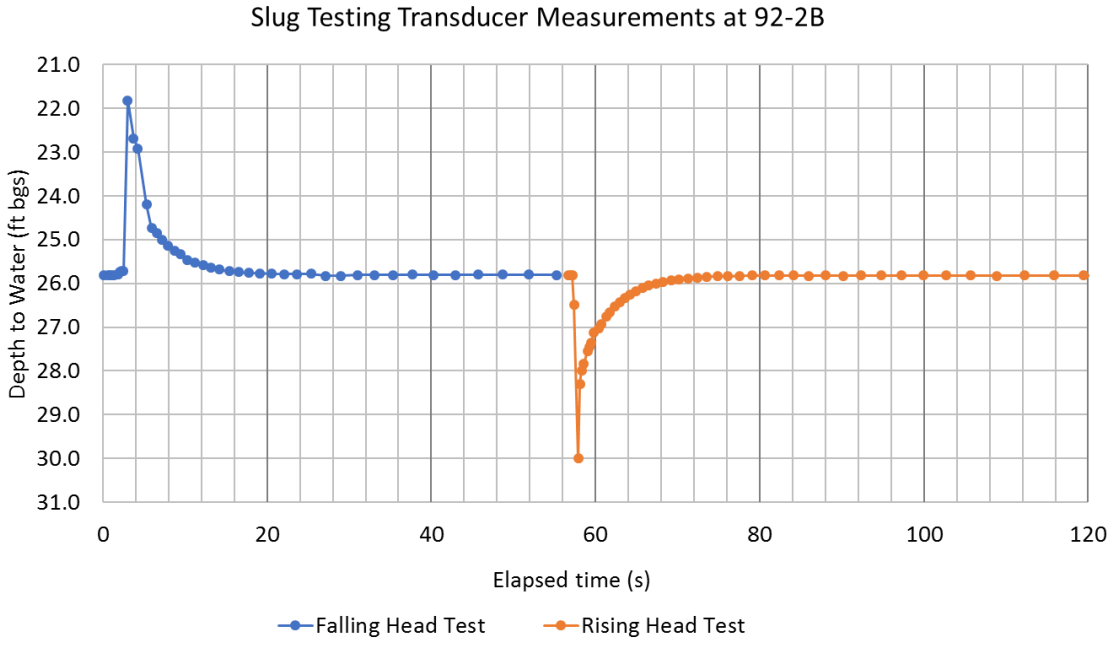


Figure 11: Depth to Water Measurements in Monitoring Well 92-2B During Slug Testing

After insertion of the mechanical slug, water levels quickly rise and "fall" back to the static water level, as exhibited in the "Falling Head Test" depth to water measurements shown in blue. When the slug is removed, the depth to water immediately drops and rises back to static water level, shown in orange on the plot. The responses to the insertion and removal of the mechanical slug occurred over a period of less than 20 seconds, indicating high hydraulic conductivity of the soils immediately surrounding the well screen.

The local hydraulic conductivity was estimated from the water level displacement using the AQTESOLV software package (Duffield, 2007). Several analytical solution methods were used to interpret the data, including the Bouwer-Rice solution (Bouwer and Rice, 1976) for unconfined aquifers and the Springer-Gelhar solution (Springer and Gelhar, 1991) for unconfined aquifers with oscillatory response (which usually occurs in aquifers with high hydraulic conductivity). An example analysis at monitoring well 19-01A is shown in **Figure 12.**

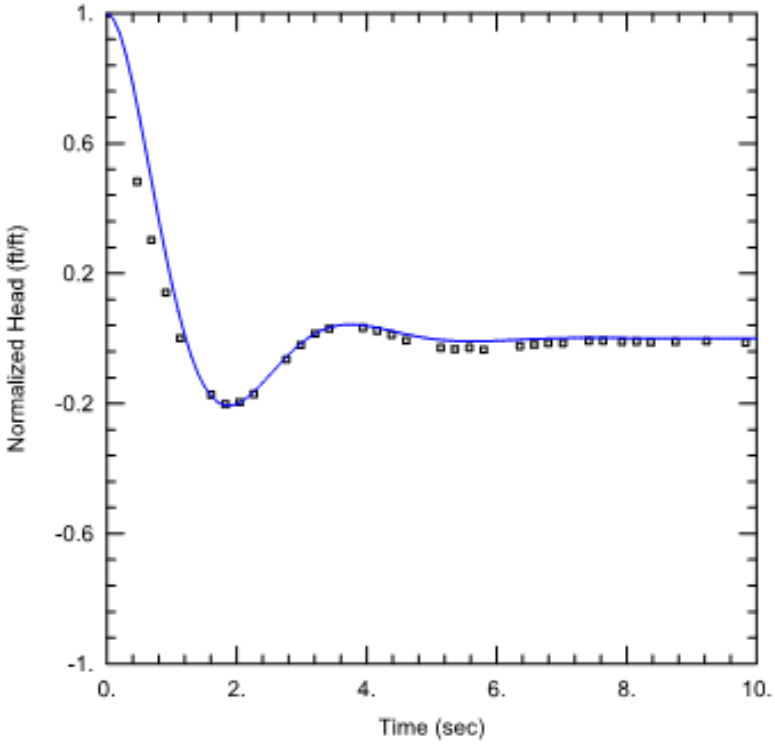


Figure 12: Rising Head Test for Well 19-01A

The observed water levels converted to normalized head in feet/feet (ft/ft) during the test are shown with the black hollow squares and the blue solid line shows the analytical solution that matches the observed data. The example in Figure 12 shows an oscillatory response, when the water level rose above the static water level after the mechanical slug removal and then dropped to the static water level after a second oscillation. The hydraulic conductivity from this analysis was 300 ft/day, which is consistent with the observed oscillatory response. The hydraulic conductivity values estimated from all slug tests ranged from 2 to 1,491 ft/day, as presented in **Table 3**.

Table 3: Hydraulic Conductivity Estimates from Slug Test Analyses

Well	Aquifer Thickness (ft bgs)	Hydraulic Conductivity, K (ft/day)	
		Minimum	Maximum
19-01A	45*	299	1,491
19-01B	> 10 *	2	30
92-16	60	308	333
92-2A	65	616	914
92-2B	80	99	103
92-4	70	504	517
C-2	40*	345	485
W-4	70	340	454

* Aquifer thickness was based on the extent of the well boring for the purpose of the analysis and may be deeper than the value reported in the table.

Most wells exhibited rapid water level responses after the insertion and removal of the slug similar to the example at 19-01A shown in **Figure 12**, indicating high permeability of the surrounding soils.

The hydraulic conductivity values estimated at 19-01B and 92-2B were lower than those estimated from the other tested wells, which was expected from subsurface soils based on boring log at the two locations. The boring log at 19-01B indicated that the screen was set in a dense sand below a local clay/silt layer. The boring log at 92-2B indicated that the screen is located within a section of finer-grained sands. The AQTESOLV results for all tests are provided in **Appendix C.**

2.4 Focused Loading and Water Level Recorders

Focused loading tests were conducted in June and July 2019 to observe the aquifer response to spatial changes in loading application. Eight rounds of testing were conducted for a period of seven days each, during which the wastewater discharge was loaded only to the beds in the focused groups. The infiltration beds were grouped into six groupings that were loaded at least once during the testing period. Submerged pressure transducers were installed prior to the start of testing to record the changes in water levels at selected monitoring wells throughout the BWPCF.

The pressure transducer installed at 92-4 and 19-01A between the dates of June 28, 2019 and July 11, 2019 was corrected for atmospheric pressure after review of the data indicated that the cable venting, which usually removes the impacts of atmospheric pressure changes from the pressure readings recorded by the transducer, was not working properly. The transducer was removed on July 11, 2019 and replaced with a transducer and cable which automatically corrected for changes in atmospheric pressure.

The loading groups are shown in the color-coded polygons in **Figure 13.** The location of the monitoring wells that the pressure transducers were installed in during testing are shown in the green circles.

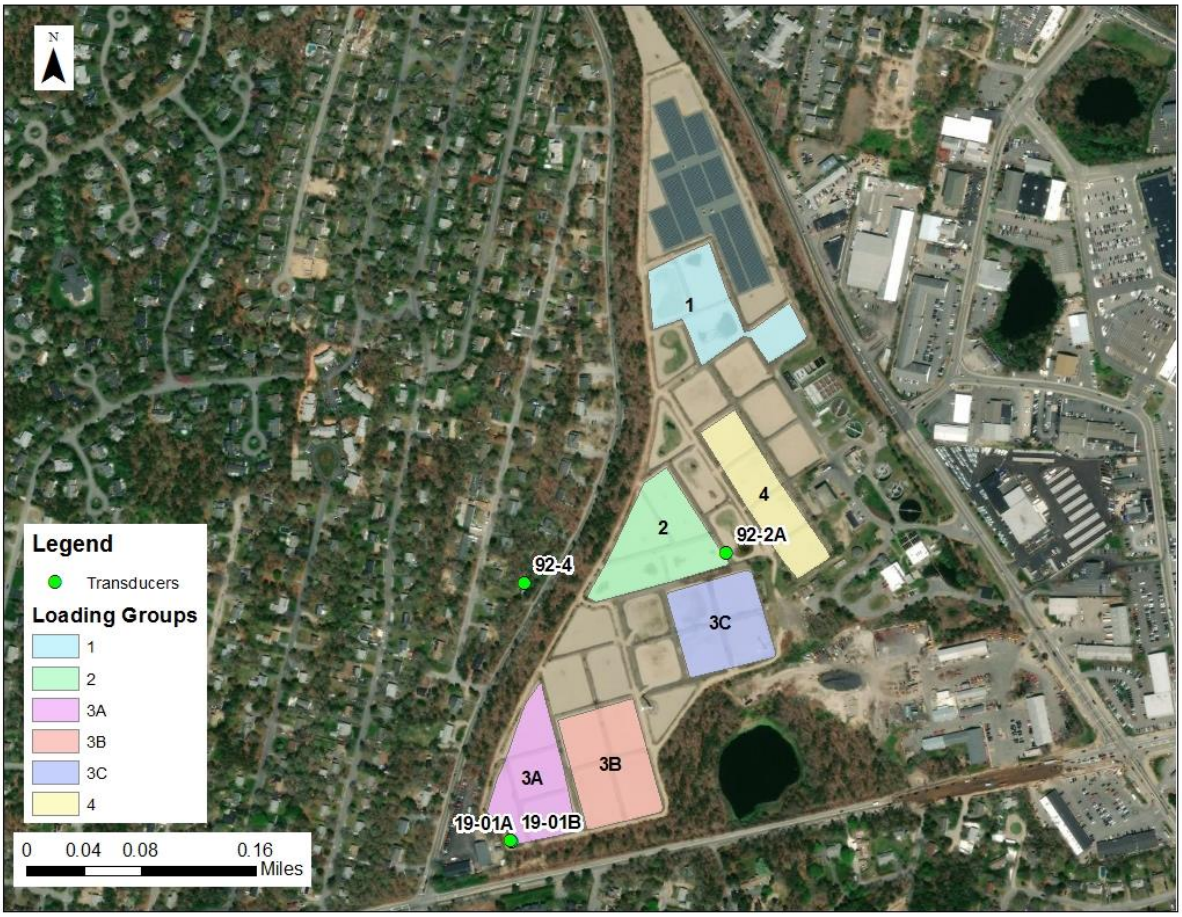


Figure 13: Focused Loading Bed Groupings and Transducer Locations

The loading groups were selected based on the ease of operation (clusters of beds that are located on the same distribution lines) and proximity to monitoring wells (new and existing). The loading groups were also selected to provide a good spatial representation of the BWPCF. The schedule for focused loading is presented in **Table 4.**

Table 4: Table of Focused Loading Test Groups, Including Average Daily Recharge and Bed Locations

Start Date	Group	Beds	Average Discharge (MGD)	Transducer Locations	
6/3	2	18, 19, 20, 21	1.8	92-4	92-2A
6/10	3A	25, 28, 29 30	1.9	92-4	92-2A
6/17	1	1, 11, 12, 13	1.8	92-4	92-2A
6/24	3C	34, 35, 36, 37	1.9	92-4	92-2A
7/1	4	25, 28, 29 30	2.0	19-01A	92-2A
7/8	3C	34, 35, 36, 37	1.9	19-01A	19-01B
7/15	3B	40, 42, 44, 46	2.0	19-01A	19-01B
7/22	3C	26, 27, 31, 32	2.1	19-01A	19-01B

As shown in **Table 4,** each loading group was tested for at least one 7-day period. The loading rate was fairly consistent throughout testing, ranging from 1.8 to 2.1 million gallons per day (MGD). The water levels recorded by the transducers are provided on **Figure 14,** along with the precipitation measured at the Barnstable Airport Weather Station and reported BWPCF flows.

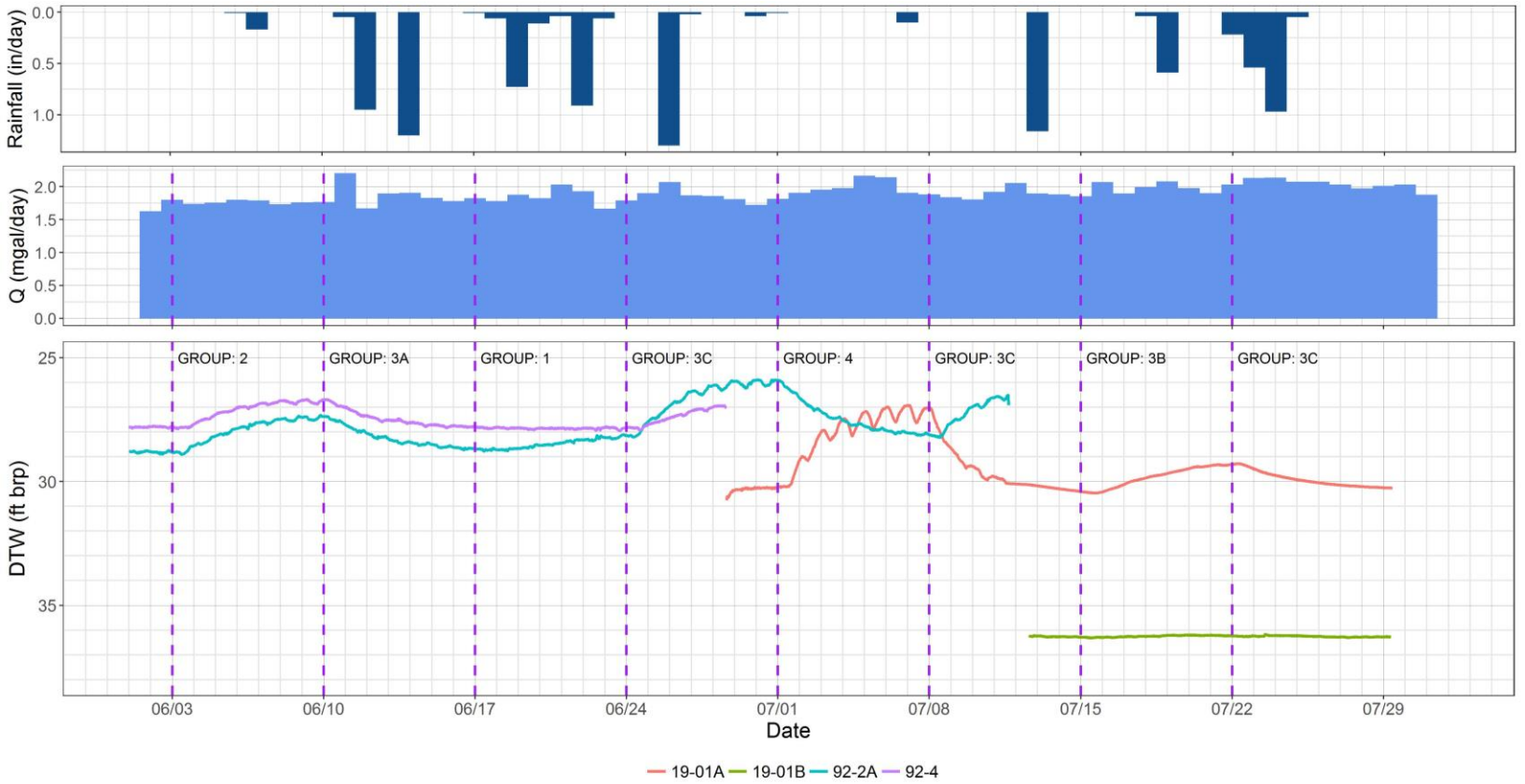


Figure 14: Depth to Water (DTW) Timeseries with Precipitation [top chart], Loading Rate [middle chart], and Loading Group Transitions

The transitions between loading groups are shown with the purple dashed lines along with the water levels in corresponding color-coded lines on the bottom chart in **Figure 14**. In general, the water levels exhibit various degrees of change in response to the focused loading. The increase in water levels in the wells screened in the upper layer ranges from approximately 1 to 4 feet. The recession periods after loading range from several days to approximately one week; however, the longer recession periods may be an indication of effects from loading in nearby groups.

The transducers were installed at 19-01A and 19-01B during the last two weeks of testing, when loading was applied to the two groups immediately adjacent to the monitoring well pair. The depth to water significantly decreases in 19-01A during testing in Group 3B but does not change significantly in 19-01B. The 19-01B well screen was installed below a clay/silt layer indicated in the boring log, and the lack of water level response supports the observation that the well is screened in a separate underlying aquifer unit that appears to be almost entirely disconnected hydraulically from the upper, shallow, water table aquifer unit.

2.5 Geophysics Transects

Geophysical surveys were conducted at the BWPCF recharge beds by Hager GeoScience (HGI) on July 11 and 12, 2019. The survey objectives were to identify the spatial variation of the depth and thickness of the clay/silt layer. Details of the investigation and results from all survey transects are including in **Appendix D**. **Figure 8** (above in **Section 2.2**) shows the transects for ground penetrating radar (GPR) as pink lines and the transects for the mult-channel analysis of surface waves (MASW) as green lines.

The boring from 19-01 shows the undifferentitated sands in the top 75 feet and a clay/silt layer at 80 ft bgs. The GPR survey line adjacent to boring 19-01 is shown in **Figure 15.** A MASW seismic survey from south to north through the site is shown in **Figure 16.** The GPR and MASW results agreed on the approximate depth of the top of clay. Cross-sections for all transects are included in **Appendix D**.

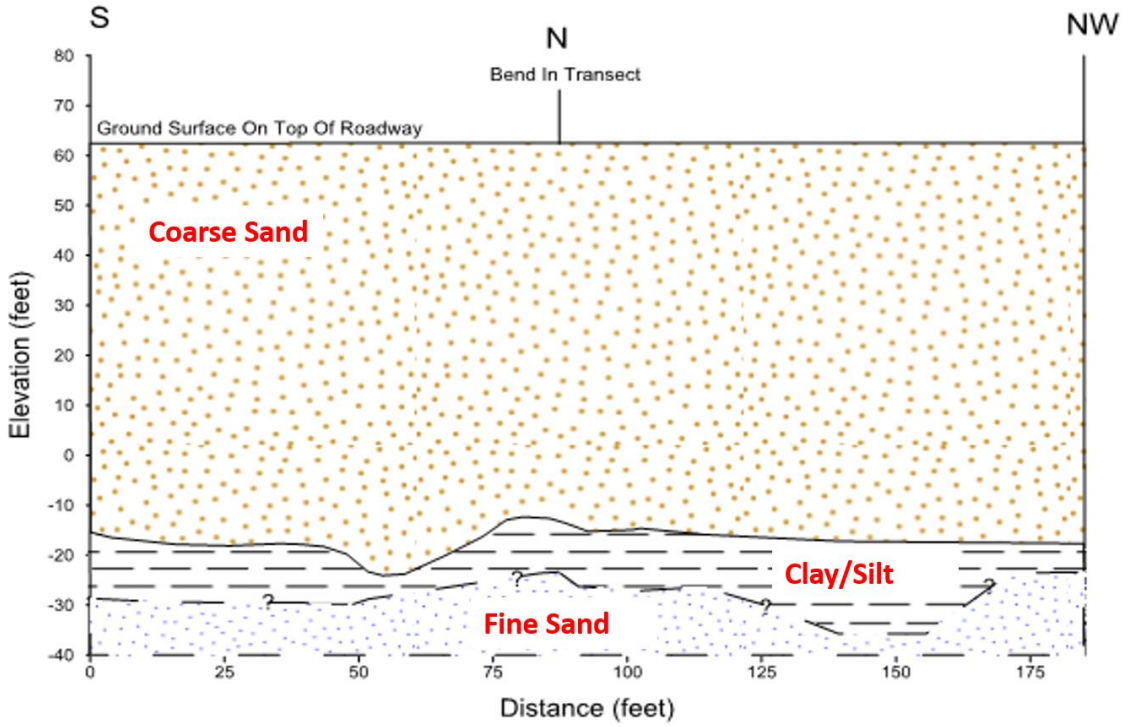


Figure 15: GPR Survey Line 1 – South to Northwest in Southwest Corner of Recharge Beds near New Boring 19-01

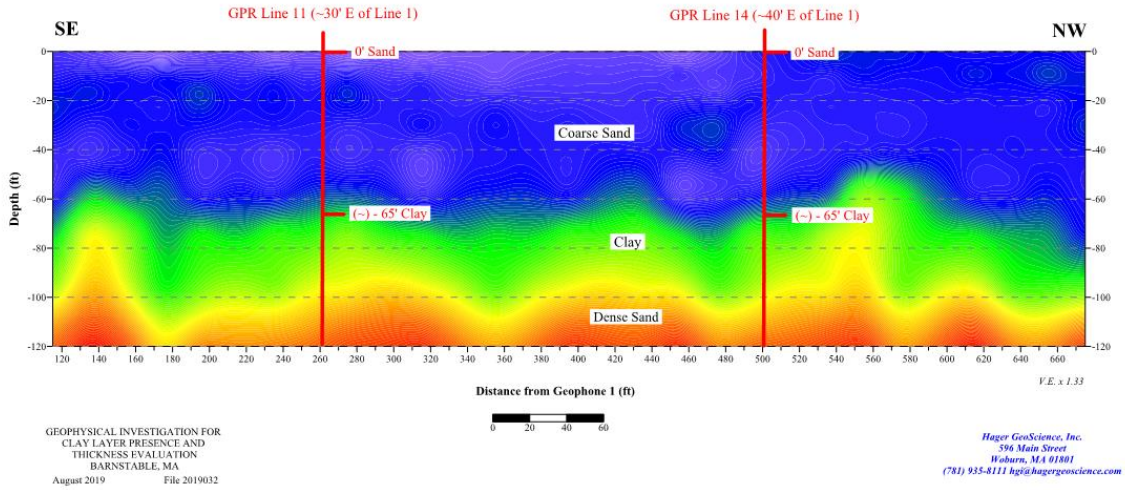


Figure 16: MASW Seismic Survey Line 1 – South to North through Beds 32, 27, 24 and 22

Interpretations of the top and bottom of the clay layer were made for the ten GPR profiles. The thickness was inferred based on the GPR signal velocity. The top of clay is estimated to be present throughout the site at depths of 55 to 107 ft bgs. The clay is 5 to 20 feet thick.

Based on the GPR and MASW seismic surveys, the estimated top of the clay elevation is shown in **Figure 17**. The top of clay is highest (red/orange) in the northern and western edges of the site near beds 11, 12, 15, and 25 (text box **(a)** in **Figure 17**). There is also a local high area under beds 40

through 49 (text box **(b)** in **Figure 17**). This helps explain why flow applied at these beds results in groundwater rise near the BWPCF office parking lot. Areas of lower clay elevation are beneath beds 18 through 21, 29 through 31, and bed 38.

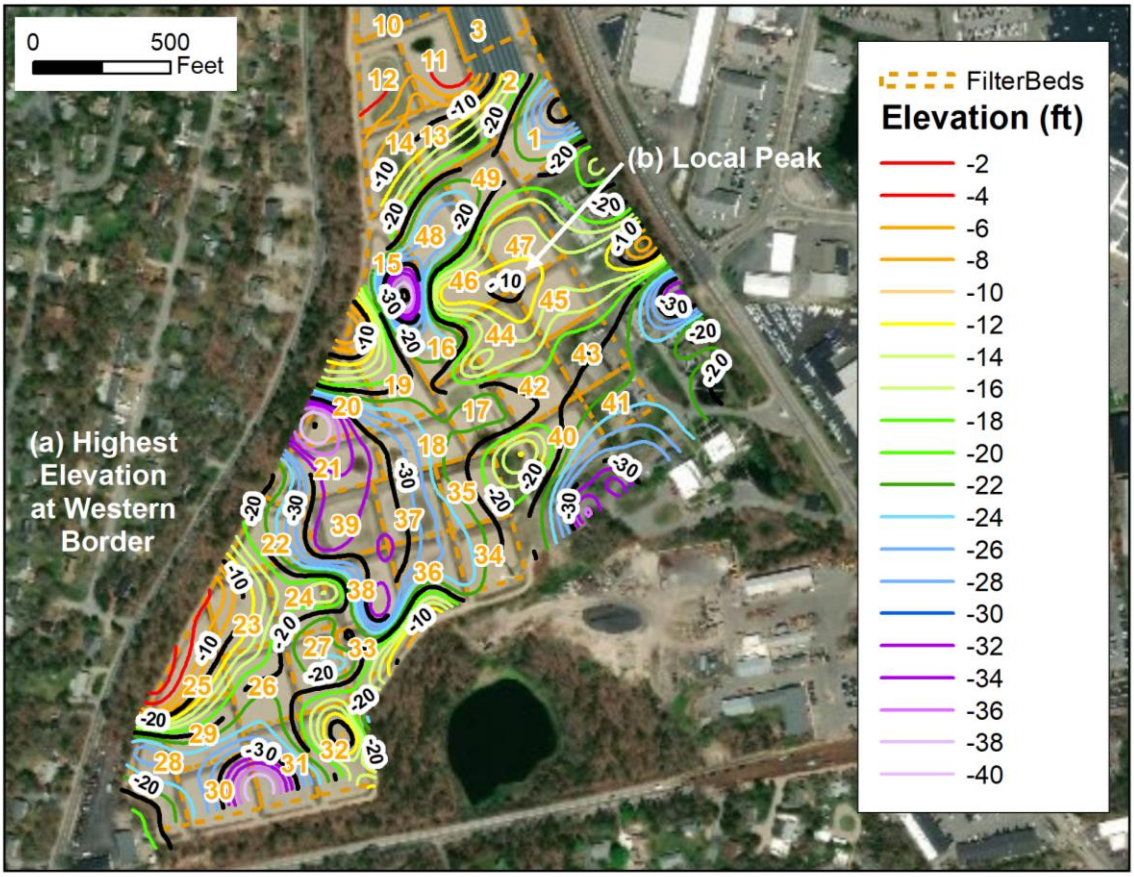


Figure 17: Estimated Top of Clay Elevation

2.6 Data Collection and Field Work Summary

The results from the field testing were used to refine the understanding of the groundwater flow in the area surrounding the BWPCF infiltration beds and update the conceptual site model and numerical groundwater flow model discussed in **Section 3**. The boring logs, GPR transects and seismic surveys were used to identify the approximate thickness and extent of a local clay layer present beneath the infiltration beds. The clay is present throughout the site at 55 to 107 feet below ground surface and ranges between 5 and 20 feet thick. The clay layer restricts vertical flow, as evidenced between the large head difference observed at 19-01A and 19-01B, as well as the lack of response in 19-01B to the focused loading tests. The evidence of the lateral extent of the clay layer is supported by the review of the boring logs from the MassDEP database, which indicates clay beneath the BWPCF and surrounding area at depths of 60 to 80 ft bgs.

The grain size analyses and slug tests were used to refine the hydraulic conductivity estimates of the coarse sand layer above the clay and fine sand layer below the clay. The horizontal hydraulic

conductivity of the coarse sand above the clay estimated from the slug tests ranged between approximately 300 to 500 feet per day. The hydraulic conductivity drops with decreasing elevation, as expected from the gradation observed in the boring logs and decreased hydraulic conductivity estimated from the slug tests conducted at 92-2B. The hydraulic conductivity in the fine sand beneath the clay, as estimated from the slug test results at 19-01B, ranges from 2 to 30 feet per day.

Section 3

Conceptual Site Model and Numerical Flow Model Development

This section describes the Conceptual Site Model (CSM) based on existing data and the results from the field work presented in **Section 2**. The CSM is then incorporated within a numerical flow model to simulate steady-state and transient flow conditions. The numerical flow model is based on previous work from the USGS. Updates to the USGS model based on the CSM are described in **Section 3.2**.

3.1 Conceptual Site Model

The groundwater aquifer on Cape Cod has been extensively studied and documented by the USGS and others (Walter and Whelan 2004, Walter et al 2016, Oldale 2001). The aquifer is a "sole-source" aquifer, serving as the only source of drinking water for communities on Cape Cod. Annual extractions by public water supplies were approximately 28 MGD in 2006.

Recharge from precipitation is the primary source of recharge to the aquifer. Estimates of recharge from USGS steady-state modeling range from 27 inches per year to 30 inches per year. Recharge at ponds is around 16 inches a year due to evaporation during the summer months. Recharge at wetlands varies depending on the growing season, but the net recharge is estimated to be zero inches per year due to evapotranspiration.

A secondary source of recharge is from treated wastewater return flow through septic systems and wastewater disposal facilities. Approximately 80% to 90% of the water extracted from local wells is returned to the aquifer through wastewater return flows.

The Cape Cod aquifer is comprised of glacial sediments over bedrock. The sediments were deposited at the margin of the continental ice shelf. The surficial geology includes glacial outwash plains, moraines and ice-contact deposits. The BWPCF recharge beds are underlain by glacial outwash sediments. These sediments are coarse near the ground surface and become finer with depth (more silt and clay).

Boring logs advanced as part of the 2019 site investigation at the BWPCF and the geophysical survey identified an extensive clay and silt layer under the site. The observed head difference of 6 ft and lack of response to changes in load locations during focused loading at the well beneath the clay/silt indicates the layer functions as an aquitard. The depth of the layer is variable from 55 to 107 ft bgs. Borings outside the site suggest the clay is laterally extensive and generally at an elevation of approximately 0 to -40 ft NGVD29.

Kettle holes, formed by the blocks of ice left by the retreating glaciers which subsequently melted, are present throughout the outwash plain. Many of these locations are now ponds or wetland areas. These ponds often do not have stream inlets or outlets and reflect the underlying groundwater table.

At the coastal boundary, the higher density saltwater forms a wedge underneath the freshwater forming a freshwater and saltwater interface, shown in **Figure 18**. There is negligible flow across the freshwater/saltwater interface and the freshwater at the coastal boundary flows upwards to discharge along the coast at harbors, Cape Cod Bay and Nantucket Sound.

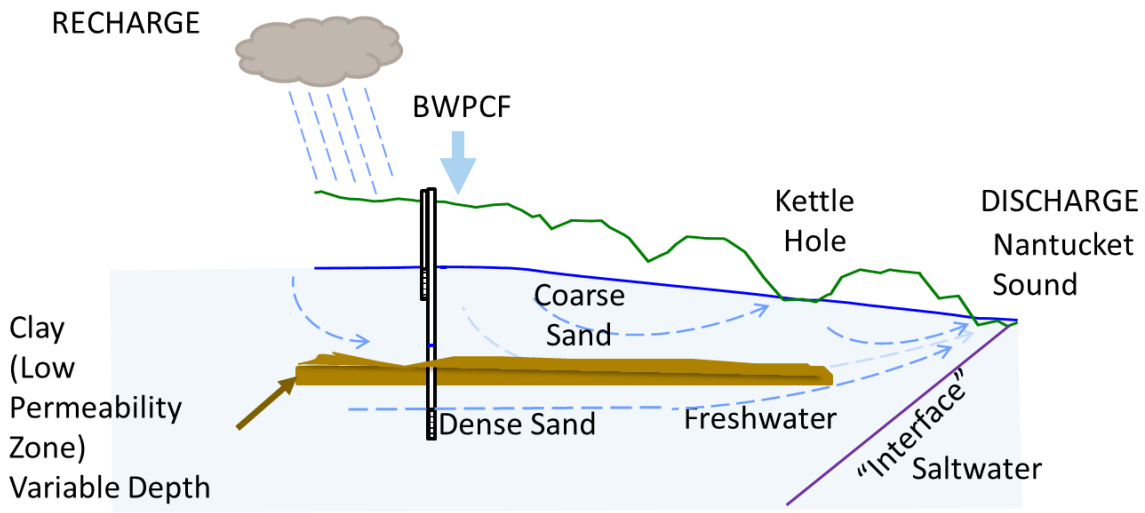


Figure 18: Conceptual Site Model – BWPCF

3.2 Numerical Groundwater Flow Model Updates

The groundwater system on Cape Cod has been studied and modeled for many decades. The previous Barnstable model (GHD, 2017) was based on a steady-state regional model developed by the USGS in the early 2000's (Walter and Whelan, 2004). This USGS model was the basis for the development of contributing areas to streams, harbors and estuaries to support the Massachusetts Estuaries Project (MEP). The USGS continues to enhance and improve the regional Cape Cod groundwater models. Recent updates in 2016 (Walter et al., 2016) improved the ability of the USGS regional model to simulate the interaction of the water table with the ground surface and transient fluctuations in the water table. These changes include the measured ground surface, updating the layering to simulate the water table in the top layer of the model, and changes to the method for simulating streams (Walter et al., 2016). The 2016 USGS model was also modified to allow for the prediction of sea level rise impacts on groundwater. The 2019 Barnstable model is based on the 2016 steady-state USGS model with updates to reflect transient inputs near the BWPCF and subsurface features identified as part of the field work for this project.

3.2.1 Grid Refinement

The base USGS model contained uniform grid cells of 400 by 400 feet. The model grid was refined in the area surrounding the BWPCF to allow for modeling the impacts of recharge applied to the individual cells. The updated model grid near the BWPCF is shown in **Figure 19.**

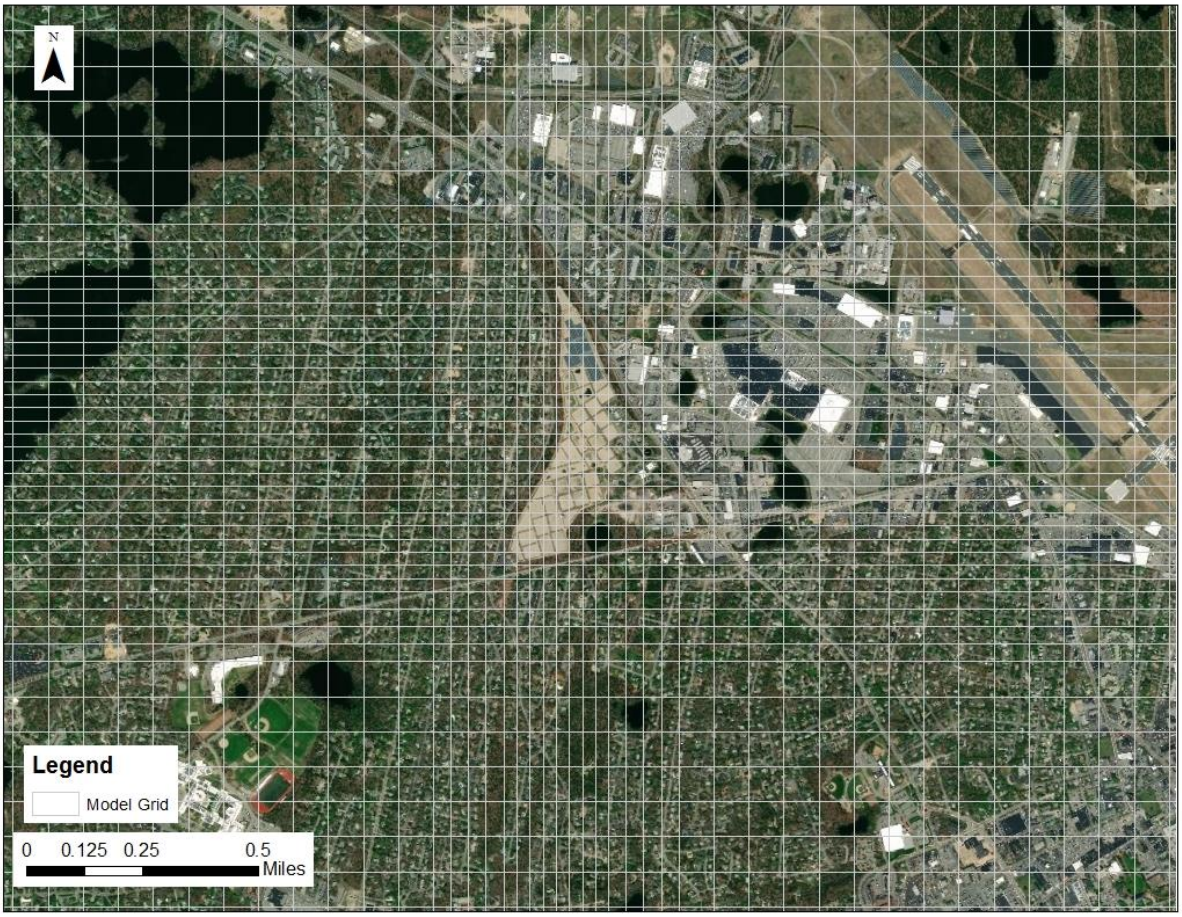


Figure 19: Updated Model Grid near the Barnstable Water Pollution Control Facility

The minimum cell size in the updated model grid is 150 by 150 feet, which better captures the area of the individual infiltration beds. Vertical discretization for simulating observed sediment layering and changes in hydraulic conductivity was taken from the USGS model and was unchanged. The clay/silt layer measured during the field work portion of this project was added to the existing vertical layering within the model, which aligned approximately with the elevation and thickness of the measured clay/silt layer. Future work could include additional vertical discretization to better approximate the top and bottom elevation of the clay layer, however, the existing model discretization was adequate for the simulation modeling presented in this report, as demonstrated by the model calibration. Improved vertical discretization of the clay layer would allow for improved simulation of highly-localized impacts, such as the ponding near the BWPCF parking lot and office building.

3.2.2 Hydraulic Conductivity Property Changes

The field work presented opportunities to update the USGS model within the vicinity of the BWPCF to better represent the local clay and sand layers. A summary of the hydraulic conductivity property changes made to the updated model are provided in **Table 5.** Hydraulic conductivity values were selected based on calibration to observed water level data.

Table 5: Hydraulic Conductivity Property Changes Summary

Aquifer Unit	Model Layers	Horizontal Hydraulic Conductivity (ft/day)	Vertical Hydraulic Conductivity (ft/day)	USGS SLR Model Horizontal Hydraulic Conductivity (ft/day)
Coarse Sand, BWPCF	1 through 3	350.0	35.0	120 to 200
Sand	1 through 3	175.0	17.5	30 to 200
Clay/Silt	4 and 5	1.0	0.01	30 to 200
Fine Sand	6	10.0	1.0	30 to 200

The clay layer located approximately 55 to 107 feet below ground surface was incorporated into the model into 10-feet thick layers sloping downward towards the south with horizontal hydraulic conductivity of 1 ft/day and vertical hydraulic conductivity of 0.01 ft/day. A sensitivity analysis was conducted on the vertical hydraulic conductivity and it was determined that the low vertical hydraulic conductivity in the clay was necessary to match the head difference at 19-01A and 19-01B, which are screened in the upper and underlying aquifer units respectively.

The slug test analyses indicated high hydraulic conductivity in the shallow coarse sand underlying the BWPCF above the clay/silt layer. The area immediately surrounding the BWPCF in the USGS model had a higher hydraulic conductivity than surrounding areas but did not include the local clay layer. A clay layer was incorporated into the model using existing vertical discretization and the horizontal hydraulic conductivity in the water table aquifer at the site (within an approximately 3,000-foot radius) was increased to 350 ft/day to reflect the results from the slug test analyses. The horizontal hydraulic conductivity in the coarse sand in the general area extending from Lake Wequaquet to Mill Creek and spanning the groundwater divide to the southern coast was increased to 175 ft/day to better match well observation points used in the calibration.

3.2.3 Storage Properties

The specific storage and specific yield properties were left unchanged from the previous USGS model (Walter et al., 2015). The specific storage and specific yield parameters were 0.000015 (/ft) and 0.25, respectively.

3.2.4 Return Flow and Recharge

Several updates were made to the return flow and recharge rates in the steady-state and transient models. The updates were made to reflect reported recharge at individual beds at the BWPCF and recharge from recorded precipitation during the transient model simulation period. The return flow and recharge rates published in the 2016 USGS model (Walter et al., 2016) were used as the basis for the updates described in this section. No changes were made to the return flow outside of the Barnstable town limits from both septic and wastewater disposal recharge.

Several updates were made to the groundwater recharge from the wastewater disposal at the BWPCF. The model grid refinements near the facility were made to better represent the recharge from individual beds or groupings of beds. The steady-state recharge at the facility was estimated from the long-term average reported recharge from January 2014 through December 2018. The transient

recharge was set to the reported rates from January 2014 through August 2019 distributed to the corresponding recharge beds. In addition to the changes due to wastewater disposal, the septic recharge was updated to remove areas within the town that are serviced by sewer systems.

Precipitation recharge was updated model-wide in the transient simulation model based on the reported precipitation recorded at the Barnstable Hyannis Airport Weather Station through the period from January 2014 through August 2019. Monthly evapotranspiration and evaporation rates were taken from the Massachusetts Crop Evapotranspiration and Potential Evaporation Grids, developed by Fennessey and Vogel (2000) and available for download online. Recharge applied to the general aquifer was estimated by scaling the recorded precipitation by a monthly factor based on the monthly aquifer recharge rate published in the 2004 USGS Report (Walter et al., 2004). Recharge applied to wetlands was estimated using the reported precipitation minus average monthly evapotranspiration and average monthly evaporation. Finally, recharge applied to open waterbodies (ponds) was estimated using the reported precipitation minus average monthly evaporation. The estimated recharge rates to the ponds and wetlands follow the method described in the 2016 USGS report (Walter et al., 2016). The updated recharge rates reflect variations between January 2014 through August 2019 while remaining consistent with the average recharge rates used in the steady-state model.

3.2.5 Groundwater Pumping

Groundwater pumping rates in the steady-state and transient models were updated to reflect recent pumping data obtained for wells located in Hyannis and those owned and operated by the Barnstable Fire District for the period between January 1, 2001 and February 28, 2019. The average annual pumping value from 2001 through 2018 used in the steady state model and maximum daily pumping rates is shown in **Table 6**.

Table 6: Public Water Supply Wells near BWPCF Owner and Withdrawal Rates

Well Owner	Well	Long-term Average Rate (MGD)	Maximum Daily Rate (MGD)
Barnstable Fire District	4020000-02G	0.07	2.55
	4020000-03G	0.20	0.76
	4020000-04G	0.20	5.50
	4020000-05G	0.04	0.71
Town of Barnstable Hyannis Water System	Airport-1	0.06	0.34
	HP	0.28	0.61
	MD-1	0.17	0.55
	MD-2	0.11	0.62
	MD-3	0.19	0.60
	MD-4	<0.01	<0.01
	MH-1	0.29	0.86
	MH-2	0.32	0.76
	MH-3	0.42	0.76
	SP	0.37	0.76
	SW-2	0.12	0.84

Section 4
Model Calibration

The steady-state and transient model updates described in **Section 3** were evaluated using the metrics presented in this section to ensure consistency with the previous USGS model and to calibrate the model to site-specific data. A comprehensive list of the model-wide and site-specific numerical model calibration points is provided in **Appendix E.** The electronic deliverable of the steady-state and transient numerical model files is provided as **Appendix F.**

4.1 Steady-state

In general, the updates to the steady-state model preserved the USGS calibration and demonstrated good model-fit in the area surrounding the BWPCF, as shown in **Figure 20** and **Figure 21.** The model-wide calibration points were taken from the data set developed for the USGS model calibration (USGS, 2016). The BWPCF-site calibration points were also added to the model-wide calibration data set.

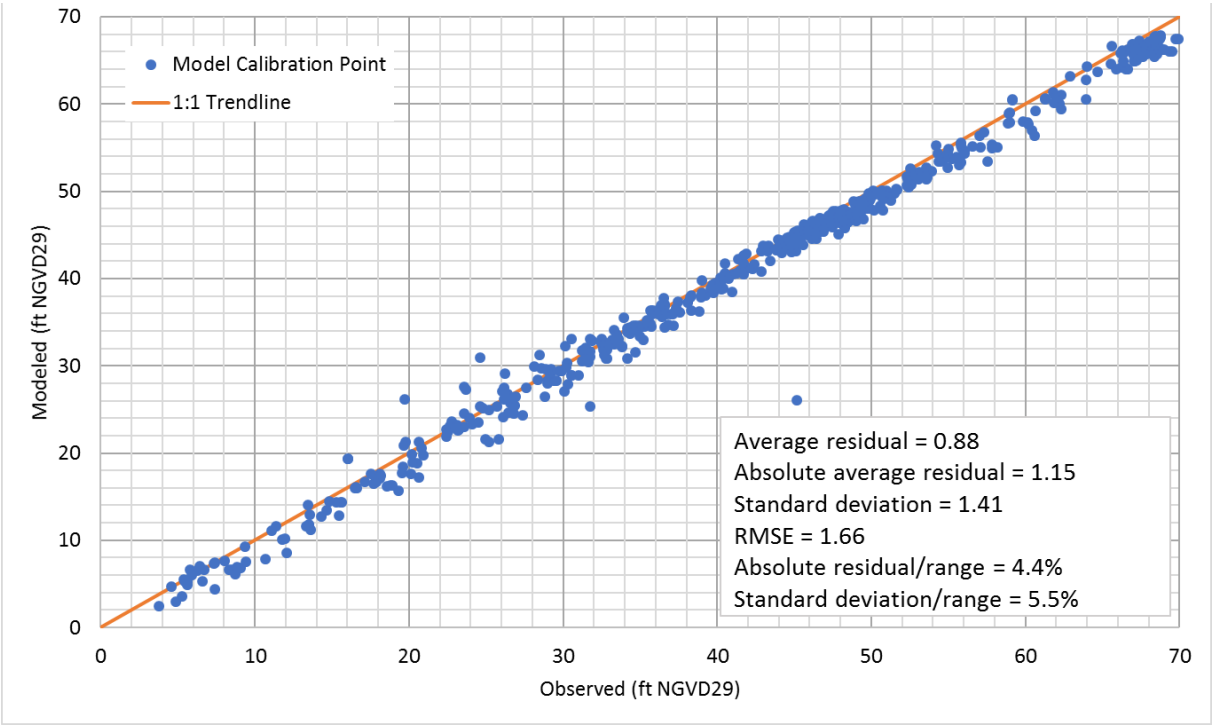


Figure 20: Long-term Observed versus Steady-State Model Simulated Groundwater Elevations – Model Wide

As shown on **Figure 20,** the model-wide calibration matched observation points well. Most model updates were concentrated in the area immediately surrounding the BWPCF, so the model-wide calibration compared to the USGS model was maintained. The average residual was 0.88 feet and the

absolute average residual was 1.15 feet. The absolute residual divided by the range and the standard deviation divided by the range were 4.4% and 5.5% respectively.

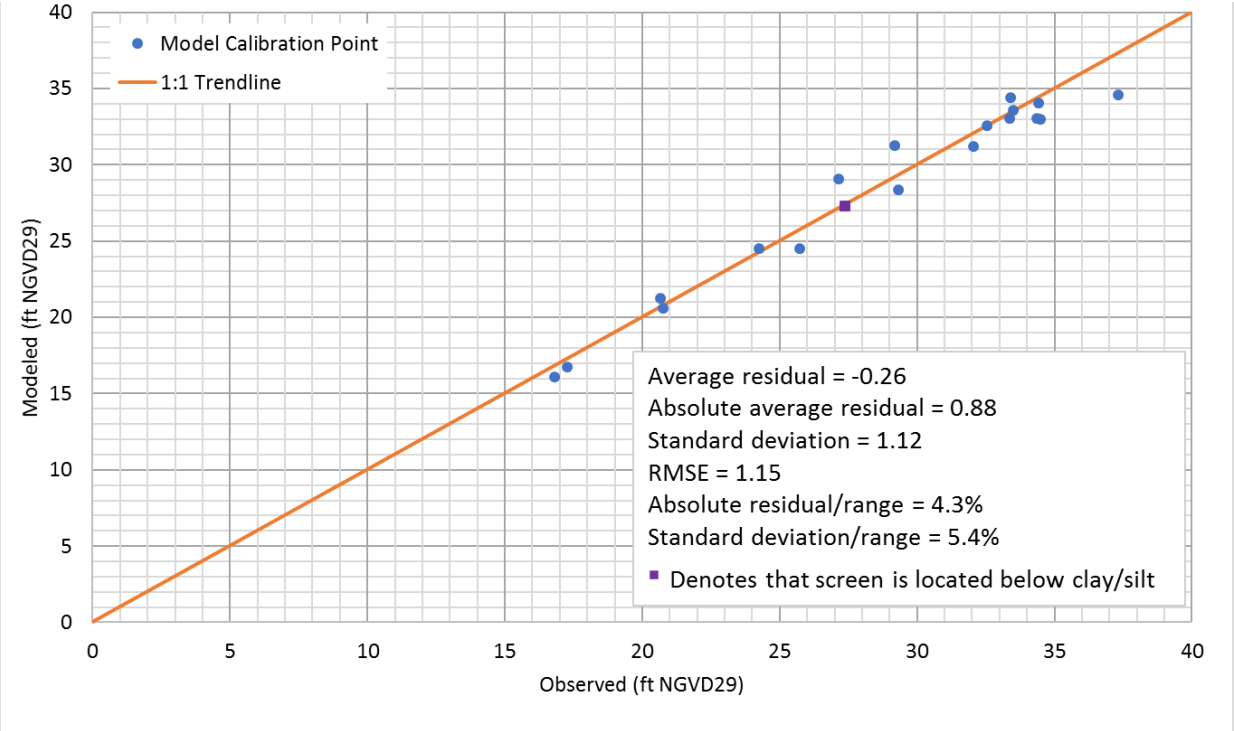


Figure 21: Long-term Observed versus Steady-State Model Simulated Groundwater Elevations – near BWPCF

As with the model-wide calibration, the calibration points located near the BWPCF match the observation points well. The average residual was -0.26 feet and the absolute average residual was 0.88 feet. The absolute residual divided by the range and the standard deviation divided by the range were 4.3% and 5.4%, respectively. The model meets the calibration metrics of the absolute residual and standard deviation divided by the range of approximately 5% for the absolute residual over the range and 10% for the standard deviation over the range. The head contours and residuals for the locations plotted on **Figure 21** are shown on **Figure 22.**

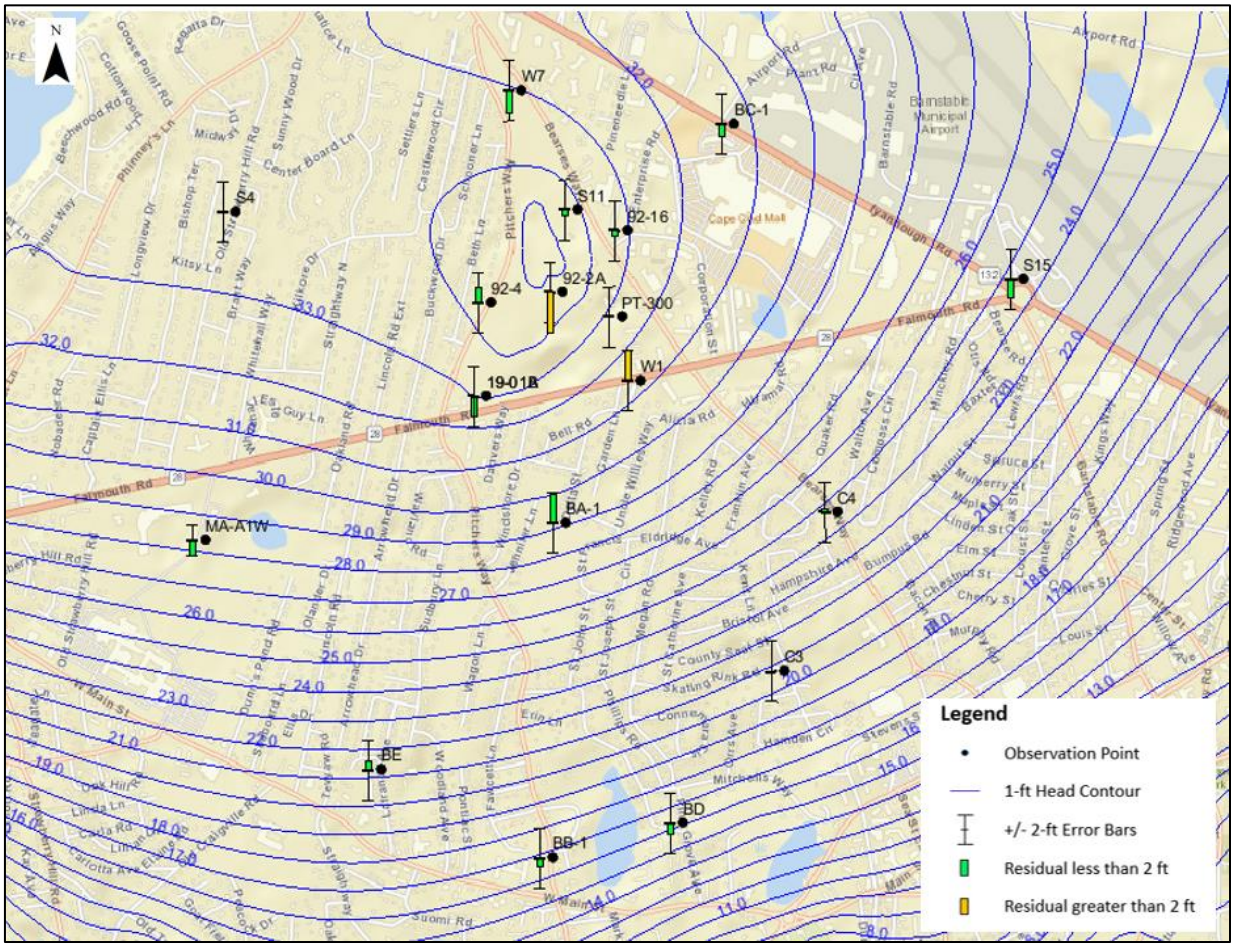


Figure 22: Long-term Observed versus Steady-State Model Simulated Groundwater Residuals and Simulated Water Table Contours - BWPCF Site

As shown in the contours shown on **Figure 22,** recharge at the site causes a local groundwater mound. The water table gradient indicates groundwater flows towards the estuaries and harbors in a south southeasterly direction away from the facility. The model residuals (observed head minus simulated head) are shown in color-coded bars corresponding to the residual length and with two-foot error bars in black. If the modeled groundwater level is within 2 feet of observation point, the residual bar is plotted in green. Yellow bars indicate that the absolute value of the residual is greater than 2 feet. In general, most calibration points are within 2 feet. Model statistics, shown on Figures 20 and 21 indicate the model is well calibrated to observed head data both for the Cape Cod region and near the BWPCF site.

In addition to the comparison of simulated and observed groundwater elevations, streamflows at select locations near the BWPCF and throughout the model domain were compared to observed values. The simulated and observed values are provided in **Figure 23.**

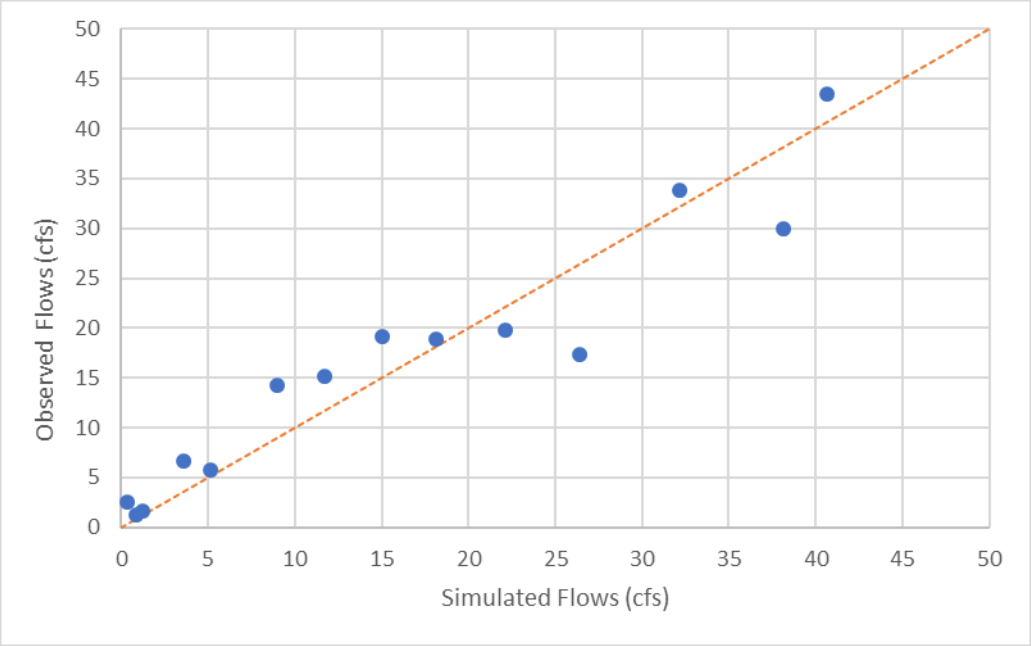


Figure 23. Streamflow at Selected Locations (USGS Gages and Near BWPCF)

The simulated streamflow values generally agree with the observed values, which were taken from Walter et al. (2016). The observed values were compiled by the USGS from several data sources, including USGS streamflow gages and streamflow data collected for the Massachusetts Estuary Project (MEP), and represent approximate streamflow values.

The model-wide steady-state groundwater flow balance is provided in **Table 7.** Published values from previous USGS modeling, including Walter and Whealan (2004) and Walter et al. (2016), are provided for comparison in the table.

Table 7: Steady-State Flow Budget and USGS Reported Values Comparison

Component	USGS Steady-State[1]	USGS Sea Level Rise Model[2]	Barnstable Steady-State Model
Recharge (MGD)	355.3	407	415
Wastewater: Septic and Recharge Beds (MGD)	21.3	24.0	23
Total Recharge (MGD)	**377**	**431**	**438**
Wells (MGD)	-24.9	-28	-28
Discharge: Streams, Coast, Estuaries (MGD)	-358	-375	-424
Total Discharge (MGD)	**-383**	**-403**	**-452**
Percent Discrepancy	*-2%*	*7%*	*-3%*
Percent Wastewater Return Flow	*86%*	*85%*	*83%*

[1] Walter and Whealan 2004. Table 2

[2] Walter et al 2016. Figure 23

Note: Positive numbers indicate flow/flux into the groundwater model. Negative numbers indicate flow/flux out of the groundwater model.

There are no major differences between the model calibration flow budget and the values published in the USGS reports. The percent discrepancy of the model calibration is within a reasonable amount (-3%), and the percent wastewater return flow aligns with the approximate range reported in the USGS reports (Walter and Whealan, 2004; Walter et al., 2016).

4.2 Transient

The changes implemented in the steady state model were applied to the transient model as appropriate. The modeled and observed groundwater levels are provided in **Figure 24** and **Figure 25** for the monitoring wells located within the BWPCF. The model results for all wells used for transient calibration are provided in **Appendix E.**

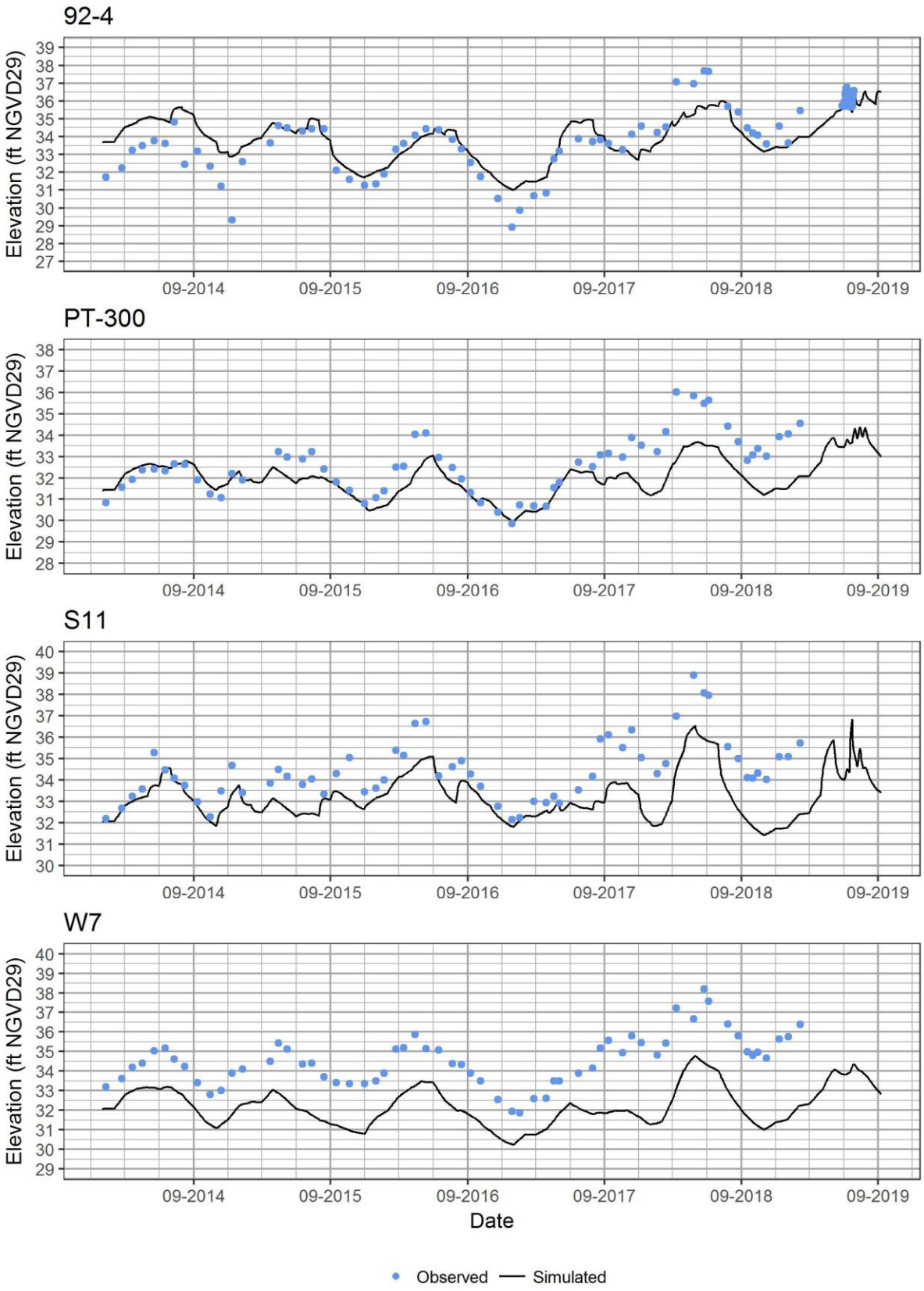


Figure 24: Observed versus Transient Model Simulated Groundwater Elevations (Full Model Simulation)

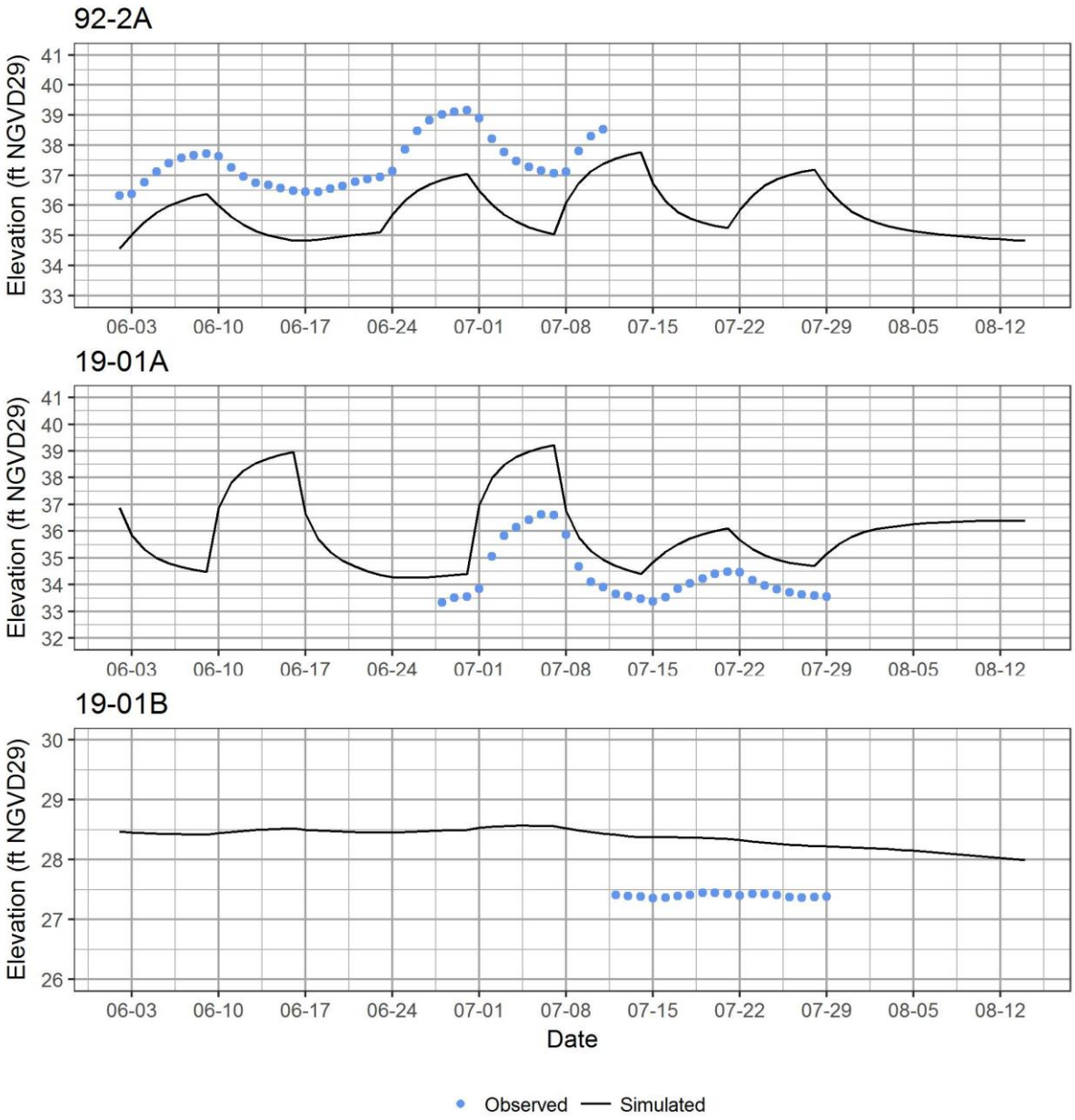


Figure 25: Observed versus Transient Model Simulated Groundwater Elevations (June through July 2019)

The modeled groundwater elevations at the seven monitoring well locations are shown in the black solid line on **Figure 24** and **Figure 25.** The observed groundwater elevations are shown on the plots in blue dots. In general, the transient model captures the seasonal fluctuation in groundwater levels at all locations and matches recent data.

4.3 Model Limitations

The Barnstable model is based on the USGS model documented in Walter et al (2016) which was developed and calibrated to provide regional groundwater flow information to assess the impacts of sea level rise. The Barnstable model was updated and calibrated based on data and hydrologic conditions for long-term average conditions and for transient conditions between 2014 and 2018. The calibration focuses on the BWPCF site and nearby areas. Updates to subsurface features, local recharge patterns and pumping withdrawals have not been included in other areas. Available data and model calibration should be reviewed to determine if additional model updates are required before simulation of scenarios in other areas.

The simulation of lakes and ponds is based on high conductivity values and horizontal flow barriers to simulate the movement of groundwater through the bottom of ponds. The simulation of lakes and ponds should be calibrated to pond water levels and inflow and outflow data prior to application of the model to estimation of pond and lake water budgets.

Estimates of steady-state and seasonal site capacity are dependent on estimated model recharge. The estimated site capacities are based on simulated average annual or average monthly conditions and do not represent all periods, particularly periods of high recharge which could limit site capacity.

The model is well calibrated to observed head and streamflow data both for the Cape Cod region and near the BWPCF site and is appropriate for simulation of existing groundwater conditions and recharge scenarios presented in this report.

Section 5
Scenarios

Five scenarios were developed and simulated utilizing the steady-state and transient calibrated models. Results were compared to baseline steady-state and transient simulations using the current recharge rates at the BWPCF. Scenario 1 looks at the transient capacity at the BWPCF recharge beds. The capacity of the beds is dependent on the groundwater table which varies seasonally. Scenarios 2 and 3 use particle tracks to evaluate the potential for impact to public water supply wells under both steady-state and transient conditions. Scenarios 4A and 4B simulates withdrawal of groundwater downgradient of the BWPCF recharge beds to reduce impacts to low-lying areas. The scenario includes recharge at the maximum day permitted flow rate of 4.2 MGD and recharge at the maximum day build-out rate of 10 MGD using steady-state simulations. Scenarios 5A and 5B simulate the impact to the water table due to a combination of sea level rise, increased groundwater withdrawals and average annual flows of 2 MGD (site capacity) and 6 MGD (build-out) using a steady-state simulation.

5.1 Baseline

Previous studies conducted for the BWPCF have recommended site recharge capacities and identified areas where the existing depth to groundwater is small and structures are present which could be impacted by increases in groundwater levels. Seven areas of concern have been identified in previous studies. These locations are shown in red on **Figure 26**.

A previous study for the BWPCF conducted by Stearns and Wheler (2005) recommended a sentinel well at PT-300 and concluded a head of 36.5 ft or higher at the site would indicate groundwater impacts in downgradient neighborhoods. The study by Stearns and Wheler recommended an average annual discharge capacity of 2.3 to 2.5 MGD. Another previous study by GHD (2017) found that a simulated average annual recharge rate of 1.6 MGD at the BWPCF did not result in depth to water of less than 8 feet downgradient of the BWPCF and identified an area of influence from a 1.6 MGD recharge rate. It is not clear in the report how the area of influence from the model scenario was determined. The GHD report identified issues with high groundwater at Independence Drive, Barnstable High School, Enterprise Road/Cape Cod Mall, and St. Francis Circle with simulated average annual recharge rates at the BWPCF of 3 MGD.

For this analysis the steady-state and transient calibrated models were used as baselines for comparison to model scenarios. The steady-state baseline simulation includes average annual recharge from precipitation, average annual return flow and average annual pumping from nearby public water supply wells. The transient baseline simulation includes aquifer recharge, BWPCF recharge and nearby public water supply transient pumping rates for the period from 2014 through 2018. Steady-state and transient simulations were also run with zero wastewater recharge at the BWPCF recharge beds for comparison with current conditions. **Figure 26** shows the steady-state simulated increase in the groundwater elevation, or “mound”, due to the average annual recharge rate 1.6 MGD, at the BWPCF site. The steady-state simulation shows increase in average groundwater

elevations due to recharge at the BWPCF of greater than 1 foot extending from Route 6 in the north to West Main St in the south.

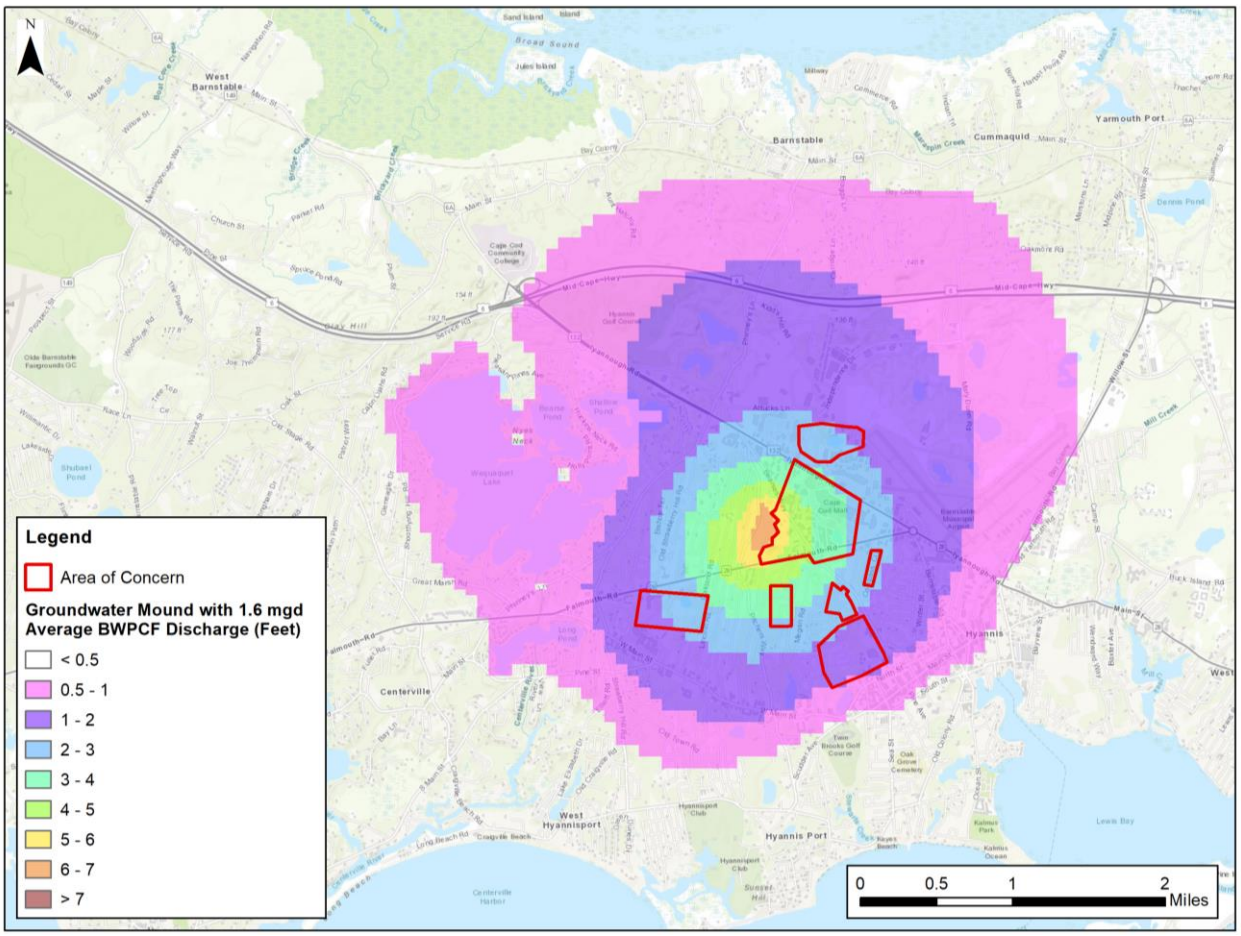


Figure 26: Groundwater Mound due to BWPCF Average Annual Recharge of 1.6 MGD

The recharge capacity of the BWPCF is limited by low-lying areas off-site where increases in the groundwater table could impact basement and low-lying structures. The depth to water is less than 8-ft in the areas identified in previous reports (Stearns and Wheler 2005 and GHD 2017) including near St. Francis Circle and Barnstable High School. **Figure 27** shows the simulated depth to groundwater if there was zero recharge at the BWPCF. This map was developed by subtracting the simulated steady-state groundwater elevations from the digital elevation model of the ground surface. **Figure 28** shows the depth to groundwater for the current average annual discharge rate of 1.6 MGD. For the zero-recharge simulation (**Figure 27**), structures near St. Francis Circle have a steady-state simulated depth to groundwater of greater than 8 feet. One structure near Barnstable High School is on the edge of the area with 6 to 8 ft depth to groundwater. In addition, near Fawcetts Pond to the south there are areas where the simulated depth to groundwater is near 8 feet. The area near Fawcetts Ponds was not identified in previous reports as an area of concern. For the simulated current average annual discharge rate of 1.6 MGD (**Figure 28**), 3 structures in the St. Francis Circle and 4 structures near the Barnstable High School show simulated depth to water of between 4 and 8 feet.

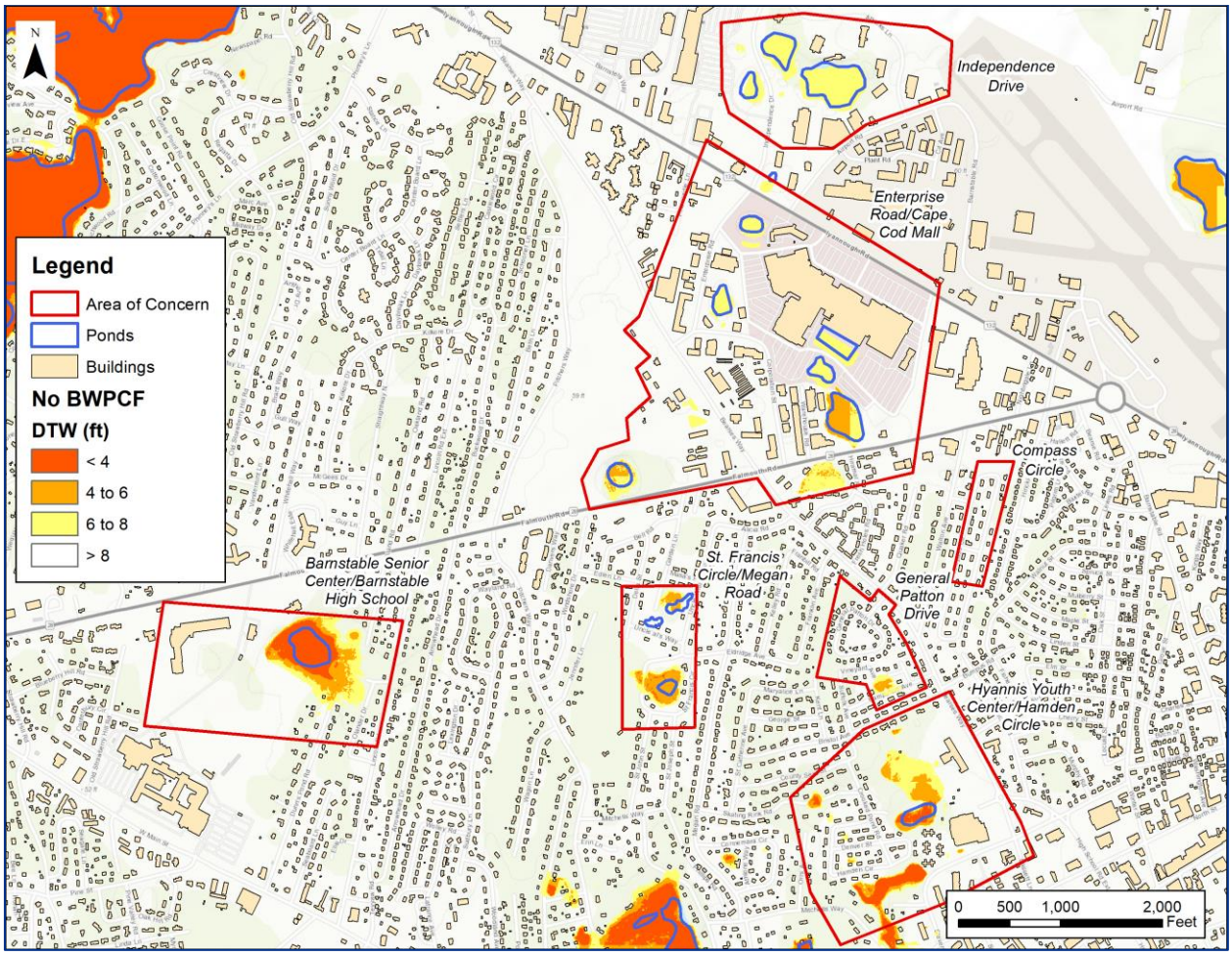


Figure 27: Depth to Groundwater – Zero Recharge at BWPCF

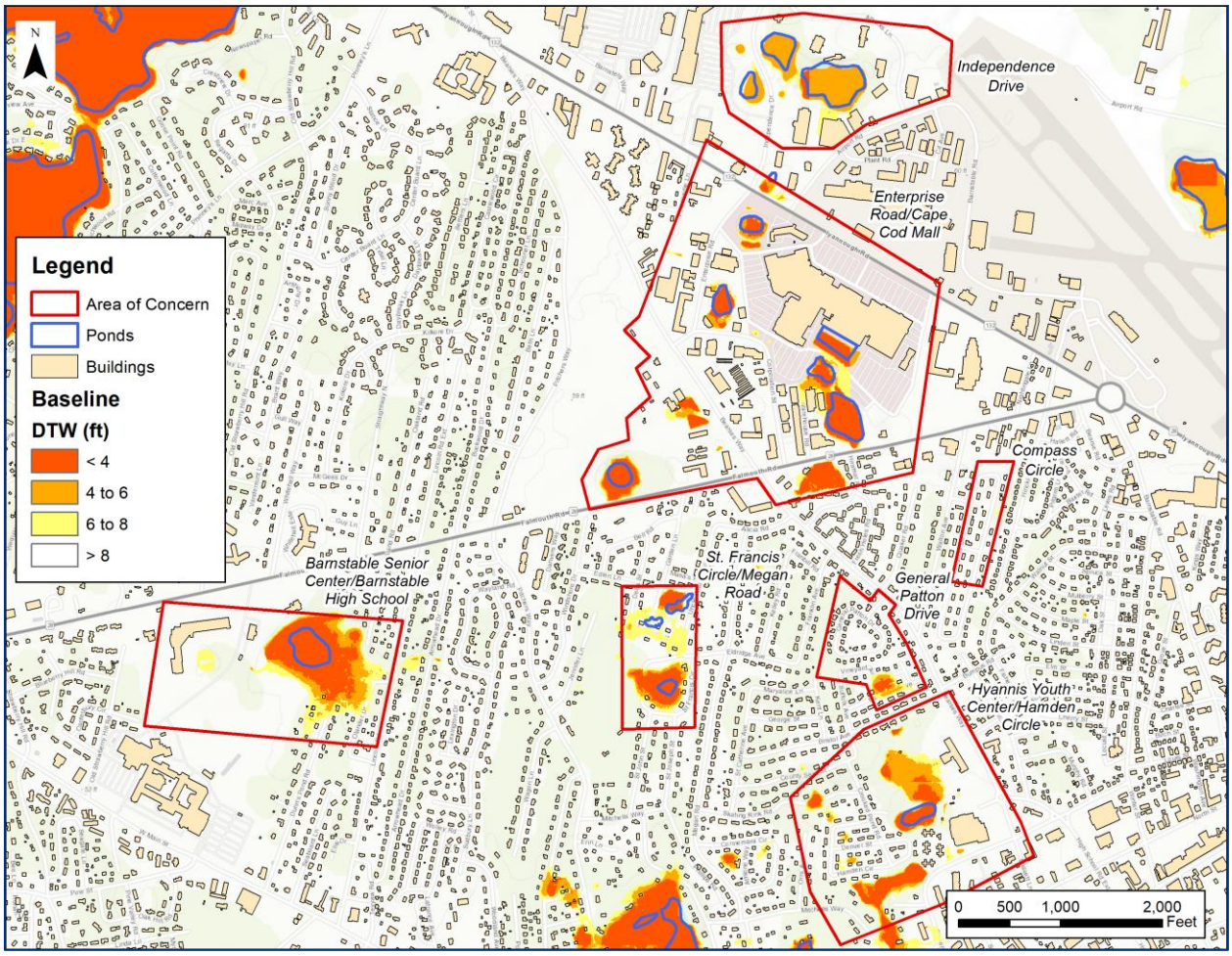
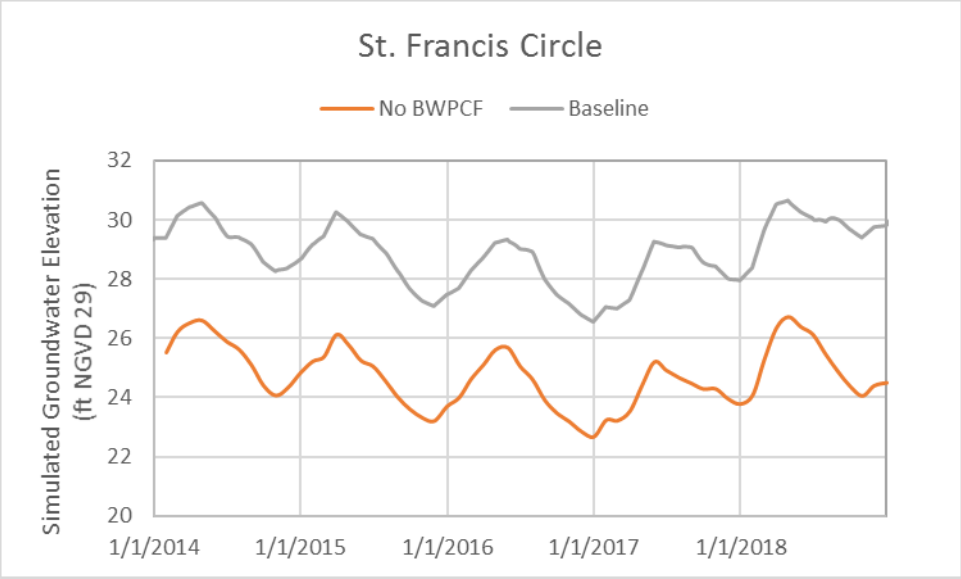


Figure 28: Depth to Groundwater – 1.6 MGD Baseline

Figure 29 shows the simulated monthly water levels at a location near St. Francis Circle for two transient simulations, zero recharge at the BWPCF and a baseline simulation with reported flows from 2014 through 2018 at the BWPCF. The two transient simulations show that the recharge flow from the last 5 years at the BWPCF increase the groundwater over 3 feet near St. Francis Circle when compared to the zero recharge simulation. Background seasonal fluctuations are between 2 to 3 feet based on the difference between the minimum and maximum water levels during a twelve month period.



Note: Ground surface at this location is 40 ft. Within 500 feet of this location, ground surface varies from 28 ft to 54 ft.

Figure 29: Simulated Groundwater Elevations near St. Francis Circle – No BWPCF and Baseline Conditions

5.2 Scenario 1 – Seasonal Capacity of BWCF

The transient seasonal capacity of the BWCP was determined by determining the average annual site capacity (2 MGD), identifying groundwater elevations at downgradient sentinel points which would be protective of basement and septic systems, and then estimating and simulating the permissible effluent discharge for each month during the 5-year simulation period.

Using the 8-ft depth to water criterion, a steady-state simulation was used to estimate the maximum head at the BWPCF that would limit potential impacts to houses at St. Francis Circle. For this simulation, the flow was assumed to be applied evenly in the southern portion of the site (recharge beds 17, 18 and 20 through 39). A steady-state recharge rate of 2 MGD at BWPCF shows a simulated depth to groundwater of 4 to 8 feet under 9 structures at St. Francis Circle and 7 structures near the Barnstable High School. (**Figure 30**). Increasing flows would result in lower depth to water and more impacted structures. Therefore, this rate of 2 MGD was identified as the estimated average annual recharge capacity for the BWPCF. Based on this simulation, target groundwater elevations were identified for sentinel points near St. Francis Circle and Barnstable High School to guide the transient capacity simulation. The groundwater elevations for the sentinel points are 31 ft for St. Francis Circle and 29.3 ft for Barnstable High School. The groundwater elevations for the sentinel points were taken from the average annual recharge capacity simulation for the BWPCF. These values reflect the groundwater elevations at points in the model that are protective of structures downgradient of the BWPCF.

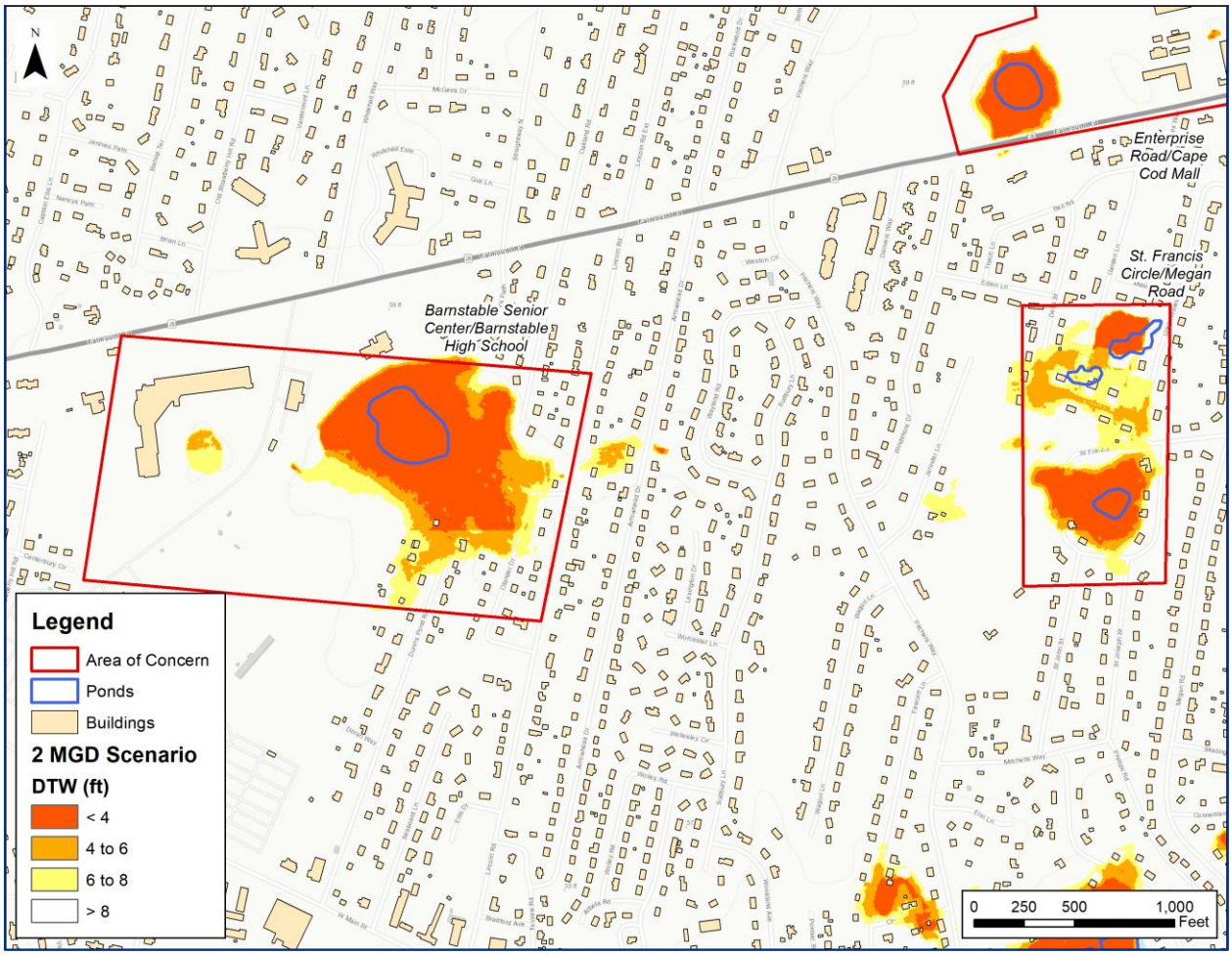


Figure 30: Depth to Groundwater – 2 MGD Planning Scenario

The transient recharge capacity was developed by first estimating the monthly recharge at the BWPCF based on the steady-state simulated water elevation at the sentinel locations. The model was then run in a transient mode to simulate the impacts of the monthly recharge on water levels and the monthly recharge iteratively adjusted to maintain the simulated water levels at the sentinel locations for each time step.

Analysis of the monthly estimated recharge from precipitation, reported BWPCF site recharge and simulated water levels near St. Francis Circle indicates that there is a lag of 3 months in the water table response to changes in recharge, due to aquifer response time. The response time in an aquifer is a function of the change in recharge and boundary conditions (i.e. pumping), the distance to the discharge and boundary locations and hydraulic and storage properties of the aquifer. The lag time was estimated based on the relationship between the sum of the previous 3-months of recharge from precipitation to simulated groundwater levels near St. Francis Circle.

Figure 31 shows the average monthly reported flow at the BWPCF in blue, which range from 1.3 MGD to 2 MGD. The yellow line shows the estimated site recharge capacity based on the linear estimate. The estimated monthly site recharge capacity ranges from 0.96 MGD to 3.1 MGD. The chart shows

that in April and May of 2016, 2017 and 2018 the reported BWPCF recharge rate was at or above the simulated site recharge capacity. In fall of 2017 and winter of 2018 there were a few months with high precipitation which resulted in high groundwater level. The simulated site recharge capacity dropped to less than the BWPCF flows for several months. This is consistent with reported issues in 2018 including parking lot flooding near the BWPCF office.

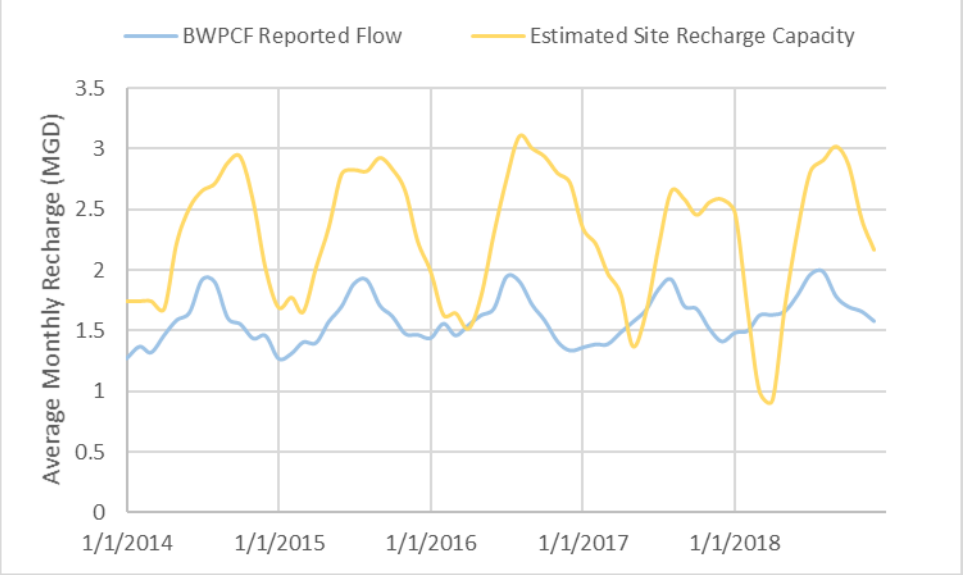


Figure 31: Monthly Reported BWPCF Recharge and Simulated Site Capacity

The Palmer Drought Severity Index (PDSI) is a monthly index developed by the National Oceanic and Atmospheric Administration (NOAA) that provides a method of estimating the severity of wet or dry (drought) periods (NOAA 2019). Negative values are assigned to indicate drought conditions and positive to indicate wetter conditions. The index generally ranges from negative to positive 6 with normal values between -0.5 to 0.5. A value of 3 to 4 is categorized as a "severe wet period" and above 4 as an "extreme wet period."

For this analysis, a timeseries of rainfall was developed from the Barnstable WWTF observed data with missing data from the Barnstable Airport. This 120-year time series was then used to calculate the specific PDSI for the Barnstable area (Cox, T. et al 2019). Starting in August of 2017 through June of 2018, the monthly PDSI values were all greater than 3, indicating severe wet periods. The PDSI values were above 4 for seven of the eleven months, indicating extreme wet periods. For the month of March 2018 the PDSI was 5.54 and for April 2018 the PDSI was 5.11.

Recurrence intervals for this volume of precipitation over a 3-month period were developed based on the long-term rainfall timeseries. Based on the analysis, the rainfall total for the 3-month period from August 2017 through October 2017 would be expected to occur every 18 years and the rainfall total from January 2018 through March 2018 would be expected to occur every 12 years.

The groundwater levels from the simulated baseline using actual BWPCF reported flows and the maximum seasonal capacity model runs at the BWPCF site, St. Francis Circle and Barnstable High School are shown in **Figure 32.** The simulated water levels at the sentinel points near St Francis Circle

and Barnstable High School generally stay below the target values of 31 ft and 29.3 ft respectively. The simulated water levels do drop below the target elevations for some periods, suggesting that seasonal capacity may be underestimated during the fall and periods of low groundwater.

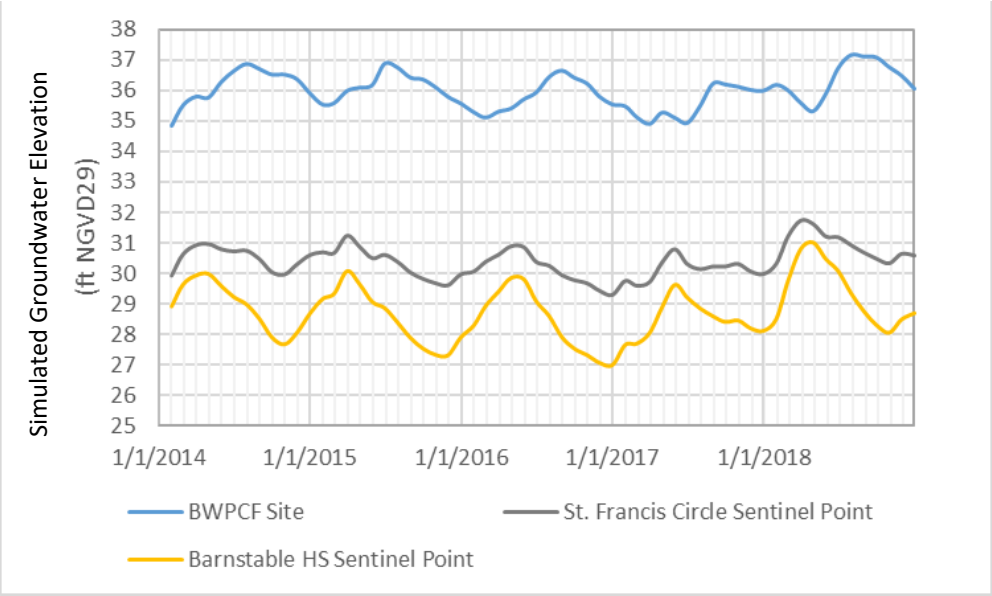


Figure 32: Simulated Groundwater Levels for Maximum Seasonal Capacity at BWPCF Site and near Areas of Concern

Results of the seasonal capacity simulation show that the capacity of the site is dependent on groundwater levels and recharge from the previous months. **Figure 33** shows the average reported flows and simulated capacity for each month at the BWPC for 2014 through 2018. The black error bars show the range in the reported and simulated monthly flows. The yellow shows the estimated plant capacity for each month along with error bars showing the range of capacities. The current flows meet or exceed the site capacity for the months from March through June. During the fall and winter, there is excess recharge capacity at the site.

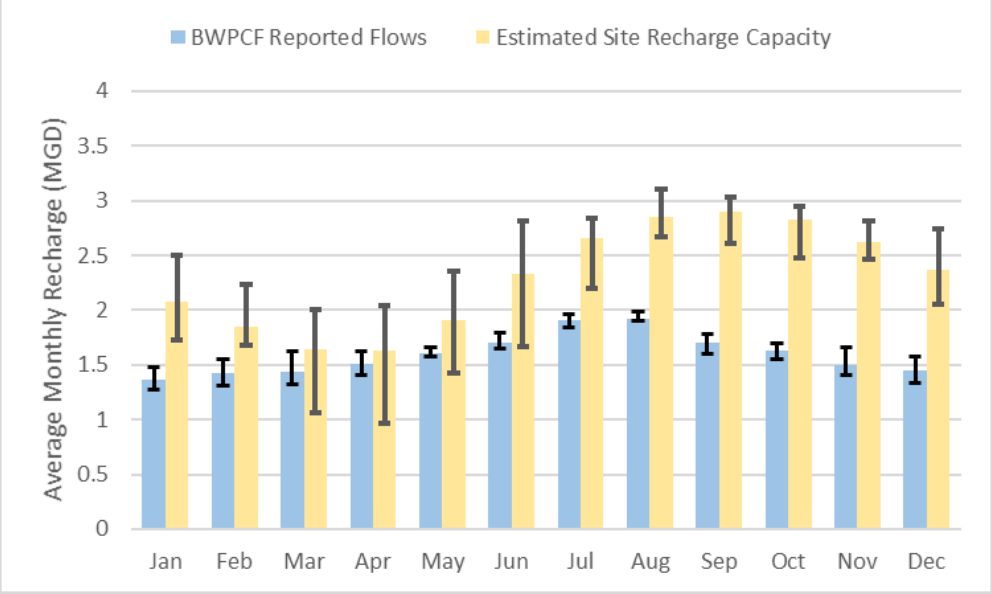


Figure 33: Average Monthly BWPCF Recharge and Simulated Site Capacity

The analysis suggests that a predictive tool for estimating site capacity and guiding operational decisions could be developed. The tool would be used to identify the acceptable BWPCF loading rate on a monthly basis, using groundwater levels from sentinel wells, background wells away from the site, and/or precipitation and temperature data. This would require collection of water level data at St. Francis Circle to evaluate the response to bed loading rates, precipitation data and identification of an off-site sentinel well which is not impacted by the BWPCF.

5.3 Scenario 2 – Travel Time to Public Water Supply Wells

The travel time to nearby public water supply wells was simulated using current pumping rates from 2014 through 2018 and the 5-year transient baseline model. The assumed porosity value was 0.3. To estimate the impact associated with wastewater discharge at the BWPCF beds, particles were released from the individual cells corresponding to the BWPCF beds. A total of 6 evenly-spaced particles were released at the water table in each cell. Two sets of particles were released in January 2014 and July 2014 to evaluate seasonal differences, if any. The resulting particle pathways at the end of the 5-year simulation are shown in **Figure 34.** No particles reach the nearby public water supply wells after a period of 5-years at the current public water supply pumping rates and average annual BWPCF recharge rates. Outside of the 5-year time of travel, there are generally no additional treatment requirements for total organic carbon (TOC).

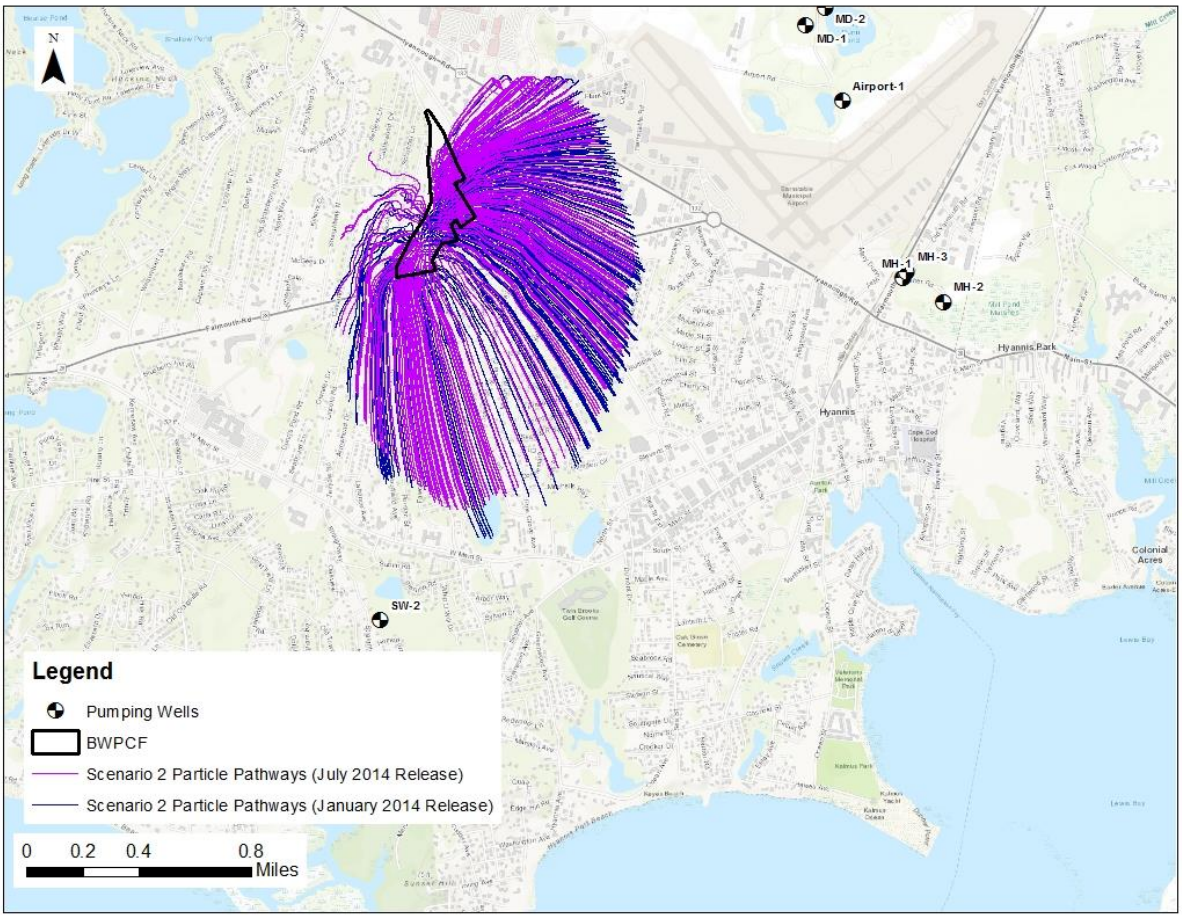


Figure 34: Simulated 5-Year Particle Pathways (January 2014 Release)

5.4 Scenario 3 – Travel Time to Public Water Supply Wells under Maximum Sustained Pumping

The travel time to nearby public water supply wells under maximum sustained pumping was estimated using the steady-state model. Average annual recharge from precipitation and the estimated average annual site capacity of 2 MGD at the BWPCF were assumed for this scenario. The potentially impacted public water supply wells identified are listed in **Table 8,** along with the simulated travel time of particles that terminate at the public water supply wells. As with Scenario 2, the assumed porosity value was 0.3. A total of 6 evenly-spaced particles were released at each cell corresponding to an individual recharge bed at the BWPCF.

Table 8: Public Water Supply Wells Withdrawal Rates and Time of Travel from BWPCF for Scenario 3

Well	Long-term Average Rate (MGD)	Maximum MassDEP Approved Withdrawal Rate (MGD)	Simulated Travel Time (years)
HP	0.28	0.72	44.1
MH-1	0.29	1.01	21.4
MH-2	0.32	1.01	26.8
MH-3	0.42	1.01	21.4
SP	0.37	1.01	17.4

The long-term average withdrawal rates for all wells are relatively consistent and range from 0.28 MGD to 0.42 MGD. The maximum MassDEP approved withdrawal rates are 0.72 MGD at Well HP in Hyannisport and 1.01 MGD for all other wells. The five public water supply wells are all located south/southeast of the BWPCF.

Particles all move radially initially from the site. The particles which flow to the west and north/northeast change directions after approximately 0.25 miles, when they are pulled south and east by the influence of the public water supply wells The screen for well SW-2 is located in a deeper aquifer unit from SP and HP, which are screened in the shallow aquifer, and thus particle pathways do not terminate at SW-2. The travel times for the particle pathways are all much greater than 5 years. The minimum travel time for each public water supply well, shown in **Table 8,** is greater than 17 years for all wells.

5.5 Scenario 4A/4B – Feasibility of Focused Groundwater Withdrawals to Improve BWPCF Capacity

The steady-state model was used to evaluate the feasibility of focused groundwater withdrawals between the BWPCF site and potentially impacted downstream areas. The goal of the scenarios was to estimate the amount of withdrawals required to maintain water levels at a reasonable depth below groundwater water. Scenario 4A simulated an average annual recharge rate of 4.2 MGD at the BWPCF and Scenario 4B an average recharge rate of 10 MGD. The scenarios assumed that the groundwater withdrawals are not recharged to the aquifer.

For these scenarios, fixed head values were simulated at locations along Route 28 and Bearses Way, shown in **Figure 35.** The fixed head values were adjusted at these locations until the groundwater elevations at sentinel points at St. Francis Circle Barnstable High School and the Cape Cod Mall matched the groundwater elevations determined as part of the steady-state capacity analysis. This allows for a depth to groundwater of greater than 8 feet under structures in these areas. The model computed flux at the fixed head locations is the estimated withdrawals required for each scenario. For the 4.2 MGD scenario, 4 wells would be installed along Route 28 and three along Bearses Way. For the 10 MGD scenario, 6 wells would be installed along Route 28 and 5 along Bearses Way.



Figure 35: Simulated Withdrawal Locations for 4.2 MGD Scenario [4A, left] and 10 MGD Scenario [4B, right]

The results indicate that 2.16 MGD would need to be withdrawn for Scenario 4A and 7.4 MGD for Scenario 4B. These results indicate that nearly all the additional flow beyond the steady-state site capacity of 2 MGD would need to be pumped and discharged far enough away from the BWPCF area to avoid water table impacts. Since the seasonal capacity of the site varies, higher withdrawal levels would be required in the late spring and following other periods of higher than normal background net recharge from precipitation. The magnitude of seasonally-driven and climatically-driven variations in withdrawals can be assessed with the transient groundwater model.

5.6 Scenario 5A/5B – Sea Level Rise Impacts

The impact of sea level rise on groundwater levels was evaluated with a steady-state USGS model containing a higher sea level and a revised freshwater-saltwater interface (USGS 2016), which represents 2 feet of sea level rise above sea levels in 2011 for central and western Cape Cod. The USGS study showed that under existing pumping and recharge conditions, a sea level rise of 2-feet will increase groundwater elevation beneath the BWPCF by approximately 0.8 feet (USGS 2016). Several updates were made to the USGS 2-foot sea level rise model in order to incorporate the findings of this Study:

- Hydraulic conductivity was updated in the vicinity of BWPCF to be consistent with changes made during model calibration.
- Pumping at public supply wells owned and operated by the Barnstable Fire District and Hyannis Water System was added using withdrawal rates in **Table 9.** The maximum withdrawal rate was attempted at each well, but at some locations, the maximum withdrawal rate caused the well to go dry. To prevent the model drying out near wells, withdrawal rates were reduced to 80 percent of the maximum rate at MH-1, MH-2, and MH-3, 70 percent of the maximum rate at MD-1, MD-2, MD-3, and MD-4, and 60 percent of the maximum rate at Airport-1. The pumping rates used for the sea level rise scenarios are nearly 4 times the long-term average pumping rates at these wells.

- No changes were made to model discretization.
- No changes were made to precipitation or return flow recharge.
- Recharge at BWPCF was applied as a fixed flux at different rates for each of the two scenarios:
  - Scenario 5A: Average annual recharge at 2 MGD to simulate seasonal site capacity; and
  - Scenario 5B: Average annual recharge at 6 MGD to simulate build-out flow at the BWPCF.

Using the 8 feet depth to water criteria, the steady-state model with 2 MGD of recharge at the BWPCF simulates a depth to water between 4 and 8 feet beneath one structure at St. Francis Circle and one structure near the Barnstable High School, shown on **Figure 36**. The groundwater table is lower in this sea level rise scenario than in the existing 2 MGD planning simulation (**Figure 30**) because of the increase in simulated withdrawals at nearby public water supply wells. The simulated pumping rates are nearly four times the rates used for the steady-state baseline and planning simulations. Differences in the simulations also exist due to the changes in the boundary conditions associated with the sea level rise and saltwater intrusion beneath the freshwater aquifer near the coastal boundary to the south.

When recharge is increased to the build-out flow at the BWCF (6 MGD), the model simulates depths to groundwater of less than 4 feet below structures near St. Francis Circle, Barnstable High School, Enterprise Road/Cape Cod Mall and near Fawcetts Pond (**Figure 37**).

Table 9: Town of Barnstable Hyannis Water System Current and Maximum Withdrawal Rates

Well	Long-term Average Rate (MGD)	Maximum Approved Withdrawal Rate (MGD)	Modeled Withdrawal Rate in Sea Level Rise Scenarios (MGD)
MH-1	0.29	1.01	0.81
MH-2	0.32	1.01	0.81
MH-3	0.42	1.01	0.81
MD-1	0.17	0.72	0.50
MD-2	0.11	1.01	0.71
MD-3	0.19	0.72	0.50
MD-4	<0.01	0.72	0.50
Airport-1	0.06	1.44	0.86
HP	0.28	0.72	0.72
SP	0.37	1.01	1.01
SW-2	0.12	1.58	1.58

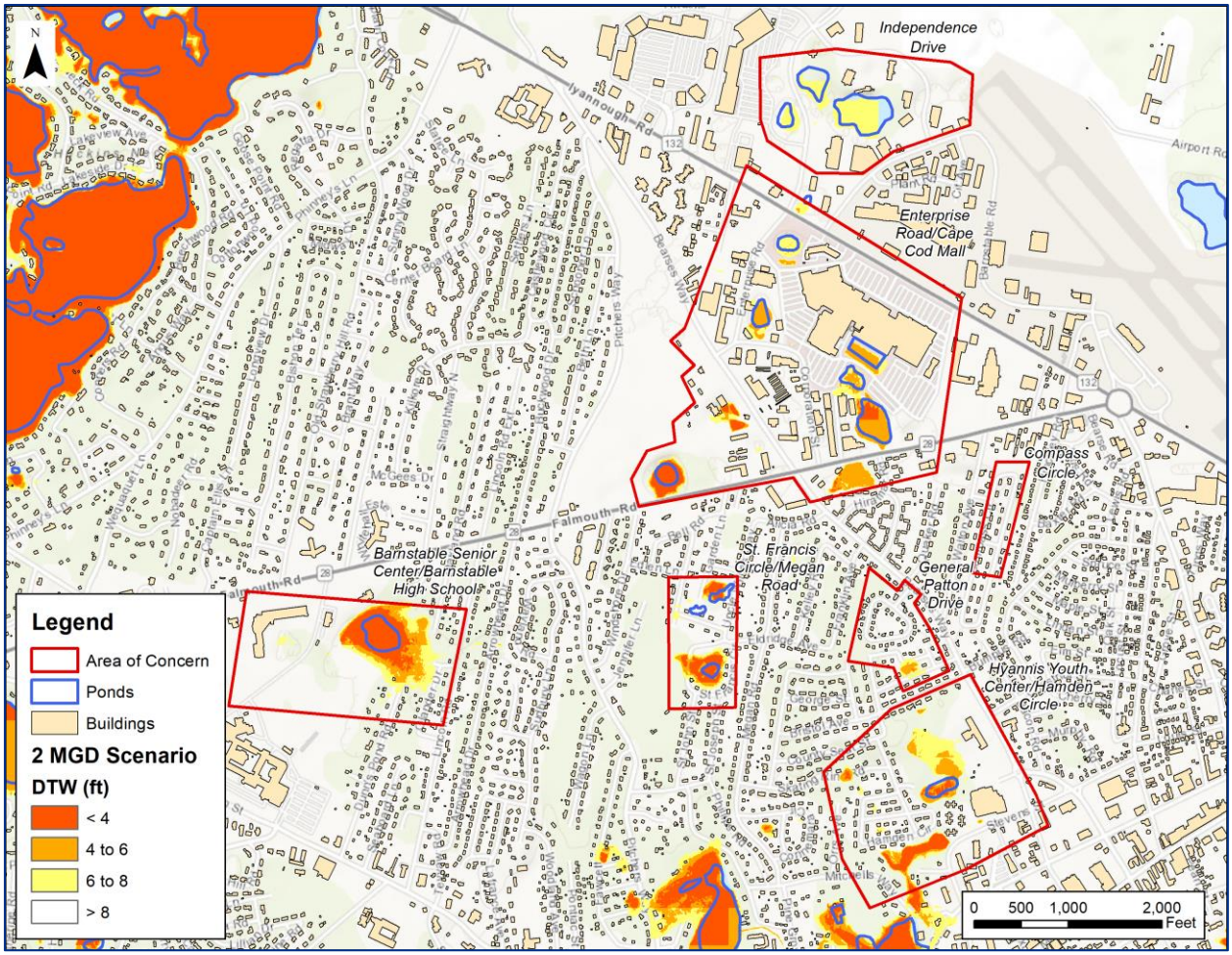


Figure 36: 2-ft Sea Level Rise Model, 2 MGD BWPCF Discharge, Depth to Water Contours

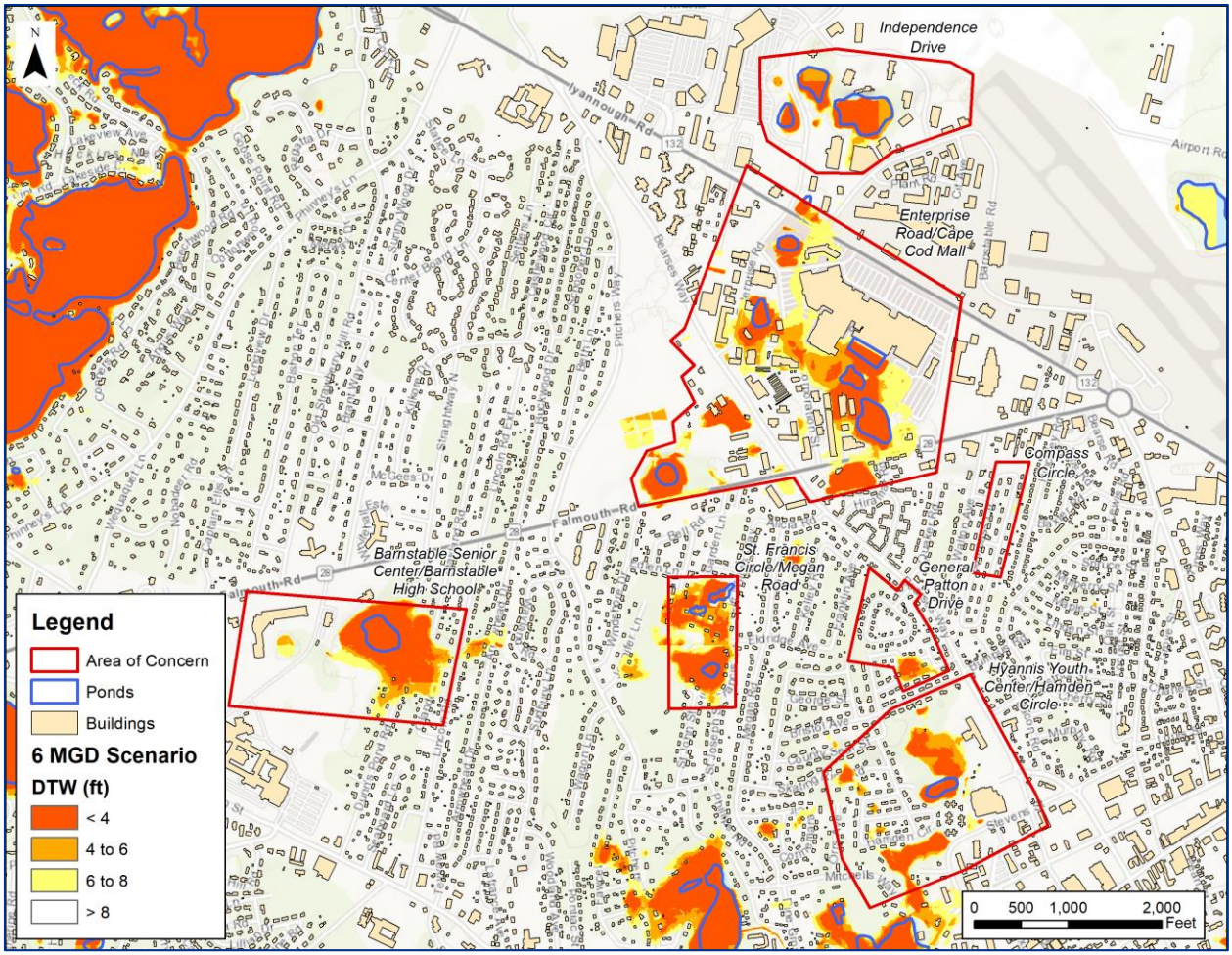


Figure 37: 2-ft Sea Level Rise Model, 6 MGD BWPCF Discharge, Depth to Water Contours

Section 6

Summary and Recommendations

Summary

Results of the study identified subsurface clay that limits the vertical movement of the groundwater. This clay is 5 to 20 feet thick and overlain on a dense sand. The dense sand has a low hydraulic conductivity so discharge of water through the clay would not likely be practical. Since the clay also limits vertical flow, subsurface discharge (groundwater injection) directly above the clay would not increase site capacity. The elevation of the clay varies which may direct flow locally.

Baseline simulations show that the mounding impacts from current average annual discharge rate of 1.6 MGD are large. Near St. Francis Circle, the BWPCF recharge increases the water table by 2 to 3 feet when compared to the zero recharge simulation. Mounding impacts of greater than 1-foot extend for over a mile radially from the site. Water levels in the aquifer respond over several months to changes in recharge, therefore, the transient nature of the system should be considered in order to fully maximize the potential recharge capacity.

Capacity is limited primarily by depth to water at low lying areas, particularly near St. Francis Circle. The site capacity varies depending on the amount of recharge from precipitation over the preceding three months. The estimated average annual site recharge capacity is 2 MGD but varies from a monthly average low of 0.96 MGD in April to as high as 3.1 MGD in August based on the hydrologic conditions from 2014 through 2018. (Scenario 1) The recharge rate for the BWPCF is currently at or near the site recharge capacity during the months of March through June.

Impacts to public water supply wells are greater than 5 years time of travel both in the transient conditions, based on the last five years of pumping and recharge, and steady-state conditions, with the higher seasonal capacity and permitted pumping rates at nearby wells. (Scenarios 2 and 3)

Withdrawal of water can reduce groundwater levels to acceptable levels off-site, however, nearly all water above the site capacity needs to be withdrawn. The feasibility of focused groundwater withdrawals was simulated using steady-state scenarios and should be reviewed in a transient simulation due to the 3-month lag in the response to changes in recharge. The simulation assumes that any water withdrawals will be discharged to the aquifer far enough from the site to prevent impacts to the water table. (Scenarios 4A and 4B)

In addition to coastal inundation, a sea level rise of 2-ft will increase the baseline groundwater elevations at the site by approximately 0.8 ft (USGS 2016). The simulations of sea level rise also included increased pumping at public water supply wells. Because of this increased pumping, steady-state simulations of recharge at the site based on the estimated site recharge capacity of 2 MGD did not show increases in the water table beneath structures. (Scenario 5A). The steady-state simulation of build-out conditions with a recharge rate of 6 MGD (Scenario 5B) showed areas with groundwater depth of less than 8 feet near St. Francis Circle, Barnstable High School, Enterprise Road/Cape Cod Mall and near Fawcetts Pond.

Recommendations

Based on the findings of this study, the following recommendations are being made:

- Use focused loading data and detailed depth to clay information to fine tune the model beneath the site and optimize bed loading. The elevation of the layer beneath beds 40 to 48 is high and it may be possible to take these beds off-line to allow for treatment plant expansion, if needed.
- Collect water level data at St. Francis Circle to evaluate the response in site bed loading rates, precipitation and groundwater levels. An off-site sentinel well which is not impacted by the BWPCF should be monitored to provide information on aquifer response to recharge from precipitation.
- Develop a predictive tool based on water levels in sentinel and downgradient wells, recorded precipitation and climate data (temperature) to estimate the actual recharge in the prior 3 months and site capacity.
- Optimize placement and pumping rates for focused feasibility withdrawals with steady-state and transient modeling. Determine the seasonal impacts to pumping withdrawals using the transient model and simulate the impacts from recharge of withdrawn water.
- Identify secondary loading sites for potential wastewater recharge. Evaluate the impact of recharge at the secondary loading sites including the additive impacts from the mounding due to the BWPCF recharge beds.
- Verify well depths and conduct downhole geophysics to identify clay layers at selected locations where data was unclear.
- Improve the simulation of lakes and ponds, particularly Wequaquet Lake, in the groundwater model using the Lake Package in MODFLOW. This will allow for simulation of the resistance of lake bed sediments to flow and simulation of water levels based on lake and pond bathymetry.
- The risks of increased effluent discharge at the BWPCF should be quantified.
- The groundwater flow model should be utilized to determine impacts to groundwater of potential effluent recharge sites.

Section 7
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Appendix A

Boring and Well Construction Data

A1 Boring and Well Construction Logs

A2 Pictures of Selected Intervals

A3 Particle Size Distribution Reports

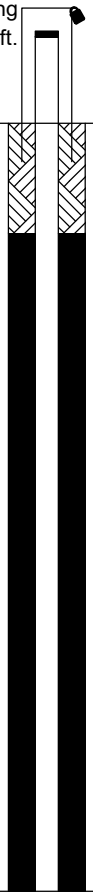
CDM Smith
75 State Street Suite 701
Boston, MA 02109

MONITORING WELL DETAIL
19-01A

Client: Town of Barnstable
Project Name: Barnstable Water Pollution Control Facility
Project Location: Barnstable, MA
Project Number: 238182

Drilling Contractor: New England Boring Contractors
Surface Elevation (ft.): NM
Drilling Method/Rig: Drive and Wash/Truck-Mounted
Total Depth (ft.): 45
Drillers: G. Twombly, Jr./T. Reed
Depth to Initial Water Level (ft. BGS): 28.56
Drilling Date: Start: 6/27/2019 **End:** 6/27/2019
Development Method: Surge and Purge
Borehole Coordinates:
Field Screening Instrument: PID
N E
Logged By: N. Castonguay
Development Date: Start 7/11/19 **End** 7/11/19
Top of Riser Elevation (ft.):

Sample Type	Sample Number	Field Instrument Reading (ppm)	Blows per 6 Inches	Stratum Designation	Material Description	Graphic Log	Elev. Depth (ft.)
SS	S-1	0.0	4 5 18 14	SW	(0-2') Dry, medium dense, brown, coarse-medium-fine SAND, little fine gravel.		0
					Advance casing and rollerbit to 3' BGS.		
SS	S-2	0.0	6 8 7 7	SW	(3-5') Dry, medium dense, brown, coarse-medium-fine SAND, little fine gravel, trace coarse gravel.		
					Advance casing and rollerbit to 8' BGS.		5
SS	S-3	0.0	7 12 11 15	SW	(8-10') Dry, medium dense, light brown, coarse-medium-fine SAND, little fine gravel with fine sand seam (1/2-1").		
					Advance casing and rollerbit to 13' BGS.		10
SS	S-4	0.0	12 14 14 15	SW	(13-15') Dry, medium dense, light brown, coarse-medium-fine SAND, some-little fine gravel, trace coarse gravel.		
					Advance casing and rollerbit to 18' BGS.		15
SS	S-5	0.0	6 6 7 8	SW	(18-20') Dry, medium dense, light brown, coarse-medium SAND, some fine sand, little fine gravel, trace coarse gravel.		
					Advance casing and rollerbit to 23' BGS.		20



EXPLANATION OF ABBREVIATIONS

DRILLING METHODS:
HSA - Hollow Stem Auger
SSA - Solid Stem Auger
HA - Hand Auger
AR - Air Rotary
AH - Air Hammer
DTR - Dual Tube Rotary
FR - Foam Rotary
MR - Mud Rotary
RC - Reverse Circulation
CT - Cable Tool
JET - Jetting
D - Driving
DTC - Drill Through Casing

SAMPLING TYPES:
AS - Auger/Grab Sample
CS - California Sampler
BX - 1.5" Rock Core
NX - 2.1" Rock Core
GP - Geoprobe
HP - Hydro Punch
SS - Split Spoon
ST - Shelby Tube
WS - Wash Sample
OTHER:
AGS - Above Ground Surface

REMARKS

19-01A installed as couplet monitoring well with 19-01B. Lithology from 19-01B from 0 to 45' BGS provided on this log.
BGS = Below Ground Surface
PID = Photoionization Detection
TBC = To Be Completed
NA = Not Applicable
NM = Not Measured
Initial depth to water measured from top of PVC 6/28/19.

Reviewed by: N. Castonguay **Date:** 8/16/19

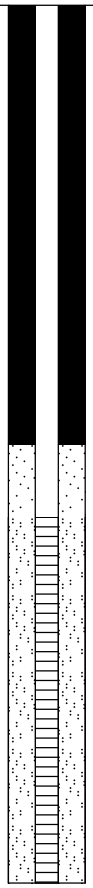
MW BARNSTABLE WPCF V2.GPJ CDM_MA.GDT 8/19/19

CDM Smith
75 State Street Suite 701
Boston, MA 02109

MONITORING WELL DETAIL
19-01A

Client: Town of Barnstable
Project Name: Barnstable Water Pollution Control Facility
Project Location: Barnstable, MA
Project Number: 238182

Sample Type	Sample Number	Field Instrument Reading (ppm)	Blows per 6 Inches	Stratum Designation	Material Description	Graphic Log	Elev. Depth (ft.)
SS	S-6	0.0	12 11 9 9	SW	(23-25') Dry, medium dense, light brown, coarse-medium-fine SAND, little fine gravel with broken rock fragments in top 1-2" (cobble).		
					Advance casing and rollerbit to 28' BGS.		25
SS	S-7	0.0	8 8 11 12	SW	(28-30') Wet, medium dense, coarse-medium-fine SAND, trace fine gravel.		
					Advance casing and rollerbit to 33' BGS.		30
SS	S-8	0.0	17 11 11 10	SW	(33-35') Wet, medium dense, coarse-medium-fine SAND, little-trace fine gravel.		
SS	S-9	0.0	5 6 8 8	SW	(35-37') Wet, medium dense, light brown, coarse-medium-fine SAND, little fine gravel, trace silt.		35
					Advance casing and rollerbit to 38' BGS.		
SS	S-10	0.0	5 6 8 10	SW	(38-40') Wet, medium dense, brown, coarse-medium-fine SAND, some fine gravel. Recovery with 3" spoon. Rock in tip of 3" spoon.		
					Advance casing and rollerbit to 43' BGS.		40
SS	S-11	0.0	8 4 4 5	SW	(43-45') Wet, loose, brown, coarse-medium-fine SAND, little fine gravel, trace coarse gravel.		
					End of exploration at 45' BGS.		45
							50
							55
							60



Well Construction Detail

MW BARNSTABLE WPCF V2.GPJ CDM_MA.GDT 8/19/19

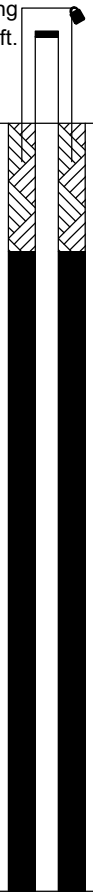
CDM Smith
75 State Street Suite 701
Boston, MA 02109

MONITORING WELL DETAIL
19-01B

Client: Town of Barnstable
Project Name: Barnstable Water Pollution Control Facility
Project Location: Barnstable, MA
Project Number: 238182

Drilling Contractor: New England Boring Contractors
Surface Elevation (ft.): NM
Drilling Method/Rig: Drive and Wash/Truck-Mounted
Total Depth (ft.): 101
Drillers: G. Twombly, Jr./T. Reed
Depth to Initial Water Level (ft. BGS): 34.75
Drilling Date: Start: 6/25/2019 **End:** 6/27/2019
Development Method: Surge and Purge
Borehole Coordinates:
Field Screening Instrument: PID
N E
Logged By: N. Castonguay
Development Date: Start 7/11/19 **End** 7/11/19
Top of Riser Elevation (ft.):

Sample Type	Sample Number	Field Instrument Reading (ppm)	Blows per 6 Inches	Stratum Designation	Material Description	Graphic Log	Elev. Depth (ft.)
SS	S-1	0.0	4 5 18 14	SW	(0-2') Dry, medium dense, brown, coarse-medium-fine SAND, little fine gravel.		0
					Advance casing and rollerbit to 3' BGS.		
SS	S-2	0.0	6 8 7 7	SW	(3-5') Dry, medium dense, brown, coarse-medium-fine SAND, little fine gravel, trace coarse gravel.		
					Advance casing and rollerbit to 8' BGS.		5
SS	S-3	0.0	7 12 11 15	SW	(8-10') Dry, medium dense, light brown, coarse-medium-fine SAND, little fine gravel with fine sand seam (1/2-1").		
					Advance casing and rollerbit to 13' BGS.		10
SS	S-4	0.0	12 14 14 15	SW	(13-15') Dry, medium dense, light brown, coarse-medium-fine SAND, some-little fine gravel, trace coarse gravel.		
					Advance casing and rollerbit to 18' BGS.		15



EXPLANATION OF ABBREVIATIONS

DRILLING METHODS:
HSA - Hollow Stem Auger
SSA - Solid Stem Auger
HA - Hand Auger
AR - Air Rotary
AH - Air Hammer
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FR - Foam Rotary
MR - Mud Rotary
RC - Reverse Circulation
CT - Cable Tool
JET - Jetting
D - Driving
DTC - Drill Through Casing

SAMPLING TYPES:
AS - Auger/Grab Sample
CS - California Sampler
BX - 1.5" Rock Core
NX - 2.1" Rock Core
GP - Geoprobe
HP - Hydro Punch
SS - Split Spoon
ST - Shelby Tube
WS - Wash Sample
OTHER:
AGS - Above Ground Surface

REMARKS

19-01B installed as couplet monitoring well with 19-01A.
BGS = Below Ground Surface
PID = Photoionization Detection
TBC = To Be Completed
NA = Not Applicable
Initial depth to water measured from top of PVC on 6/28/19.

Reviewed by: N. Castonguay **Date:** 8/16/19

MW BARNSTABLE WPCF V2.GPJ CDM_MA.GDT 8/19/19

CDM Smith
75 State Street Suite 701
Boston, MA 02109

MONITORING WELL DETAIL
19-01B

Client: Town of Barnstable
Project Name: Barnstable Water Pollution Control Facility
Project Location: Barnstable, MA
Project Number: 238182

Sample Type	Sample Number	Field Instrument Reading (ppm)	Blows per 6 Inches	Stratum Designation	Material Description	Graphic Log	Elev. Depth (ft.)	Well Construction Detail
SS	S-5	0.0	6 6 7 8	SW	(18-20') Dry, medium dense, light brown, coarse-medium SAND, some fine sand, little fine gravel, trace coarse gravel.			
					Advance casing and rollerbit to 23' BGS.		20	
SS	S-6	0.0	12 11 9 9	SW	(23-25') Dry, medium dense, light brown, coarse-medium-fine SAND, little fine gravel with broken rock fragments in top 1-2" (cobble).			
					Advance casing and rollerbit to 28' BGS.		25	
SS	S-7	0.0	8 8 11 12	SW	(28-30') Wet, medium dense, coarse-medium-fine SAND, trace fine gravel.			
					Advance casing and rollerbit to 33' BGS.		30	(0-91') 2" Schedule 40 PVC Riser
SS	S-8	0.0	17 11 11 10	SW	(33-35') Wet, medium dense, coarse-medium-fine SAND, little-trace fine gravel.			
SS	S-9	0.0	5 6 8 8	SW	(35-37') Wet, medium dense, light brown, coarse-medium-fine SAND, little fine gravel, trace silt.		35	
					Advance casing and rollerbit to 38' BGS.			
SS	S-10	0.0	5 6 8 10	SW	(38-40') Wet, medium dense, brown, coarse-medium-fine SAND, some fine gravel. Recovery with 3" spoon. Rock in tip of 3" spoon.			
					Advance casing and rollerbit to 43' BGS.		40	
SS	S-11	0.0	8 4 4 5	SW	(43-45') Wet, loose, brown, coarse-medium-fine SAND, little fine gravel, trace coarse gravel.			
					Advance casing and rollerbit to 48' BGS.		45	
SS	S-12	0.0	9 9 8 10	SW	(48-50') Wet, medium dense, brown, coarse-medium-fine SAND, little-trace fine gravel. Recovery with 3" spoon.			
					Advance casing and rollerbit to 53' BGS.		50	
			10 13	SW	(53-55') Wet, medium dense, brown, coasrse-medium-fine SAND, little silt, trace			

CDM Smith
75 State Street Suite 701
Boston, MA 02109

MONITORING WELL DETAIL
19-01B

Client: Town of Barnstable
Project Name: Barnstable Water Pollution Control Facility
Project Location: Barnstable, MA
Project Number: 238182

Sample Type	Sample Number	Field Instrument Reading (ppm)	Blows per 6 Inches	Stratum Designation	Material Description	Graphic Log	Elev. Depth (ft.)	Well Construction Detail
SS	S-13	0.0	12 14		coarse gravel.			
					Advance casing and rollerbit to 58' BGS.		55	
SS	S-14	0.0	14 18 50 115/8"	SW	(58-60') Top 4": Wet, very dense, light brown, medium-fine SAND, little silt. Bottom 8": Wet, very dense, light brown, coarse-medium SAND, some fine sand.			
					Advance casing and rollerbit to 63' BGS.		60	
SS	S-15	0.0	16 17 15 16		(63-65') No recovery with 2" and 3" spoons.			
					Advance casing and rollerbit to 68' BGS.		65	
SS	S-16	0.0	12 12 13 14	SW	(68-70') Wet, medium dense, light brown, medium-fine SAND, little silt, trace coarse sand.			
					Advance casing and rollerbit to 73' BGS.		70	
SS	S-17	0.0	7 9 11 14	SW	(73-75') Wet, medium dense, light brown, coarse-medium-fine SAND to medium-fine SAND, little silt, trace fine gravel.			
					Advance casing and rollerbit to 78' BGS. Fine grained material (silt, clay) coming up while advancing rollerbit.		75	
SS	S-18	0.0	5 6 5 6	CL-ML	(78-80') Wet, stiff, light grey, SILT and CLAY, trace fine sand.			
SS	S-19	0.0	8 10 8 11	CL-ML	(80-82') Wet, very stiff, light grey, SILT and CLAY, trace fine sand.		80	
					Advance rollerbit to 83' BGS. Open borehole in clay.			
SS	S-20	0.0	9 18 15 13	CL-ML	(83-85') Wet, hard, light grey, SILT and CLAY, trace fine sand.			
					Advance rollerbit to 88' BGS. Drilled through silt and clay 85-88' BGS.		85	
SS	S-21	0.0	16 23 26 27	SP	(88-90') Top 3": Wet, hard, light grey, SILT and CLAY. Middle 13": Wet, very dense, light grey, fine			

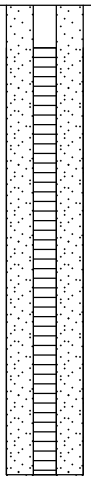
MW BARNSTABLE WPCF V2.GPJ CDM_MA.GDT 8/19/19

CDM Smith
75 State Street Suite 701
Boston, MA 02109

MONITORING WELL DETAIL
19-01B

Client: Town of Barnstable
Project Name: Barnstable Water Pollution Control Facility
Project Location: Barnstable, MA
Project Number: 238182

Sample Type	Sample Number	Field Instrument Reading (ppm)	Blows per 6 Inches	Stratum Designation	Material Description	Graphic Log	Elev. Depth (ft.)	Well Construction Detail
SS	S-22	0.0	20 15 35 46	SP	SAND and SILT, trace clay. Top 8": Wet, very dense, light grey, fine SAND, some-little silt. (90-92') Wet, very dense, light grey, fine SAND, little silt, trace clay.		90	(90-101') #2 Silica Sand
SS	S-23	0.0	29 32 23 29	SP	(92-94') Wet, very dense, light grey, fine SAND, little silt.			
SS	S-24	0.0	16 19 34 42	SP	(94-96') Top 10": Wet, very dense, light grey-light brown, fine SAND, little silt. Bottom 6": Wet, very dense, light grey-light brown, medium-fine SAND, little silt.		95	(91-101') 2" (0.1") Slot Schedule 40 PVC Screen
SS	S-25	0.0	34 61 79 12	SP	(96-98') Wet, very dense, light grey-light brown, medium-fine SAND, some coarse sand, little silt. Advance casing and rollerbit 98' BGS.			
SS	S-26	0.0	32 53 43 46	SP	(98-100') Wet, very dense, light grey-light brown, medium-fine SAND, little silt, trace coarse sand.			
					End of exploration at 101' BGS.		100	
							105	
							110	
							115	
							120	
							125	



MW BARNSTABLE WPCF V2.GPJ CDM_MA.GDT 8/19/19

CDM Smith

75 State Street Suite 701
Boston, MA 02109

BOREHOLE LOG
19-02

Client: Town of Barnstable
Project Name: Barnstable Water Pollution Control Facility
Project Location: Barnstable, MA
Project Number: 238182

Drilling Contractor: New England Boring Contractors
Surface Elevation (ft.): NM
Drilling Method/Rig: Drive and Wash/Truck-Mounted
Total Depth (ft.): 65
Drillers: G. Twombly, Jr./T. Reed
Depth to Initial Water Level (ft. BGS): ~3 (See Remarks)
Drilling Date: Start: 6/27/2019 **End:** 6/28/2019
Abandonment Method: Bentonite Chips to Ground Surface
Borehole Coordinates:
Field Screening Instrument: PID
N E
Logged By: N. Castonguay

Sample Type	Sample Number	Sample Recovery (Inches)	Elev. Depth (ft.)	Field Instrument Reading (ppm)	Blows per 6 Inches	Graphic Log	Stratum Designation	Material Description
SS	S-1	24/18	0	0.0	4 6 3 4		SW	(0-2') Dry, loose, brown, coarse-medium-fine SAND, some fine gravel, trace coarse gravel and silt.
								Advance casing and rollerbit to 3' BGS.
SS	S-2	24/8		0.0	8 4 5 4		SW	(3-5') Wet, loose, brown, coarse-medium-fine SAND, little fine gravel, trace coarse gravel. No recovery with 2" spoon. Recovery with 3" spoon.
			5					Advance casing and rollerbit to 8' BGS.
SS	S-3	24/5		0.0	6 3 6 6		SW	(8-10') Wet, loose, light brown, coarse-medium-fine SAND, trace coarse-fine gravel.
			10					Advance casing and rollerbit to 13' BGS.
SS	S-4	24/10		0.0	4 5 6 6		SW	(13-15') Wet, medium dense, light brown, coarse-medium-fine SAND.
			15					Advance casing and rollerbit to 18' BGS.
SS	S-5	24/10		0.0	6 6 5 5		SW	(18-20') Wet, medium dense, light brown, coarse-medium-fine SAND, trace coarse-fine gravel.
			20					Advance casing and rollerbit to 23' BGS.
SS	S-6	24/6		0.0	10 7 6 5		SW	(23-25') Wet, medium dense, light brown, coarse-medium-fine SAND, little fine gravel, trace coarse gravel. No recovery with 2" spoon. Recovery with 3" spoon.
			25					Advance casing and rollerbit to 28' BGS.
SS	S-7	24/10		0.0	2 2 4 4		SW	(28-30') Wet, loose, light brown, coarse-medium-fine SAND, little fine gravel, trace coarse gravel.

EXPLANATION OF ABBREVIATIONS

DRILLING METHODS:
HSA - Hollow Stem Auger
SSA - Solid Stem Auger
HA - Hand Auger
AR - Air Rotary
DTR - Dual Tube Rotary
FR - Foam Rotary
MR - Mud Rotary
RC - Reverse Circulation
CT - Cable Tool
JET - Jetting
D - Driving
DTC - Drill Through Casing

SAMPLING TYPES:
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CS - California Sampler
BX - 1.5" Rock Core
NX - 2.1" Rock Core
GP - Geoprobe
HP - Hydro Punch
SS - Split Spoon
ST - Shelby Tube
WS - Wash Sample
OTHER:
AGS - Above Ground Surface

REMARKS

BGS = Below Ground Surface
PID = Photoionization Detection
NA = Not Applicable
NM = Not Measured

Depth to water at 19-02 estimated based on water level at nearby pond on 6/28/19.

Reviewed by: N. Castonguay **Date:** 8/16/19

WASM_BL BARNSTABLE WPCF V2.GPJ CDM_MA.GDT 8/19/19

CDM Smith
CDM Smith
75 State Street Suite 701
Boston, MA 02109

BOREHOLE LOG
19-02

Client: Town of Barnstable
Project Name: Barnstable Water Pollution Control Facility
Project Location: Barnstable, MA
Project Number: 238182

Sample Type	Sample Number	Sample Recovery (Inches)	Elev. Depth (ft.)	Field Instrument Reading (ppm)	Blows per 6 Inches	Graphic Log	Stratum Designation	Material Description
			30					Advance casing and rollerbit to 33' BGS.
SS	S-8	24/13		0.0	3 3 3 4		SW	(33-35') Wet, loose, light brown, coarse-medium-fine SAND, little-trace fine gravel.
			35					Advance casing and rollerbit to 38' BGS.
SS	S-9	24/13		0.0	4 4 4 5		SW	(38-40') Wet, loose, light brown, coarse-medium-fine SAND, trace fine gravel.
			40					Advance casing and rollerbit to 43' BGS.
SS	S-10	24/18		0.0	2 3 3 4		SP	(43-45') Wet, loose, light brown, fine SAND, little silt, trace coarse-medium sand.
			45					Advance casing and rollerbit to 48' BGS.
SS	S-11	24/9		0.0	2 5 8 14		SP	(48-50') Wet, medium dense, light brown, medium-fine SAND.
			50					Advance casing and rollerbit to 53' BGS.
SS	S-12	24/22		0.0	10 11 10 10		SP	(53-55') Top 20": Wet, medium dense, light grey, fine SAND, some silt. Bottom 2": Wet, medium dense, light grey, fine SAND, some silt, little clay.
			55					Advance casing and rollerbit to 58' BGS.
SS	S-13	24/12		0.0	36 40 39 40		SP	(58-60') Wet, very dense, light grey, fine SAND, some silt, trace clay.
			60					Advance casing and rollerbit to 63' BGS.
SS	S-14	24/16		0.0	9 14 19 22		ML-SM	(63-65') Wet, dense, light grey-grey, fine SAND and SILT, some clay.
			65					End of exploration at 65' BGS.
			70					
			75					

WASM_BL BARNSTABLE WPCF V2.GPJ CDM_MA.GDT 8/19/19

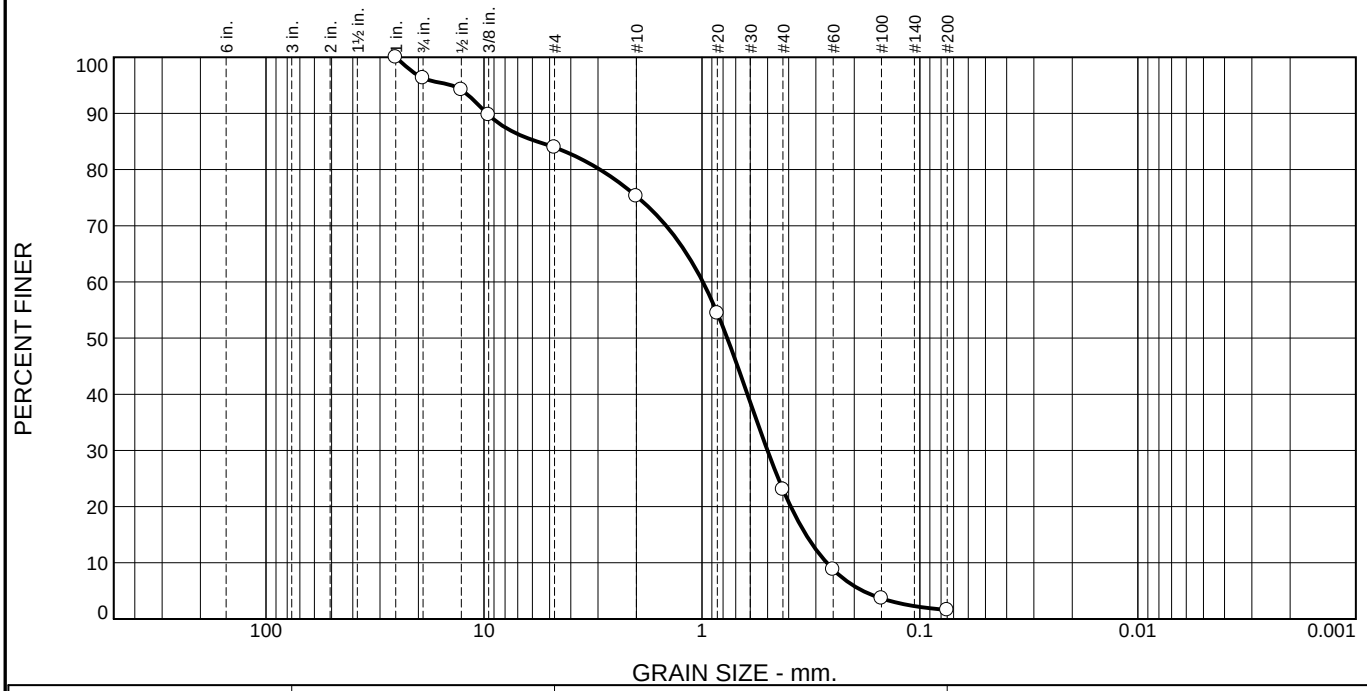


Figure A-1 Picture of Coarse Sand Sample (38 through 40 feet below ground surface)



Figure A-2 Picture of Clay/Silt Sample (78 through 80 feet below ground surface)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	3.7	12.3	8.7	52.3	21.4	1.6	

Test Results (ASTM D6913 & ASTM D1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
0.75"	96.3		
0.5"	94.2		
0.375"	89.7		
#4	84.0		
#10	75.3		
#20	54.4		
#40	23.0		
#60	8.8		
#100	3.7		
#200	1.6		

* (no specification provided)

Material Description

Light brown poorly graded sand with gravel

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 9.6910 D_{85}= 5.7019 D_{60}= 0.9906
D_{50}= 0.7653 D_{30}= 0.5007 D_{15}= 0.3330
D_{10}= 0.2677 C_u= 3.70 C_c= 0.95

Remarks

As received MC = 14.5%

Date Received: 8/28/19 **Date Tested:** 9/3/19

Tested By: MP

Checked By: MP

Title: Laboratory Manager

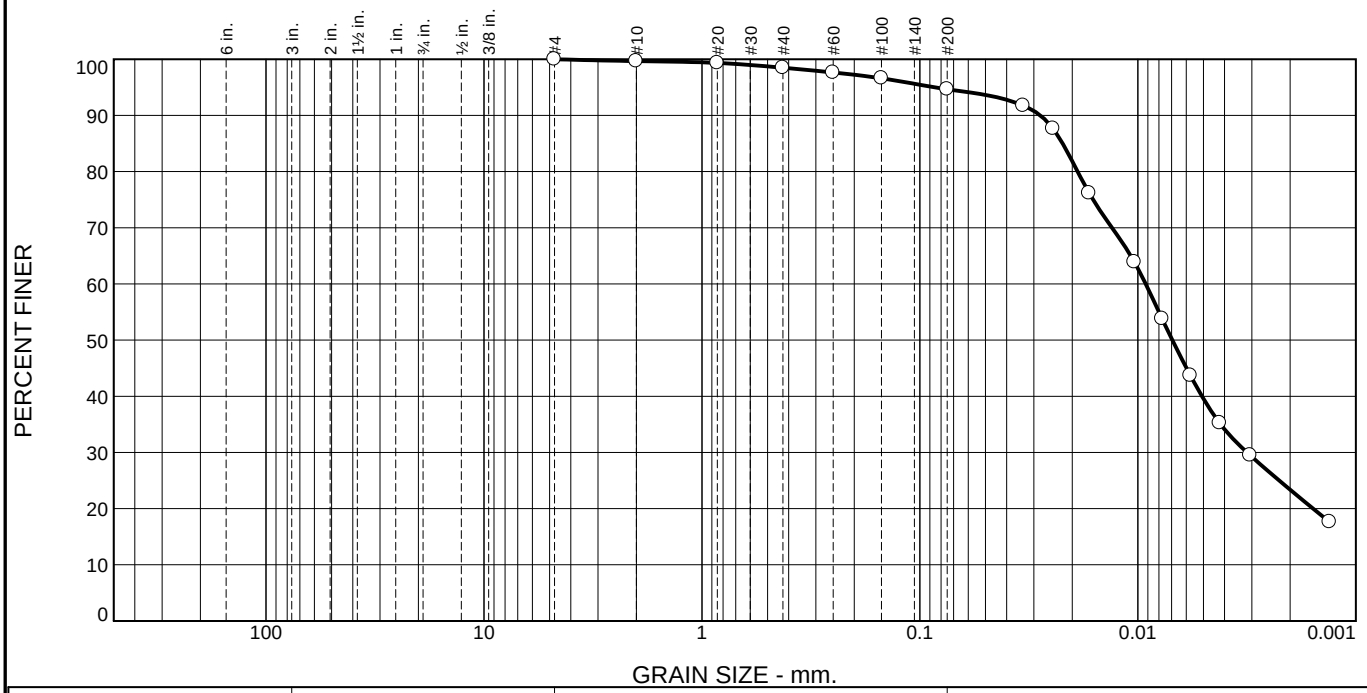
Source of Sample: 19-01 **Depth:** 35-45' **Date Sampled:** 6/25/19
Sample Number: S-9, 10, 11

CDM Smith

Boston, Massachusetts

Client: Barnstable, MA
Project: Barnstable Water Pollution Control Facility
Barnstable, MA
Project No: 97318.238182 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.3	1.2	3.8	55.1	39.6

Test Results (ASTM D6913 & D7928 & ASTM D1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#10	99.7		
#20	99.3		
#40	98.5		
#60	97.6		
#100	96.6		
#200	94.7		
0.0336 mm.	91.7		
0.0245 mm.	87.6		
0.0167 mm.	76.2		
0.0104 mm.	63.9		
0.0077 mm.	53.8		
0.0057 mm.	43.7		
0.0042 mm.	35.2		
0.0031 mm.	29.5		
0.0013 mm.	17.6		

* (no specification provided)

Material Description

Gray lean clay

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= **AASHTO (M 145)=**

Coefficients

D_{90}= 0.0280 D_{85}= 0.0221 D_{60}= 0.0092
D_{50}= 0.0069 D_{30}= 0.0032 D_{15}=
D_{10}= C_u= C_c=

Remarks

As received MC = 28.0%

Date Received: 8/28/19 **Date Tested:** 9/4/19

Tested By: MP

Checked By: MP

Title: Laboratory Manager

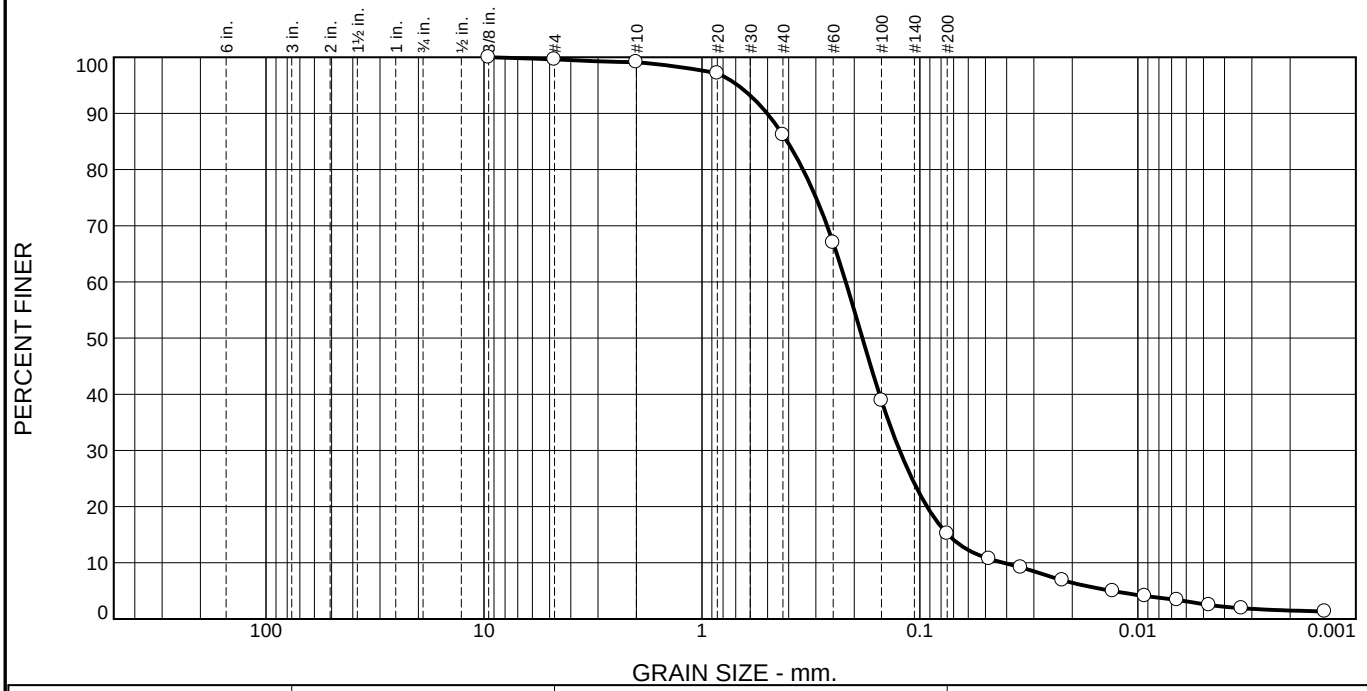
Source of Sample: 19-01 **Depth:** 78-85'
Sample Number: S-18, 19, 20 **Date Sampled:** 6/26/19

CDM Smith

Boston, Massachusetts

Client: Barnstable, MA
Project: Barnstable Water Pollution Control Facility
Barnstable, MA
Project No: 97318.238182 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.4	0.5	12.9	71.0	12.6	2.6

Test Results (ASTM D6913 & D7928 & ASTM D1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.375"	100.0		
#4	99.6		
#10	99.1		
#20	97.2		
#40	86.2		
#60	67.0		
#100	38.9		
#200	15.2		
0.0482 mm.	10.7		
0.0345 mm.	9.2		
0.0222 mm.	6.9		
0.0130 mm.	5.0		
0.0093 mm.	4.1		
0.0066 mm.	3.4		
0.0047 mm.	2.5		
0.0033 mm.	1.9		
0.0014 mm.	1.3		

* (no specification provided)

Material Description

Gray-brown silty sand

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 0.5022 D_{85}= 0.4061 D_{60}= 0.2189
D_{50}= 0.1836 D_{30}= 0.1239 D_{15}= 0.0742
D_{10}= 0.0414 C_u= 5.29 C_c= 1.69

Remarks

As received MC = 19.0%

Date Received: 8/28/19 **Date Tested:** 9/4/19

Tested By: MP

Checked By: MP

Title: Laboratory Manager

Source of Sample: 19-01 **Depth:** 91-100' **Date Sampled:** 6/26/19
Sample Number: S-24, 25, 26

CDM Smith

Boston, Massachusetts

Client: Barnstable, MA
Project: Barnstable Water Pollution Control Facility
Barnstable, MA
Project No: 97318.238182 **Figure**

Appendix B

Survey Data

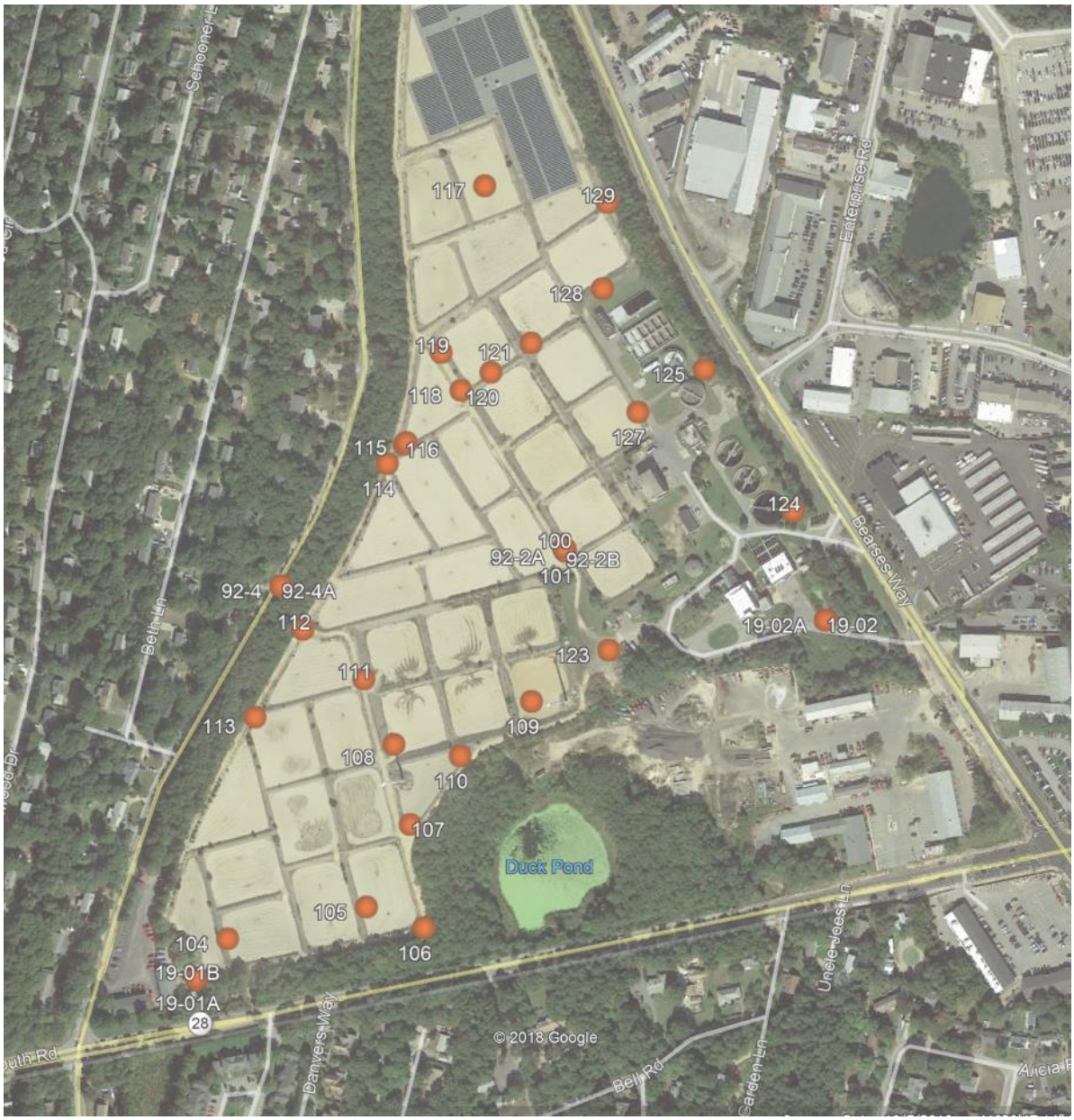
Town of Barnstable WPCF – Well and Elevation Survey

POINT	NORTHING	EASTING	ELEVATION	DESCRIPTION
92-4	2705281.05	981972.15	62.66	Ground elevation
92-4	2705280.76	981972.07	64.25	Top of PVC Pipe
19-02	2705210.64	983414.63	36.96	BORING
19-02	2705209.58	983415.67	37.31	Ground elevation
92-2A	2705390.97	982717.26	64.28	Top of PVC pipe
100	2705391.01	982717.40	63.18	Ground elevation
92-2B	2705383.95	982721.02	64.72	Top of PVC pipe
101	2705383.77	982721.01	63.47	Ground elevation
19-01 (A)	2704248.32	981763.31	62.94	Concrete base 19-01(A)
			65.96	Top of casing
			65.15	Top of PVC Pipe
19-01 (B)	2704243.76	981762.69	62.78	Concrete base 19-01(B)
			65.81	Top of Casing
			64.86	Top of PVC Pipe
104	2704351.95	981843.82	57.48	PAINTED ROCK
105	2704440.21	982208.69	56.94	Ground
106	2704387.83	982361.34	61.95	PINK PAINT MARK
107	2704658.76	982321.41	57.34	PAINTED ROCK
108	2704867.92	982274.82	51.80	PAINTED ROCK
109	2704986.00	982637.33	50.57	Ground
110	2704840.92	982451.06	57.38	PAINTED ROCK
111	2705039.82	982193.91	63.22	Ground
112	2705168.10	982031.41	63.58	PAINTED ROCK
113	2704935.24	981907.97	63.03	Ground
114	2705606.28	982248.24	65.38	PAINTED ROCK
115	2705663.04	982296.83	58.60	PAINTED ROCK
116	2705657.29	982291.57	58.32	Ground
117	2706340.63	982494.52	58.89	Ground
118	2705801.55	982439.84	63.19	PAINTED ROCK
119	2705900.25	982385.85	62.83	Ground
120	2705850.89	982518.15	56.13	Ground
121	2705929.41	982623.11	56.10	PAINTED ROCK
123	2705123.93	982840.00	53.61	Ground
124	2705497.57	983322.52	54.58	Ground
125	2705866.66	983082.88	54.72	Ground
127	2705751.29	982907.91	60.54	Ground
128	2706074.54	982809.72	61.53	Ground
129	2706300.85	982819.02	61.36	Ground

Vertical datum = NAVD88
Horizontal datum = NAD83

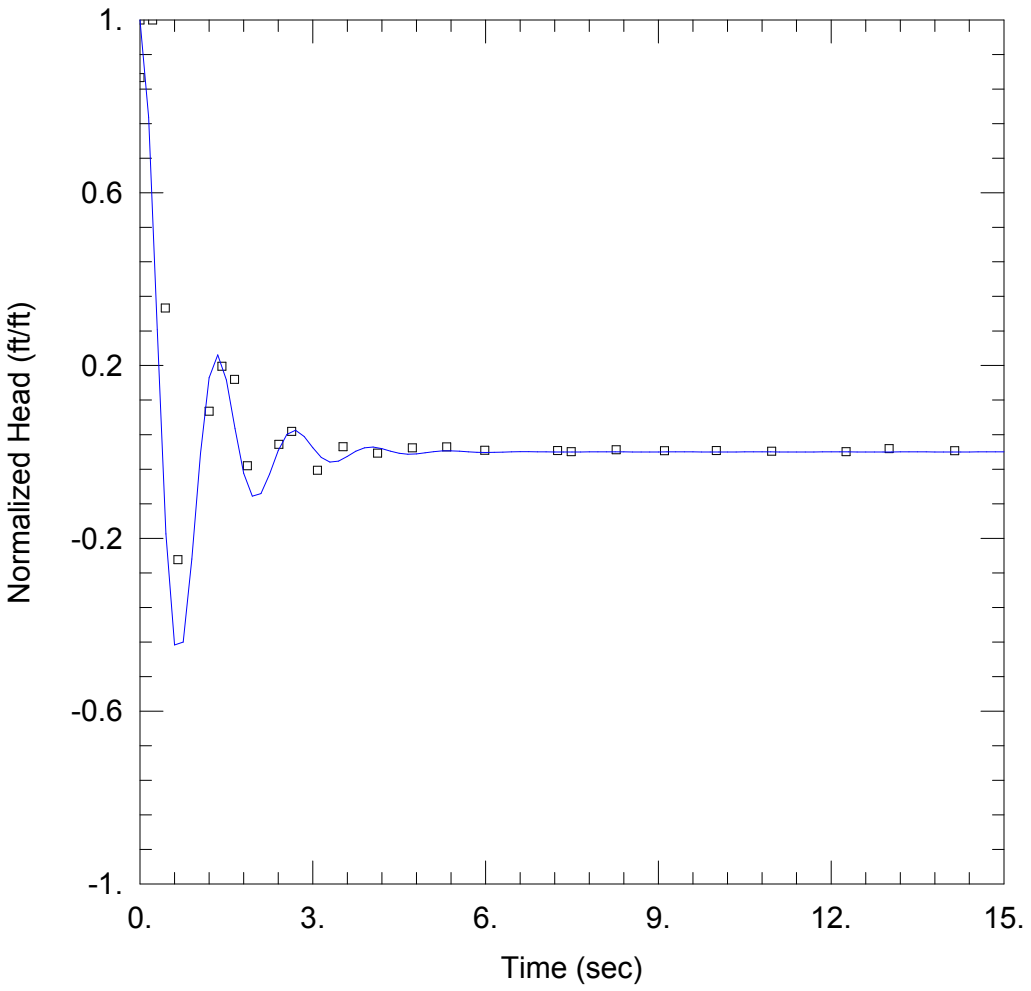
1 Per email correspondence with SMC dated 9/17/2019

SURVEY POINT LOCATIONS



Appendix C

Slug Test Analyses



WELL TEST ANALYSIS

Data Set: \...\19_01A_Falling_Springer.aqt
Date: 07/31/19 Time: 09:46:16

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 19-01A
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 16.93 ft Anisotropy Ratio (Kz/Kr): 0.1

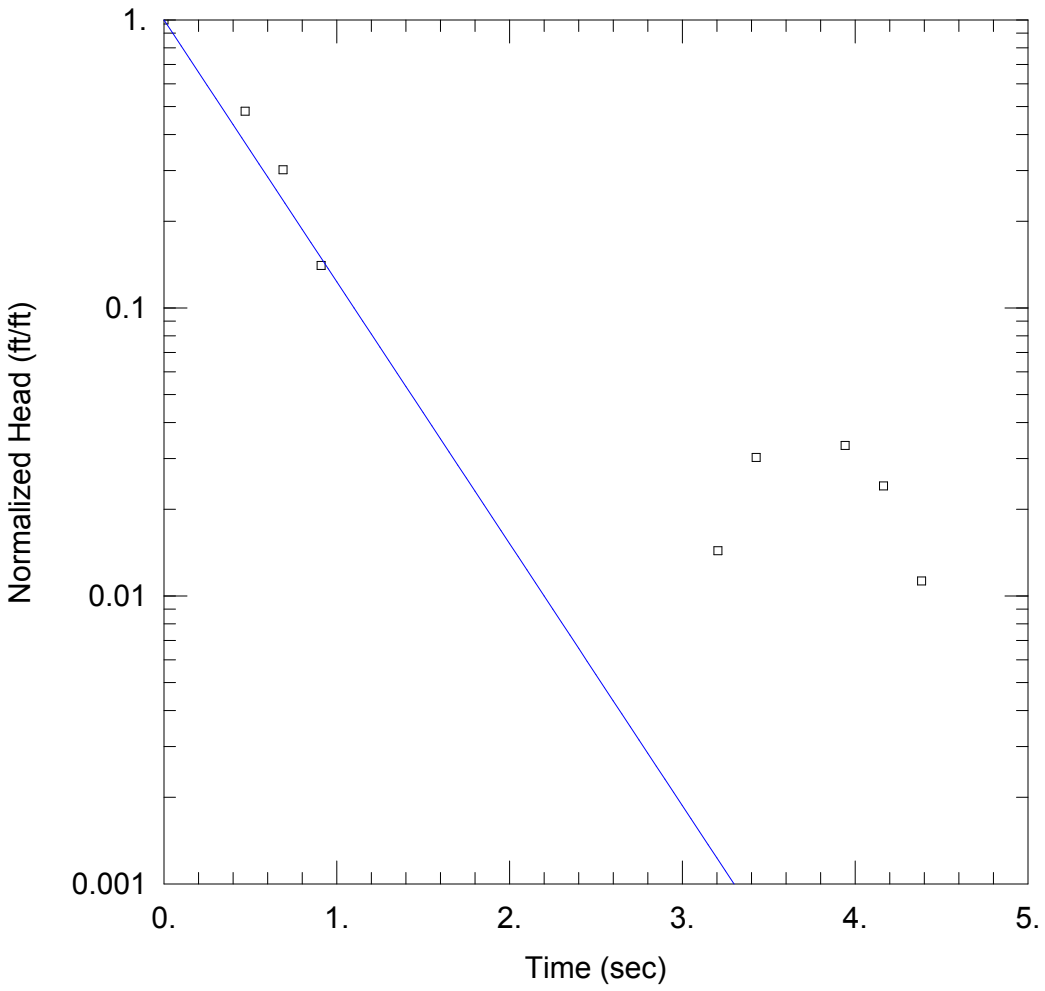
WELL DATA (19-01A)

Initial Displacement: 1.811 ft
Total Well Penetration Depth: 16.93 ft
Casing Radius: 0.08 ft
Static Water Column Height: 16.93 ft
Screen Length: 10. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Springer-Gelhar

K = 1491.4 ft/day Le = 1.38 ft



WELL TEST ANALYSIS

Data Set: \...\19_01A_Rising_Bouwer.aqt
Date: 07/31/19 Time: 10:18:29

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 19-01A
Test Date: 7/12/2019

AQUIFER DATA

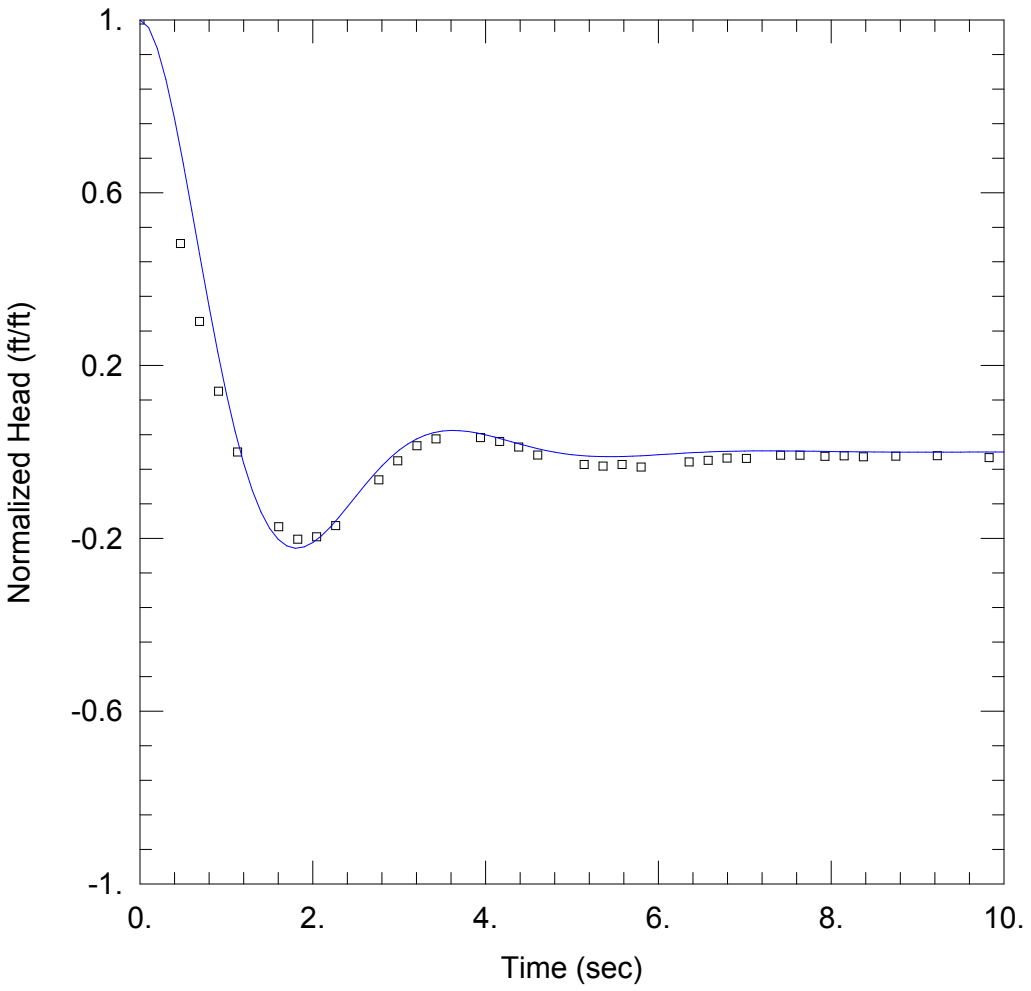
Saturated Thickness: 16.93 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (19.01A)

Initial Displacement: -1.951 ft
Total Well Penetration Depth: 16.93 ft
Casing Radius: 0.08 ft
Static Water Column Height: 16.93 ft
Screen Length: 10. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 298.9 ft/day
y0 = -1.951 ft



WELL TEST ANALYSIS

Data Set: \...\19_01A_Rising_Butler.aqt
Date: 07/31/19 Time: 10:19:53

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 19-01A
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 16.93 ft Anisotropy Ratio (Kz/Kr): 0.1

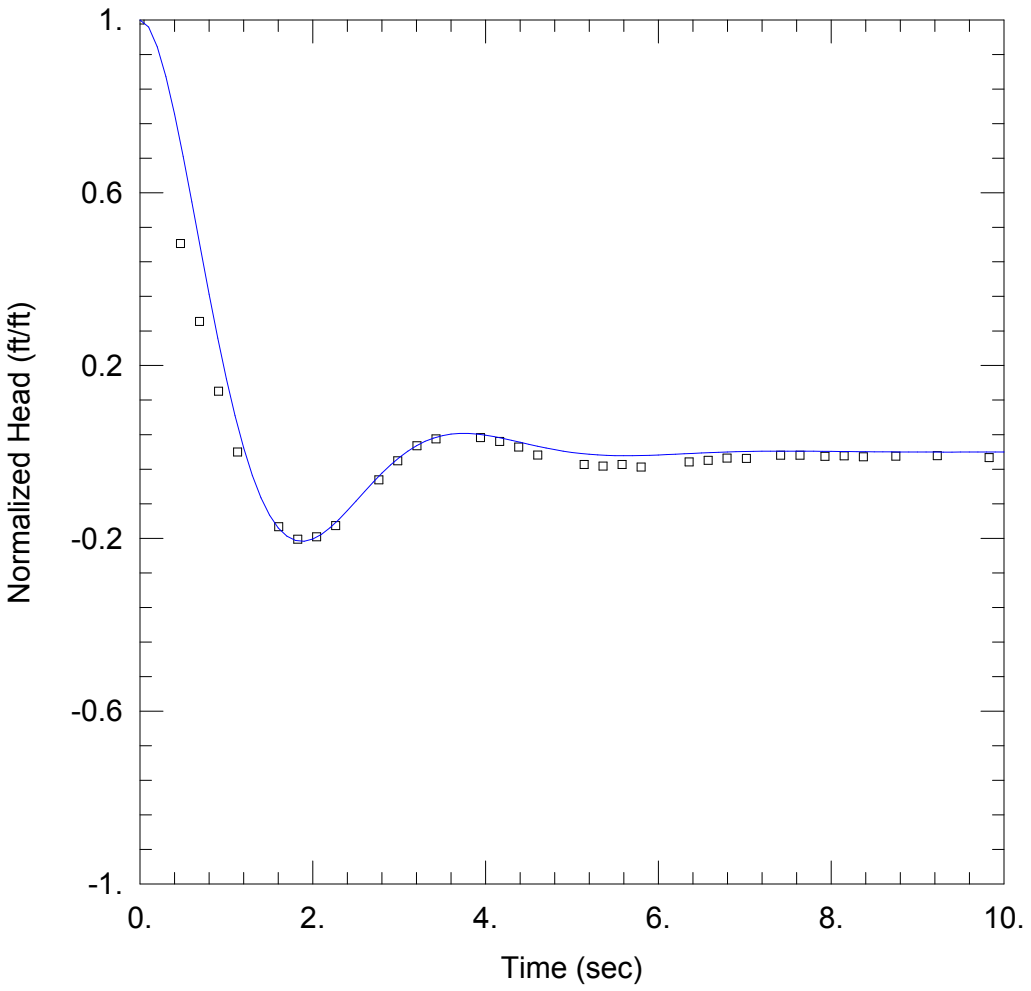
WELL DATA (19.01A)

Initial Displacement: -1.951 ft
Total Well Penetration Depth: 16.93 ft
Casing Radius: 0.08 ft
Static Water Column Height: 16.93 ft
Screen Length: 10. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Confined Solution Method: Butler

K = 411.4 ft/day Le = 8.71 ft



WELL TEST ANALYSIS

Data Set: \...\19_01A_Rising_Springer.aqt
Date: 07/31/19 Time: 10:16:30

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 19-01A
Test Date: 7/12/2019

AQUIFER DATA

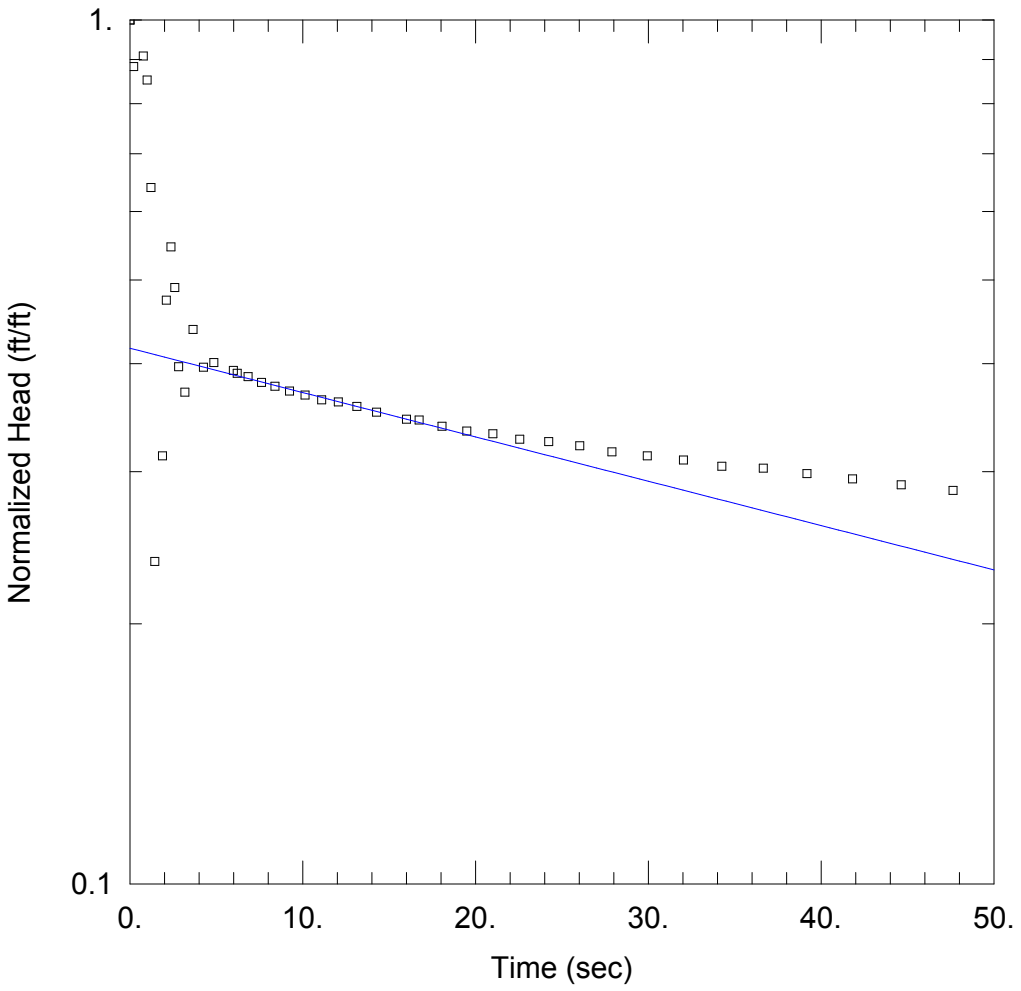
Saturated Thickness: 16.93 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (19.01A)

Initial Displacement: -1.951 ft
Total Well Penetration Depth: 16.93 ft
Casing Radius: 0.08 ft
Static Water Column Height: 16.93 ft
Screen Length: 10. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 298.9 ft/day
Le = 9.141 ft



WELL TEST ANALYSIS

Data Set: \...\19_01B_Falling_Bouwer.aqt
Date: 08/05/19 Time: 08:58:17

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 19-01B
Test Date: 7/12/2019

AQUIFER DATA

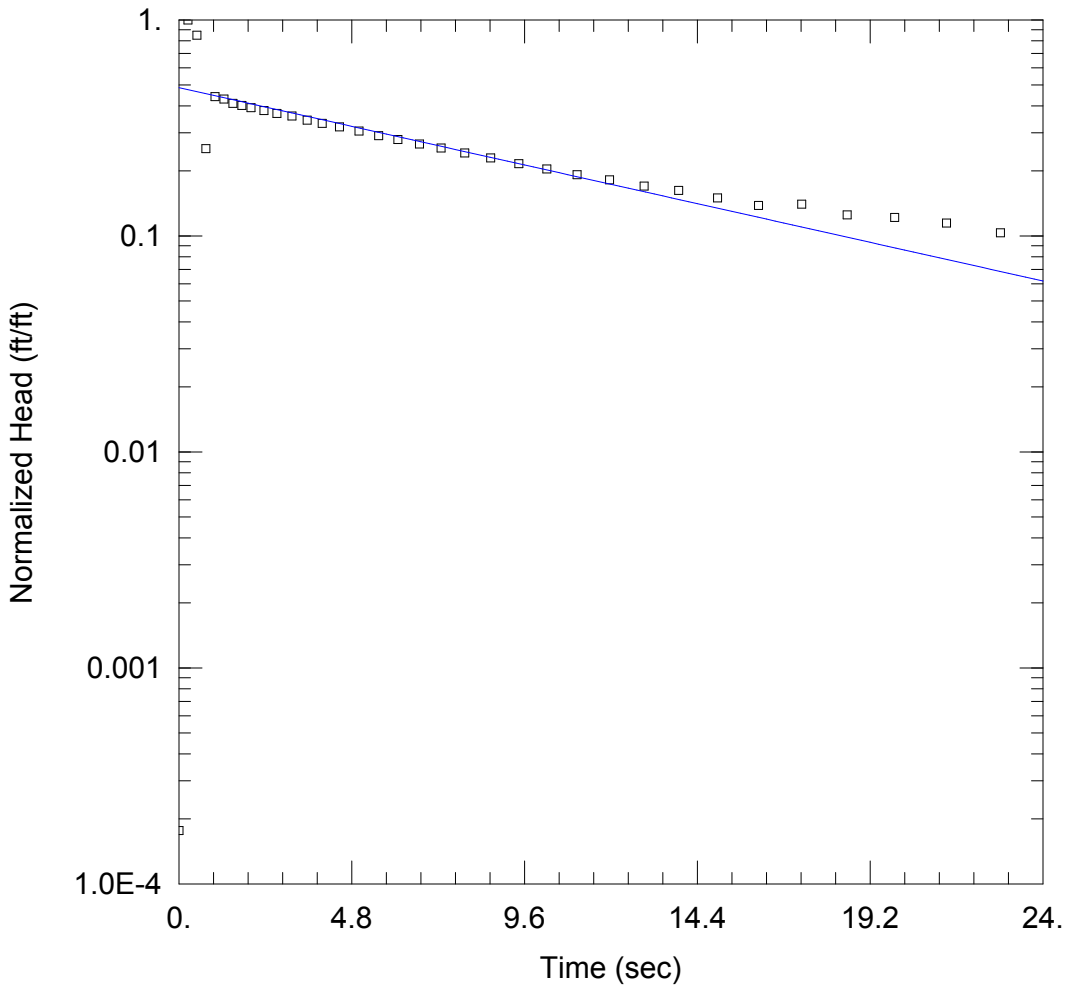
Saturated Thickness: 11. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (19-01B)

Initial Displacement: 3.883 ft
Total Well Penetration Depth: 11. ft
Casing Radius: 0.08 ft
Static Water Column Height: 66.79 ft
Screen Length: 10. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 1.588 ft/day
y0 = 1.619 ft



WELL TEST ANALYSIS

Data Set: \...\19_01B_Rising_Bouwer.aqt
Date: 07/31/19 Time: 10:52:11

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 19-01B
Test Date: 7/12/2019

AQUIFER DATA

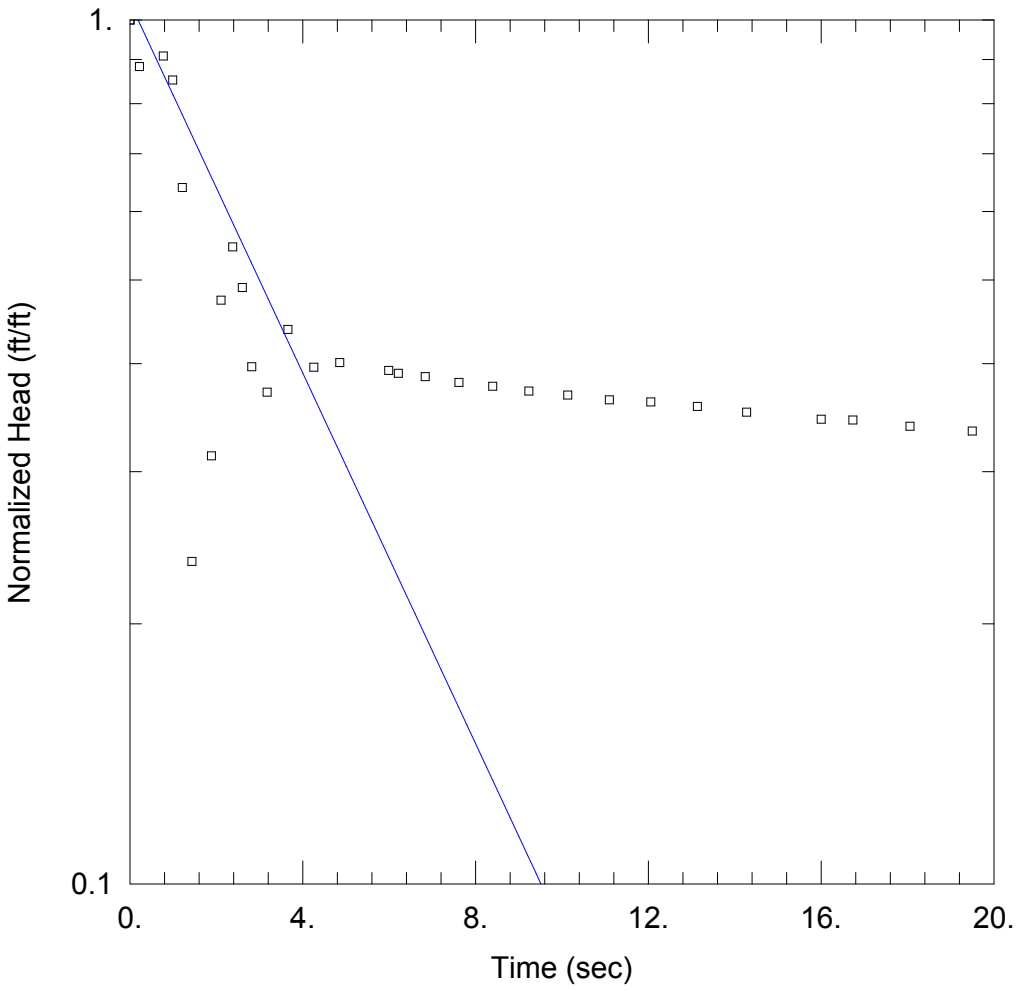
Saturated Thickness: 11. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (19-01B)

Initial Displacement: -5.662 ft
Total Well Penetration Depth: 11. ft
Casing Radius: 0.08 ft
Static Water Column Height: 66.79 ft
Screen Length: 10. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 11.54 ft/day
y0 = -2.75 ft



WELL TEST ANALYSIS

Data Set: \...\19_01B_Falling_100ft_Bouwer.aqt
Date: 08/07/19 Time: 17:06:14

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 19-01B
Test Date: 7/12/2019

AQUIFER DATA

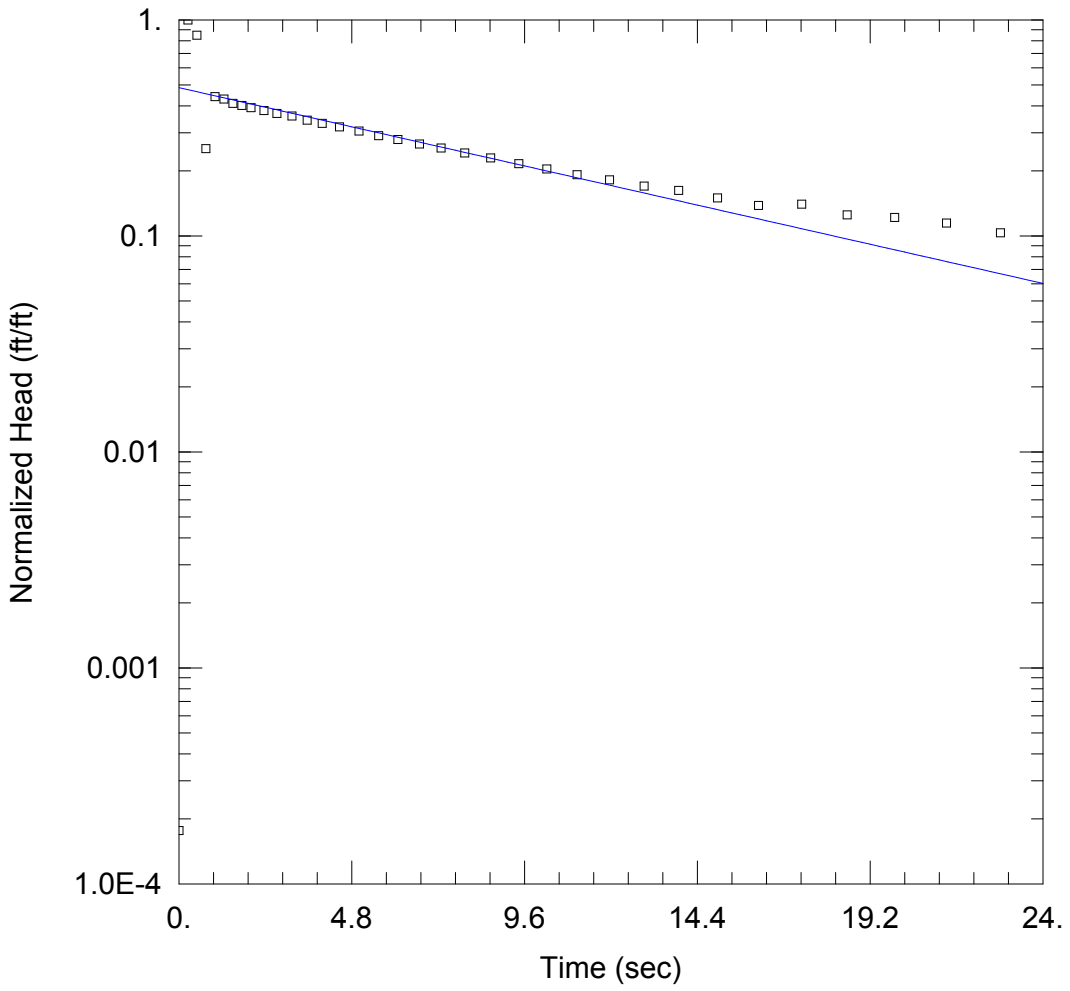
Saturated Thickness: 11. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (19-01B)

Initial Displacement: 3.883 ft
Total Well Penetration Depth: 11. ft
Casing Radius: 0.08 ft
Static Water Column Height: 66.79 ft
Screen Length: 10. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 33.18 ft/day
y0 = 4.066 ft



WELL TEST ANALYSIS

Data Set: \...\19_01B_Rising_100_ftBouwer.aqt
Date: 08/07/19 Time: 17:07:08

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 19-01B
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 0.1

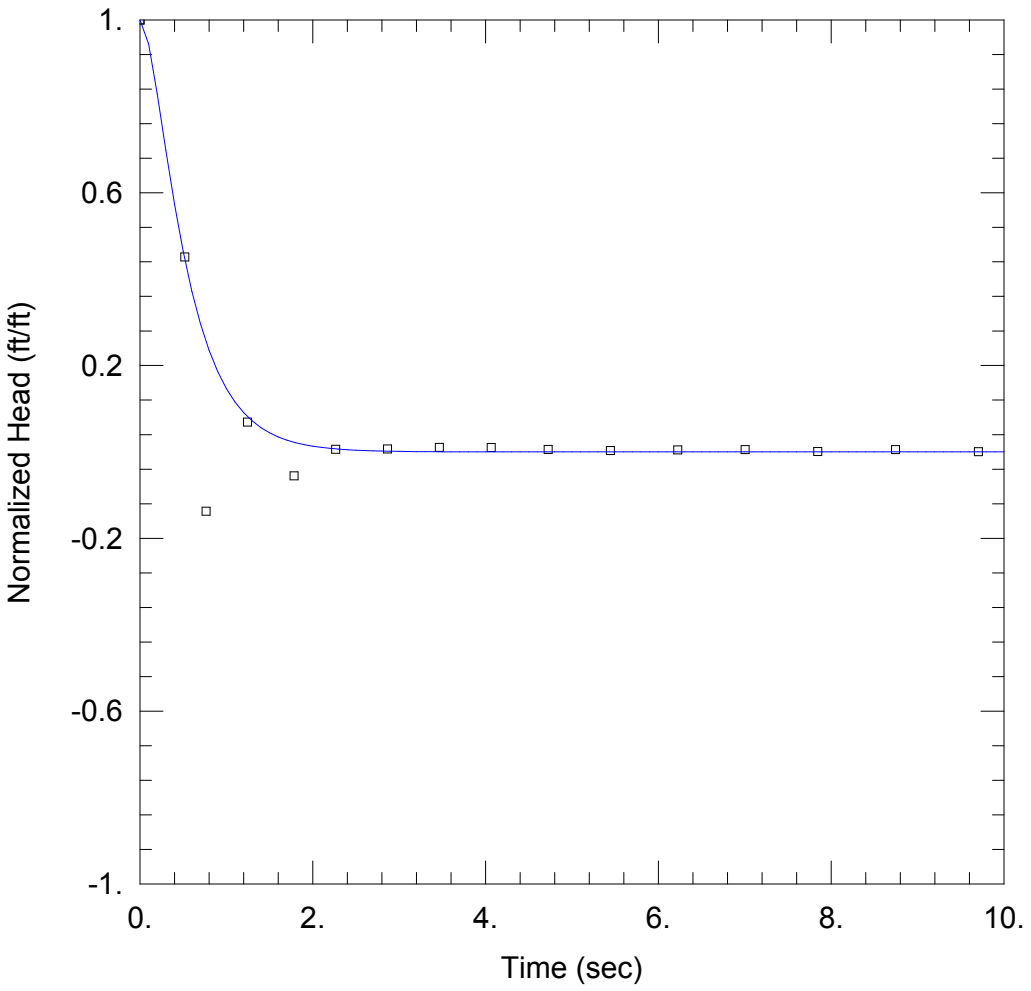
WELL DATA (19-01B)

Initial Displacement: -5.662 ft
Total Well Penetration Depth: 11. ft
Casing Radius: 0.08 ft
Static Water Column Height: 66.79 ft
Screen Length: 10. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 10.53 ft/day
y0 = -2.75 ft



WELL TEST ANALYSIS

Data Set: \...\92-2A_Falling_Springer.aqt
Date: 08/07/19 Time: 16:42:10

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 92-2A
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 39.51 ft Anisotropy Ratio (Kz/Kr): 0.1

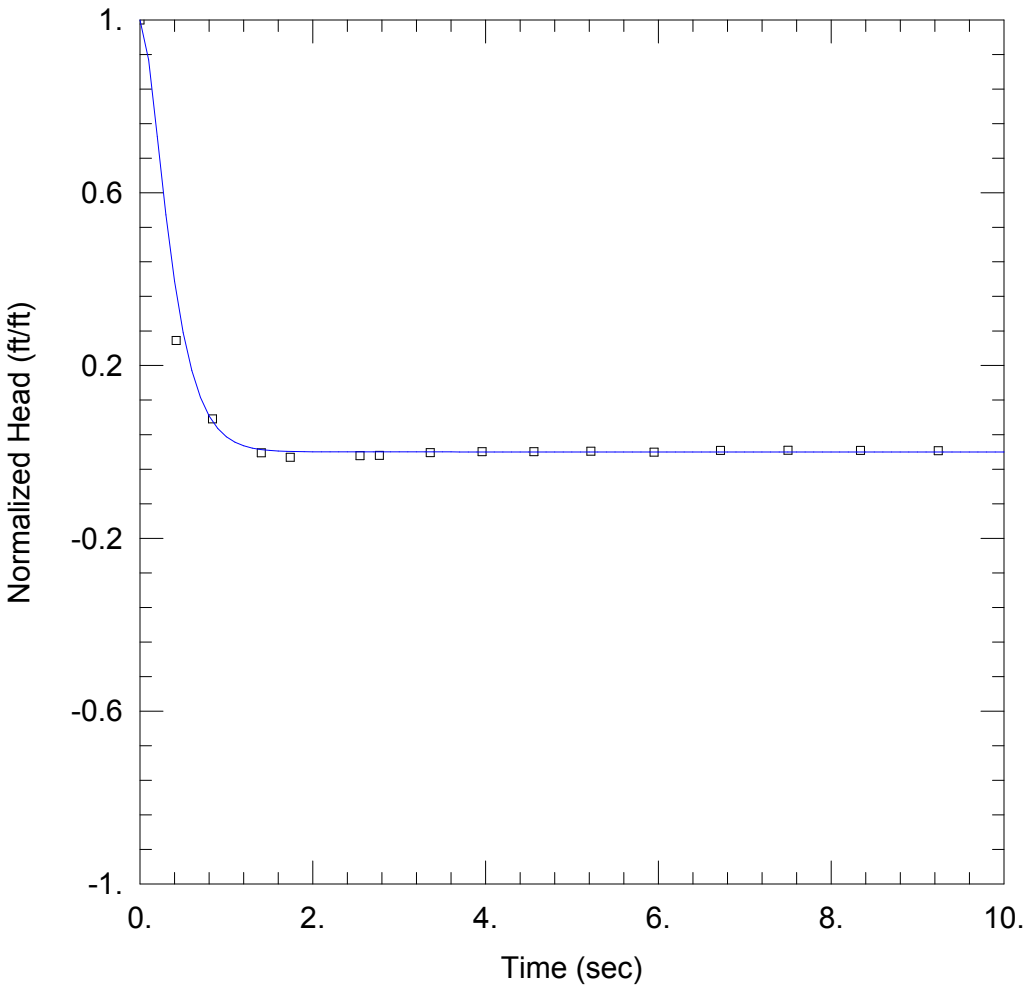
WELL DATA (92-4)

Initial Displacement: 2.453 ft
Total Well Penetration Depth: 12.51 ft
Casing Radius: 0.08 ft
Static Water Column Height: 12.61 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Springer-Gelhar

K = 616.3 ft/day Le = 2.188 ft



WELL TEST ANALYSIS

Data Set: \...\92_2A_Rising_Springer.aqt
Date: 08/07/19 Time: 16:39:33

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 92-2A
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 39.51 ft Anisotropy Ratio (Kz/Kr): 0.1

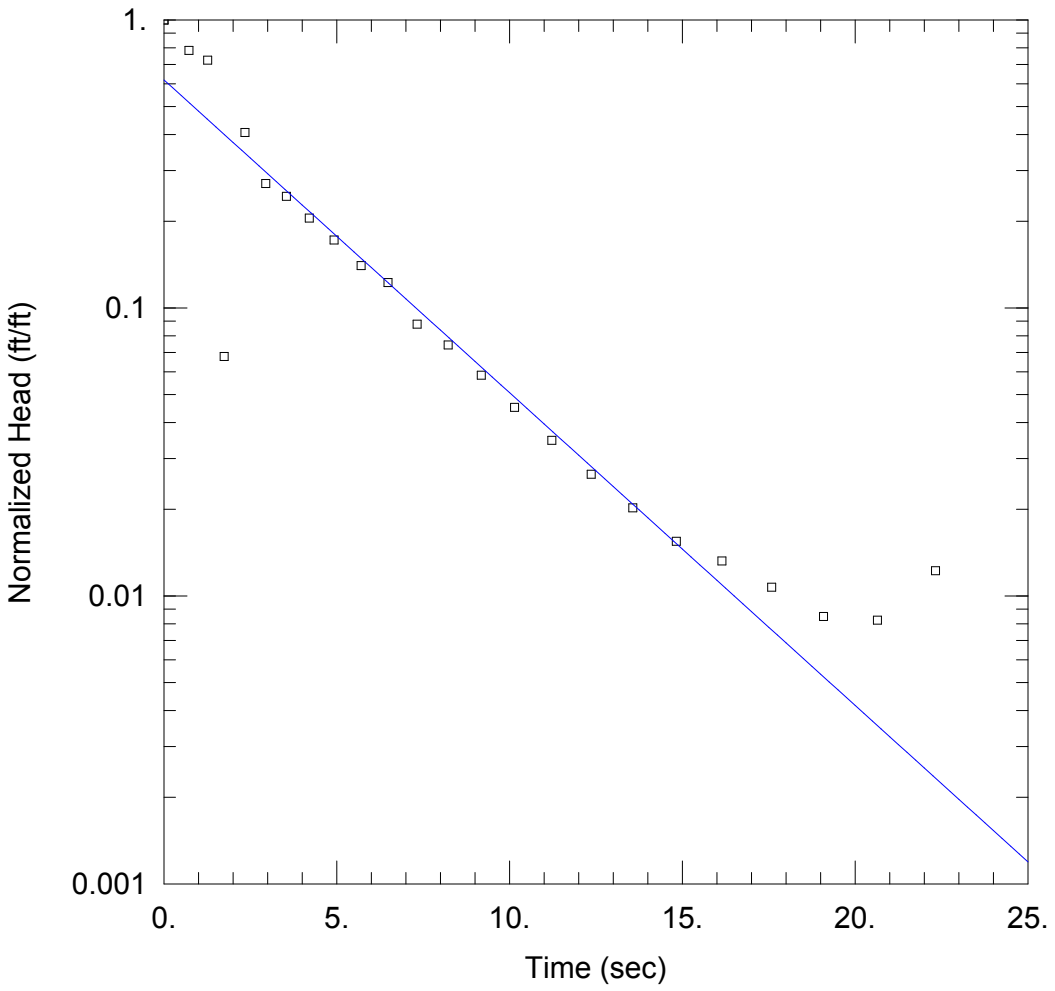
WELL DATA (92-2A)

Initial Displacement: -4.085 ft
Total Well Penetration Depth: 12.61 ft
Casing Radius: 0.08 ft
Static Water Column Height: 12.61 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Springer-Gelhar

K = 913.9 ft/day Le = 1.259 ft



WELL TEST ANALYSIS

Data Set: \...\92_2B_Falling_Bouwer.aqt
Date: 08/05/19 Time: 15:19:05

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 92-2B
Test Date: 7/12/2019

AQUIFER DATA

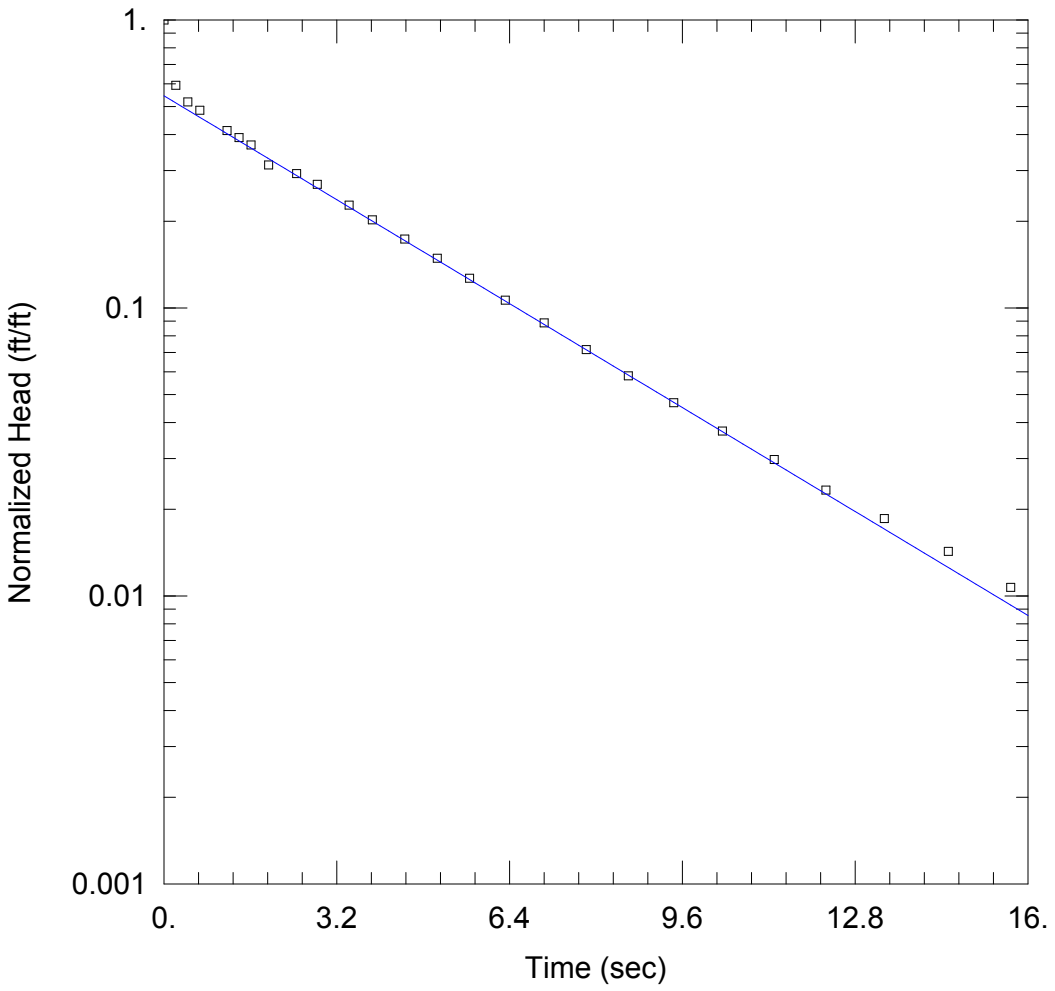
Saturated Thickness: 54.17 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (92-2B)

Initial Displacement: 4.008 ft
Total Well Penetration Depth: 37.49 ft
Casing Radius: 0.08 ft
Static Water Column Height: 37.49 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 99.38 ft/day
y0 = 2.481 ft



WELL TEST ANALYSIS

Data Set: \...\92_2B_Rising_Bouwer.aqt
Date: 08/07/19 Time: 16:23:36

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 92-2B
Test Date: 7/12/2019

AQUIFER DATA

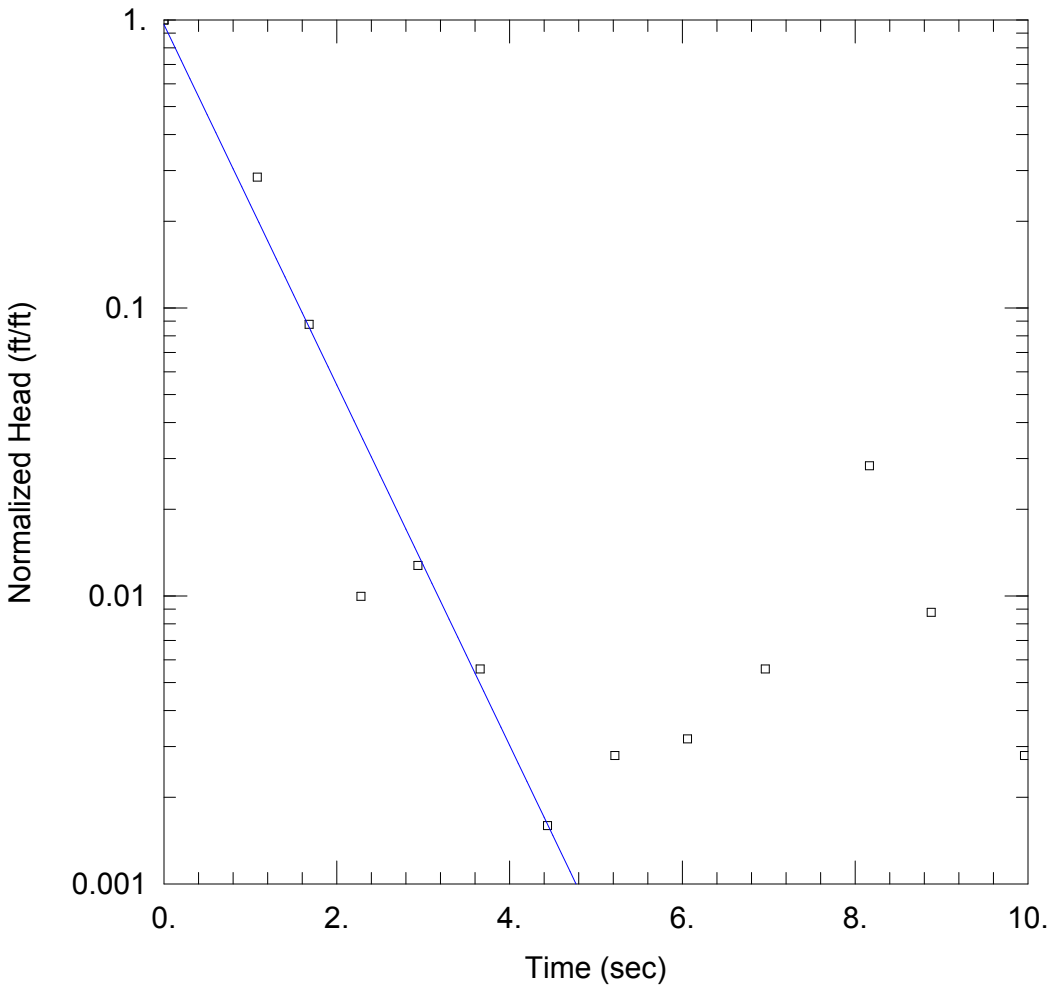
Saturated Thickness: 54.17 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (92-2B)

Initial Displacement: -4.202 ft
Total Well Penetration Depth: 37.49 ft
Casing Radius: 0.08 ft
Static Water Column Height: 37.52 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 103.2 ft/day
y0 = -2.291 ft



WELL TEST ANALYSIS

Data Set: \...\92_4_Falling_Bouwer.aqt
Date: 08/05/19 Time: 15:41:14

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 92-4
Test Date: 7/12/2019

AQUIFER DATA

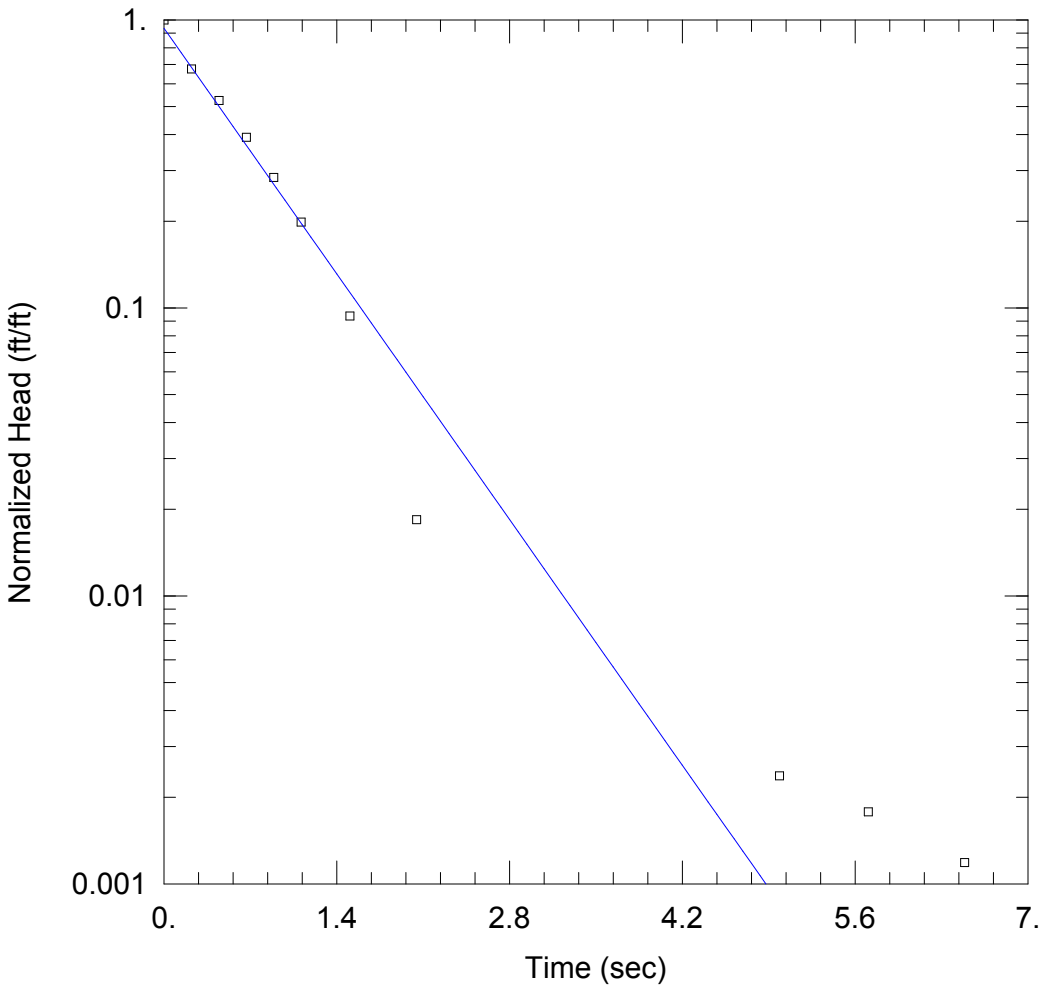
Saturated Thickness: 44.27 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (92-4)

Initial Displacement: 2.509 ft
Total Well Penetration Depth: 13.35 ft
Casing Radius: 0.08 ft
Static Water Column Height: 13.35 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 517.1 ft/day
y0 = 2.417 ft



WELL TEST ANALYSIS

Data Set: \...\92_4_Rising_Bouwer.aqt
Date: 08/05/19 Time: 15:45:35

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 92-4
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 44.27 ft Anisotropy Ratio (Kz/Kr): 0.1

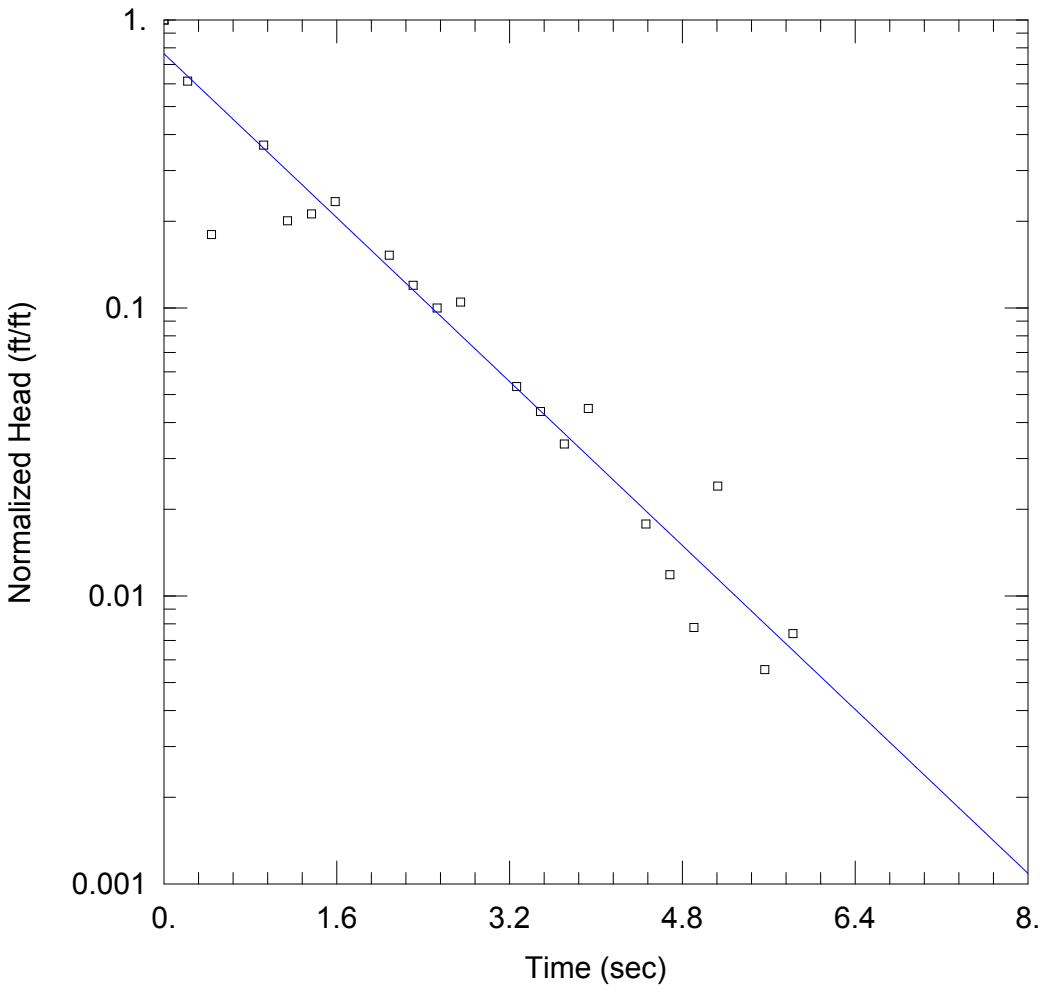
WELL DATA (92-4)

Initial Displacement: -3.372 ft
Total Well Penetration Depth: 13.35 ft
Casing Radius: 0.08 ft
Static Water Column Height: 13.36 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 503.6 ft/day y0 = -3.154 ft



WELL TEST ANALYSIS

Data Set: \...\92_16_Falling_Bouwer.aqt
Date: 08/05/19 Time: 15:51:08

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 92-16
Test Date: 7/12/2019

AQUIFER DATA

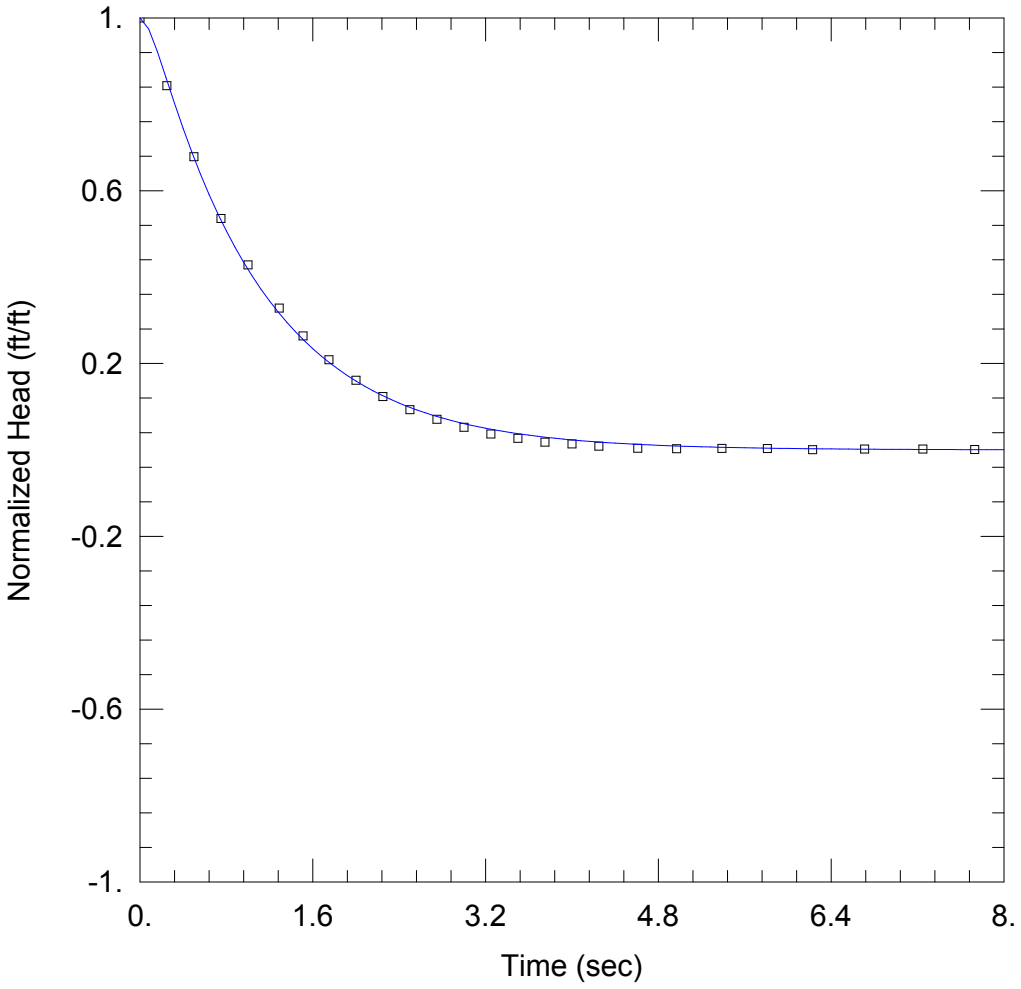
Saturated Thickness: 50.77 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (92-16)

Initial Displacement: 2.702 ft
Total Well Penetration Depth: 20.77 ft
Casing Radius: 0.08 ft
Static Water Column Height: 20.77 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 307.9 ft/day
y0 = 2.062 ft



WELL TEST ANALYSIS

Data Set: \...\92_16_Rising_Springer.aqt
Date: 08/06/19 Time: 10:28:17

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: 92-16
Test Date: 7/12/2019

AQUIFER DATA

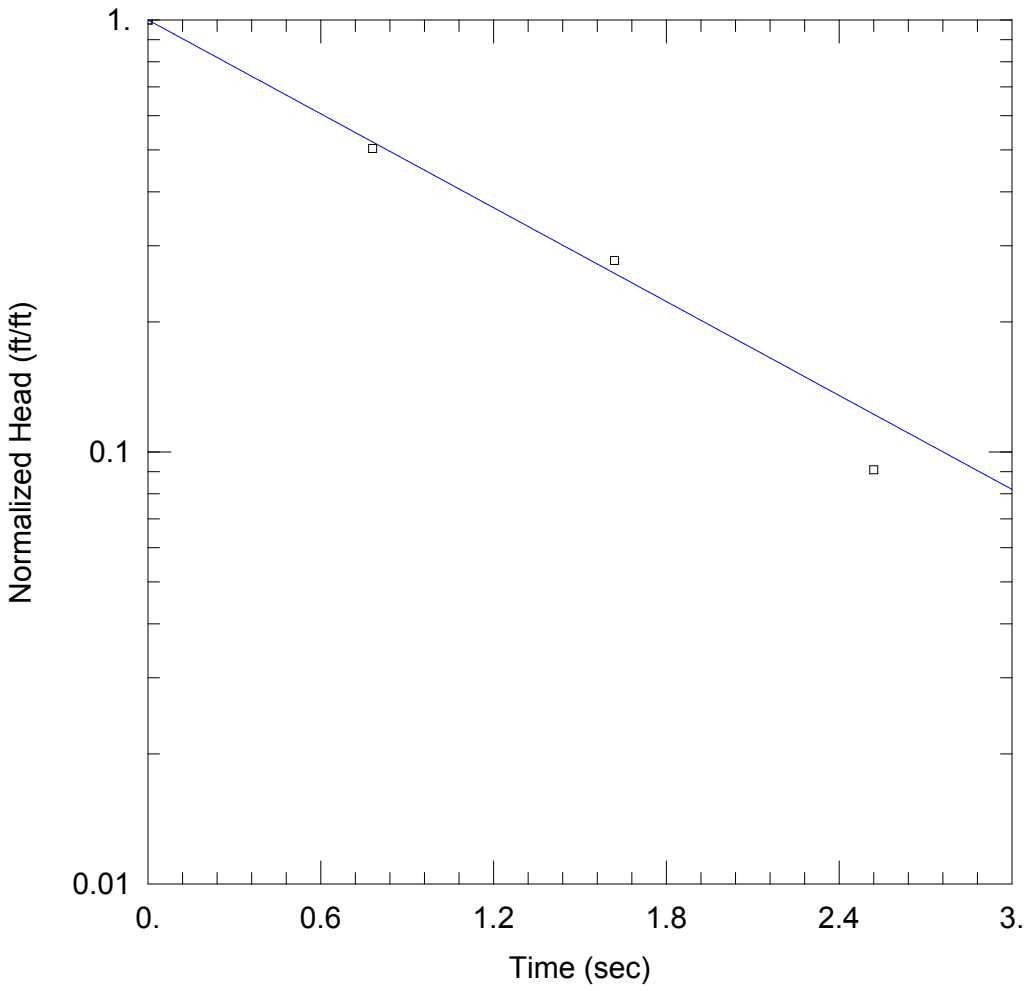
Saturated Thickness: 50.77 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (92-16)

Initial Displacement: -3.622 ft
Total Well Penetration Depth: 20.77 ft
Casing Radius: 0.08 ft
Static Water Column Height: 20.77 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 333.3 ft/day
Le = 3.02 ft



WELL TEST ANALYSIS

Data Set: \...\C2_Falling.aqt
Date: 07/31/19 Time: 08:42:41

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: C-2
Test Date: 7/12/2019

AQUIFER DATA

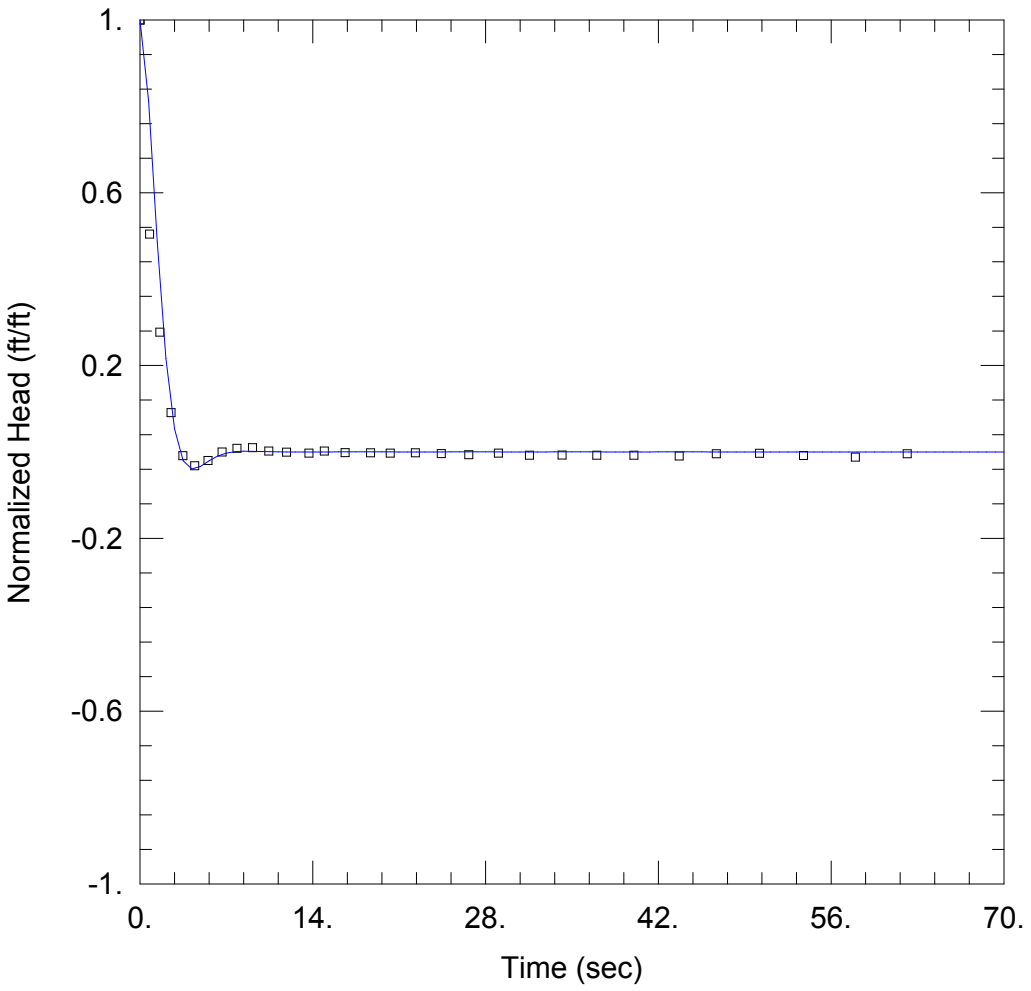
Saturated Thickness: 30.68 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (C-2)

Initial Displacement: 1.803 ft
Total Well Penetration Depth: 30.68 ft
Casing Radius: 0.08 ft
Static Water Column Height: 30.68 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 391.8 ft/day
y0 = 1.803 ft



WELL TEST ANALYSIS

Data Set: \...\C2_Falling_Springer.aqt
Date: 07/31/19 Time: 08:59:53

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: C-2
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 30.68 ft Anisotropy Ratio (Kz/Kr): 0.1

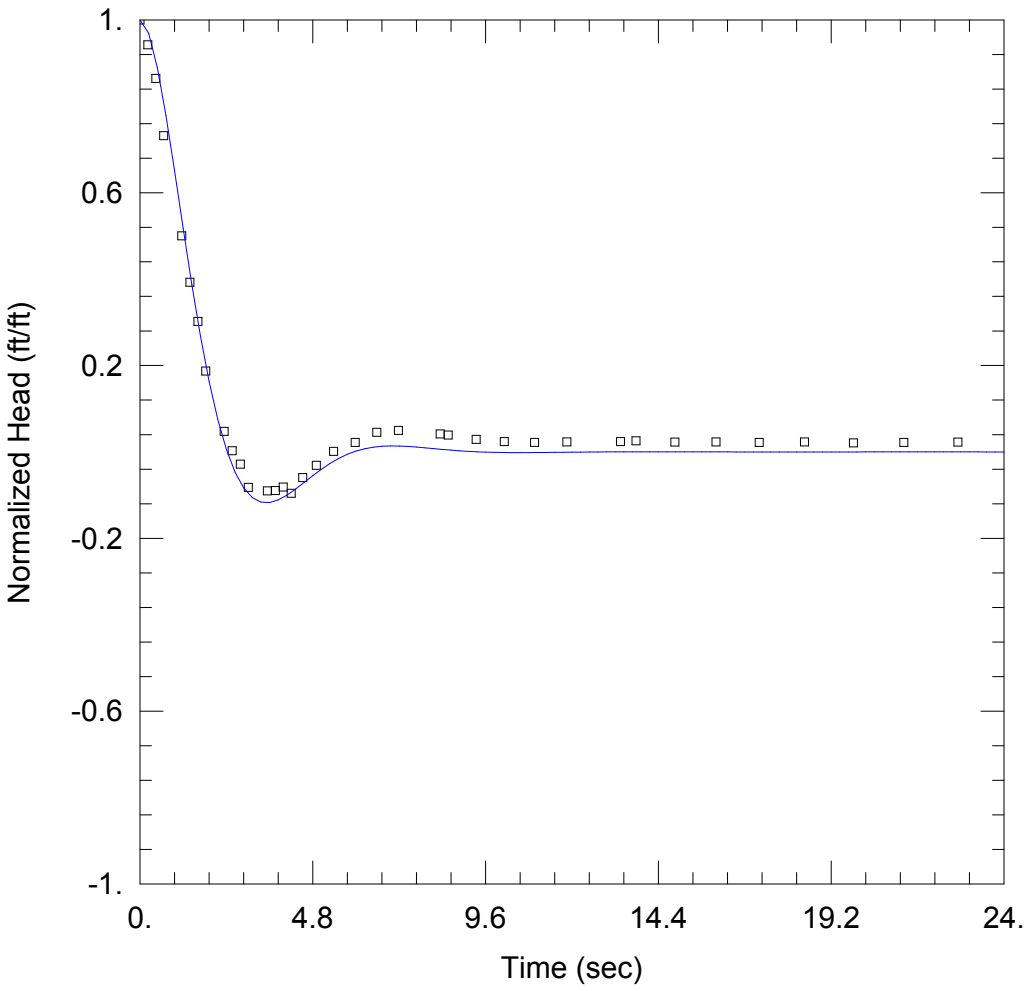
WELL DATA (C-2)

Initial Displacement: 1.803 ft
Total Well Penetration Depth: 30.68 ft
Casing Radius: 0.08 ft
Static Water Column Height: 30.68 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Springer-Gelhar

K = 345.3 ft/day Le = 29. ft



WELL TEST ANALYSIS

Data Set: \...\C2_Rising_Butler.aqt
Date: 07/31/19 Time: 09:05:07

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: C-2
Test Date: 7/12/2019

AQUIFER DATA

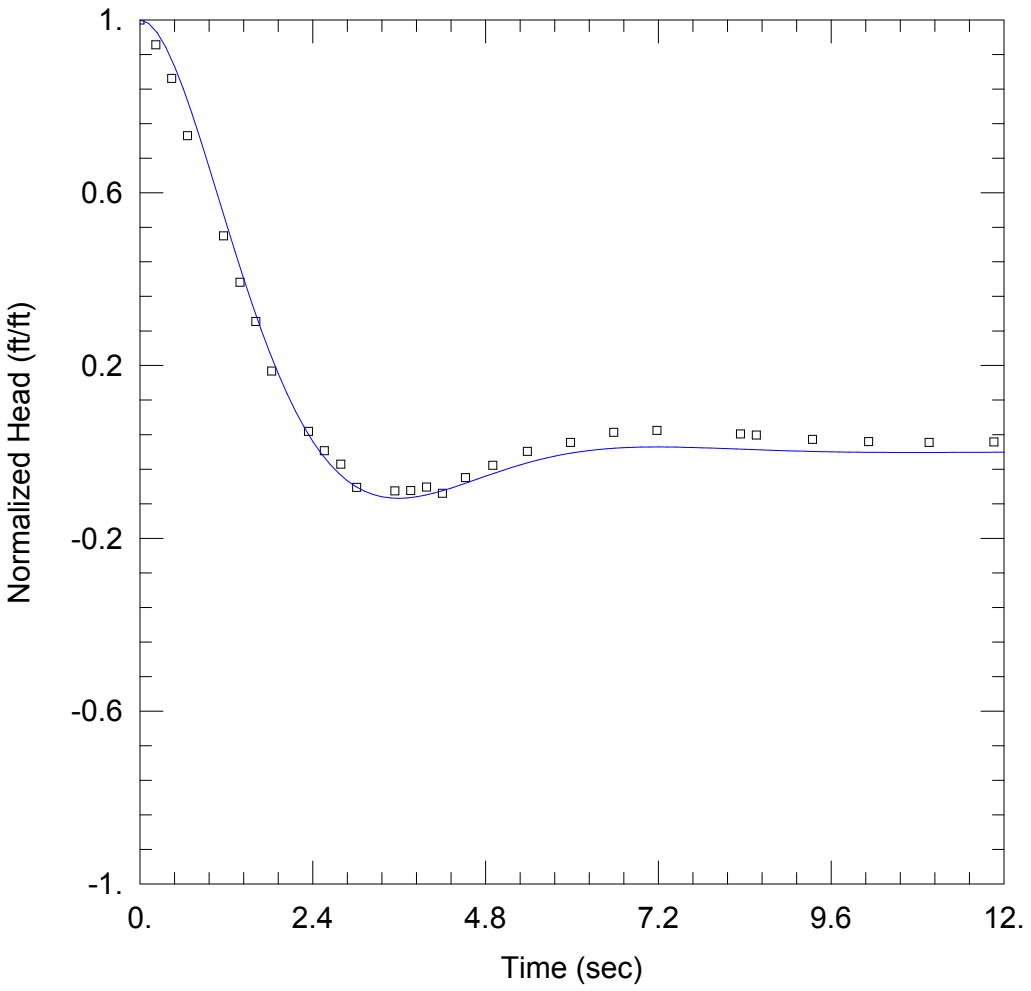
Saturated Thickness: 30.68 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (C-2)

Initial Displacement: -1.721 ft
Total Well Penetration Depth: 30.68 ft
Casing Radius: 0.08 ft
Static Water Column Height: 30.68 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler
K = 484.9 ft/day
Le = 27.42 ft



WELL TEST ANALYSIS

Data Set: \...\C2_Rising_Springer.aqt
Date: 08/07/19 Time: 16:18:19

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: C-2
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 30.68 ft Anisotropy Ratio (Kz/Kr): 0.1

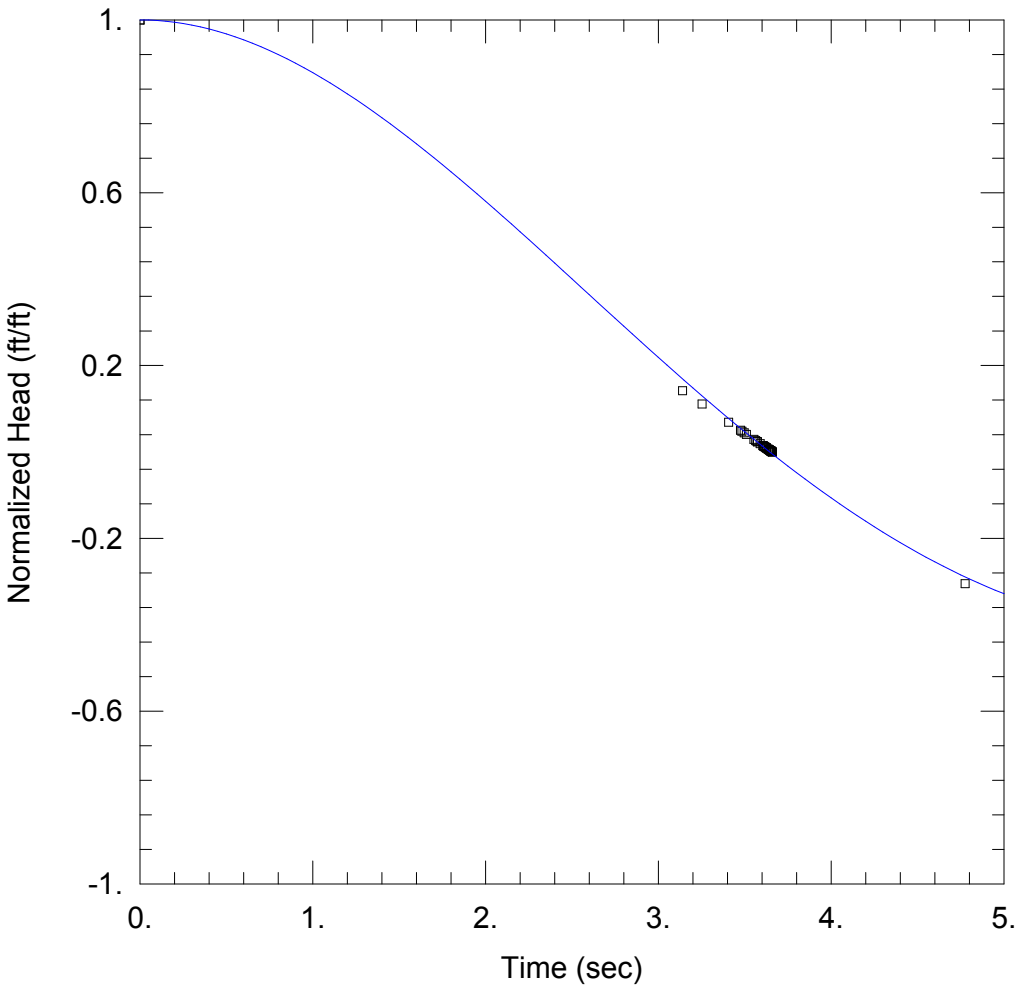
WELL DATA (C-2)

Initial Displacement: -1.721 ft
Total Well Penetration Depth: 30.68 ft
Casing Radius: 0.08 ft
Static Water Column Height: 30.68 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Springer-Gelhar

K = 435.3 ft/day Le = 27.94 ft



WELL TEST ANALYSIS

Data Set: \...\W_4_Falling_Springer.aqt
Date: 08/06/19 Time: 10:40:38

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: W-4
Test Date: 7/12/2019

AQUIFER DATA

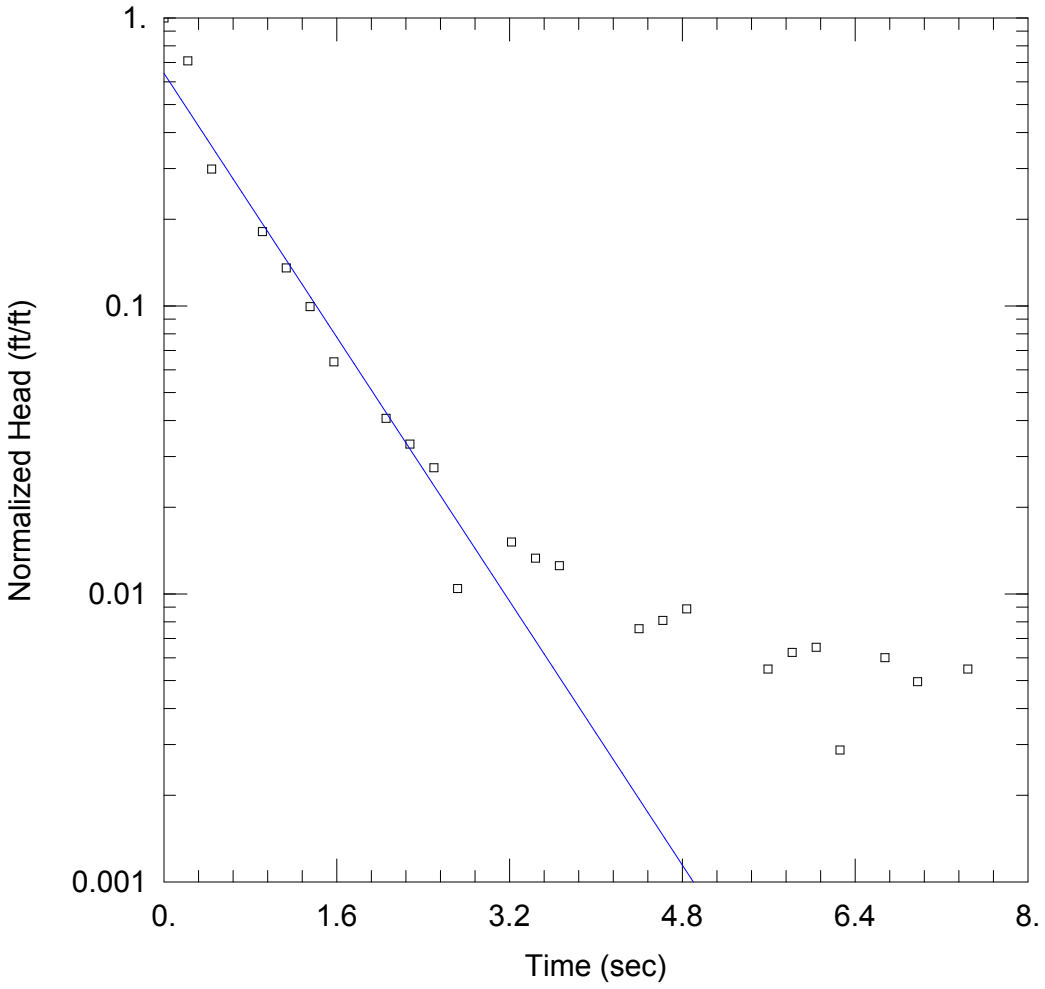
Saturated Thickness: 66.42 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (W-4)

Initial Displacement: 3.659 ft
Total Well Penetration Depth: 9.13 ft
Casing Radius: 0.08 ft
Static Water Column Height: 9.133 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 340.3 ft/day
Le = 117.7 ft



WELL TEST ANALYSIS

Data Set: \...\W_4_Rising_Bouwer.aqt
Date: 08/05/19 Time: 16:17:55

PROJECT INFORMATION

Client: Barnstable WPCF
Test Well: W-4
Test Date: 7/12/2019

AQUIFER DATA

Saturated Thickness: 66.42 ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (W-4)

Initial Displacement: -3.831 ft
Total Well Penetration Depth: 9.13 ft
Casing Radius: 0.08 ft
Static Water Column Height: 9.116 ft
Screen Length: 3. ft
Well Radius: 0.08 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 453.5 ft/day
y0 = -2.46 ft

Appendix D

Geophysical Investigation for Clay Layer Presence and Thickness Evaluation

Hager GeoScience, Inc.

HAGER GEOSCIENCE, INC.

GEOPHYSICAL INVESTIGATION FOR CLAY LAYER PRESENCE AND THICKNESS EVALUATION WATER POLLUTION CONTROL FACILITY BARNSTABLE, MA

August 2nd, 2019
File 2019032

Prepared for:
CDM Smith
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Prepared by:
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EDWOSB CERTIFICATION AWARD
U.S. Women's Chamber of Commerce
EDWOSB Federal
Certified Economically Disadvantaged Women-Owned Small Business

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PLATE

Plate 1 GPR and Seismic Transect Locations
Plate 2 Depth to Top of Clay Contour Plot
Plate 3 Elevation of Top of Clay Contour Plot

FIGURES

Figures 1-10 GPR Transects 1 to 18
Figure S1 MASW Line 1
Figure S2 MASW Line 2
Figure S3 MASW Line 3
Figure S4 MASW Line 4

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1.0 INTRODUCTION

This report details the results of an integrated geophysical investigation conducted by Hager GeoScience, Inc. (HGI) for CDM Smith (CDM) at the site of recharge beds at the Water Pollution Control Facility (WPCF) in Barnstable, Massachusetts.

The objective of the survey was to define the local stratigraphy, with focus on the evaluation of the presence and thickness of a clay layer.

2.0 DATA ACQUISITION

HGI performed all survey activities on July 11th and 12th, 2019. Plate 1, a base map created from the HGI field notes, grid marks, GPS, and Bing maps, shows the locations of the seismic and GPR surveys.

2.1 GPR Survey

HGI personnel used a Geophysical Survey Systems Inc. (GSSI) SIR-20 digital acquisition system and a multiple low frequency (MLF) high-powered antenna system operated at 35 MHz to collect data along 18 transects. The data were displayed on a color monitor for in-field quality control while being simultaneously recorded to the system's internal memory. The GPR data are recorded as two-way travel time and reflection amplitude, in which measurements are made of the time for the input radar wave pulse to reflect back to the antenna from a subsurface change in electrical properties, and the relative energy of the reflected signal.

Table 1 provides the data acquisition parameters used for the GPR data collection.

Table 1
GPR Data Acquisition Parameters

Antenna Frequency (MHz)	Range (ns)	Survey Mode	Scan Rate (per sec)	Scan Rate (per ft)	Sample Rate (samples)	Max. Effective Signal Depth (ft)
35 MHz	1400	Point	64	0.5	1024	20-120

Data from the GPR survey were downloaded to a PC at the HGI office for processing and analysis using GSSI's RADAN® 7 software.

2.2 MASW Survey

The MASW survey used both active and passive data collection methods to collect MASW data along 4 transects. The active method used a 90-pound propelled energy source (PEG) to generate a broadband frequency spectrum of surface waves. Lower frequency surface waves generated from various distal (passive) sources were also recorded using passive data collection techniques. Active and passive data sets were processed separately to produce dispersion images for each data

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set, with the separate dispersion images combined for analysis. Longer wavelengths associated with passive low-frequency energy can improve the depth resolution of MASW Vs modeling.

HGI personnel collected MASW data using a linear array of 4.5-Hz geophones. Seismic records were collected using a 24 channel array and a common offset "roll-along" and "streamer" data acquisition technique, where both the recording geophone array and source were advanced along the line by a specified distance until the total line length distance was reached.

Active records were collected in roll-along fashion, using 24 geophones, a 10-foot geophone spacing and a roll distance of 20 feet per shot. Passive records were collected for select active array configurations. Active data were acquired using a sampling interval of 1000 ms over a record length of 1 s. Passive data were sampled at 2 ms over a record length of 15 s. The expanded passive time window is designed to record arrivals of lower-frequency surface waves generated from natural sources (e.g., ocean waves).

For both active and passive data collection, geophone arrays were attached to HGI's Geometrics Geode® 24- or 48-channel exploration seismograph unit via a seismic cable that relays the motion-induced electrical signals from individual sensors to the seismograph.

Table 2 provides the data acquisition parameters used for the active MASW survey.

Table 2
Active MASW Survey Acquisition Parameters

Line	Source Offset (ft)	Number of Records	Station Spacing (ft)	Total Line Length (ft)	Sample Rate (ms)	Recording Time (sec)
1	20	29	10	790	1	1
2	20	31	10	840	1	1
3	20	20	10	630	1	1
4	20	46	10	1070	1	1

2.4 GPS Survey

HGI used its Sokkia RTK GRX2 GPS system to locate surface features and transects. Where an RTK solution was achieved, the Sokkia system provided a relative accuracy of less than 0.164 feet horizontally and 0.328 feet vertically. All points were recorded in the Massachusetts Cape and Islands State Plane 83F coordinate system. The data were later adjusted to National Spatial Reference System (NSRS) coordinates using the National Oceanic and Atmospheric Administration (NOAA) Online Positioning User Service (OPUS).

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3.0 DATA REDUCTION AND ANALYSIS

Following the field data collection, the geophysical data were downloaded to a PC at the HGI office, where they were archived, processed, and analyzed using the following proprietary software:

- GPR analysis: GSSI's RADAN® 7
- MASW analysis: ParkSEIS© 3.0
- Graphic Presentations: Adobe Acrobat®, Golden Software© Surfer 12, AutoCAD® Map3D 2019, Microsoft© Excel

Section 5 provides a discussion of each method and its limitations.

3.1 GPR Survey

GPR data were processed and analyzed on HGI computers using GSSI's RADAN® 7 software. Prior to analysis, the raw GPR data required processing to reduce the detrimental effects of site-specific noise associated with interfering background frequency signals, destructive reflections from surface and buried objects, and general signal attenuation. Several iterations of GPR data processing and analysis were necessary to mitigate the detrimental effects and enhance the reflections associated with the clay layer.

GPR depths were calculated by converting two-way travel times to the GPR reflectors using radar propagation velocities estimated through reference to lookup tables of published values from GSSI and other sources, performing hyperbolic curve fitting when point reflectors were visible, and previous experience. Dielectric choice was further constrained by correlation with borehole data for the site provided by CDM Smith. Using borehole information from the log for monitoring well 19-01(b) a dielectric of 20 for undifferentiated sand and 50 for clay/silt was determined to be appropriate.

Annotated GPR records depicting interpreted subsurface features are provided as Figures G1 & G2, following the text.

3.2 MASW Survey

MASW survey data were analyzed using ParkSEIS© software and Excel®. ParkSEIS© was used to perform a surface-wave dispersion analysis for each shot gather, which was used to develop 1D Vs depth models representing the midpoint of each array position. The individual 1D Vs depth profiles were compiled to produce a 2D Vs depth profile.

In order to reduce the effects of an errant 1D Vs depth model among many 1D values across the site, the 1D Vs depth profiles are evaluated in context with one another as an interpolated model. This approach is supported by the concept that the geologic or anthropogenic processes responsible for the sediment distribution and, therefore, the Vs distribution, are a system of deposition definable by trend analysis. With this technique, the spatial characteristics of soil Vs reflect either

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the geologic or anthropogenic processes responsible for their distribution and are, therefore, more valid than values for any one single point.

Using this methodology, individual 1D profiles were compiled to form an XYZ matrix of distance, depth, and Vs values for each line. A 2D velocity model was then created from the matrix by grid interpolation using a kriging algorithm. The Vs trend analysis is represented as a 2D depth model visualized as a color-filled contour plot. Distances are expressed as feet from geophone 1.

4.0 RESULTS

The area of the Barnstable Water Pollution Control Facility (WPCF) is part of the "arm" of Cape Cod, which was primarily created by the Laurentide ice sheet during the Wisconsin glaciation. Interlobed glacial advance created the Sandwich moraine and glacio-deltaic outwash deposited sand, silt and clay into glacial Lake Nantucket Sound. During glacial re-advance and recession events, ice-thrusted sediments were eroded and re-deposited in the Barnstable Plain in glacial alluvial valleys, lakes and kettles.

Boring log 19-01(b) shows undifferentiated sands in the top 75 feet, followed by an approximately 10-foot-thick clay/silt layer above a fine grained sand. Cross sections provided by CDM Smith infer a clay/silt layer approximately 80 feet below ground surface. Both the GPR and MASW seismic survey results mapped a stratigraphic layer near these depths.

The results for the GPR and MASW surveys are shown in Figures 1 to 10, S1 to S4, and Plates 2 and 3. They show that the GPR and MASW results agree on the approximate depth of the top of the clay layer. The results for MASW lines 1 through 4 (Figures S1 to S4) show that the clay layer has a characteristic shear wave velocity (Vs) ranging from 900 to 1100 ft/sec, with the boundary between the upper coarse sand and the clay at a Vs of 1000 ft/sec.

An interpreted top and bottom of clay boundary is shown in each of the 10 GPR profiles (Figures 1-10). The bottom of clay is an inferred thickness based on an estimated GPR signal velocity for the clay. The depth to the top of the clay surface and clay thickness varies across the site, as. Figures 3 and G2 illustrate. The depth to clay over the entire survey area ranged from 55 to 107 feet below ground surface or 0 to -44 feet in elevation (NAVD 88). Clay thickness ranged from 5 to 20 feet.

Site-wide clay depth and elevation contour models were created by integrating the GPR and seismic data (Plates 2 and 3). Elevation data incorporated into the site elevation model were taken from HGI's GPS data, which is not a comprehensive site elevation survey.

The contour plots show trends in clay layer depth and elevation, including localized areas where the clay elevation is low. Areas of higher clay elevation may channel water toward lower elevations as water migrates along the top of the relatively impermeable clay layer, providing a preferential pathway for groundwater flow beneath the site.

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5.0 THE GEOPHYSICAL METHODS

5.1 Ground Penetrating Radar (GPR)

5.1.1 Description of the Method. The principle of ground penetrating radar (GPR) is the same as that used by police radar, except that GPR transmits electromagnetic energy into the ground. The energy is reflected back to the surface from interfaces between materials with contrasting electrical (dielectric and conductivity) and physical properties. The greater the contrast between two materials in the subsurface, the stronger the reflection observed on the GPR record. The depth of GPR signal penetration depends on the properties of the subsurface materials and the frequency of the antenna used to collect radar data. Lower frequency antennas provide greater signal penetration, but result in lower object resolution.

5.1.2 Data Collection. HGI collects GPR data using a Geophysical Survey Systems (GSSI) SIR 20 ground penetrating radar system. Data are digitally recorded on the internal hard drive of the GPR system. System controls allow the GPR operator to filter out noise, attributed to coupling noise caused by conductive soil conditions, spurious noise caused by local EMF fields, and internal system noise. For shallow surveys, we use antennas with center frequencies ranging from 2000- to 400-megahertz (MHz). For deeper penetration, we use lower frequency antennas ranging from 350 MHz to 15 MHz, depending on the anticipated target depth and the degree of signal penetration. All of these antenna configurations can collect data in continuous mode, distance mode, or as discrete point measurements using signal-stacking techniques. Since there is a trade-off between signal penetration and resolution, test data are sometimes collected using antennas with several different frequencies, with the highest frequency antenna that produces the highest quality data used. In some cases, data are collected with several antenna frequencies.

The horizontal scale of the GPR record shows distance along the survey traverse. In the continuous data collection mode, the horizontal scale on each GPR record is determined by the antenna speed along the surface. When a survey wheel is used, the GPR system records data with a fixed number of traces per unit distance. The GPR record is automatically marked at specified distance intervals along the survey line. The vertical scale of the radar record is determined by the velocity of the transmitted signal in the media under study and the range setting, or recording time window of the GPR system. The recording time interval, or range, represents the maximum two-way travel time in which data are recorded. The conversion of the two-way travel time of the transmitted signals to depth is determined by the propagation velocity of the GPR signal, which is site (media) specific. When little or no information is available about the makeup of subsurface materials, we estimate propagation velocities from handbook values and experience at similar sites or by CDP velocity surveys with a bi-static antenna.

5.1.3 Data Processing. After completion of data collection, the GPR data are transferred to a PC for review and processing using RADAN® 7 software. When appropriate, we prepare 3D models of GPR data, which can be sliced in the X, Y, and Z directions.

The size, shape, and amplitude of GPR reflections are used to interpret GPR data. Objects such as metallic UST's and utilities produce reflections with high amplitude and distinctive hyperbolic

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shapes. Clay, concrete pipes, boulders and other in-situ features may produce radar signatures of similar shape but lower amplitude. The boundaries between saturated and unsaturated materials such as sand and clay, bedrock and overburden, generally also produce strong reflections.

5.1.4 Limitations of the Method. GPR signal penetration is site-specific and is determined by the dielectric properties of local soil and fill materials. GPR signals propagate well in resistive materials such as sand and gravel; however, soils containing clay, ash- or cinder-laden fill or fill saturated with brackish or otherwise electrically conductive groundwater cause GPR signal attenuation and loss of target resolution. Concrete containing rebar or wire mesh also inhibits signal penetration.

The interpreted depths of objects detected using GPR are based on on-site calibration, handbook values, and/or estimated GPR signal propagation velocities from similar sites. GPR velocities and depth estimates may vary if the medium under investigation or soil water content is not uniform throughout the site.

The MLF GPR antenna is unshielded and produces a signal pattern that emanates in all directions from the antenna. Therefore, objects may be detected before the antenna is located directly over them. GPR anomalies may appear larger than actual target dimensions.

GPR interpretation is more subjective than other geophysical methods. The interpretive method is based on the identification of reflection patterns that do not uniquely identify a subsurface target. Borings, test pits, site utility plans and other ground-truth are recommended to verify the interpreted GPR results.

5.2 Multi-Channel Analysis of Surface Waves (MASW)

5.2.1 Description of the Method. The multi-channel analysis of surface waves (MASW) method uses the dispersion analysis of Rayleigh-type surface waves to extract a shear wave velocity depth profile. A 2D shear wave velocity field accurate to within 15% can be produced by acquiring many individual multi-channel surface wave data gathers and inverting the surface wave dispersion curves to form a series of 1D shear wave profiles. Discrete individual cells that make up the shear wave velocity field provide a measure of resolution potential and are dependent on the frequency range of the data and source spacing. Variations in the shear wave velocity field representative of an anomalous subsurface can easily be interpreted on shear wave velocity field contours. As generally applied, the method focuses on surface wave energy with frequencies ranging from 2 to over 60 Hz (frequency and associated wavelengths are indicative of depth of investigation) and is relatively insensitive to cultural noise and surface conditions (e.g., asphalt, grass, gravel, mud, etc.). By incorporating common mid-point (CMP)-style roll-along acquisition (seismic reflection method) with multi-channel acquisition, sufficient redundancy and resolution exist to interpret anomalies evident across several 1D profiles.[1] The MASW method can use both active and passive sources to generate surface waves.

[1] Miller, R.D., Xia, J., Park, C.B., and Ivanov, J., 2000. Shear wave velocity field from surface waves to detect anomalies in the subsurface: Proceedings of the First International Conference on the Application of Geophysical Methodologies to Transportation Facilities and Infrastructure, St. Louis, Dec. 11-15.

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Advantages of using the shear wave velocity field (calculated from surface waves) to detect, delineate, and/or map anomalous subsurface materials include the insensitivity of MASW to velocity inversions and cultural noise, ease of generating and propagating surface wave energy in comparison to body wave energy, and its sensitivity to changes in velocity. Compression-wave velocity (V_p) is one of the valuable by-products obtainable from the same data set used for shear wave (V_s) analysis through a different processing step. Standard processing routines are available to enhance record quality prior to the analysis.

5.2.2 Data Collection. We collect seismic data using our Geometrics Geode© exploration seismograph system with 24- or 48-channel geophone arrays and 4.5-Hz OYO geophones/receivers mounted on a land-streamer system. Geophone spacing depends on the depth of investigation, but is between 5 to 30 feet.

For active seismic source surveys, energy is generated by ramming a steel plate with a 90-pound propelled energy generator (PEG-40Kg) or with a Betsy seisgun that uses 8- or 12-gauge industrial blanks to create an airwave. The quality of the seismic signal for each shot point is verified in the field. The seismograph records all seismic data to an internal hard drive and floppy disk, from which it is transferred to a PC.

5.2.3 Data Analysis and Interpretation. Data reduction and analysis of MASW data are performed using ParkSEIS® software. Data reduction and analysis begin with the consolidation and reformatting of individual shot gathers for each line into a single multi-record file format. The survey geometry is defined for each seismic record. Dispersion curve analysis is then performed for each shot gather in the multi-record file by examining the change in phase velocity vs. frequency using the fundamental mode component of the dispersion data. Non-linear in version modeling of each dispersion curve is performed and results in a 1D mid-point representation of V_s and V_p depth profiles. Interpolation of the 1D data using a kriging algorithm produces a 2D grid of the V_s data. Color-filled contour profile plots are then generated from the V_s grid.

5.2.4 Limitations of the Method. Site-specific testing is required to evaluate background noise levels, to demonstrate the recording of meaningful surface wave data, and to estimate signal-to-noise (S-N) values. Acquisition parameters, such as receiver/shot coupling, shot offset, receiver spacing, sampling rate, record length, and other parameters are also site-specific. For records exhibiting low S-N levels, shots must be added to stack the coherent parts of the signal, which helps mitigate the detrimental effects of random environmental noise.

The MASW and other surface wave methods are primarily designed to obtain Vs of lower velocity soils (relative to high velocity bedrock). Because of the high seismic velocities of most rock types, significantly longer geophone arrays than space allows are required to measure Raleigh wave dispersion in rock.

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5.3 RTK GNSS Global Positioning System (GPS)

5.3.1 Description of the Method. The RTK GPS system consists of a base (reference) receiver and a roving receiver. The base receiver remains stationary during a survey and is mounted on a tribrach and tripod. A rover receiver is used to record points remotely and can be mounted on a staff, vehicle, or other object. The base provides real-time corrections to the rover over a radio connection. The system can produce accuracy on a centimeter scale, but the level of accuracy depends on factors that include the geometry of the transmitting satellites and the receivers' view of the horizons (e.g., the density of buildings and trees). The data can be collected as quickly as 1 Hz or 1 reading per second.

5.3.2 Data Collection and Processing. We perform our GPS surveys using a Sokkia RTK GRX2 GPS system. The base station can be set up over a known or unknown point, with the position taken from satellite information. Once the system has achieved a fixed solution for the rover receiver, data points can be collected with survey-grade (centimeter-scale) precision. When GPS points are being collected at a site where the fixed solution is constantly lost and gained, points are checked multiple times for precision. All data points are saved to an Allegro CX field computer.

The GPS data are corrected automatically by the base receiver in the field prior to being recorded. If the base station is located on an unknown point that is later defined, the GPS data can be corrected in the office to fit the real world coordinates.

5.3.3 Limitations of the Method. The quality of the GPS signal is site-specific. The base and rover receiver need to have clear views of the horizon and good satellite geometry to achieve the highest level of accuracy and precision. Although a fixed solution can be achieved in wooded environments or sites with taller buildings, it may take more time to achieve the solutions, the fixed solution may be lost frequently when moving the rover, and in some cases the fixed solution may be wrong. Each of these situations requires longer to locate data points accurately and precisely. When the point is too close to a building, beneath a building overhang, under a tree, or obscured by some other object, a fixed solution may not be possible.

When the base station is set up over an unknown point, the survey data location can be at least several tens of meters from the real world location. The data points will have survey grade precision relative to the location of the base station and other data points, but will have a real world accuracy discrepancy.

HGI does not guarantee to produce a surveyor-quality map from its GPS data, as this is not its profession. If survey-level accuracy is critical for a project, we recommend hiring professional surveyors for that purpose.

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Legend

- GPR Transect
- Seismic Transect

N

Plate 1	
August, 2019	2019032

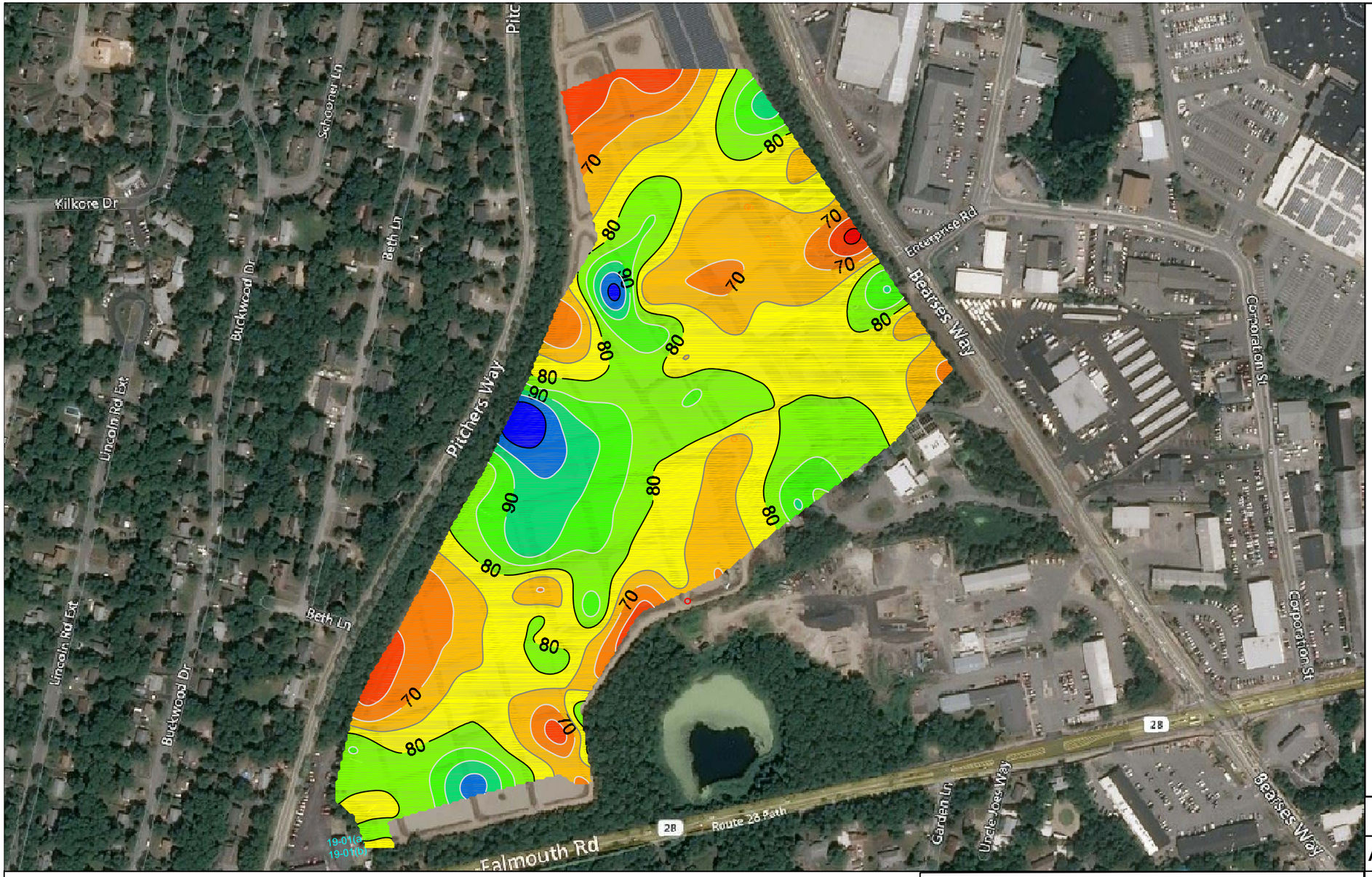
GPR & Seismic Transects Barnstable, MA

NOTES:
1.) The base map was created from HGI field notes, grid marks, GPS, and Bing Maps.
2.) HGI's contributions to the base map are listed in the legend.

0 300 600 Feet

Hager GeoScience, Inc.
596 Main Street, Woburn, MA 01801
(781) 935-8111 hgi@hagergeoscience.com

NOT ALL SUBSURFACE FEATURES MAY BE DEPICTED ON THIS MAP



Legend

Depth (feet)

110
105
100
95
90
85
80
75
70
65
60
55
50

N

Plate 2

August, 2019 | 2019032

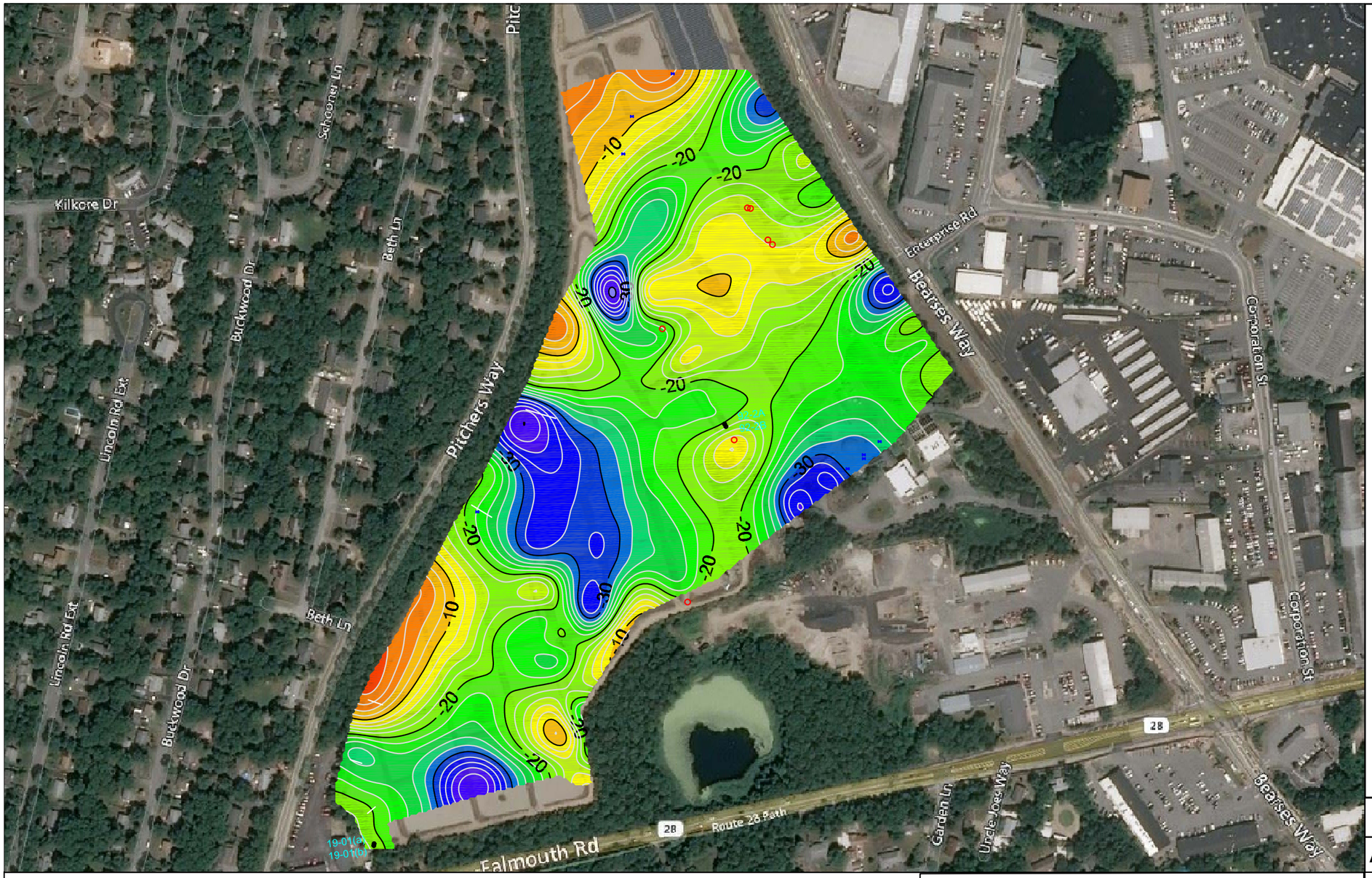
Depth to Top of Clay Contour Plot Barnstable, MA

NOTES:
1.) The base map was created from HGI field notes, grid marks, GPS, and Bing Maps.
2.) HGI's contributions to the base map are listed in the legend.

0 300 600 Feet

Hager GeoScience, Inc.
596 Main Street, Woburn, MA 01801
(781) 935-8111 hgi@hagergeoscience.com

NOT ALL SUBSURFACE FEATURES MAY BE DEPICTED ON THIS MAP



Legend

Elevation (feet)

-2
-6
-10
-14
-18
-22
-26
-30
-34
-38
-42
-46
-50

N

Plate 3

August, 2019 | 2019032

Elevation of Top of Clay Contour Plot Barnstable, MA

NOTES:
1.) The base map was created from HGI field notes, grid marks, GPS, and Bing Maps.
2.) HGI's contributions to the base map are listed in the legend.

0 300 600 Feet

Hager GeoScience, Inc.
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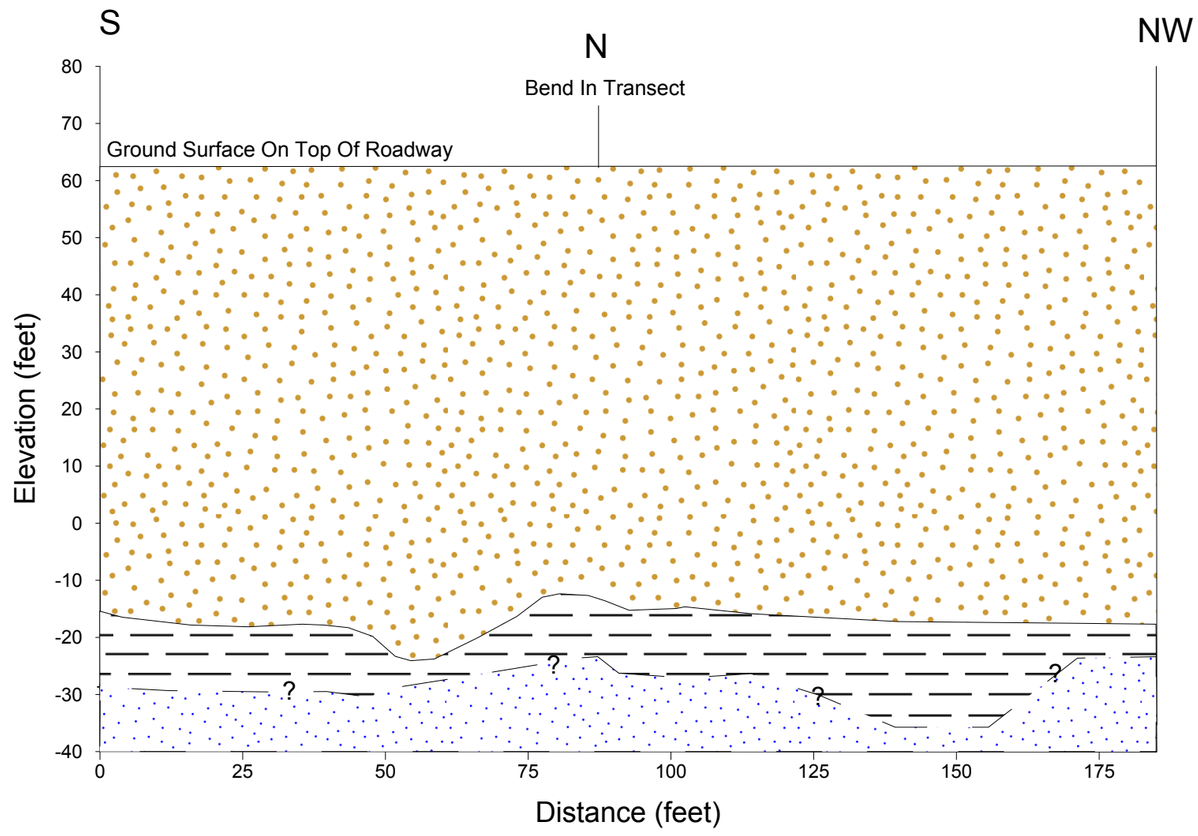
NOT ALL SUBSURFACE FEATURES MAY BE DEPICTED ON THIS MAP

Figure 1
Barnstable WPCF
GPR Transect 1A-B Interpretation
South to Northwest
Barnstable, MA



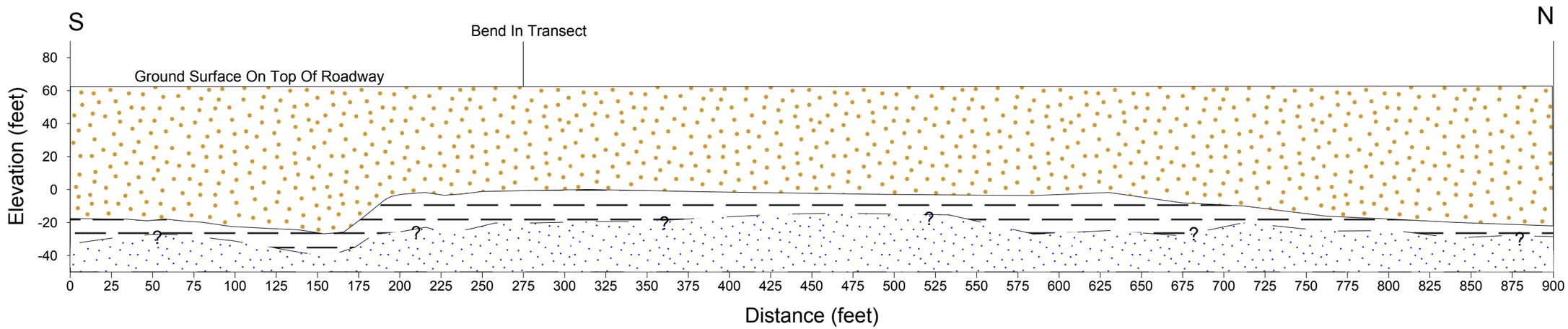
Undifferentiated Sand

Clay / Silt

Fine Grained Sand



Figure 2
Barnstable WPCF
GPR Transect 2A-C Interpretation
South to Northeast
Barnstable, MA



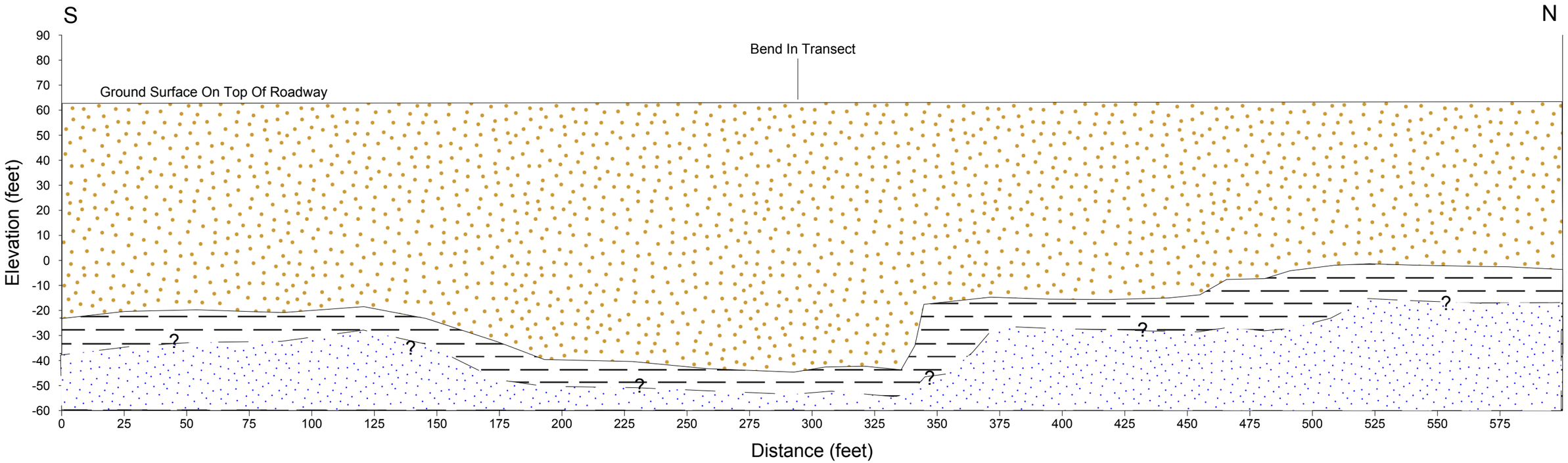
Undifferentiated Sand

Clay / Silt

Fine Grained Sand



Figure 3
Barnstable WPCF
GPR Transect 3-4 Interpretation
South to North
Barnstable, MA



Undifferentiated Sand

Clay / Silt

Fine Grained Sand

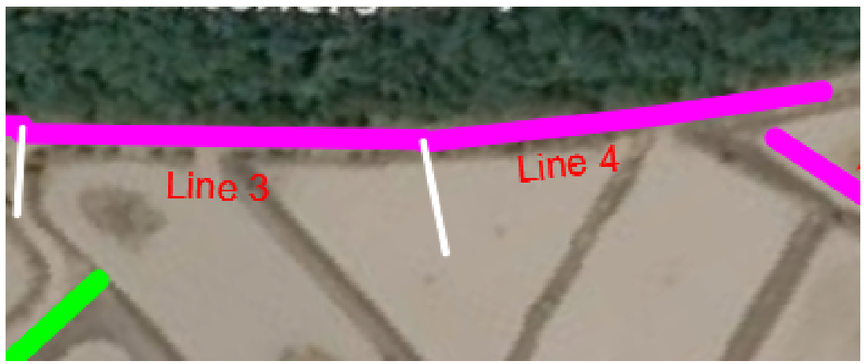
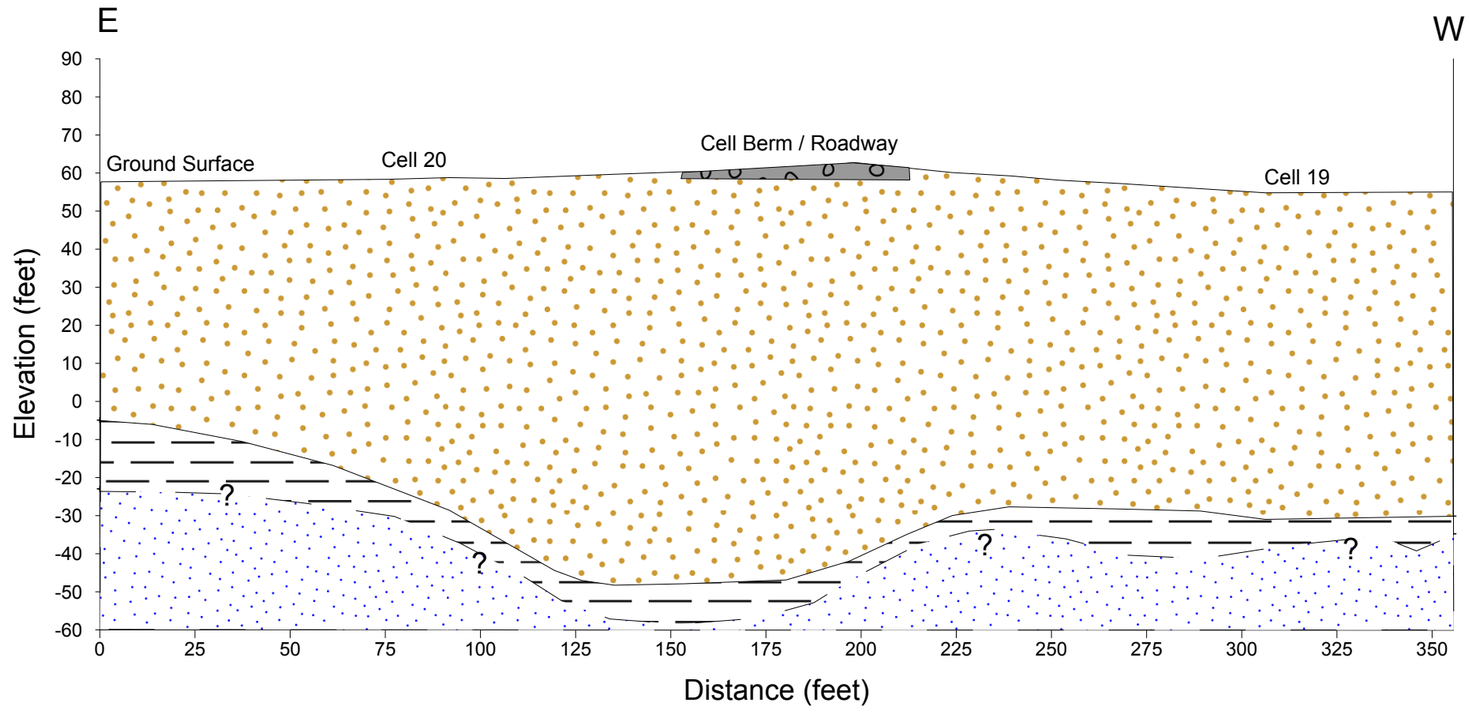
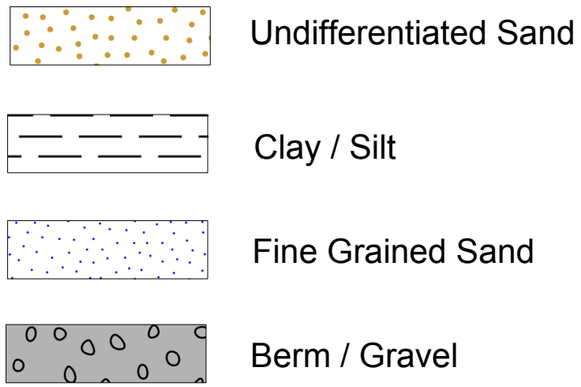


Figure 4
Barnstable WPCF
GPR Transect 5-6 Interpretation
East to West
Barnstable, MA





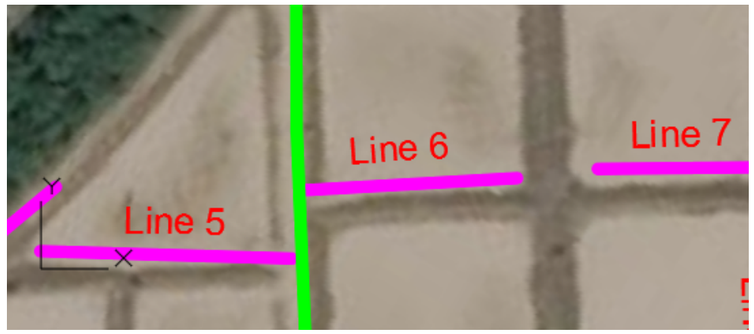
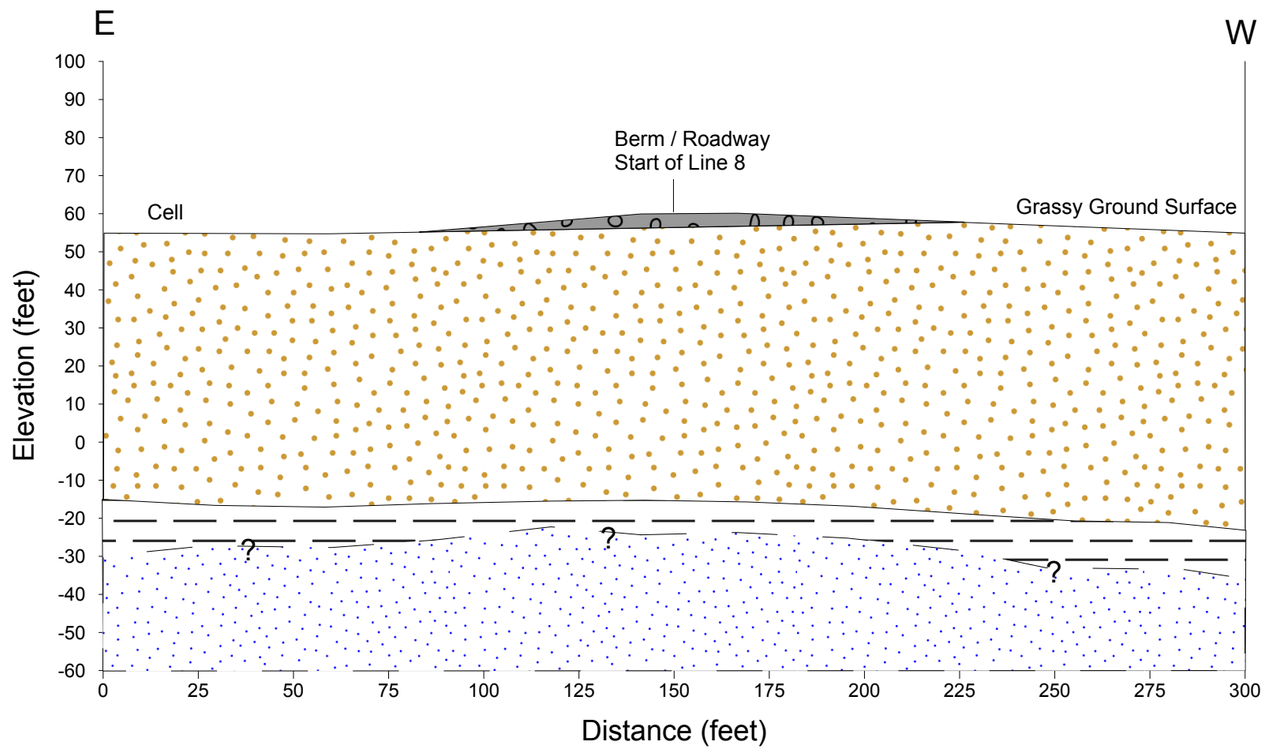


Figure 5
Barnstable WPCF
GPR Transect 7 Interpretation
East to West
Barnstable, MA



Undifferentiated Sand

Clay / Silt

Fine Grained Sand

Berm / Gravel

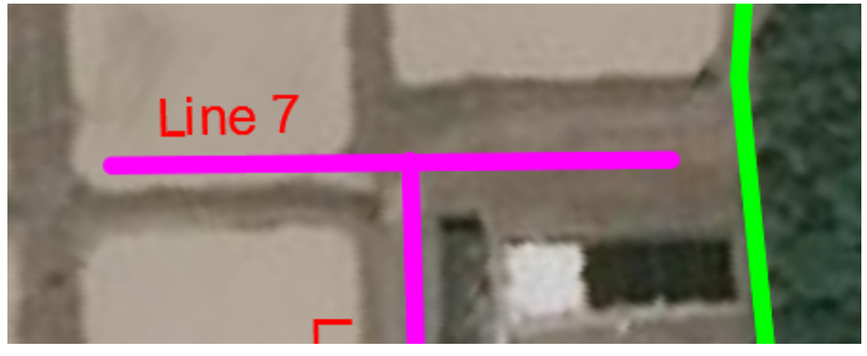
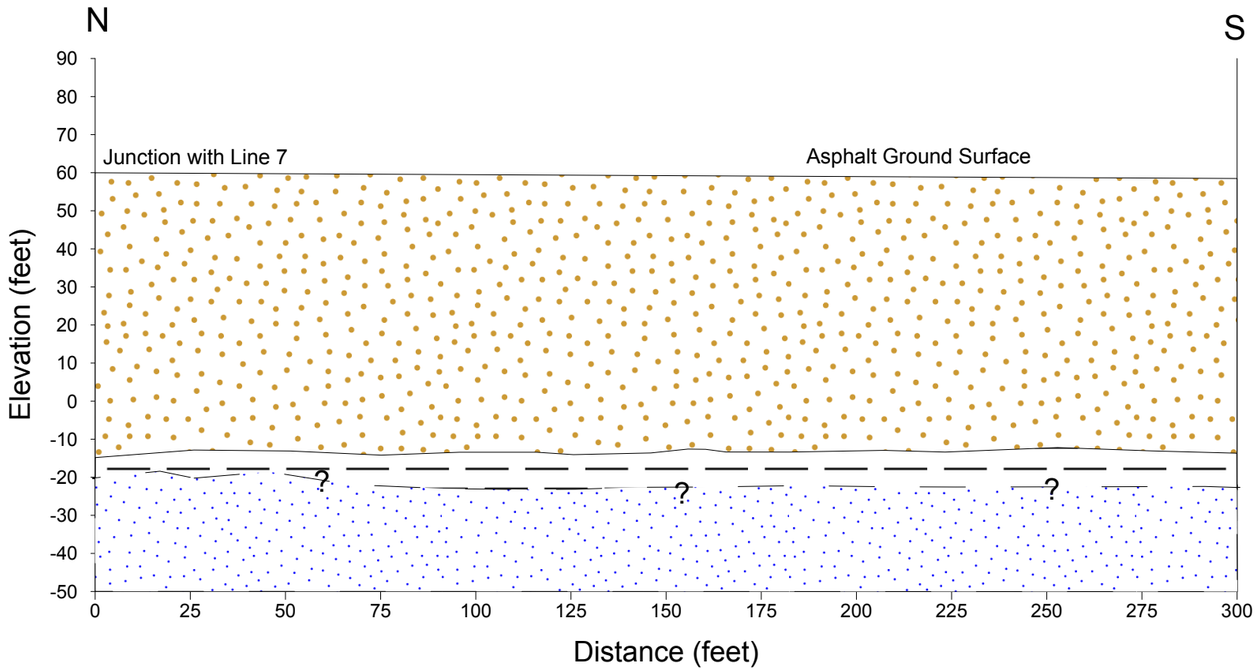


Figure 6
Barnstable WPCF
GPR Transect 8 Interpretation
North to South
Barnstable, MA



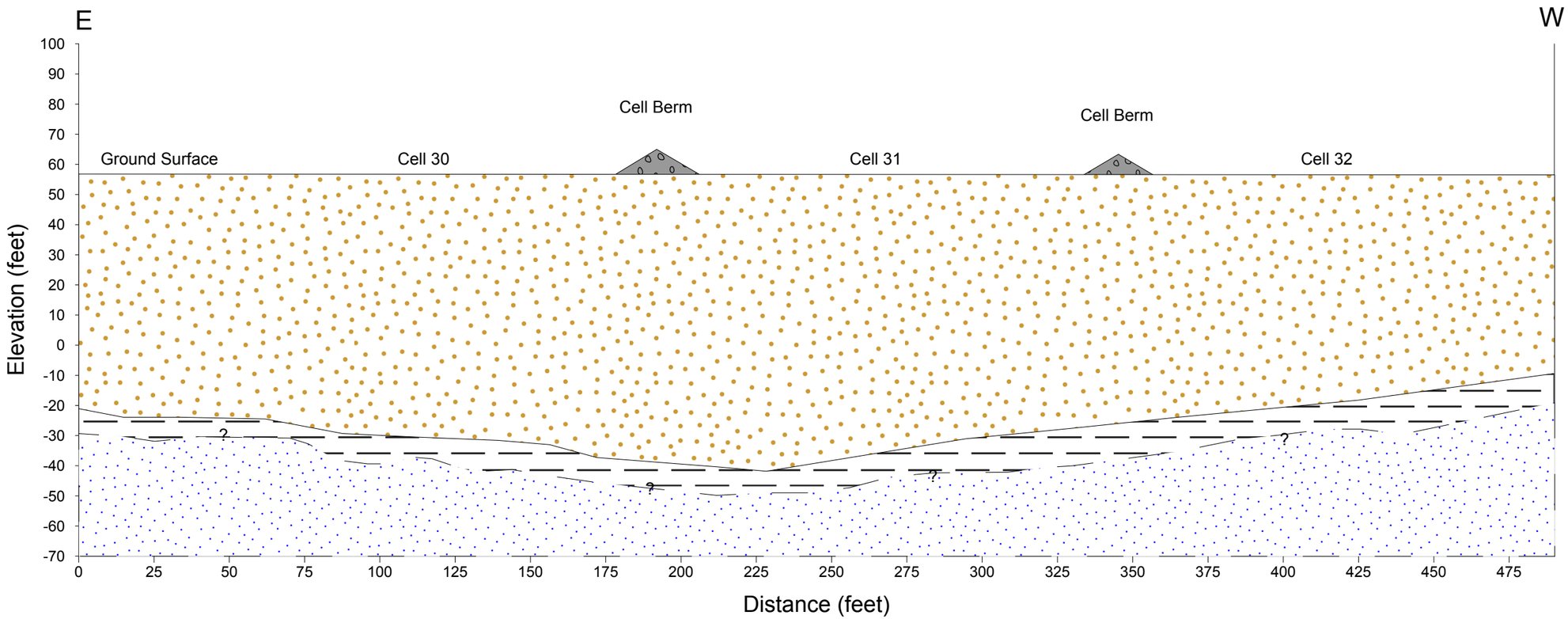
Undifferentiated Sand

Clay / Silt

Fine Grained Sand



Figure 7
Barnstable WPCF
GPR Transect 9-11 Interpretation
East to West
Barnstable, MA



Undifferentiated Sand

Clay / Silt

Fine Grained Sand

Berm / Gravel

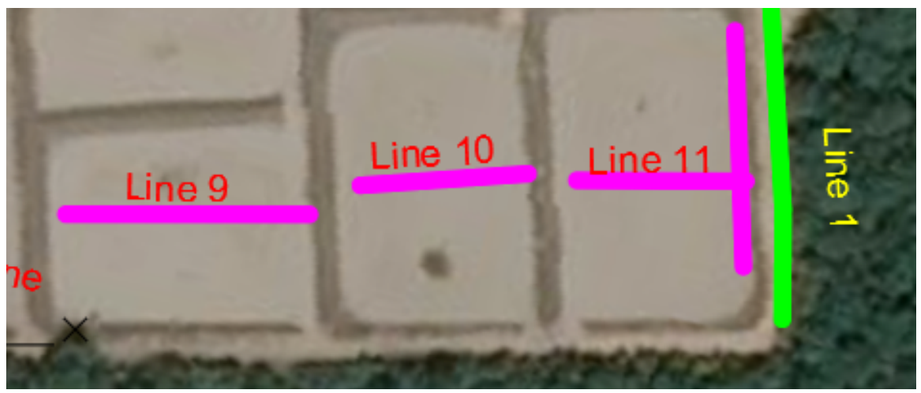


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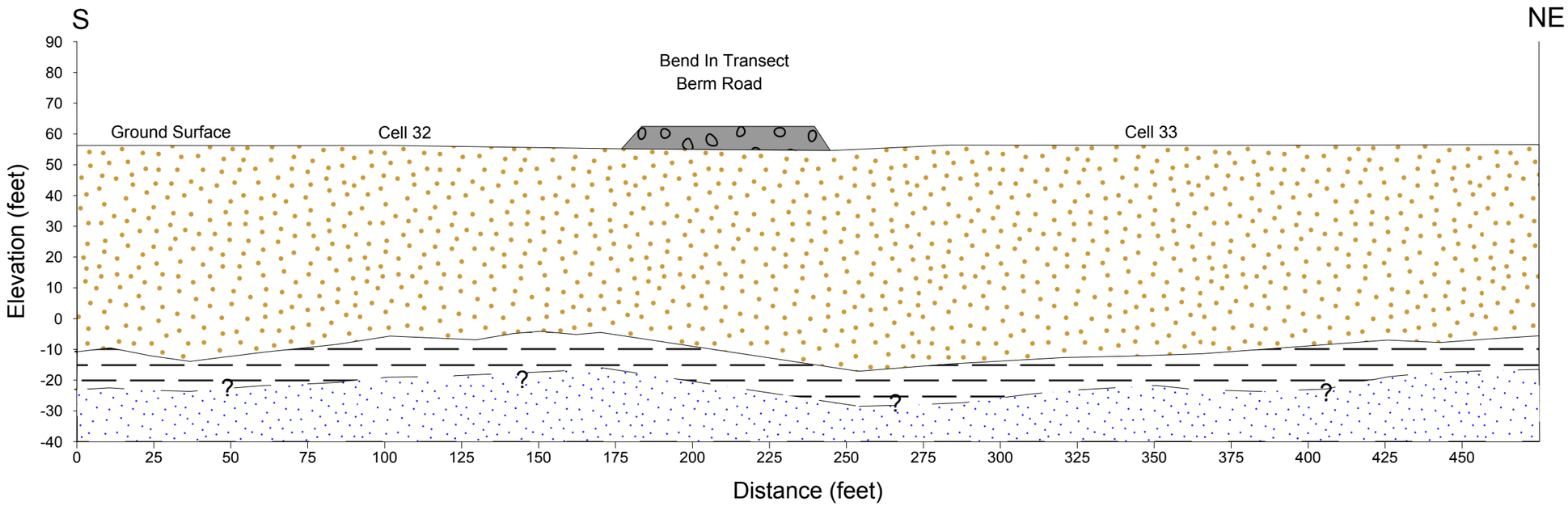
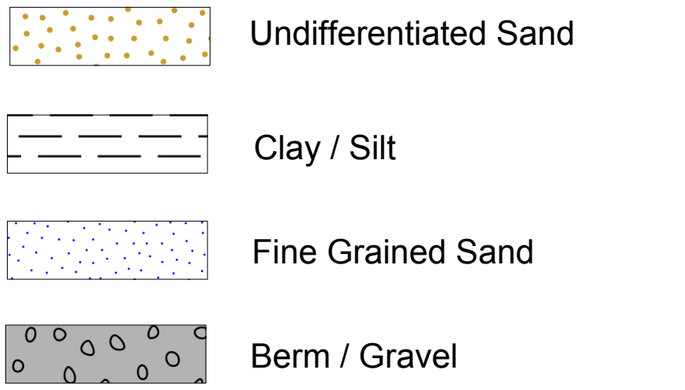
Figure 8
Barnstable WPCF
GPR Transect 12-13 Interpretation
South to Northeast
Barnstable, MA





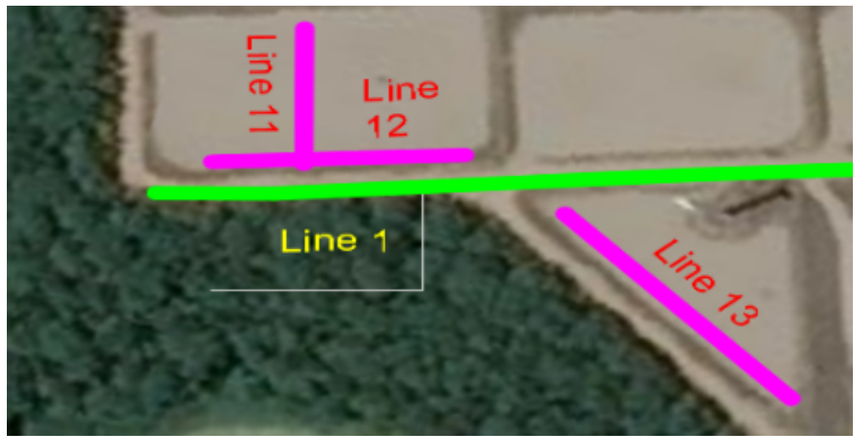
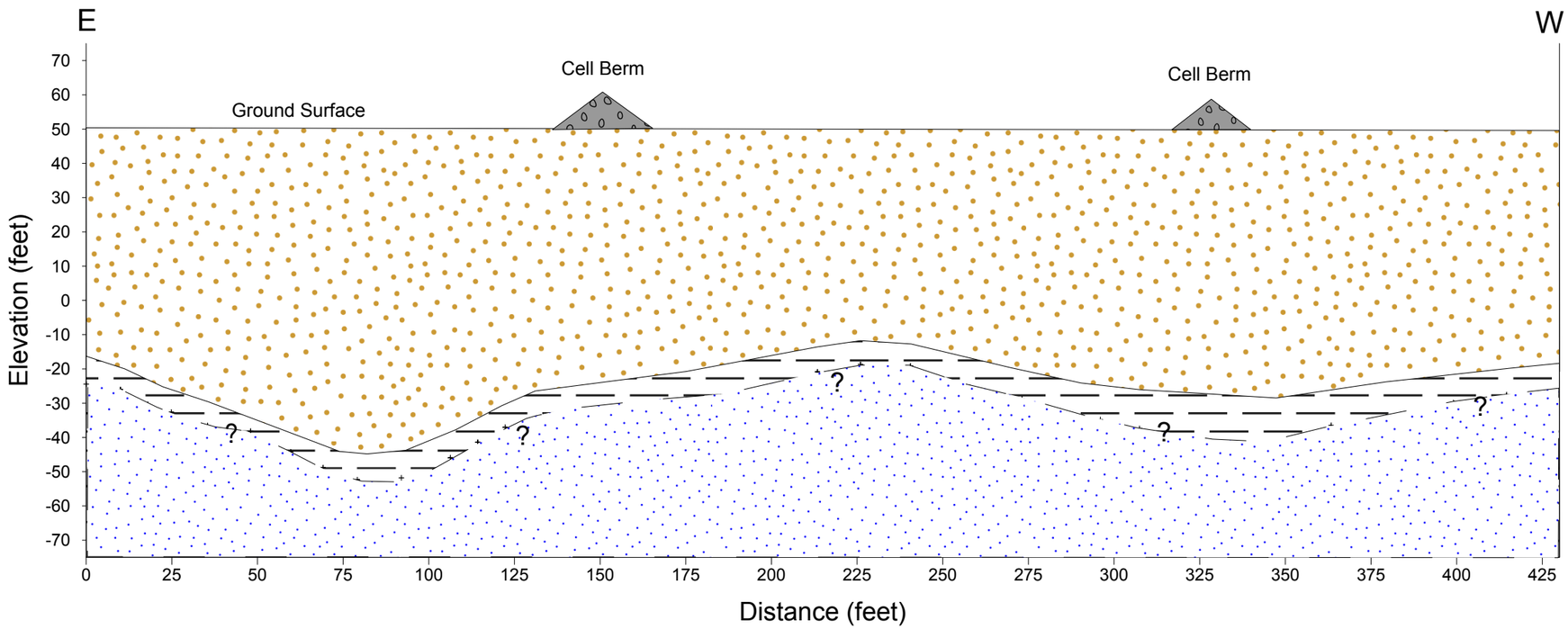


Figure 9
Barnstable WPCF
GPR Transect 14-16 Interpretation
East to West
Barnstable, MA



Undifferentiated Sand

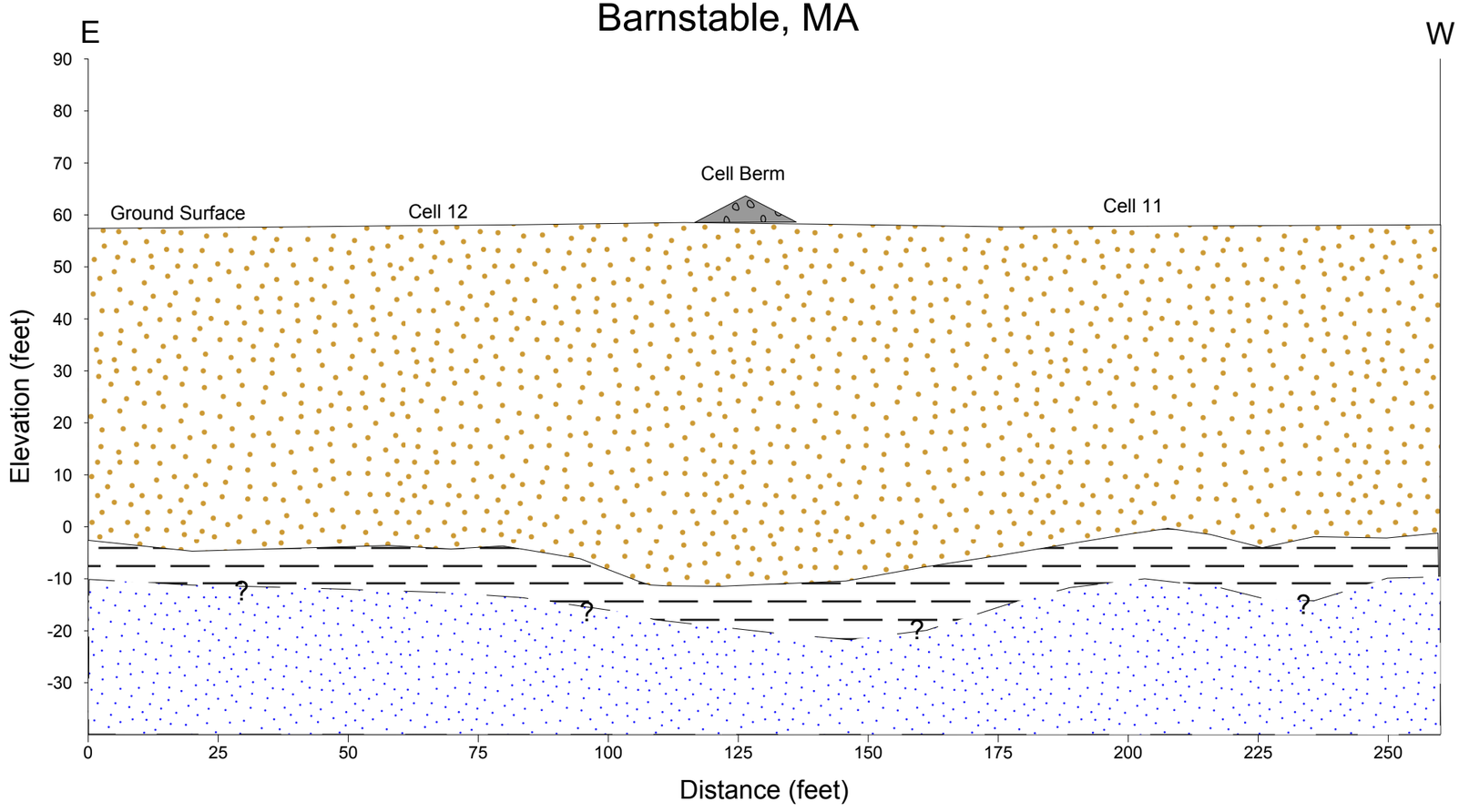
Clay / Silt

Fine Grained Sand

Berm / Gravel

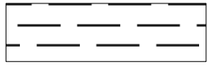


Figure 10
Barnstable WPCF
GPR Transect 17-18 Interpretation
East to West
Barnstable, MA

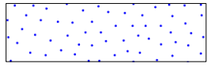




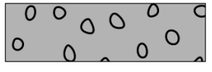
Undifferentiated Sand



Clay / Silt



Fine Grained Sand



Berm / Gravel



Figure G1
Clay Boundary Radargrams
GPR Transects 9 and 10

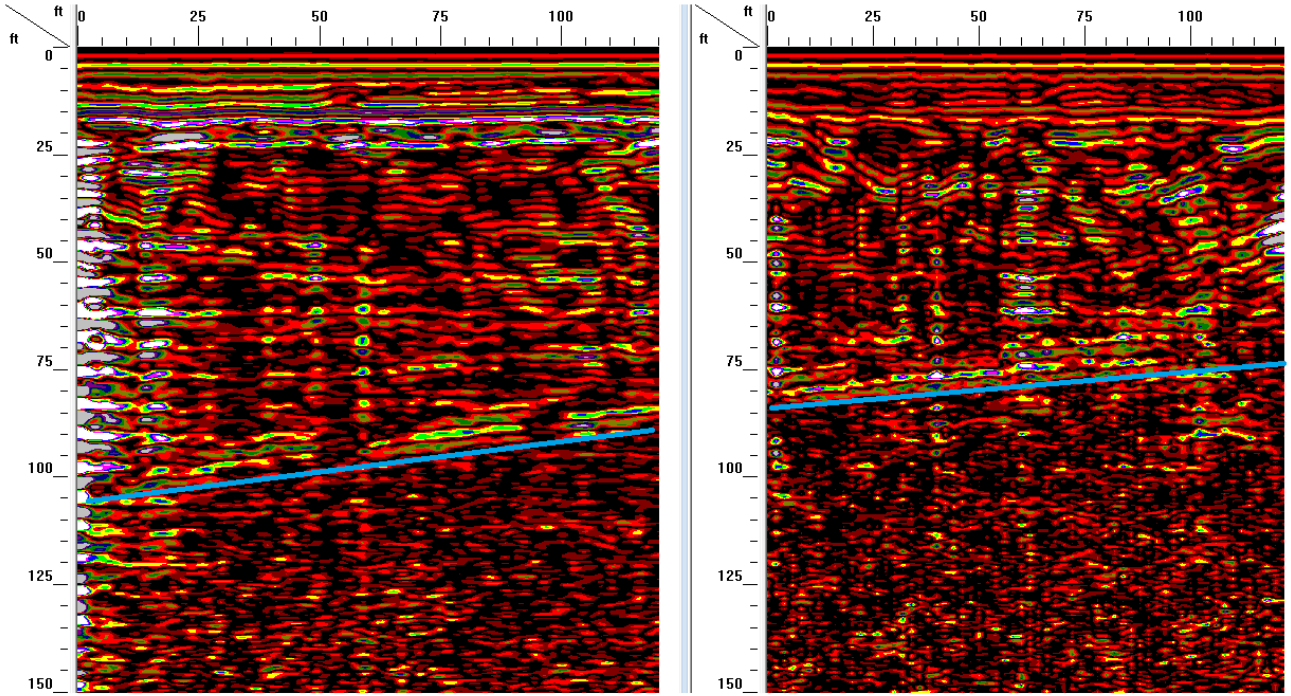


Figure G1. The above radargrams show the boundary between undifferentiated sand and the top of clay/silt. The boundary between the two units is annotated in blue.

Figure G2
Clay Thickness Radargrams
GPR Transects 3 and 4

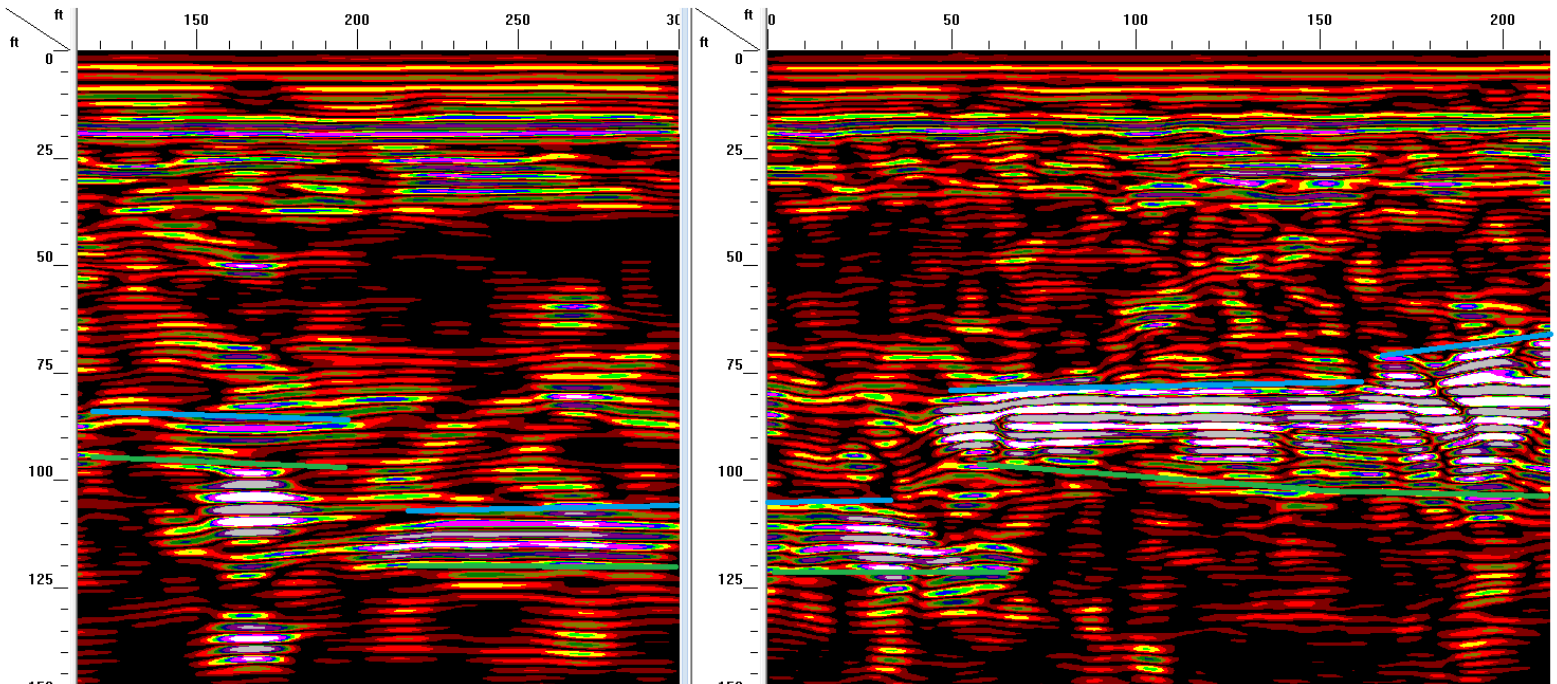
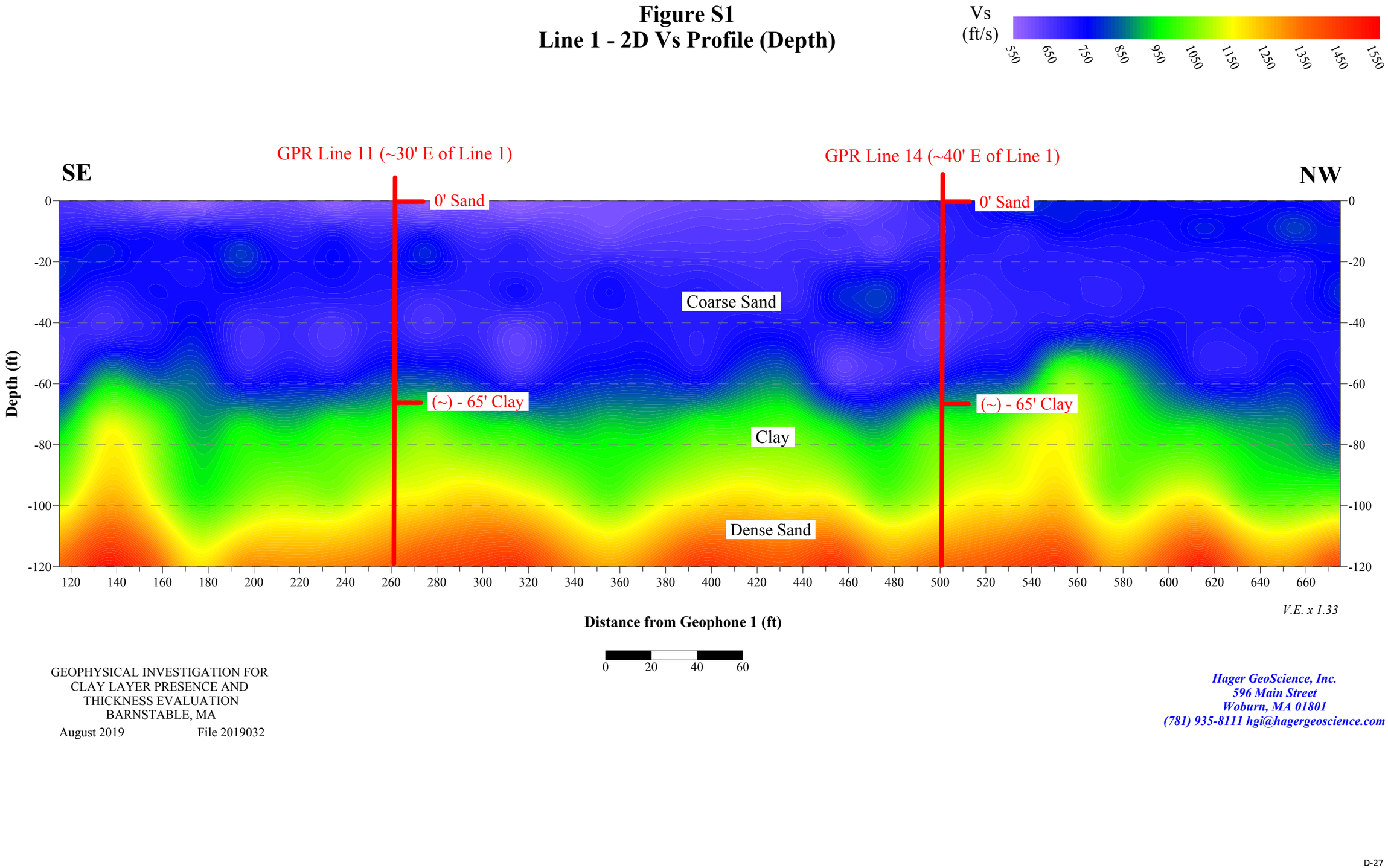


Figure G2. The above radargrams are examples of clay thickness estimations. The interpreted top of clay is highlighted in blue and the bottom of clay is highlighted in green.

Figure S1
Line 1 - 2D Vs Profile (Depth)



GEOPHYSICAL INVESTIGATION FOR
CLAY LAYER PRESENCE AND
THICKNESS EVALUATION
BARNSTABLE, MA

August 2019 File 2019032

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Figure S2
Line 2 - 2D Vs Profile (Depth)

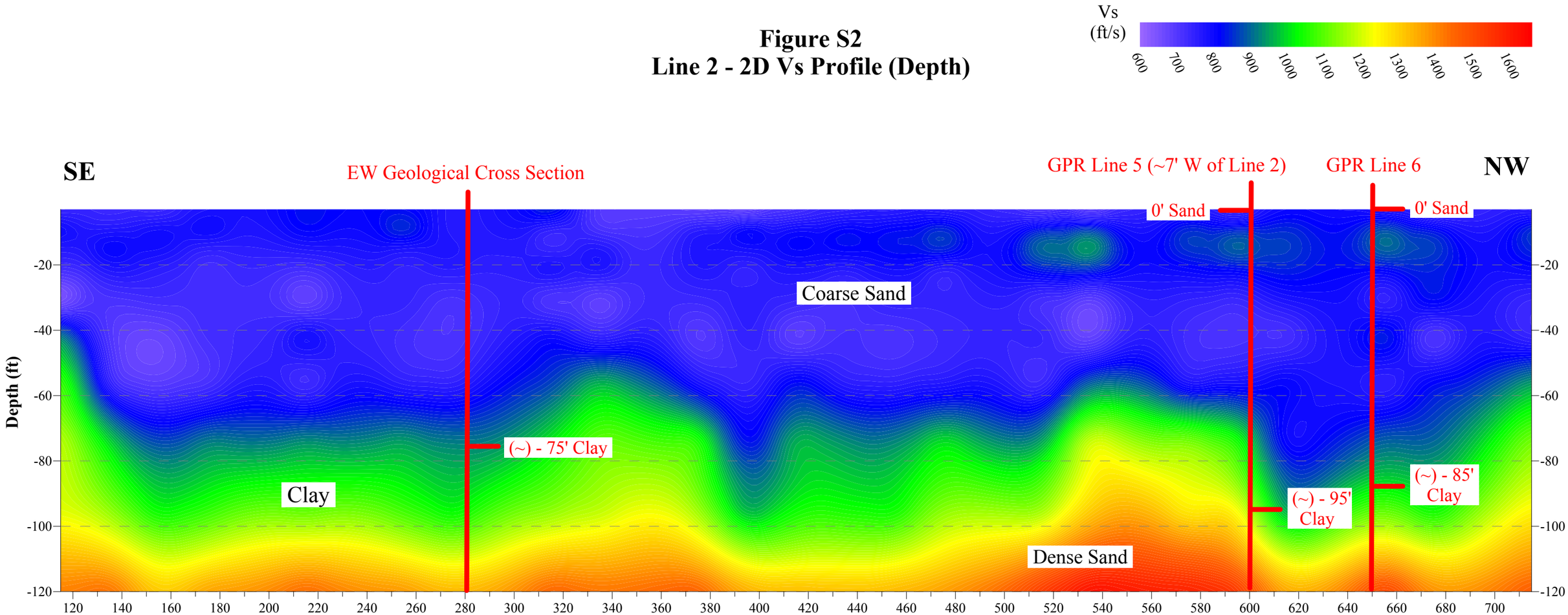

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Figure S3
Line 3 - 2D Vs Profile (Depth)

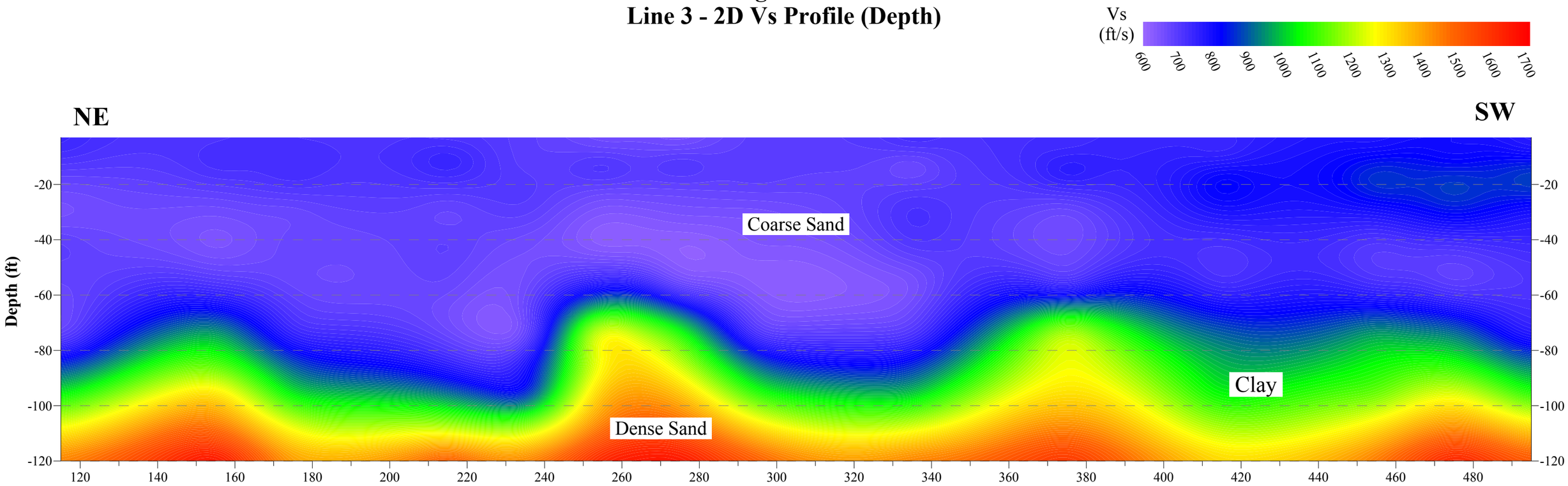

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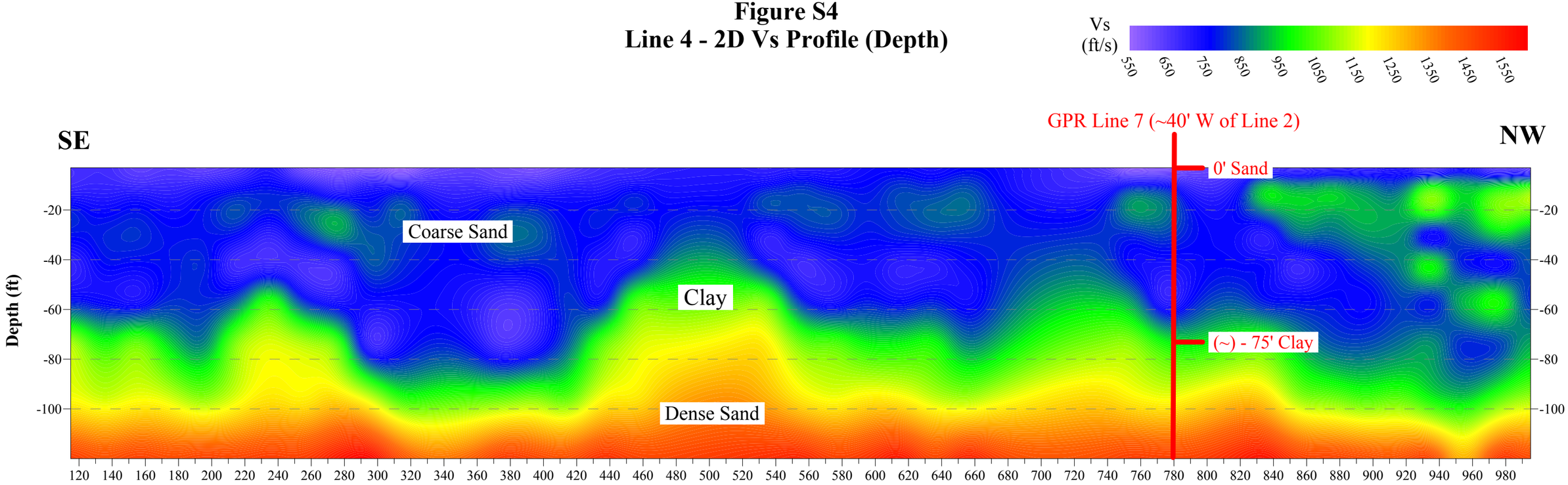
Figure S4
Line 4 - 2D Vs Profile (Depth)



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Appendix E

Numerical Model Calibration Data

E1 Steady-State Calibration Point Data

E2 Transient Calibration Plots

Table E1 Steady State Calibration Point Data

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
92-16	927094.2	245363.6	13.0	33.4	33.0	0.4
92-4	925669.0	244609.9	23.6	33.4	34.4	-1.0
BA-1	926448.5	242306.4	-26.5	27.1	29.1	-2.0
BB-1	926313.6	238812.1	-31.3	17.3	16.7	0.6
BC-1	928204.1	246474.6	-10.0	32.0	31.2	0.8
BD	927672.2	239175.8	-20.5	16.8	16.1	0.7
BE	924521.8	239731.6	4.1	20.7	21.3	-0.6
C3	928731.5	240760.6	-17.7	20.8	20.6	0.2
C4	929290.2	242422.6	-11.6	24.3	24.5	-0.2
PT-300	927038.4	244462.5	8.9	32.6	32.6	0.0
S11	926572.3	245580.5	13.1	34.4	34.1	0.3
S15	931229.0	244855.1	0.1	25.7	24.5	1.2
S4	923000.5	245555.8	8.2	33.5	33.6	-0.1
W1	927230.3	243792.2	36.2	29.2	31.2	-2.0
W7	925986.3	246824.0	19.1	34.5	33.0	1.5
92-2A	926415.0	244721.0	32.0	37.3	34.6	2.7
19-01A	925618.7	243634.8	24.0	34.3	33.0	1.3
19-01B	925618.5	243634.6	-38.0	27.4	27.3	0.1
MA-A1W	922686.3	242127.4	21.4	29.3	28.3	1.0
00mp0571c	869941.8	233141.6	17.5	36.4	35.6	0.8
00mw0512c	867325.0	235466.3	13.0	46.6	46.1	0.5
00mw0512d	867325.0	235466.4	33.0	46.3	46.1	0.2
00mw0512e	867325.0	235466.5	47.0	47.2	46.1	1.1
00mw0514c	863739.0	235361.3	2.5	47.2	47.2	0.0
00mw0515c	868766.0	235410.1	10.0	45.6	43.9	1.7
00mw0515d	868766.0	235409.3	30.0	45.1	43.9	1.2
00mw0526b	866407.6	232512.0	-16.1	39.0	39.8	-0.8
00mw0527	864159.9	235065.9	0.4	46.9	46.1	0.8
00mw0530	866722.0	236583.0	47.4	49.6	49.1	0.5
00mw0531	867657.0	237110.0	49.0	51.0	50.1	0.9
00mw0537b	868293.0	235249.0	22.7	44.9	44.2	0.7
00mw0538a	869499.0	235753.0	-36.3	44.8	43.4	1.4
00mw0539a	868118.5	233600.3	-36.4	39.6	38.9	0.7
00mw0539d	868115.4	233602.9	38.5	39.6	38.9	0.7
00mw0542a	868819.0	234137.0	-8.5	40.2	39.5	0.7
00mw0542c	868818.0	234131.0	25.9	39.9	39.4	0.5
00mw0544a	869848.4	233455.1	-39.6	36.7	35.9	0.8

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
00mw0544b	869844.2	233452.7	-9.5	36.5	35.9	0.6
00mw0544c	869839.7	233450.3	20.5	35.8	35.9	-0.1
00mw0547a	865546.9	233699.0	-60.3	43.0	43.7	-0.7
00mw0547b	865539.5	233701.0	-10.3	43.3	43.8	-0.5
00mw0549	866254.0	232304.1	-63.3	40.2	40.1	0.1
00mw0561	869459.0	234553.0	-6.9	40.4	40.0	0.4
00mw0562a	869522.3	233158.7	-86.8	36.6	37.0	-0.4
00mw0562c	869517.6	233160.0	34.5	37.5	37.4	0.1
00mw0567	868445.0	235487.0	38.2	45.4	44.7	0.7
00mw0570a	868951.0	234618.0	-15.2	41.8	41.0	0.8
00mw0570b	868941.0	234608.0	29.8	41.5	40.9	0.6
00mw0581a	865658.0	231689.0	-189.5	40.5	41.7	-1.2
00mw0581b	865658.0	231688.9	-44.7	41.7	41.8	-0.1
00mw0582a	865768.0	230847.6	-123.8	40.5	40.6	-0.1
00mw0583a	868211.6	229136.9	-247.3	36.4	36.7	-0.3
00mw0583b	868201.7	229146.0	-127.5	36.5	36.8	-0.3
00mw0583d	868201.8	229145.9	25.0	36.6	36.9	-0.3
00mw0584b	869061.7	230339.0	-100.8	36.3	36.5	-0.2
00mw0587a	870295.5	228166.0	-115.1	32.6	32.4	0.2
00mw0587b	870295.5	228165.9	-17.2	32.6	32.4	0.2
00mw0588a	870005.4	226494.2	-59.5	31.3	31.7	-0.4
00mw0588b	870005.4	226494.1	20.5	31.3	31.8	-0.5
00mw0589a	863783.3	229647.6	-200.2	41.7	42.6	-0.9
00mw0589c	863783.3	229636.9	0.2	41.9	42.8	-0.9
00mw0591a	868002.9	225506.5	-203.4	31.8	32.9	-1.1
00mw0591b	868010.3	225507.6	-115.5	31.8	32.9	-1.1
00mw0605a	866133.3	231991.6	-138.7	40.5	40.2	0.3
00mw0606b	864321.4	228714.5	-126.8	40.0	39.4	0.6
00mw0607a	865600.2	230390.8	-135.7	40.5	40.5	0.0
00mw0608a	866603.8	230291.2	-199.3	39.2	38.1	1.1
00mw0608b	866603.5	230291.5	-129.0	39.0	38.0	1.0
02mw0003d	855495.3	232853.2	-77.0	43.3	43.2	0.1
02mw1251	855297.4	232437.7	-104.1	43.5	42.1	1.4
03mp0091b	863337.0	234059.0	-121.3	45.6	44.9	0.7
03mp0091d	863337.0	234059.0	-50.3	45.3	44.8	0.5
03mp0091e	863337.0	234059.0	-10.8	44.7	44.8	-0.1
03mw0022a	860937.2	246957.4	-4.6	64.7	63.7	1.0
03mw0028a	860560.0	244884.0	-55.0	61.8	61.4	0.4

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
03mw0029z	859671.5	243272.4	-98.3	60.7	59.2	1.5
03mw0033	860737.9	242679.6	-32.5	59.0	59.1	-0.1
03mw0034	861408.1	242374.6	-32.0	58.9	58.9	0.0
03mw0037	855936.9	240061.5	-68.4	56.1	54.3	1.8
03mw0041a	859479.0	237546.0	-112.0	54.9	52.7	2.2
03mw0043b	858301.0	238004.0	12.9	55.8	53.3	2.5
03mw0045	860523.6	240291.5	-18.0	57.0	56.3	0.7
03mw0048	856391.0	242750.0	5.8	57.3	56.8	0.5
03mw0052a	862083.0	237261.0	-148.8	53.1	51.4	1.7
03mw0053	861957.0	236427.0	-50.0	50.1	50.1	0.0
03mw0054a	863056.7	234642.2	-69.1	46.1	46.2	-0.1
03mw0054b	863067.9	234663.5	-17.4	45.6	46.2	-0.6
03mw0063	861783.0	234483.0	-143.2	48.8	46.9	1.9
03mw0064	863279.9	233685.1	-172.2	45.2	44.6	0.6
03mw0069	857535.7	243263.7	0.3	59.8	58.0	1.8
03mw0070b	857089.4	242333.4	13.2	60.4	57.0	3.4
03mw0088	858692.5	236189.4	3.0	52.3	50.7	1.6
03mw0089	857835.6	236774.7	-5.9	53.6	51.6	2.0
03mw0094a	857831.9	238153.8	-115.7	54.4	53.4	1.0
03mw0094b	857831.9	238153.9	13.3	57.6	53.4	4.2
03mw0095b	860448.3	235515.4	-14.1	49.8	49.0	0.8
03mw0096	861103.5	238387.6	-29.3	55.2	53.7	1.5
03mw0098	859728.1	236412.0	-15.8	52.6	50.8	1.8
03mw0100a	857547.1	239674.6	-99.6	55.9	54.9	1.0
03mw0100b	857549.2	239667.9	17.3	57.9	54.9	3.0
03mw0101b	858052.4	239631.4	-23.3	56.6	55.1	1.5
03mw0102a	862129.9	234421.8	-168.4	48.2	46.6	1.6
03mw0102b	862129.8	234421.8	-63.4	46.6	46.6	0.0
03mw0103b	862370.7	233749.6	-122.6	45.3	45.5	-0.2
03mw0103c	862370.6	233749.5	-67.9	45.5	45.5	0.0
03mw0104b	862625.5	234502.6	-40.2	46.8	46.4	0.4
03mw0105b	863880.9	235496.7	-73.7	47.4	47.4	0.0
03mw0107a	859402.8	244771.7	-88.8	63.9	60.6	3.3
03mw0107b	859402.8	244771.9	-18.9	61.3	60.6	0.7
03mw0109a	860311.9	241697.5	-88.5	58.8	57.8	1.0
03mw0109b	860311.9	241697.2	-30.5	59.0	57.9	1.1
03mw0110a	859982.8	239258.3	-139.2	57.1	55.1	2.0
03mw0110b	859982.7	239258.7	-58.8	58.2	55.1	3.1

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
03mw0111a	861443.6	239483.3	-137.2	54.2	55.2	-1.0
03mw0111b	861451.5	239480.0	-21.5	55.8	55.2	0.6
03mw0112a	861451.8	243346.0	-79.7	62.2	60.1	2.1
03mw0112b	861457.0	243356.9	-43.7	61.9	60.1	1.8
03mw0113a	861593.9	236159.9	-158.4	49.8	49.7	0.1
03mw0113b	861593.6	236160.3	-58.4	51.5	49.8	1.7
03mw0114a	862703.6	236189.8	-116.2	49.9	49.4	0.5
03mw0114b	862703.4	236189.4	-72.2	49.9	49.4	0.5
03mw0116b	859064.7	239726.5	-47.4	55.8	55.5	0.3
03mw0117a	860626.6	237353.6	-142.8	52.9	52.1	0.8
03mw0117b	860626.5	237353.5	-42.3	53.1	52.2	0.9
03mw0118a	862473.7	238056.7	-122.6	52.6	52.6	0.0
03mw0118b	862473.7	238056.4	-38.6	53.6	52.7	0.9
03mw0201d	862936.3	235495.5	-72.3	49.7	48.0	1.7
03mw0201e	862938.1	235500.1	-97.0	49.9	48.0	1.9
03mw0201f	862936.3	235495.7	-132.3	49.7	48.0	1.7
03mw0205c	862887.1	235393.2	-50.9	50.8	47.9	2.9
03mw0205e	862887.2	235393.3	-100.9	50.2	47.9	2.3
03mw0206b	862904.9	235385.2	-25.3	49.4	47.8	1.6
03mw0209c	863163.7	235004.4	-81.6	46.7	46.9	-0.2
03mw0209d	863159.3	235006.9	-104.4	47.2	46.9	0.3
03mw0209e	863163.5	235004.6	-125.6	48.2	46.9	1.3
03mw0209f	863159.2	235006.6	-147.2	48.0	46.9	1.1
03mw0210b	863022.3	234833.5	-60.0	48.6	46.6	2.0
03mw0210d	863019.8	234828.9	-106.0	48.5	46.6	1.9
03mw0211c	863037.6	234825.4	-82.7	49.0	46.6	2.4
03mw0211e	863037.9	234825.5	-126.7	46.2	46.6	-0.4
03mw0214a	863106.4	234795.7	-39.2	47.0	46.5	0.5
03mw0214b	863101.6	234798.8	-65.7	46.3	46.5	-0.2
03mw0214f	863101.9	234798.8	-148.5	46.1	46.5	-0.4
03mw0214g	863106.7	234795.6	-169.3	47.2	46.5	0.7
03mw0219e	863156.3	234854.3	-127.9	48.0	46.6	1.4
03mw0220e	863148.0	234726.0	-125.7	48.2	46.3	1.9
03mw0221f	862926.8	235287.6	-142.4	49.3	47.6	1.7
03mw0222d	862967.1	235417.9	-78.1	49.1	47.9	1.2
03mw0224c	862971.1	235003.3	-82.5	47.2	47.0	0.2
03mw0224e	862970.8	235003.4	-127.3	47.9	47.0	0.9
03mw2108a	859807.3	239079.2	-49.8	55.0	54.8	0.2

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
03mw2109a	859799.7	238679.2	-51.1	55.0	54.3	0.7
03mw2141a	859618.8	235833.3	-9.5	51.0	49.8	1.2
03mw2148a	859424.1	239518.2	-54.9	57.9	55.3	2.6
03mw2160a	860290.8	237821.3	-20.1	55.7	53.0	2.7
03mw2406a	860993.0	235535.7	-71.9	49.2	48.9	0.3
03mw2408a	860315.4	236836.1	-114.9	52.5	51.3	1.2
03mw2408b	860315.4	236836.3	-74.9	53.6	51.3	2.3
03mw2409a	859615.5	235827.8	-81.4	50.7	49.8	0.9
03uw0025b	863116.7	249310.2	53.0	66.8	66.2	0.6
19-01A	925618.7	243634.8	20.0	30.5	33.0	-2.5
19-01B	925618.5	243634.6	-38.0	23.7	27.3	-3.6
27mw0010	860324.0	248547.0	31.1	65.6	64.6	1.0
27mw0015b	856640.0	246110.0	28.3	62.3	59.5	2.8
27mw0017b	858137.1	246283.5	34.9	62.3	61.0	1.3
27mw0019	858790.0	245560.0	-1.2	61.9	60.9	1.0
27mw0023a	854329.0	241466.0	-10.6	55.5	53.9	1.6
27mw0026a	851836.0	241450.0	-39.5	50.8	49.2	1.6
27mw0029	853517.0	240013.0	-29.6	52.3	51.7	0.6
27mw0038	845537.0	240292.0	25.6	30.3	27.9	2.4
27mw0043	848290.0	239458.0	-27.2	40.3	38.7	1.6
27mw0047	845198.0	239744.0	-24.1	28.8	26.4	2.4
27mw0064a	841613.0	241429.0	-82.5	9.1	6.8	2.3
27mw0064b	841613.0	241429.0	-31.5	8.9	6.6	2.3
27mw0088	851322.0	245415.0	-27.5	52.4	50.4	2.0
27mw0091a	843624.0	240569.6	-82.8	20.1	17.6	2.5
27mw0091b	843623.9	240569.0	-36.8	19.6	17.7	1.9
27mw0095	855897.1	244655.3	-125.0	60.2	57.7	2.5
27mw0097a	853974.2	243237.5	-8.3	56.0	54.7	1.3
27mw0105a	848191.0	240087.6	-91.0	41.0	38.4	2.6
27mw0109b	842577.6	241021.4	-34.1	14.3	12.7	1.6
27mw0110a	848163.0	240580.5	-90.6	39.7	38.4	1.3
27mw0568a	842834.0	245268.0	-50.1	13.5	11.8	1.7
27mw0568z	842814.0	245234.0	-130.1	13.5	11.7	1.8
27mw0605c	842363.6	244938.5	-55.9	12.0	10.2	1.8
27mw0605d	842363.4	244938.1	-85.9	11.8	10.1	1.7
28mw0573	864552.2	236273.8	8.3	49.7	48.9	0.8
28mw0575	864510.7	235807.9	36.3	48.5	47.6	0.9
28mw0591f	865316.0	236160.8	22.1	49.0	48.5	0.5

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
28mw0595c	864663.4	236144.1	42.5	49.4	48.5	0.9
28mw0596	865006.5	236770.9	20.7	50.4	49.8	0.6
28mw0597a	865028.4	237930.7	-3.6	52.7	52.0	0.7
30mw0316a	861574.1	234072.8	-65.3	48.4	46.4	2.0
30mw0425b	860989.3	235555.8	37.6	49.9	48.9	1.0
30mw0425z	860985.2	235538.0	-51.3	49.7	48.9	0.8
30mw0426b	861244.8	235537.5	41.7	48.9	48.8	0.1
30mw0430	861371.0	235548.0	42.1	49.3	48.8	0.5
30mw0581b	862111.1	232701.3	-85.4	44.0	44.5	-0.5
30mw0581c	862111.1	232695.6	-30.9	44.1	44.4	-0.3
30mw0589	860535.0	232824.0	19.6	47.9	45.1	2.8
32mw2001	851725.1	233556.1	-127.1	42.8	40.8	2.0
36mw0002	870832.0	241852.0	54.3	59.2	60.5	-1.3
36mw0007	870793.0	241934.0	56.2	59.2	60.6	-1.4
37mw0002	867543.0	236492.0	47.9	49.3	48.6	0.7
38mw0061	859267.0	238325.0	-32.5	54.9	53.8	1.1
38mw0063	859826.9	238001.2	-36.0	54.5	53.4	1.1
39mw0004	864258.8	238090.1	51.4	53.9	52.3	1.6
39mw0005a	864238.5	237924.4	35.8	53.6	52.0	1.6
58mw0004	860775.0	260891.0	58.4	66.2	65.8	0.4
69mw1279a	853308.0	226830.0	-31.2	31.7	33.1	-1.4
69mw1279b	853279.0	226843.0	-60.5	32.5	33.1	-0.6
69mw1287	853883.7	222441.1	-165.1	25.2	24.9	0.3
69mw1293a	853639.0	224586.7	-148.0	28.1	29.9	-1.8
69mw1298	853423.2	222092.4	-110.9	24.1	23.3	0.8
69mw1299	853580.6	222108.5	-110.9	24.5	23.5	1.0
69mw1306b	853147.9	221775.1	-181.7	23.2	22.6	0.6
69mw1309	853511.5	221709.0	-101.1	23.2	22.7	0.5
69mw1400b	853905.6	228651.8	-156.9	35.3	34.6	0.7
69mw1402	854334.4	227794.1	-65.5	33.3	34.1	-0.8
69mw1412	856237.2	233729.9	-99.7	46.6	45.8	0.8
69mw1413	855294.8	233639.9	-124.2	45.3	44.8	0.5
69mw1421	856762.1	234725.2	-52.2	49.8	48.1	1.7
69mw1501	852532.2	226176.7	-27.6	31.4	31.6	-0.2
69mw1509	847561.3	234811.0	-67.0	35.7	34.8	0.9
69mw1510b	851278.5	235799.4	10.4	45.1	43.1	2.0
69mw1515	854726.5	236975.4	-11.8	51.7	50.2	1.5
69mw1518	853331.4	236072.9	-50.6	49.5	46.8	2.7

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
69mw1519	850034.9	235940.7	-32.3	42.3	41.1	1.2
69mw1522b	850516.4	233624.9	-71.5	40.4	38.9	1.5
69mw1526	853310.0	238536.4	-69.2	51.6	50.3	1.3
69mw1532a	847819.5	233794.4	-163.2	35.7	34.5	1.2
69mw1532b	847819.5	233794.0	-63.2	35.2	34.5	0.7
69mw1534b	848366.9	233206.6	-62.2	36.8	34.7	2.1
69mw1538	852108.8	238668.0	-53.8	49.2	47.9	1.3
69mw1540	847808.1	230210.7	-121.3	32.8	30.8	2.0
69mw1541	851323.7	235820.3	-125.5	43.9	43.2	0.7
69mw1542	845950.6	231574.9	-87.2	29.9	29.4	0.5
69mw1543	846876.8	231035.1	-138.3	31.6	30.5	1.1
69mw1544	846963.7	234240.8	-157.7	35.0	33.3	1.7
69mw1545a	844333.9	231362.0	-138.5	26.6	25.7	0.9
69mw1545b	844334.0	231362.3	-41.5	26.6	25.7	0.9
90jb0001b	869662.3	250130.6	35.1	67.3	66.0	1.3
90jb0001c	869662.9	250135.5	-9.8	67.7	66.0	1.7
90jb0001d	869657.5	250137.1	-34.9	68.2	66.0	2.2
90jb0004a	870035.7	250041.6	1.5	67.5	65.7	1.8
90jb0004c	870042.1	250054.7	33.3	67.0	65.7	1.3
90mp0060c	868100.4	251174.6	-44.5	67.2	66.7	0.5
90mp0060d	868100.4	251174.6	-20.0	68.2	66.7	1.5
90mp0060f	868100.4	251174.6	35.0	68.3	66.7	1.6
90mw0003	868334.1	252801.7	10.4	68.1	67.2	0.9
90mw0005	868331.9	252810.1	-30.0	68.5	67.2	1.3
90mw0007	868181.6	253701.1	-24.3	69.8	67.5	2.3
90mw0010	867959.7	251901.4	62.7	67.0	66.8	0.2
90mw0011	867958.3	251906.7	30.2	67.0	66.8	0.2
90mw0019	868025.1	253982.3	-9.2	68.4	67.6	0.8
90mw0021	867576.6	254657.3	-8.8	68.8	67.9	0.9
90mw0022	867113.0	254101.0	-9.4	68.4	67.7	0.7
90mw0025	868877.0	251335.0	-7.5	67.6	66.6	1.0
90mw0033	869914.0	252110.0	-5.1	68.3	66.6	1.7
90mw0034	868645.0	253868.0	35.0	69.9	67.5	2.4
90mw0038	867752.0	254294.0	39.7	68.5	67.7	0.8
90mw0039	868615.0	253860.0	44.6	68.7	67.5	1.2
90mw0041	868529.0	254309.0	31.8	68.8	67.7	1.1
90mw0042	870394.0	251163.0	-1.5	67.6	66.0	1.6
90mw0054	866999.9	252663.5	-25.7	67.4	67.3	0.1

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
90mw0064	870280.4	250673.9	-64.0	68.5	65.8	2.7
90mw0065	870709.0	251100.3	17.8	66.4	65.8	0.6
90mw0066	869438.3	250478.5	-58.6	68.4	66.2	2.2
90mw0068	869837.4	250521.6	-2.1	67.9	66.0	1.9
90mw0077	870269.1	250683.3	-6.1	68.0	65.9	2.1
90mw0078	869195.6	250677.9	-8.9	67.8	66.3	1.5
90mw0079a	869754.9	250936.9	2.8	68.7	66.2	2.5
90mw0081	869428.6	251267.0	33.3	68.7	66.4	2.3
90mw0083	869448.8	250477.5	22.8	67.2	66.2	1.0
90mw0084b	869844.1	250533.8	28.4	67.1	66.0	1.1
90mw0085b	868553.1	250328.6	21.9	68.5	66.5	2.0
90mw0086a	870189.5	251651.9	-67.8	69.0	66.3	2.7
90mw0086c	870185.4	251645.4	-3.2	66.7	66.3	0.4
90mw0086d	870185.5	251645.6	28.4	68.9	66.3	2.6
90mw0087b	870406.1	250945.8	31.8	67.6	65.9	1.7
90mw0089a	870330.2	250397.7	-83.5	67.7	65.7	2.0
90mw0089b	870330.3	250397.4	-52.5	67.4	65.7	1.7
90mw0089e	870345.4	250399.5	22.6	67.2	65.7	1.5
90mw0089f	870345.5	250399.6	57.6	67.1	65.7	1.4
90mw0090a	870194.0	250159.9	-77.2	68.6	65.7	2.9
90mw0090b	870193.9	250159.6	-57.0	67.9	65.7	2.2
90mw0090c	870192.1	250153.0	-37.2	67.2	65.7	1.5
90mw0090d	870191.9	250153.1	-12.0	67.2	65.7	1.5
90mw0090e	870190.0	250146.2	17.8	67.0	65.7	1.3
90mw0091c	869198.4	249986.2	-32.5	67.8	66.2	1.6
90mw0091d	869196.8	249979.2	-7.3	66.3	66.2	0.1
91mw0522a	864833.1	234002.3	-54.4	44.2	44.2	0.0
92-16	927094.2	245363.6	13.0	33.6	33.0	0.6
92-2A	926415.0	244721.0	32.0	37.2	34.6	2.6
92-4	925669.0	244609.9	29.3	35.0	34.4	0.6
95mw0102a	855744.1	217877.2	-49.1	16.6	16.0	0.6
95mw0102b	855745.1	217883.6	-24.2	16.5	16.0	0.5
95mw0107a	861841.5	234310.3	-100.4	48.3	46.6	1.7
95mw0107b	861841.3	234310.2	29.6	47.1	46.6	0.5
95mw0108b	862085.3	233227.7	-33.4	45.9	45.0	0.9
95mw0109b	861809.4	232708.2	-25.1	44.5	44.6	-0.1
95mw0109c	861806.5	232719.6	4.5	44.6	44.6	0.0
95mw0208a	859587.5	225451.6	-66.9	34.8	34.6	0.2

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
95mw0209a	859838.4	229554.4	-41.6	40.5	40.5	0.0
95mw0209b	859838.0	229554.4	-11.6	41.0	40.5	0.5
95mw0211a	861084.3	227277.9	-153.7	36.6	37.7	-1.1
95mw0212a	861789.8	226874.8	-109.1	36.4	37.0	-0.6
95mw0604f	858798.3	219320.3	-56.2	22.4	22.7	-0.3
95mw0605f	858741.5	219218.5	-57.2	22.5	22.4	0.1
95mw1172b	860830.4	225937.0	-37.9	33.9	35.5	-1.6
95pz0002a	858299.4	217590.7	-104.6	18.1	17.6	0.5
98mw0001	867596.0	237670.0	46.4	52.4	51.4	1.0
a230	933892.4	244208.6	5.2	18.9	16.3	2.6
a247	933028.5	256850.0	-9.0	20.2	18.9	1.3
a254	910655.7	244798.4	4.5	35.6	35.0	0.6
a292	924620.0	250455.1	-11.2	33.8	32.2	1.6
a294	921793.4	257299.4	-31.9	18.1	17.4	0.7
a306	922686.3	242127.4	16.4	29.0	28.3	0.7
a307	905159.6	229744.0	-4.8	5.6	5.2	0.4
a313	894775.3	240036.9	11.1	26.6	25.9	0.7
a314	903287.6	256848.6	-101.0	33.3	32.4	0.9
a315	903287.6	256848.6	14.8	33.0	32.5	0.5
AshumetPd	863778.2	232162.6	1.1	45.1	43.9	1.2
AuntEdiesPd	991018.5	261196.3	31.3	31.3	30.5	0.8
b198	844757.0	253224.6	0.6	22.4	21.8	0.6
b214	851002.2	265134.4	-43.9	46.1	44.5	1.6
b215_0083	851002.2	265134.4	18.1	46.4	44.5	1.9
BA-1	926448.5	242306.4	12.0	26.2	29.1	-2.9
BakersPd	969614.2	265058.2	23.6	23.6	27.6	-4.0
BB-1	926313.6	238812.1	14.6	17.1	16.7	0.4
BC-1	928204.1	246474.6	11.0	32.7	31.2	1.5
BD	927672.2	239175.8	13.3	16.6	16.1	0.5
BE	924521.8	239731.6	30.5	20.7	21.3	-0.6
BlueberryPd	994657.3	281698.4	26.1	26.1	24.1	2.0
bmw105	979871.6	269006.1	-63.4	29.4	28.3	1.1
bmw21	999956.0	278554.8	13.6	26.9	25.4	1.5
bmw22	1000891.0	285859.8	-0.1	19.6	18.4	1.2
bmw44	980398.7	273873.9	-5.9	26.9	26.4	0.5
bmw45	986378.3	269923.1	21.1	31.5	32.1	-0.6
bmw46	1003967.0	274574.7	-38.4	27.4	24.4	3.0
bmw79	978482.1	265845.3	-64.4	29.0	28.0	1.0

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
bmw83	979871.6	269006.1	-63.6	29.6	28.3	1.3
bmw85	979115.0	264235.9	-49.5	31.0	28.9	2.1
bmw86	979115.0	264235.9	-53.2	30.6	28.9	1.7
C2	927614.8	243994.8	12.2	24.6	30.9	-6.3
C3	928731.5	240760.6	18.4	20.8	20.6	0.2
C4	929290.2	242422.6	20.3	23.6	24.5	-0.9
cgw138	1004350.0	252512.2	-7.2	11.4	11.6	-0.2
cgw177	1017403.0	256791.9	-10.3	12.1	8.6	3.5
CrockerPd	839151.6	225958.8	1.1	15.3	14.4	0.9
CrystalLake	1013771.8	285586.0	13.6	13.6	11.2	2.4
d135	962736.9	263873.7	-17.0	16.1	19.4	-3.3
dgw100	959723.1	267471.3	25.7	45.1	26.0	19.1
dgw123	970067.1	270366.7	-18.3	32.8	30.8	2.0
dgw135	962736.9	263873.7	-17.0	16.1	19.4	-3.3
dgw157	970781.6	263595.5	-16.1	25.7	25.3	0.4
dgw158	967971.9	258995.5	-19.1	18.8	16.3	2.5
dgw160	973078.4	252800.3	-36.9	8.5	6.7	1.8
dgw169	957687.6	276550.8	-66.7	5.6	4.9	0.7
dgw172	972850.8	252796.7	-273.8	6.4	7.0	-0.6
dgw173	972850.8	252796.7	-151.6	8.9	6.9	2.0
dgw247	961971.0	269227.1	-27.5	26.2	27.5	-1.3
dgw88	971893.4	260475.0	2.7	25.2	21.3	3.9
ecmwamp05a	863567.0	234405.4	-47.0	45.0	44.8	0.2
ecmwbkr01d	856679.2	217227.2	-54.6	15.6	14.3	1.3
ecmwbkr01m	856679.2	217227.1	-14.6	15.6	14.3	1.3
ecsgamp01	862176.3	232624.6	45.0	45.0	44.3	0.7
ecsgsnp	866615.5	249861.2	65.6	65.6	66.6	-1.0
egw36	1016569.0	315999.9	-6.3	13.5	12.9	0.6
egw37	1009534.0	307168.6	0.4	8.4	6.6	1.8
f166_0067	859743.8	225789.7	-23.1	35.5	35.2	0.3
f167_0055	859546.7	229918.5	-3.1	41.5	40.8	0.7
f168_0018	859867.7	226260.8	28.6	36.2	36.0	0.2
f169_0050	853322.9	226589.6	-8.4	32.4	32.8	-0.4
f172	838916.2	216014.5	-44.7	9.4	9.2	0.2
f173_0069	858438.1	223245.6	-35.6	30.3	30.3	0.0
f175_0050	864459.2	221022.4	-18.0	26.2	26.2	0.0
f176_0044	865014.9	219997.2	-2.3	22.8	23.6	-0.8
f179_0052	844403.2	236316.3	1.0	26.5	24.7	1.8

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
f181	848186.2	209025.5	-18.6	5.8	6.6	-0.8
f182_0069	858453.9	222503.8	-35.0	29.2	29.0	0.2
f185_0057	864122.6	218737.9	-27.4	19.8	21.3	-1.5
f225_0020	860746.5	229199.1	35.8	41.7	40.5	1.2
f226_0021	861416.1	230781.6	39.9	44.2	42.9	1.3
f230_0058	861170.7	234109.2	28.9	47.2	46.6	0.6
f231_0057	861255.9	234033.2	37.8	48.0	46.5	1.5
f232_0058	861355.9	233986.8	42.3	47.9	46.4	1.5
f234_0099	858347.9	234605.1	-1.1	48.2	47.9	0.3
f235_0094	859449.0	234265.1	7.4	48.0	47.1	0.9
f236_0121	860461.4	233706.5	-21.6	48.2	46.1	2.1
f238_0106	858914.4	232139.5	-9.7	44.4	43.8	0.6
f239_0010	862114.9	232399.0	43.1	45.0	44.2	0.8
f239_0064	862114.2	232396.9	-11.2	44.8	44.2	0.6
f239_0121	862114.3	232386.8	-68.6	45.3	44.3	1.0
f240_0095	857354.2	231269.9	-3.6	42.1	41.3	0.8
f241_0098	856646.1	233018.4	1.1	44.5	44.3	0.2
f242_0077	857008.0	229264.9	-14.2	38.1	37.3	0.8
f243_0045	854446.2	231968.8	18.1	41.3	40.6	0.7
f244_0119	861592.7	231694.6	-48.6	44.2	43.9	0.3
f245_0025	860370.3	227581.3	25.2	38.3	38.1	0.2
f248_0010	863703.1	228220.0	36.7	39.7	39.3	0.4
f253_0019	862601.3	225153.6	27.5	34.3	33.7	0.6
f254_0216	861696.4	231250.4	-159.0	44.0	43.5	0.5
f262_0126	860295.8	227448.9	-78.3	38.3	37.9	0.4
f267_0136	859569.8	229890.5	-79.9	41.7	40.8	0.9
f271_0084	858963.9	223577.4	-46.9	31.5	31.1	0.4
f275_0072	859905.6	223815.6	2.3	31.8	31.7	0.1
f282_0083	858471.3	225525.6	-35.5	34.2	34.3	-0.1
f300_0118	862347.3	232806.5	-70.2	44.8	44.4	0.4
f302_0020	855278.5	224341.5	21.3	30.2	32.2	-2.0
f303_0020	853615.1	222840.4	9.6	24.8	25.1	-0.3
f343_0036	861581.3	233725.1	33.5	46.7	45.9	0.8
f343_0057	861584.4	233723.1	13.1	46.6	45.9	0.7
f343_0079	861586.7	233719.1	-9.4	46.6	45.9	0.7
f343_0099	861585.9	233720.1	-29.1	46.6	45.9	0.7
f343_0114	861590.4	233728.2	-43.9	47.0	45.9	1.1
f343_0129	861586.6	233726.2	-58.5	46.8	45.9	0.9

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
f343_0145	861588.8	233734.3	-74.8	47.5	45.9	1.6
f345_0031	861409.6	232916.4	38.0	45.4	45.0	0.4
f346_0032	861837.8	233001.2	28.0	45.1	44.9	0.2
f347_0020	861816.0	233387.6	41.0	45.8	45.4	0.4
f347_0031	861816.8	233384.6	29.9	46.0	45.4	0.6
f347_0046	861815.9	233389.6	14.9	45.7	45.4	0.3
f347_0067	861829.5	233396.9	-5.9	46.0	45.4	0.6
f347_0101	861815.1	233393.7	-40.2	45.9	45.4	0.5
f347_0116	861810.6	233392.6	-55.0	46.0	45.4	0.6
f347_0131	861813.6	233397.7	-70.0	46.4	45.4	1.0
f347_0145	861809.8	233396.6	-83.7	45.1	45.4	-0.3
f348_0073	862666.2	230107.3	-21.2	42.9	43.2	-0.3
f351_0016	858832.8	224027.4	23.0	32.6	31.9	0.7
f352_0016	859826.6	225314.9	29.5	34.3	34.4	-0.1
f353_0016	859498.8	225491.4	27.4	34.6	34.6	0.0
f355_0104	859022.7	225126.8	-30.9	34.2	33.9	0.3
f356_0134	859865.0	224528.8	-67.8	33.2	33.0	0.2
f357_0099	860490.9	224262.5	-27.3	32.7	32.5	0.2
f358_0119	857956.9	226015.9	-44.6	35.0	34.6	0.4
f359_0088	861214.6	224088.4	-17.0	33.8	32.2	1.6
f369_0055	859722.6	226602.3	-5.4	37.3	36.4	0.9
f370_0054	859560.8	226464.9	-4.8	37.6	36.1	1.5
f371_0056	859664.2	226465.0	-6.3	38.8	36.2	2.6
f373_0024	859603.8	226562.5	25.9	38.3	36.3	2.0
f373_0060	859606.9	226562.6	-6.7	35.8	36.3	-0.5
f373_0061	859598.5	226562.5	-7.5	35.8	36.3	-0.5
f373_0073	859601.5	226562.5	2.5	36.1	36.3	-0.2
f373_0082	859609.1	226563.6	-32.6	35.7	36.3	-0.6
f373_0113	859612.2	226563.7	-63.3	37.4	36.3	1.1
f376_0037	861603.9	233605.9	31.9	46.0	45.8	0.2
f377_0037	861574.4	233461.8	31.6	45.9	45.6	0.3
f378_0040	861794.7	233723.4	31.5	46.0	45.8	0.2
f379_0034	861964.5	233619.1	35.4	45.7	45.6	0.1
f380_0032	861822.5	233212.6	28.1	45.3	45.2	0.1
f381_0056	861435.1	233350.9	24.8	45.7	45.5	0.2
f382_0032	861598.0	233113.9	30.3	45.8	45.2	0.6
f383_0023	861550.4	233299.6	42.6	46.0	45.4	0.6
f383_0030	861552.7	233296.6	35.8	45.6	45.4	0.2

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
f383_0032	861559.6	233291.6	32.6	45.6	45.4	0.2
f383_0040	861555.0	233295.6	25.2	46.1	45.4	0.7
f383_0061	861556.6	233292.6	4.8	45.9	45.4	0.5
f383_0082	861561.2	233288.6	-17.1	45.9	45.4	0.5
f383_0106	861545.9	233294.5	-40.7	46.2	45.4	0.8
f383_0129	861548.2	233292.5	-63.1	46.7	45.4	1.3
f384_0033	861728.8	233372.5	28.9	45.6	45.4	0.2
f385_0032	861719.8	233562.7	34.9	45.8	45.7	0.1
f387_0039	861579.9	232904.1	27.0	45.4	45.0	0.4
f388_0037	862136.1	233217.1	33.2	45.1	45.0	0.1
f388_0072	862138.4	233216.1	-2.4	45.3	45.0	0.3
f389_0028	860322.6	227432.0	20.2	38.9	37.9	1.0
f391_0028	858958.1	223555.0	9.2	31.6	31.0	0.6
f392_0028	858961.8	223566.2	9.3	31.8	31.1	0.7
f414_0036	862028.6	233391.0	32.9	45.9	45.3	0.6
f415_0029	861600.4	233717.2	41.1	46.5	45.9	0.6
f416_0058	861582.5	233144.1	8.6	45.4	45.2	0.2
f417_0064	861679.0	233680.6	18.6	46.2	45.8	0.4
f418_0141	857460.5	226253.3	-65.7	34.6	34.5	0.1
f419_0021	861801.1	233084.8	38.2	45.2	45.0	0.2
f420_0036	861924.2	232542.6	25.2	44.6	44.4	0.2
f421_0031	861805.8	232740.7	26.6	44.9	44.7	0.2
f422_0045	861478.2	232556.8	29.0	45.1	44.7	0.4
f422_0065	861476.7	232553.8	9.3	46.3	44.6	1.7
f424_0020	862118.0	232733.0	41.3	44.8	44.4	0.4
f424_0089	862113.1	232692.5	-30.7	45.3	44.4	0.9
f428_0010	858318.6	222851.5	23.0	28.9	29.6	-0.7
f429_0078	857914.2	222320.7	-44.6	28.4	28.4	0.0
f430_0075	857709.6	221579.5	-44.7	26.4	26.7	-0.3
f431_0065	857459.1	222943.2	-28.9	29.7	29.5	0.2
f432_0092	862345.2	233666.9	-22.5	46.9	45.4	1.5
f433_0090	856789.8	221619.9	-30.2	26.4	26.4	0.0
f434_0060	861616.0	233408.6	9.4	46.4	45.5	0.9
f436_0141	856881.6	219495.2	-115.1	20.2	19.9	0.3
f438_0035	861174.8	221198.9	19.0	27.6	27.5	0.1
f439_0045	855211.3	220552.9	15.5	22.7	23.1	-0.4
f441_0047	854684.5	221962.3	13.4	24.6	25.4	-0.8
f443_0089	858749.8	219596.8	-29.7	23.1	23.2	-0.1

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
f459_0136	855467.4	222354.5	-73.5	26.1	27.1	-1.0
f460_0100	860878.8	224226.3	-28.4	33.6	32.4	1.2
f461_0019	860008.3	226188.5	28.0	37.0	35.9	1.1
f462_0019	859715.5	226284.4	29.3	37.1	35.9	1.2
f463_0020	860010.3	226688.5	26.3	37.4	36.7	0.7
f470_0106	859318.0	219066.7	-46.9	22.6	22.5	0.1
f474_0100	859953.0	222768.5	-30.8	30.2	29.8	0.4
f480_0042	854657.9	222730.3	19.1	30.1	27.0	3.1
f482_0029	848861.6	213267.0	0.8	11.1	11.1	0.0
f484_0108	856113.8	214678.6	-95.0	10.7	7.9	2.8
f486_0115	854262.5	218575.7	-95.1	17.7	16.4	1.3
f487_0023	855532.1	216443.6	-2.3	13.3	11.6	1.7
f488_0047	865360.2	224437.8	21.7	32.8	31.9	0.9
f492_0007	859235.2	212424.3	1.3	5.3	3.5	1.8
f495_0010	866504.8	220141.7	14.8	19.7	20.8	-1.1
f497_0108	856471.7	212546.7	-72.8	5.4	5.5	-0.1
f498_0040	862136.4	215751.6	9.7	17.9	16.7	1.2
f499_0018	866138.5	215745.3	0.8	6.7	6.7	0.0
f501_0087	858262.9	217587.2	-34.6	17.5	17.6	-0.1
f502_0128	858195.4	220248.7	-66.9	23.9	24.0	-0.1
f567_0136	862060.4	233465.3	-66.2	45.0	45.3	-0.3
f572_0071	861720.2	233872.4	26.2	47.0	46.1	0.9
f577_0081	861453.0	233990.9	14.4	47.4	46.3	1.1
GriffithsPd	984427.4	273358.6	34.2	34.2	30.8	3.4
hjw133	1005183.0	265687.2	-27.5	25.8	21.5	4.3
hjw141	1007465.0	265322.1	-19.5	19.3	15.7	3.6
hjw143	1008137.0	265941.3	-32.5	13.5	14.0	-0.5
hjw145	980379.6	261118.3	-2.1	31.8	25.4	6.4
hjw148	990143.6	253383.6	13.3	20.7	17.2	3.5
hjw150	999271.0	261029.6	14.7	30.6	28.9	1.7
hjw152	979933.0	246634.7	-92.0	3.8	2.4	1.4
hjw156	997468.3	246623.5	-87.4	4.9	2.9	2.0
hjw195	976513.1	246882.9	3.4	5.6	5.3	0.3
hjw196	976513.1	246882.9	4.6	5.5	5.3	0.2
hjw197	976513.1	246882.9	4.5	6.6	5.3	1.3
hjw198	976513.1	246882.9	3.5	5.6	5.3	0.3
JemimaPd	1012888.0	305911.9	8.0	8.7	6.1	2.6
m021	879399.9	230635.9	-1.2	23.6	23.0	0.6

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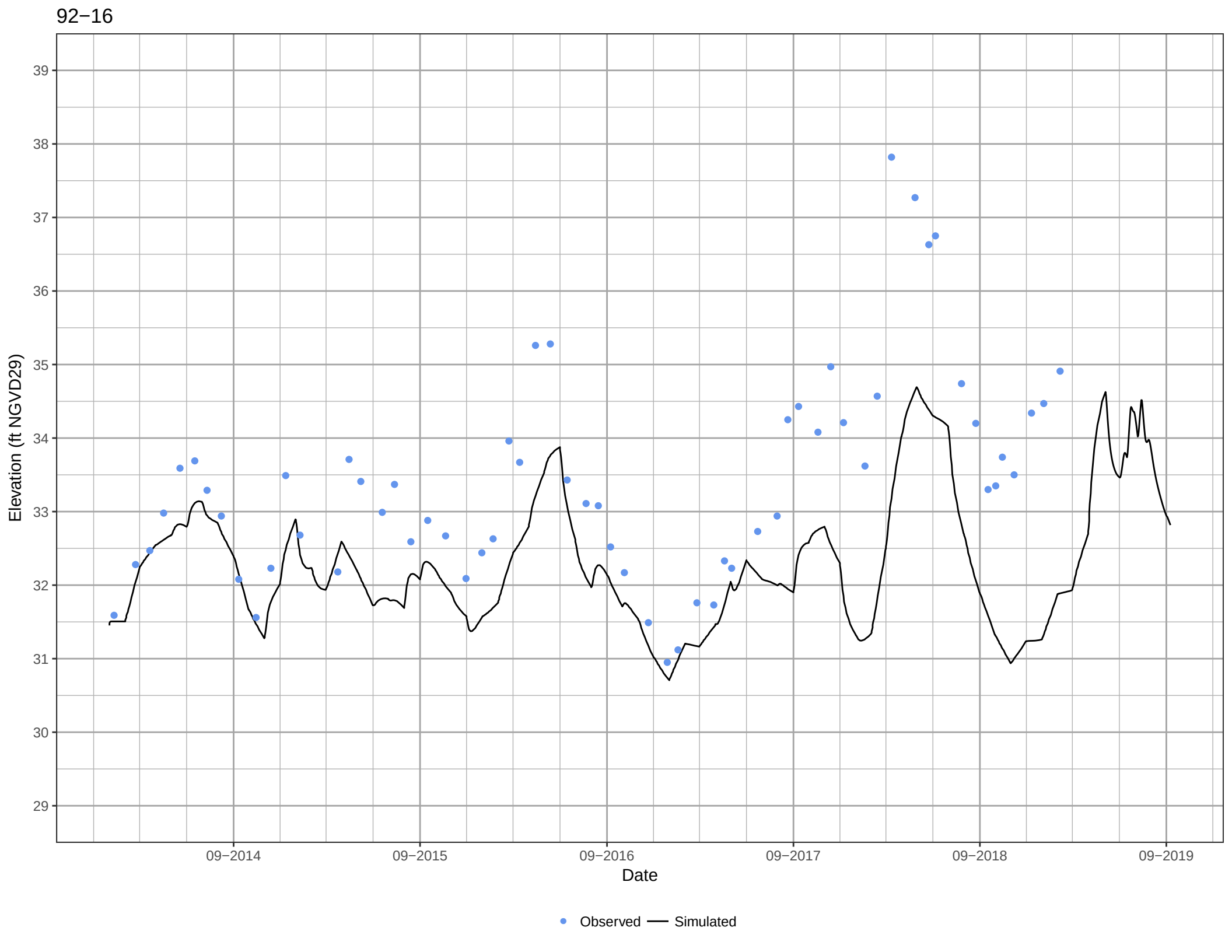
m026	876678.6	216735.4	-293.7	7.4	7.3	0.1
m029	876678.6	216735.4	-25.7	7.4	7.4	0.0
m057_0008	865423.3	229244.7	34.4	39.0	38.3	0.7
m058_0011	864532.9	229859.2	38.7	41.4	42.2	-0.8
m066_0012	864631.1	230376.5	38.0	44.8	43.1	1.7
m069_0035	865248.8	229695.2	30.3	40.8	40.0	0.8
m070_0024	865389.6	229466.0	22.9	40.0	39.0	1.0
m204_0009	863333.4	234047.5	45.1	45.0	44.7	0.3
m205_0032	863031.1	233854.8	43.9	45.2	45.0	0.2
mw_01m2	862620.4	260320.0	24.5	69.3	66.0	3.3
mw_18m1	873183.6	266389.0	-70.7	60.6	56.4	4.2
mw_25	860994.0	260280.6	67.0	69.5	66.1	3.4
mw_31m	859727.3	254181.2	35.6	70.2	66.3	3.9
mw_31s	859727.3	254182.2	53.1	68.4	66.3	2.1
mw_32m	856913.3	254007.7	-3.3	66.3	64.2	2.1
mw_32s	856913.3	254008.7	14.2	66.5	64.2	2.3
mw_33d	856771.9	253851.4	-20.0	66.6	64.0	2.6
mw_33m	856771.9	253852.4	-2.5	66.6	64.0	2.6
mw_33s	856771.9	253853.4	15.0	65.9	64.0	1.9
mw_34m1	857747.0	253831.7	-11.1	67.0	64.9	2.1
mw_34m2	857750.3	253831.7	8.9	66.4	64.9	1.5
mw_34m3	857747.0	253834.9	28.9	67.1	64.9	2.2
mw_35m2	857069.1	253742.7	49.1	64.0	64.3	-0.3
mw_36m2	857808.3	253907.9	7.5	67.2	65.0	2.2
mw_38m3	860596.1	261589.4	12.1	67.6	65.4	2.2
mw_38m4	860599.4	261586.1	50.1	68.4	65.4	3.0
mw_42m3	854147.1	267659.9	-50.7	51.1	49.5	1.6
mw_43m2	859730.4	264610.2	-6.9	62.9	63.2	-0.3
mw_57s	873281.9	257894.5	67.1	67.2	66.5	0.7
mw_64m2	859709.3	251953.9	57.4	67.7	65.8	1.9
mw_65m2	855014.2	274586.0	18.2	28.6	29.7	-1.1
mw_65s	855011.0	274589.2	28.7	29.2	29.7	-0.5
mw_67s	859452.3	274243.0	34.1	42.4	41.6	0.8
mw_77m1	858891.0	254005.9	-33.6	68.2	65.8	2.4
mw_80m1	850472.3	258071.1	-40.6	50.6	48.3	2.3
mw_80m2	850469.0	258071.2	-9.5	49.5	48.3	1.2
osw22	1016927.0	291810.9	-12.2	4.6	4.7	-0.1
osw24	1011646.0	277645.1	-1.3	18.6	16.2	2.4

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
osw25	1008372.0	287103.5	-0.8	15.5	12.8	2.7
PT-300	927038.4	244462.5	8.9	32.9	32.6	0.3
RunnPd	961204.6	264862.2	24.0	25.0	21.6	3.4
RuthPd	1000385.6	277308.5	26.4	26.4	26.2	0.2
s006_0060	859727.6	235226.8	43.3	49.2	48.7	0.5
S11	926572.3	245580.5	24.5	34.7	34.1	0.6
S15	931229.0	244855.1	23.3	26.8	24.5	2.3
s252	899009.3	270965.2	-5.0	6.2	6.5	-0.3
s253	886869.2	253198.9	39.7	61.3	60.5	0.8
s258_0084	880980.6	244421.7	23.1	54.3	54.3	0.0
s261_0160	875633.2	266526.4	39.1	60.1	57.9	2.2
s262_0027	861230.5	234200.0	46.8	48.0	46.7	1.3
s263_0111	866866.2	277154.2	17.0	36.6	34.4	2.2
s305_0032	861132.1	234169.5	45.1	48.6	46.7	1.9
s306_0035	861295.4	234093.4	44.5	48.4	46.5	1.9
s307_0059	860507.6	235826.7	49.4	51.0	49.5	1.5
s308_0055	860685.3	235554.3	49.0	49.7	49.0	0.7
s309_0055	860494.5	235570.4	49.4	50.0	49.1	0.9
s310_0057	860375.8	235729.0	49.9	50.7	49.4	1.3
s311_0059	859963.8	235628.3	47.1	50.7	49.4	1.3
s312_0054	859974.4	236043.4	50.4	50.7	50.1	0.6
s313_0038	862530.7	234053.6	18.4	48.3	45.8	2.5
s314_0051	860948.7	234268.7	27.8	48.2	46.9	1.3
s316_0134	861580.8	234113.8	-37.6	47.4	46.4	1.0
s316_0148	861573.7	234063.1	-50.0	46.8	46.4	0.4
s317_0051	860924.8	234369.6	19.1	47.9	47.0	0.9
s344_0111	861917.8	233854.4	-29.8	46.9	45.9	1.0
s383_0053	858902.8	235652.9	50.6	50.2	49.7	0.5
s386_0058	859126.5	235269.7	48.2	49.6	48.9	0.7
s395_0028	860700.9	234495.7	45.5	48.1	47.3	0.8
S4	923000.5	245555.8	32.8	33.5	33.6	-0.1
s421_0068	860987.5	235554.7	37.6	51.3	48.9	2.4
s423_0058	861401.3	234675.6	31.6	47.9	47.4	0.5
s432_0023	861033.1	234804.1	46.0	48.0	47.7	0.3
s434_0014	860828.6	234820.0	45.5	47.6	47.8	-0.2
s434_0025	860811.5	234792.5	32.0	47.7	47.7	0.0
s434_0076	860819.9	234786.5	-18.5	48.0	47.7	0.3
s439_0054	861842.7	234722.1	46.1	47.9	47.3	0.6

Observation Point Name	X Coordinate (MA State Plane)	Y Coordinate (MA State Plane)	Z Coordinate (ft NGVD29)	Observed Head (ft NGVD29)	Computed Head (ft NGVD29)	Residual (ft)
s440_0078	861537.5	234382.6	2.8	47.4	46.9	0.5
s469_0036	861353.1	234101.1	34.4	47.6	46.5	1.1
s476_0142	861957.2	236427.0	-50.0	50.7	50.1	0.6
s477_0155	862867.3	235384.5	-60.0	48.1	47.9	0.2
s478_0059	862363.7	234450.6	45.5	47.4	46.5	0.9
s590_0074	860675.4	234265.6	22.3	46.7	46.9	-0.2
S7	924380.0	243159.0	27.0	34.7	31.5	3.2
SnakePd	867431.4	250233.3	1.1	68.5	66.7	1.8
SpectaclePd	884650.3	257771.1	1.1	64.0	62.8	1.2
UncleHarveysPd	1021262.1	287830.0	7.4	7.4	4.4	3.0
W1	927230.3	243792.2	17.7	28.5	31.2	-2.7
W4	926879.7	241596.6	7.4	19.7	26.2	-6.5
W7	925986.3	246824.0	29.1	35.2	33.0	2.2
WashPd	1009966.7	278324.1	20.0	20.5	18.8	1.7
WeeksPd	866405.0	249012.0	67.6	67.6	66.5	1.1
WhitePd	1013958.4	254199.5	14.0	14.7	13.4	1.3
y085	938950.3	251367.7	-28.7	21.0	19.7	1.3
y089	950343.4	250726.4	-4.5	18.1	17.1	1.0
y093	949602.7	259623.6	-21.4	9.4	7.6	1.8
y094	945400.8	241137.0	-6.8	8.0	7.6	0.4
y096	956128.4	244639.0	-6.4	5.9	6.0	-0.1
y098	944015.5	257819.5	-2.1	14.8	14.5	0.3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09−2018
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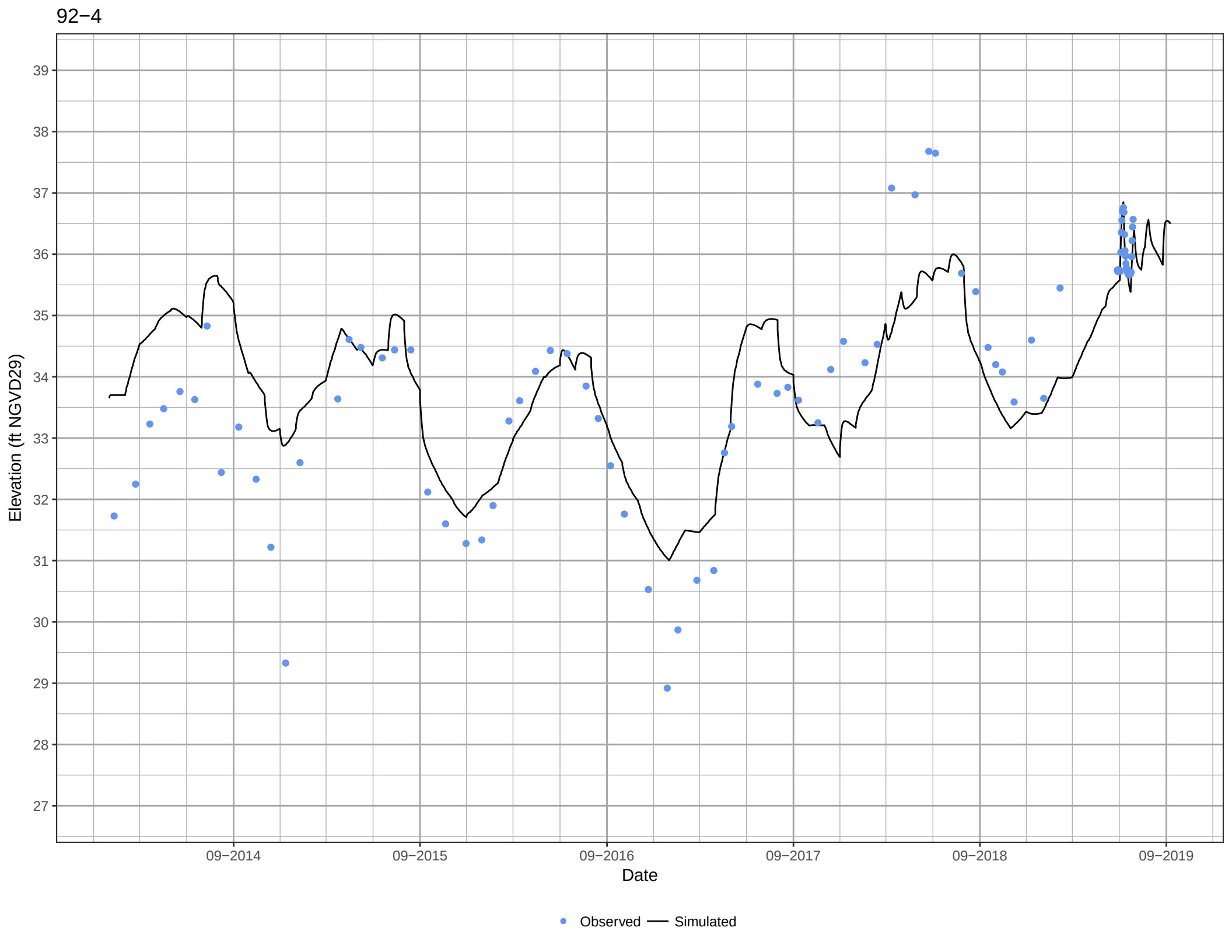
Date
Observed
Simulated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Elevation (ft NGVD29)
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Date
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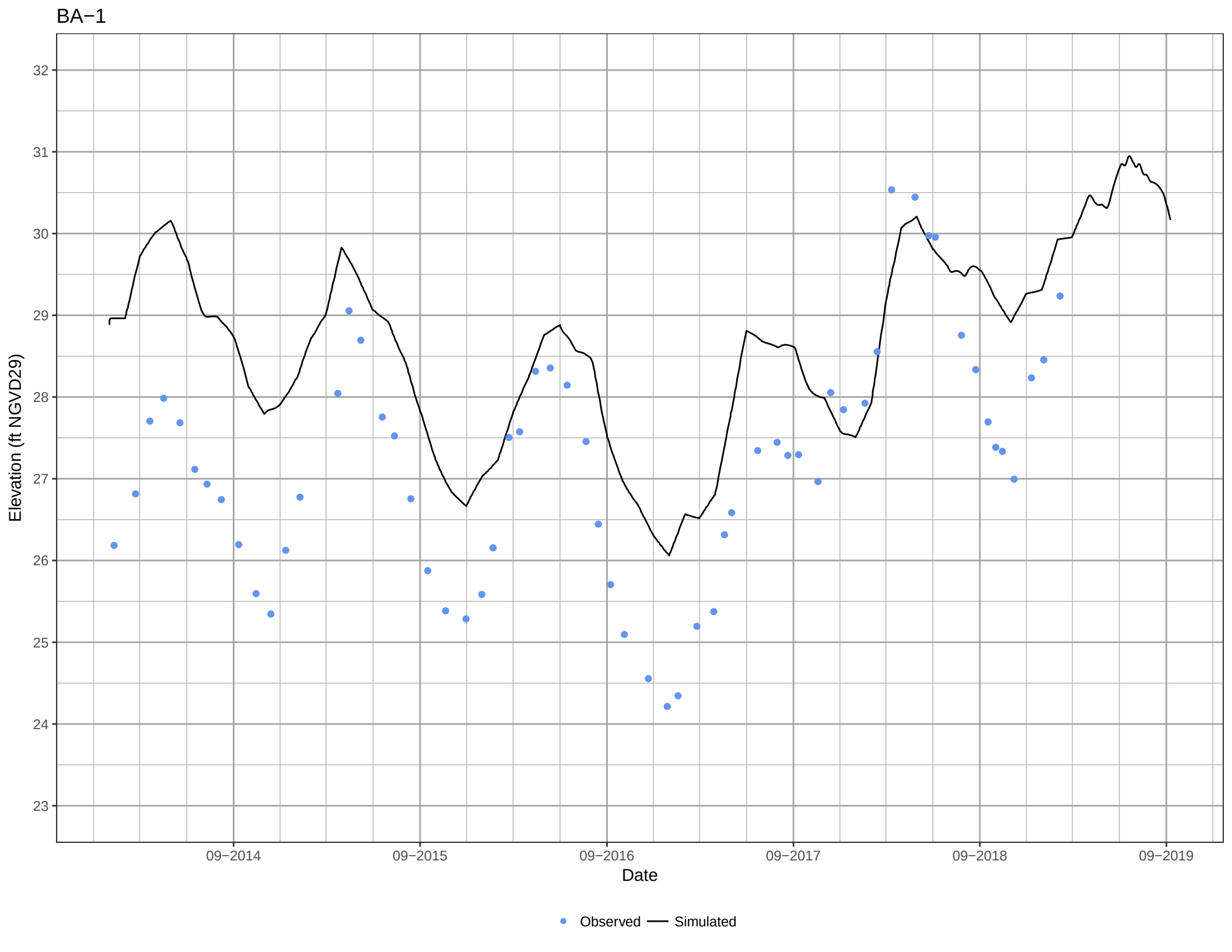
BA−1
32
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Date
Observed
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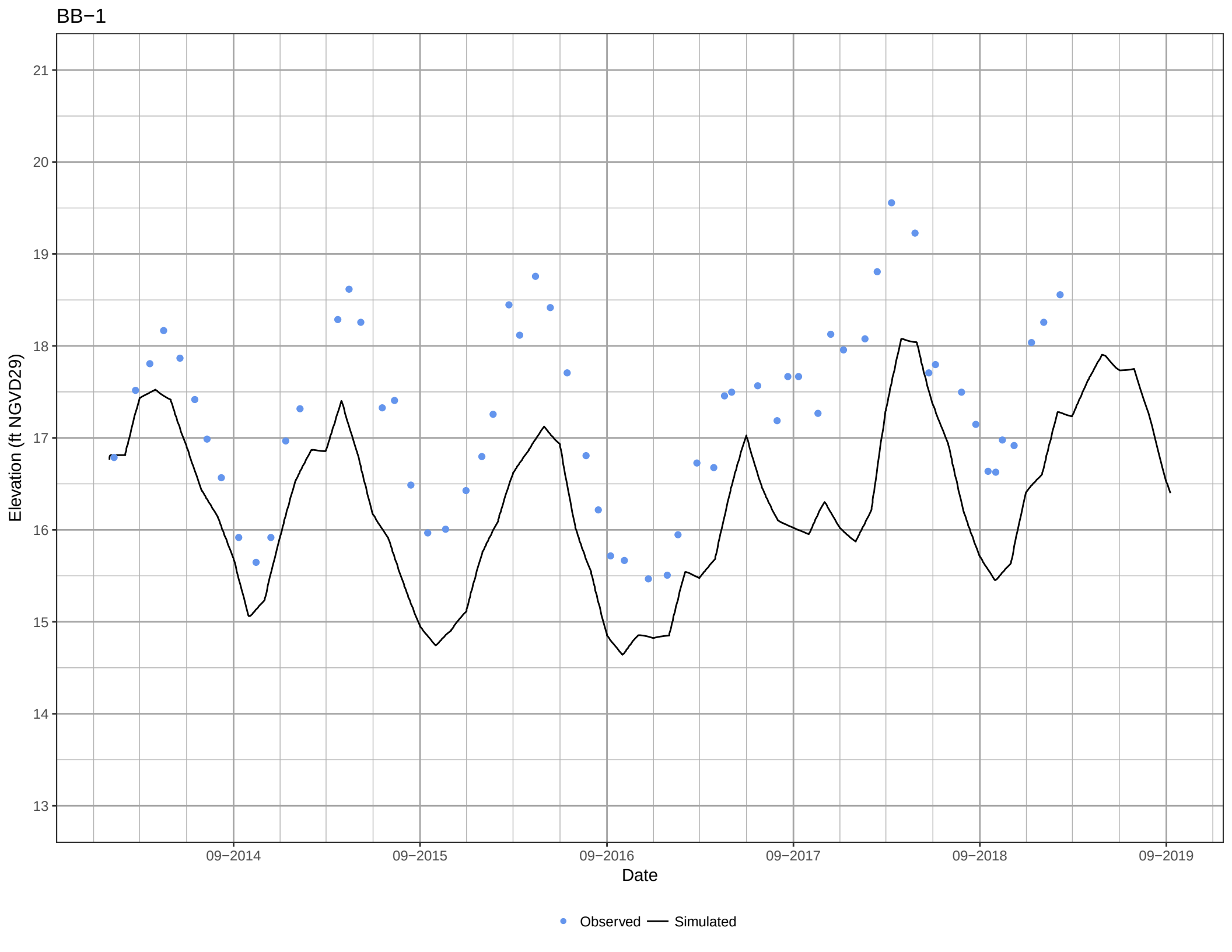
BB−1
Elevation (ft NGVD29)
21
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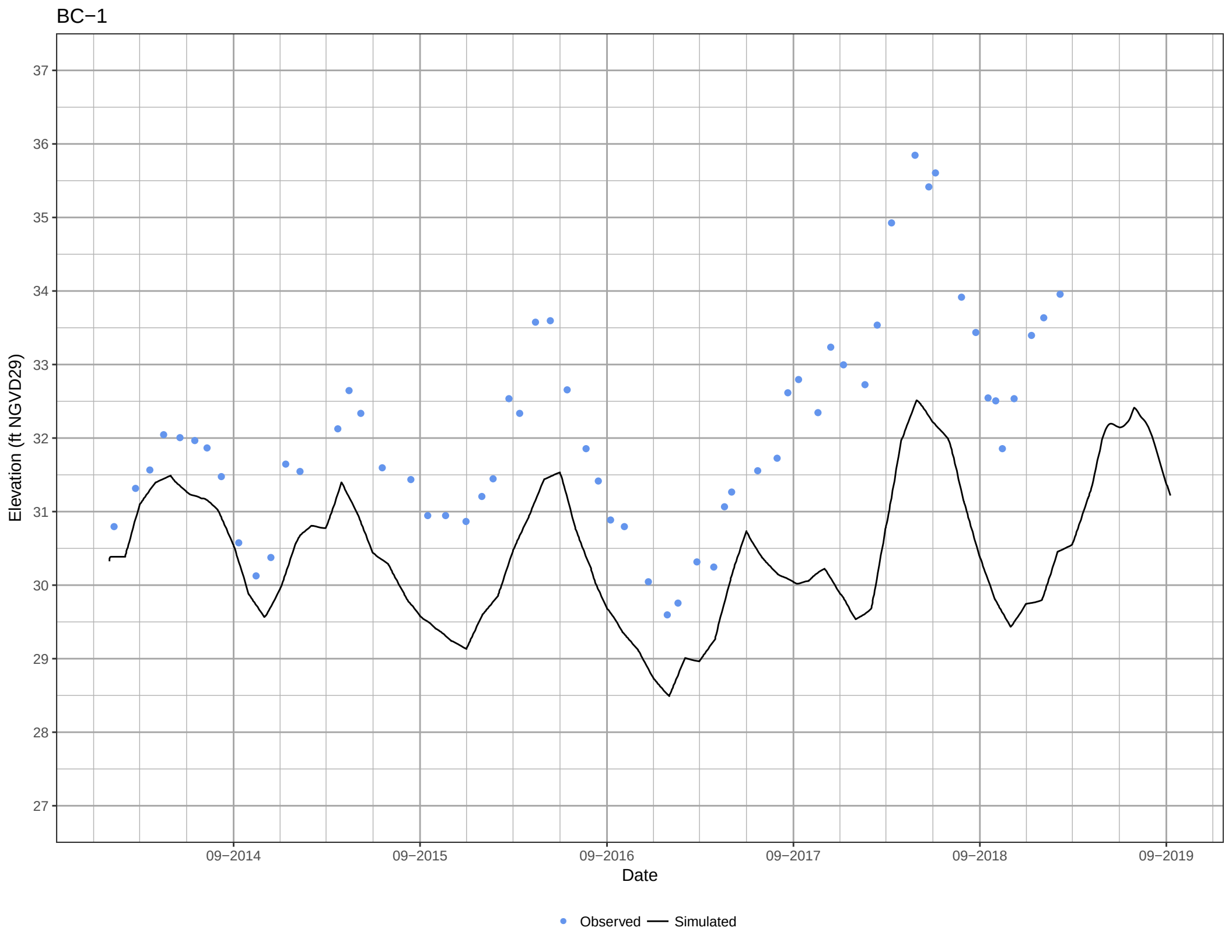
Date
Observed
Simulated


BC−1
Elevation (ft NGVD29)
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09−2014
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Date
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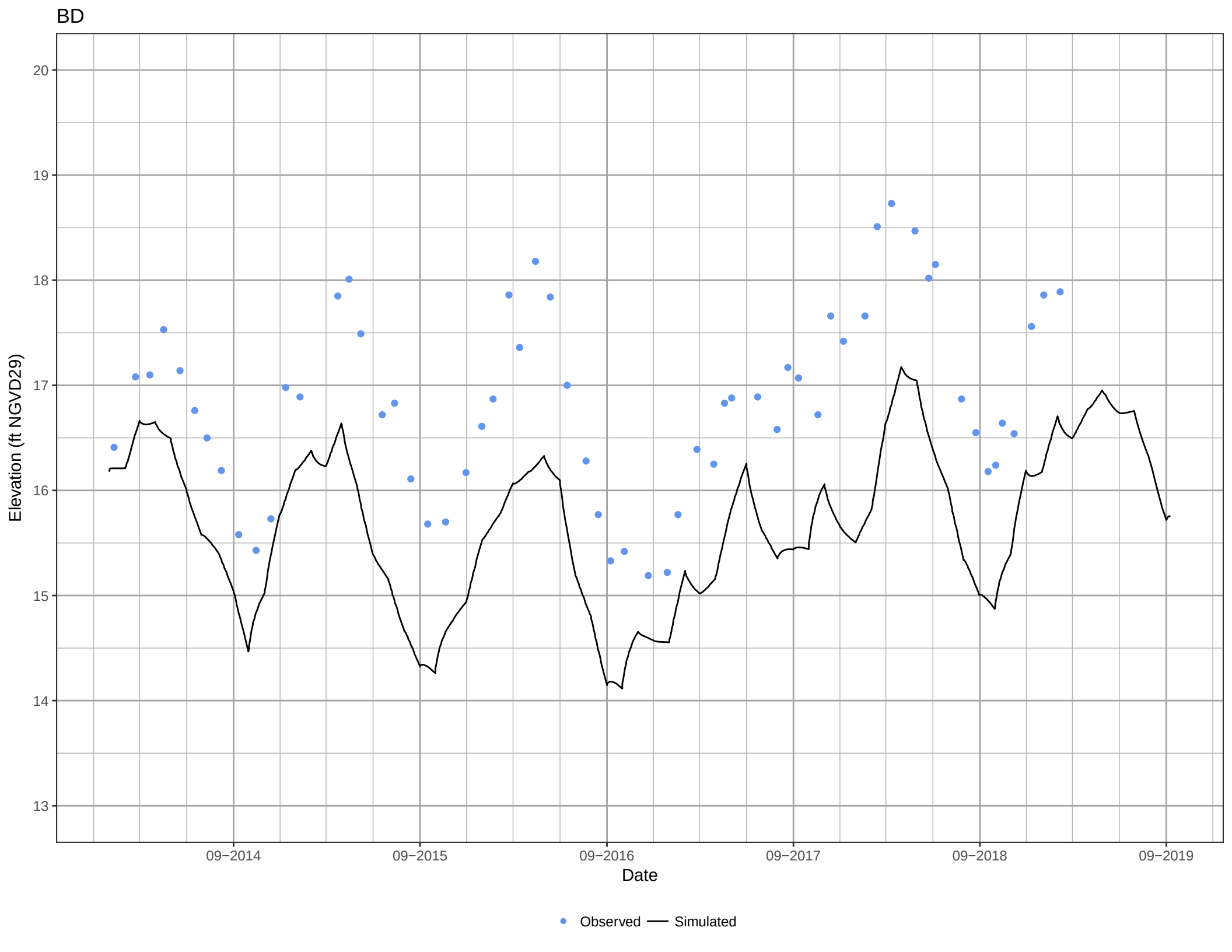
Simulated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Elevation (ft NGVD29)
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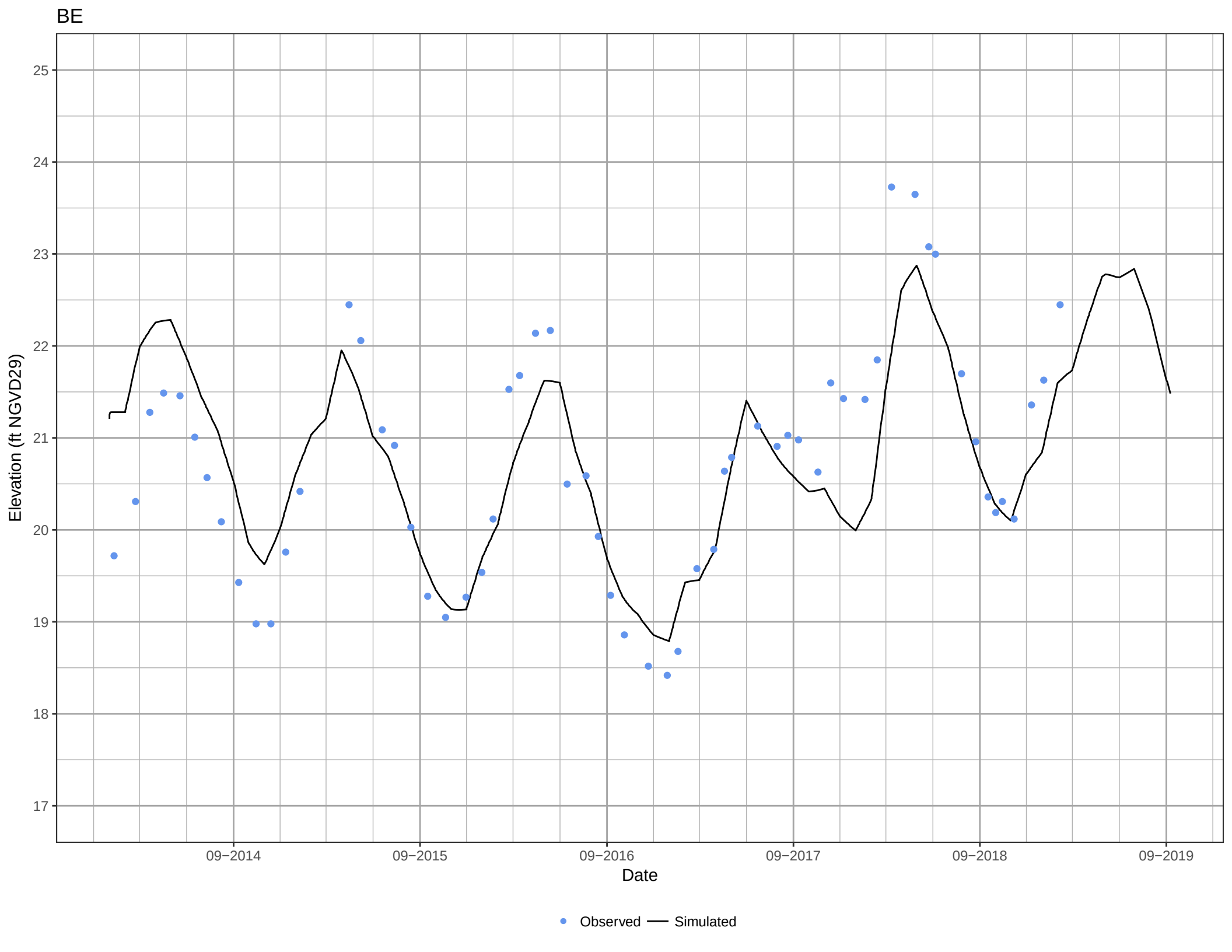
Date
Observed
Simulated


BE
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Elevation (ft NGVD29)
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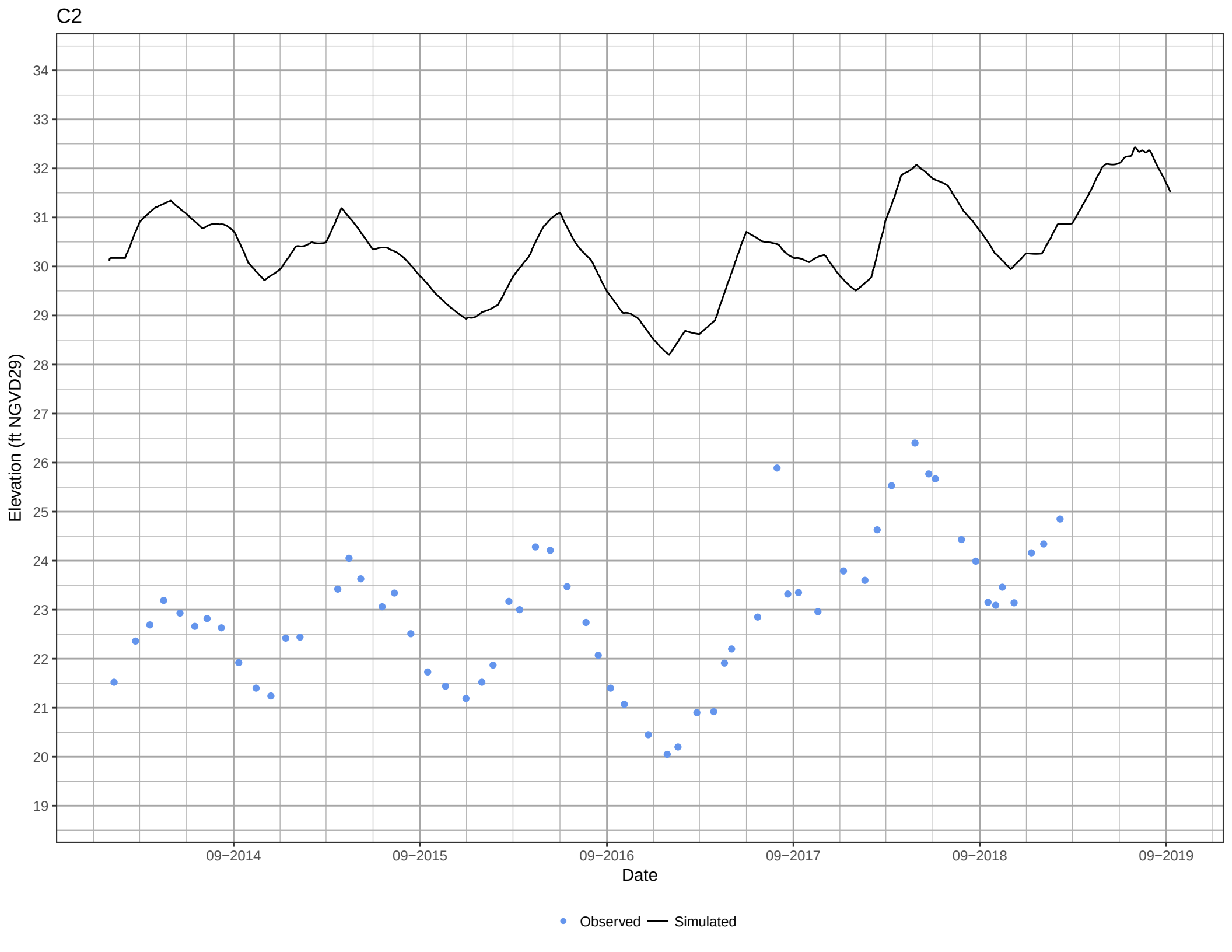
Date
Observed
Simulated


C2
Elevation (ft NGVD29)
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Date
Observed
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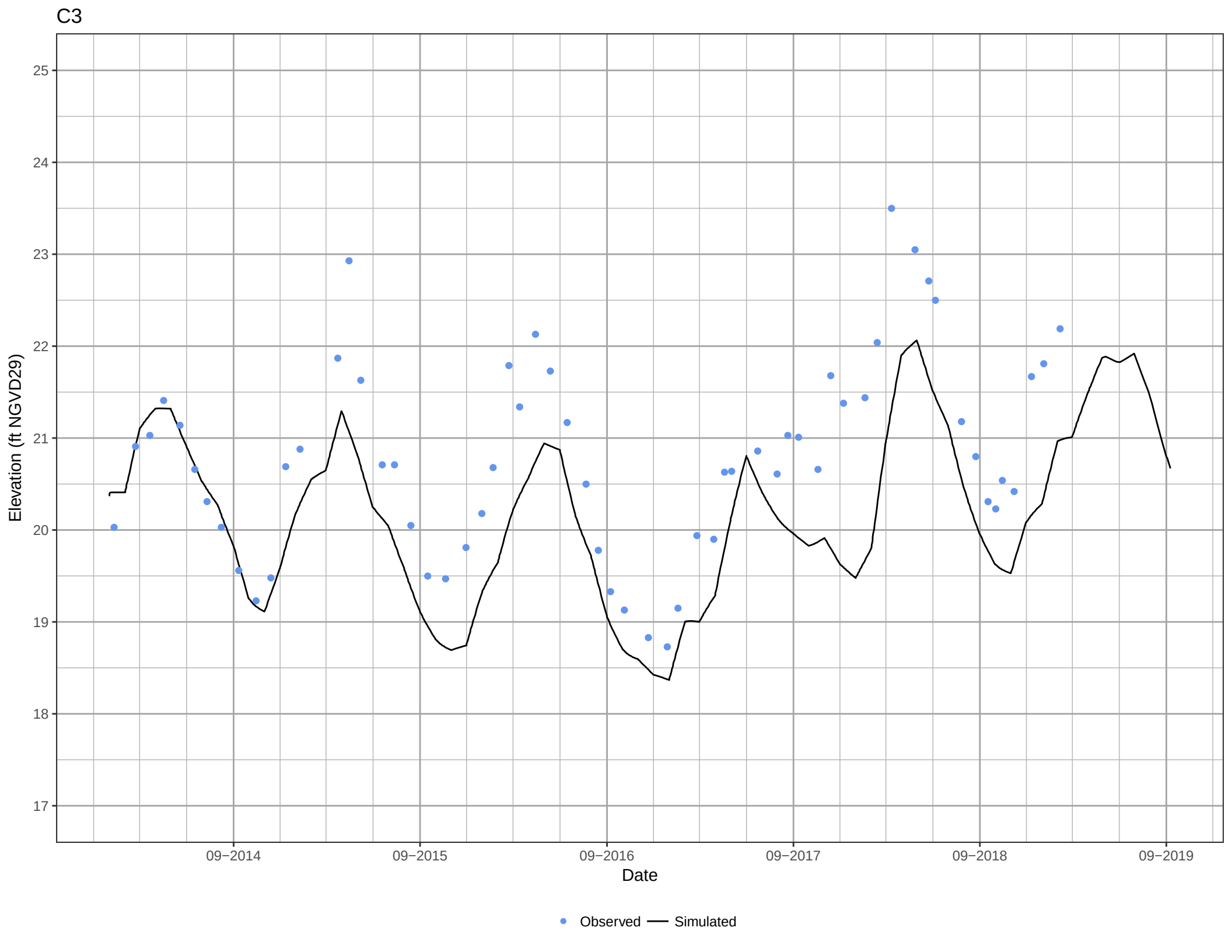
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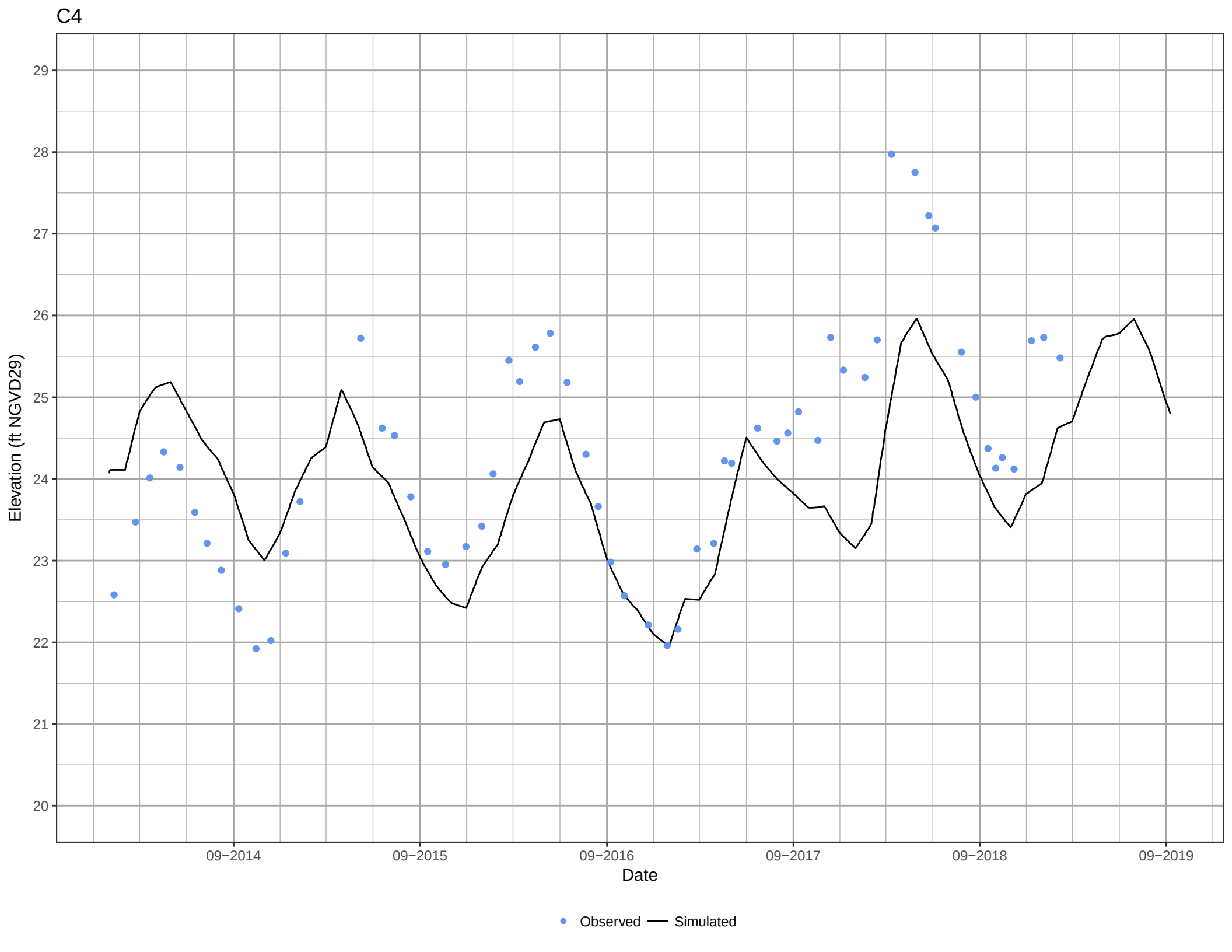
C4
Elevation (ft NGVD29)
29
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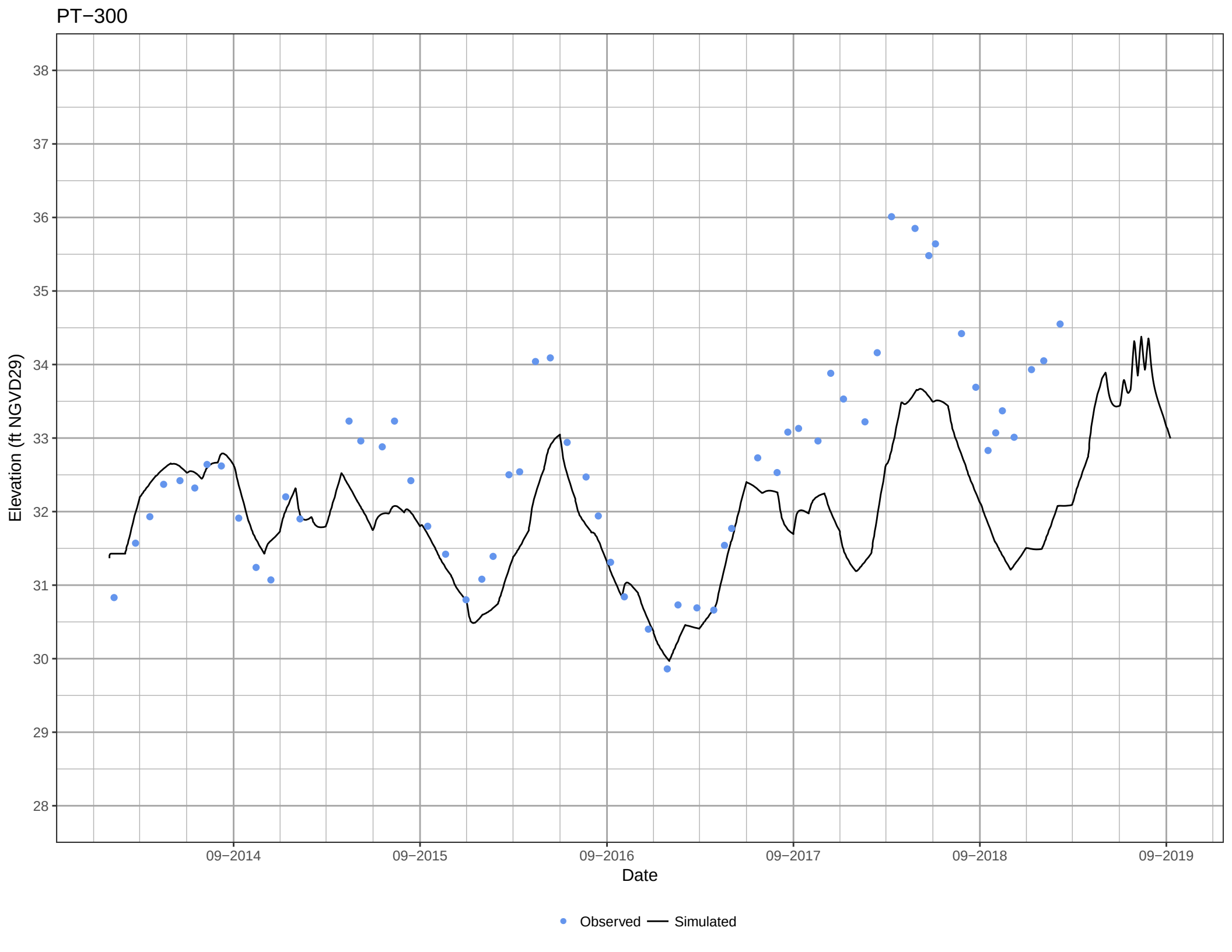
PT−300
Elevation (ft NGVD29)
38
37
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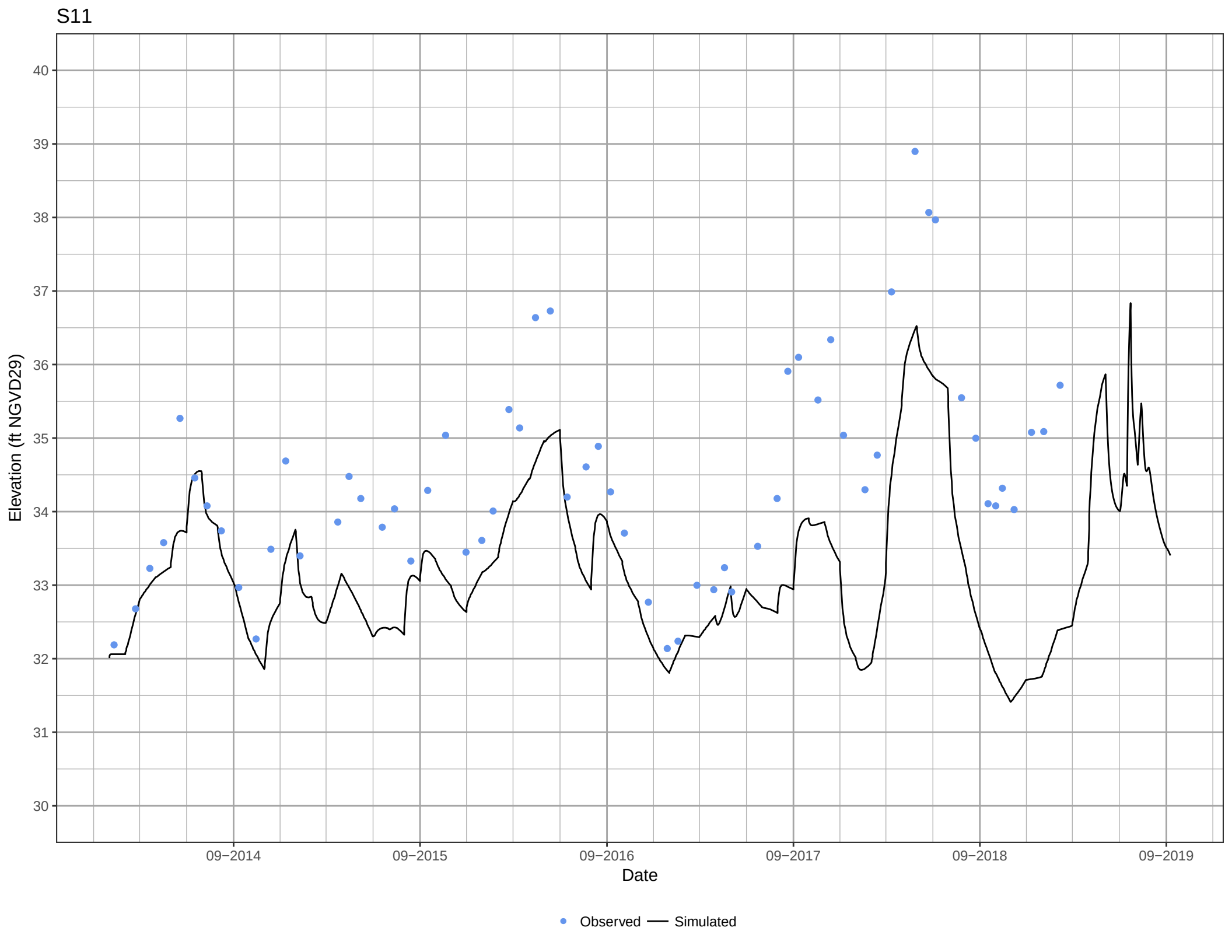
Date
Observed
Simulated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Elevation (ft NGVD29)
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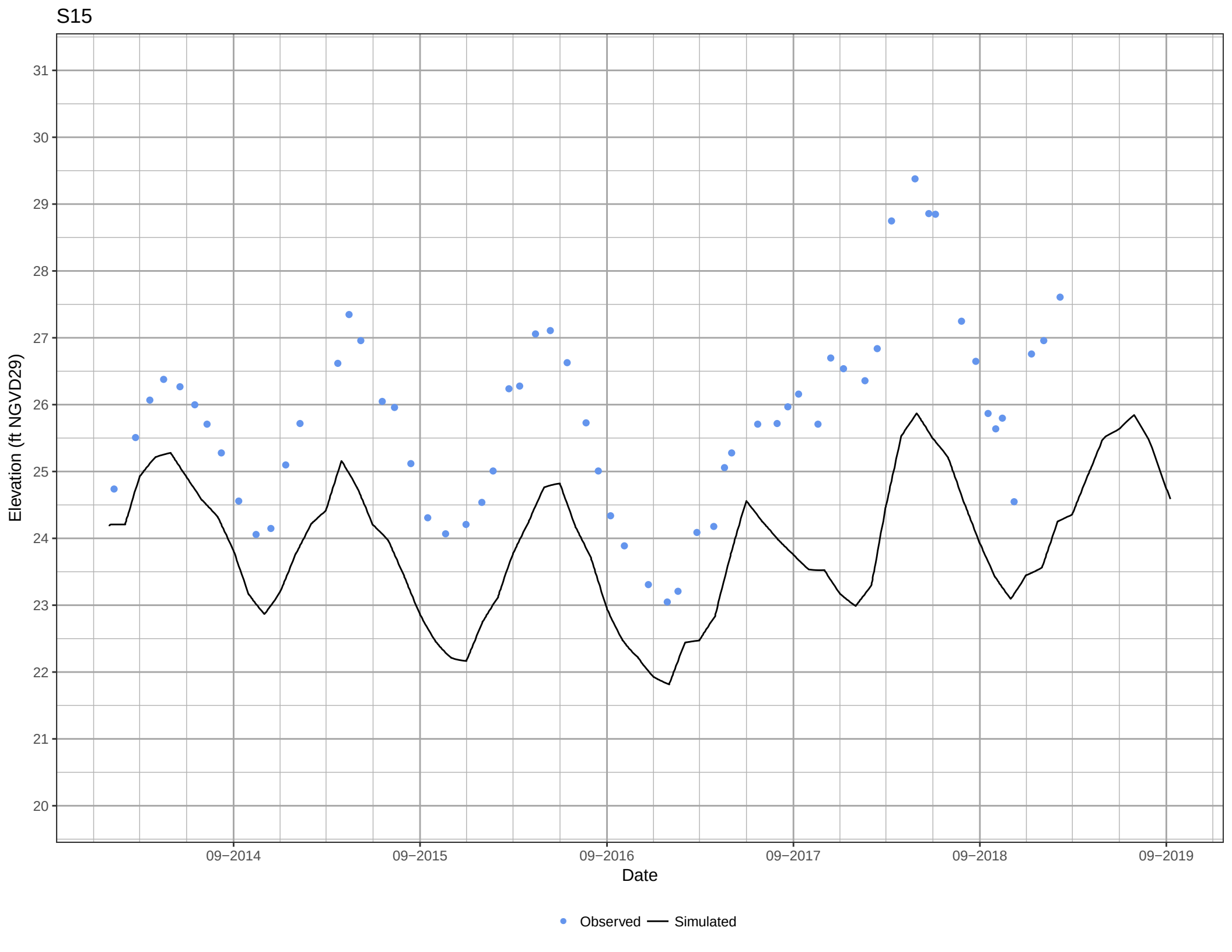
Date
Observed
Simulated


S15
Elevation (ft NGVD29)
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Date
Observed
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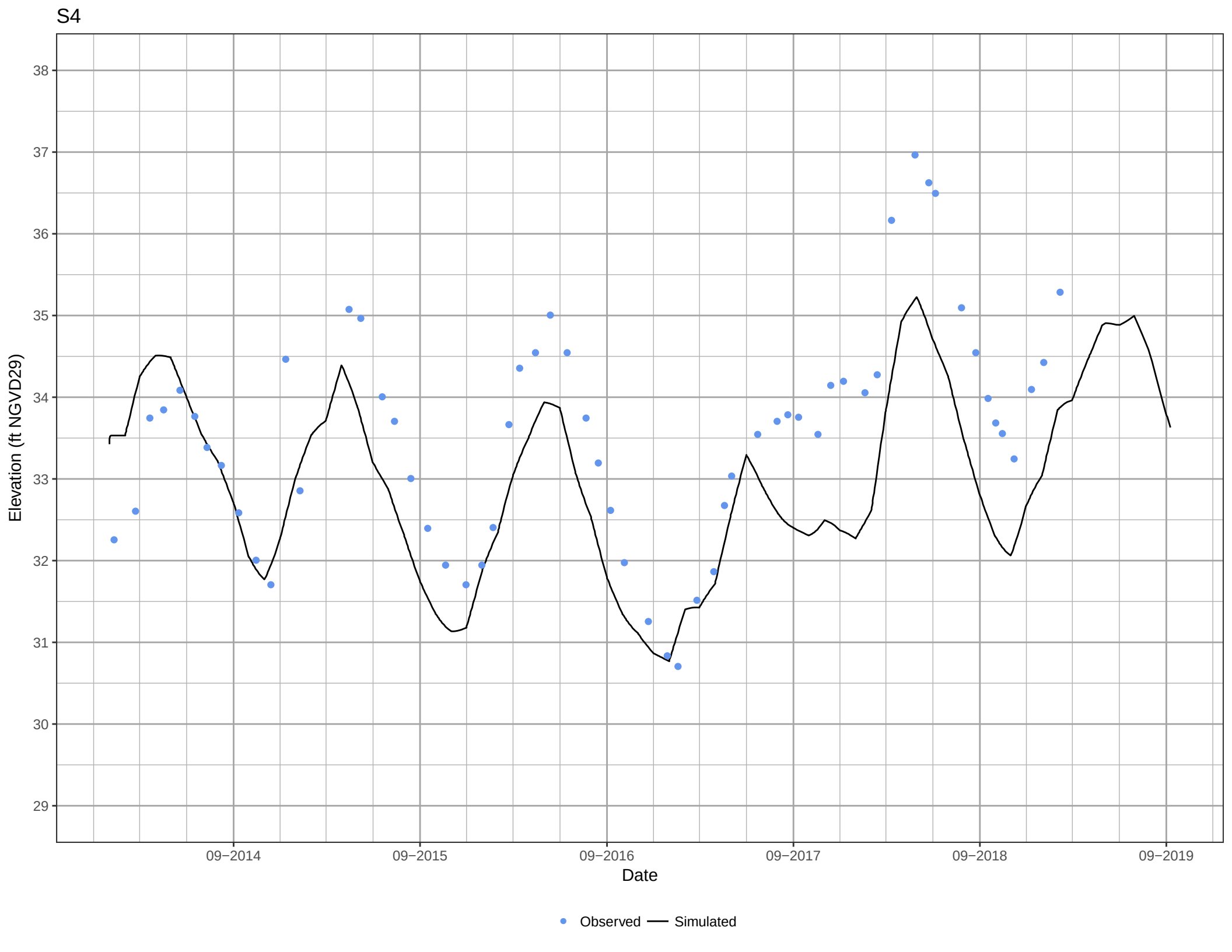
S4
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Elevation (ft NGVD29)
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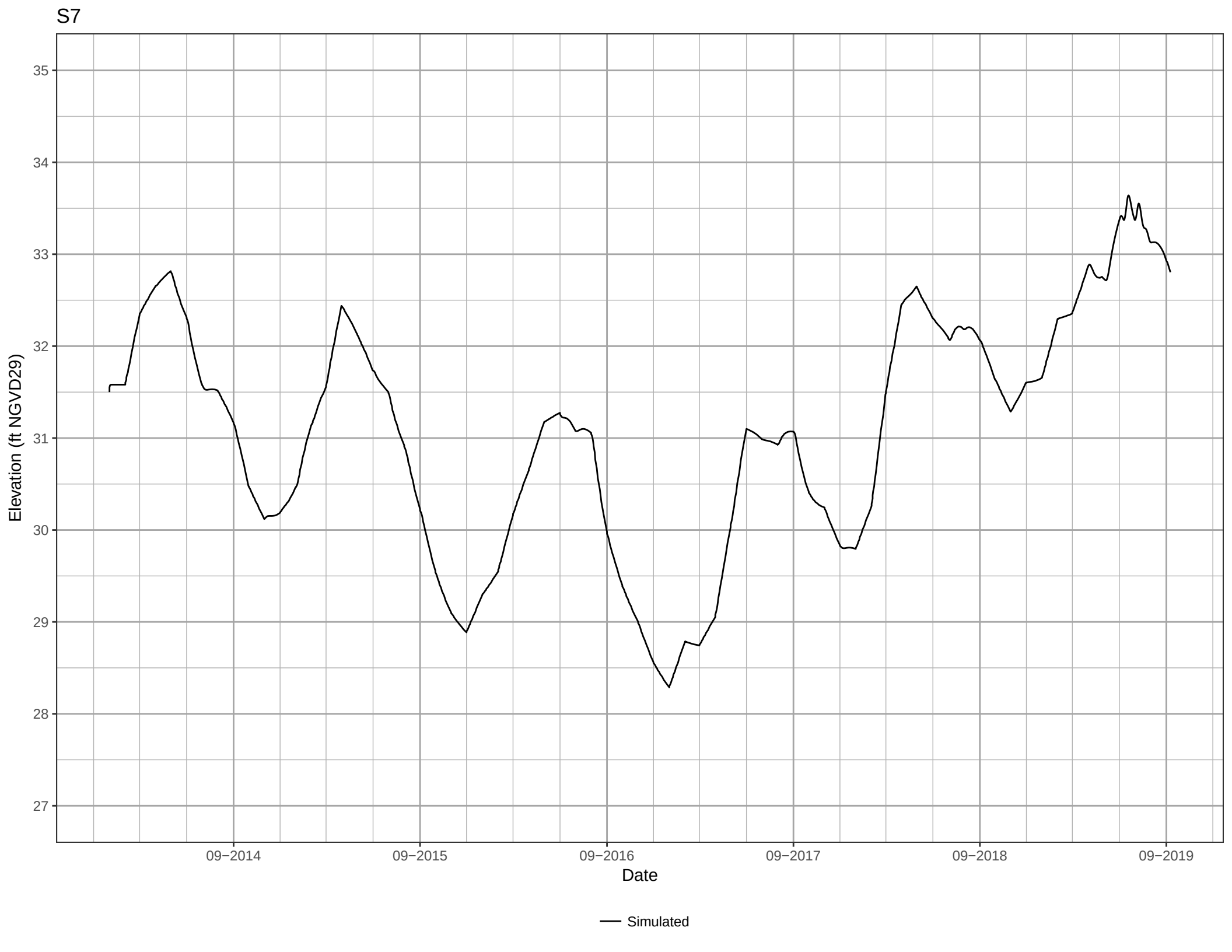
Date
Observed
Simulated


S7
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Elevation (ft NGVD29)
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Date
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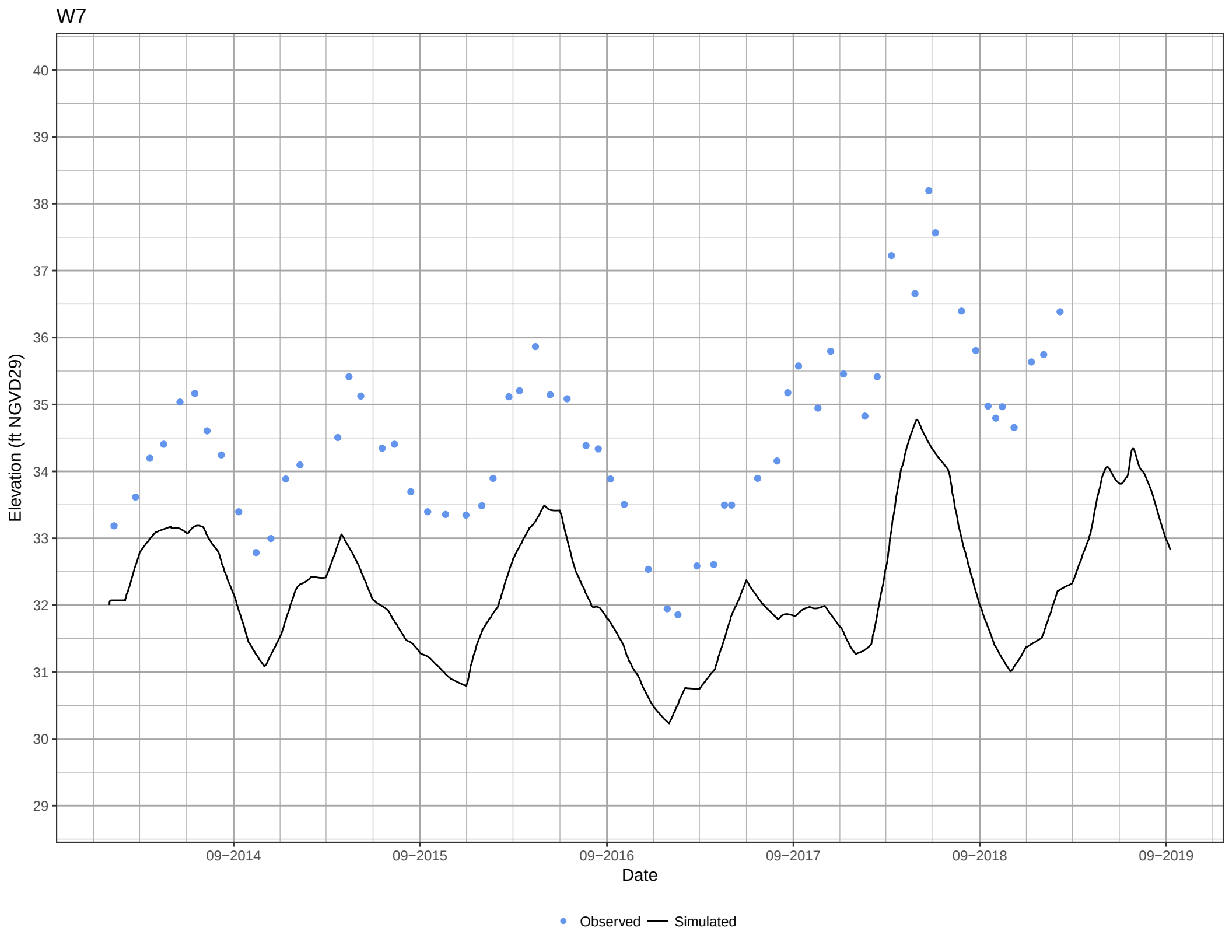
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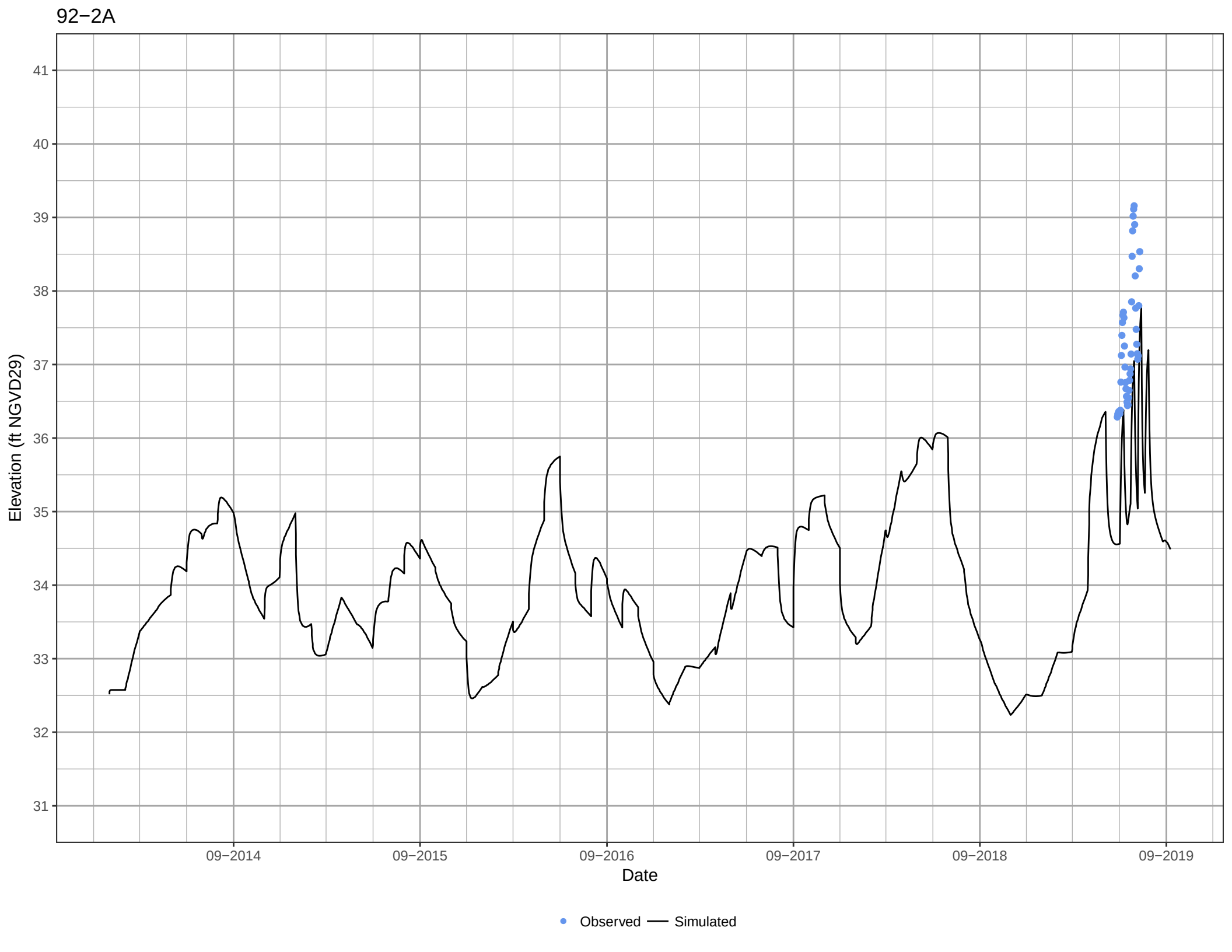
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Elevation (ft NGVD29)
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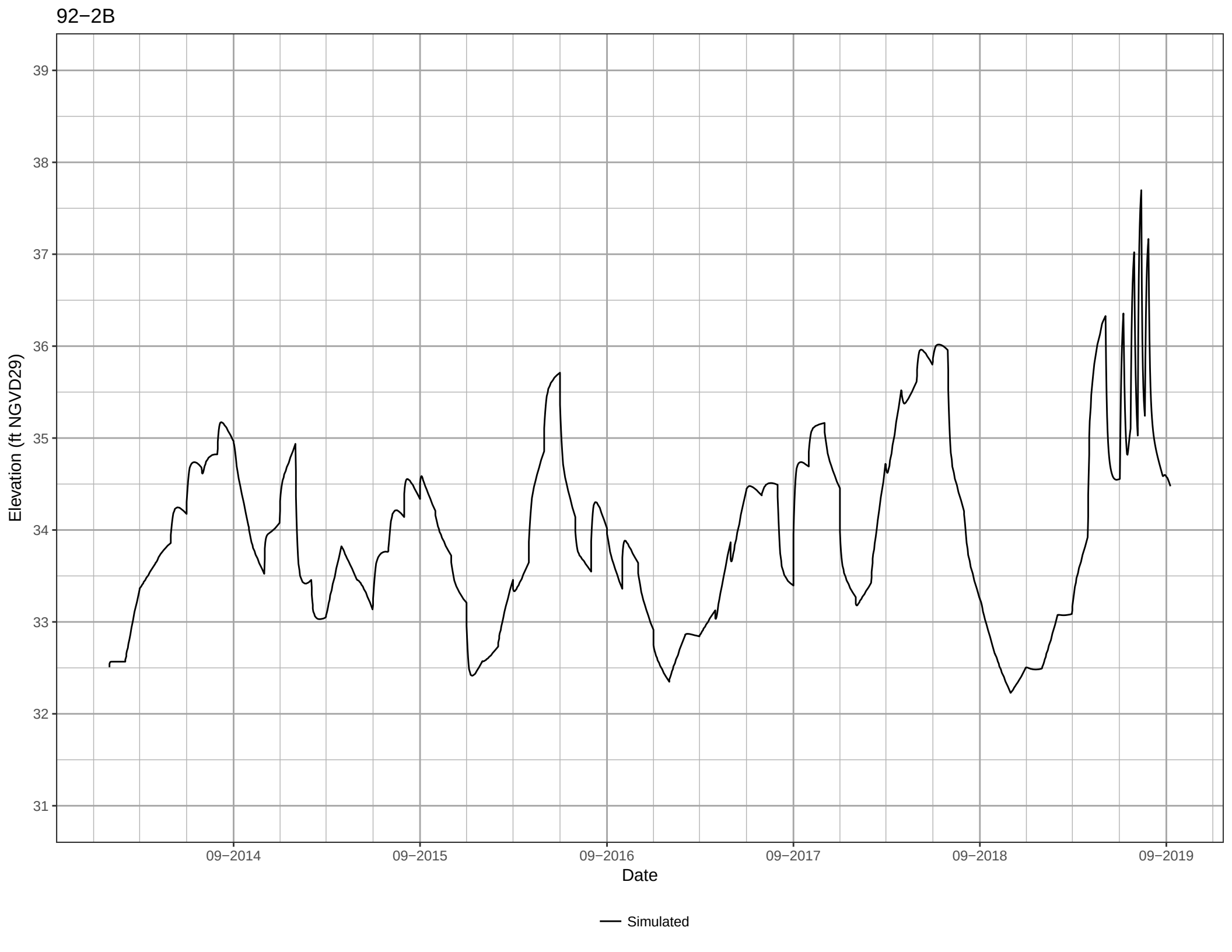
92−2B
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Elevation (ft NGVD29)
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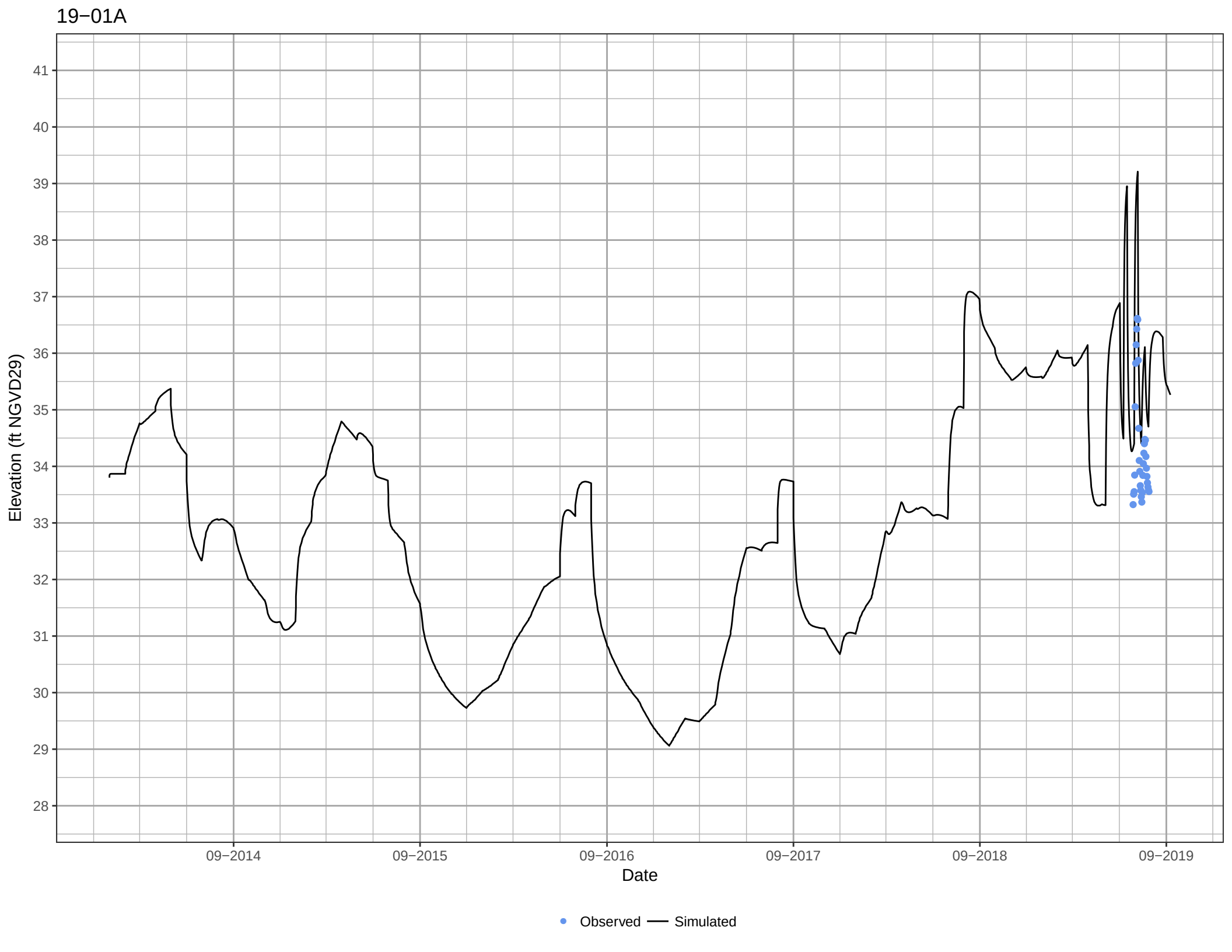
19−01A
Elevation (ft NGVD29)
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Date
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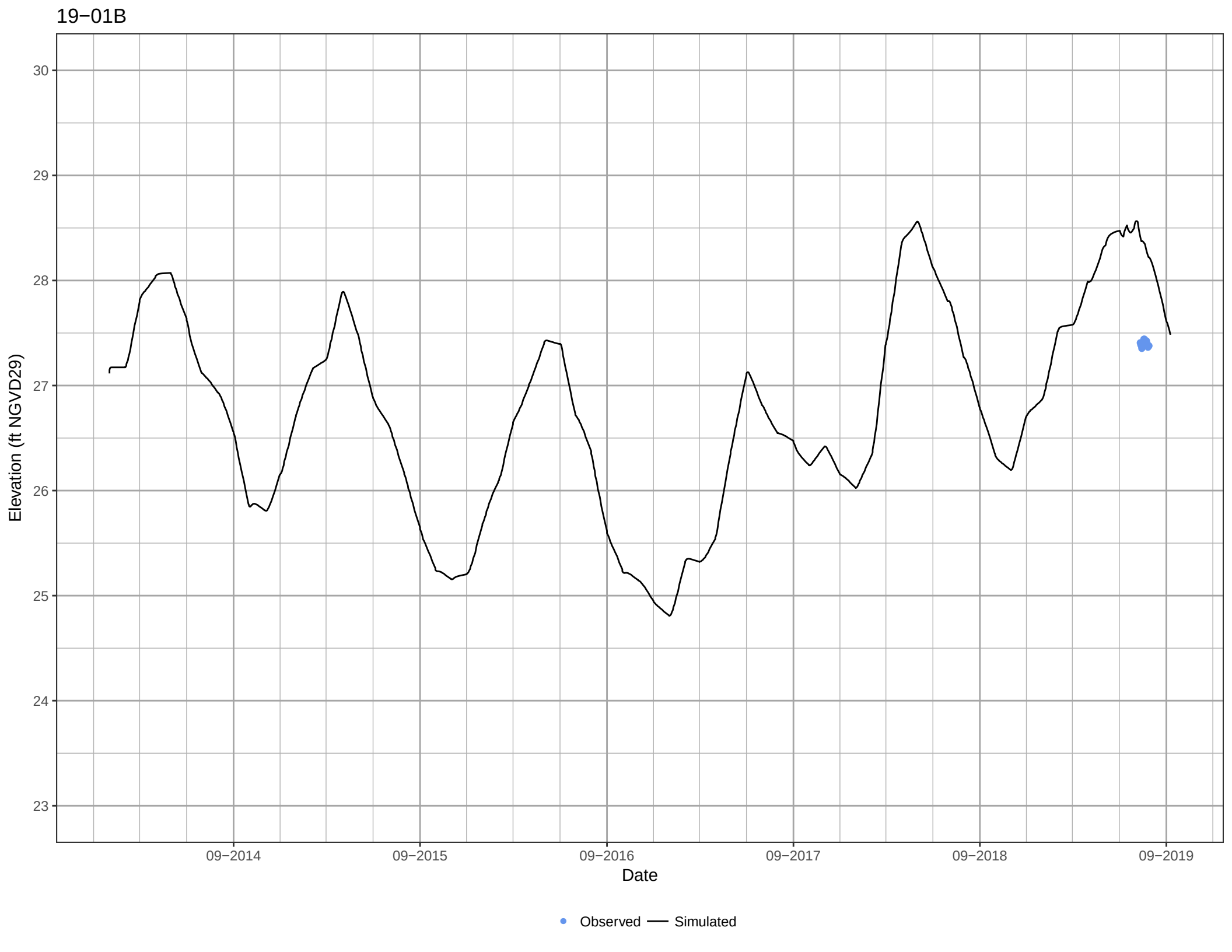
19−01B
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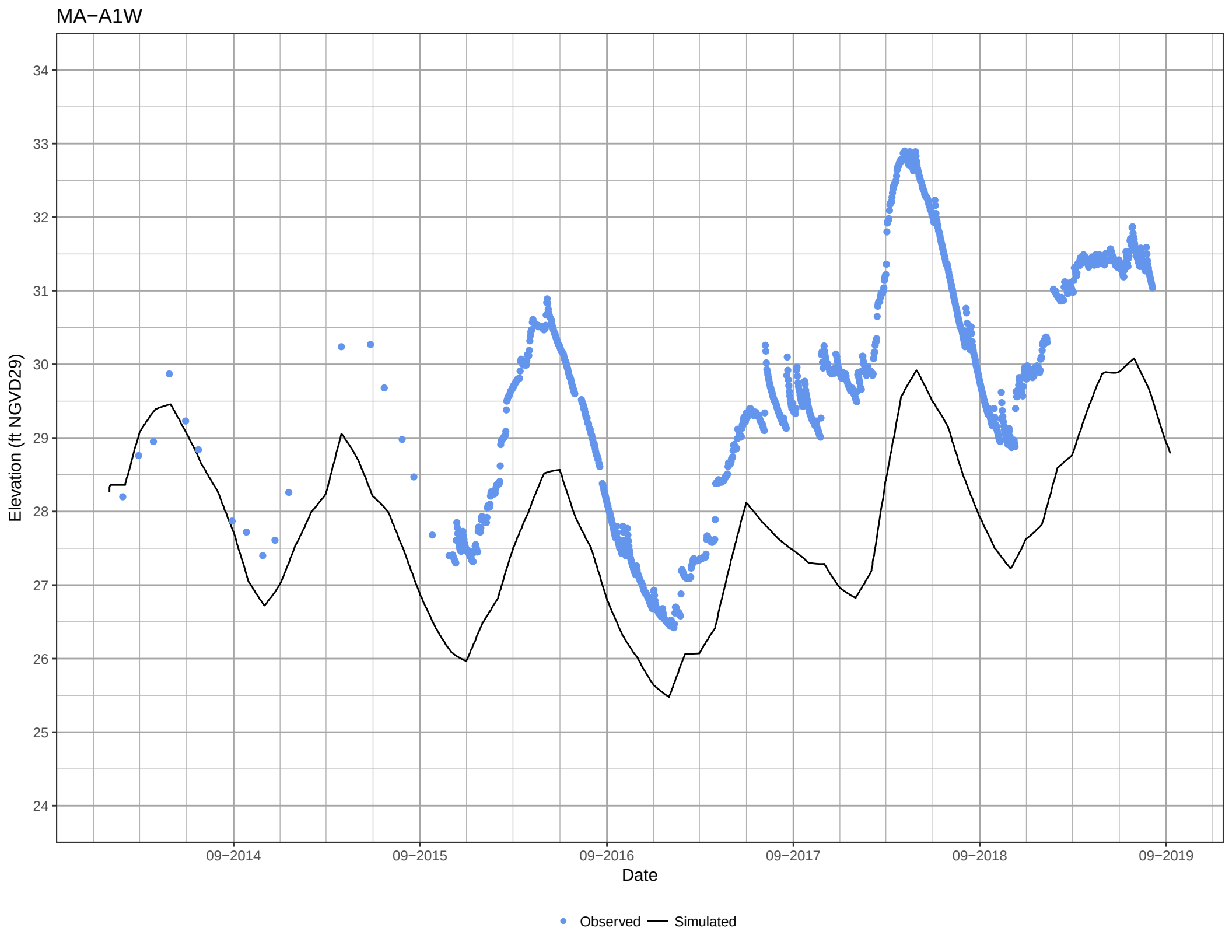
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Elevation (ft NGVD29)
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Date
Observed
Simulated

Appendix YY

Effluent Outfall Preliminary Feasibility Review

WRIGHT-PIERCE
Engineering a Better Environment

MEMORANDUM

TO:	Griffin Beaudoin – Town of Barnstable	**DATE:**	10/23/2020
FROM:	Neil Cheseldine, Ed Leonard	**PROJECT NO.:**	20157B
SUBJECT:	Barnstable CWMP – Effluent Outfall Preliminary Feasibility Review		

INTRODUCTION

As a part of its Comprehensive Wastewater Management Plan (CWMP), the Town is interested in conducting a "desktop" preliminary feasibility review of an ocean outfall in order to supplement the existing effluent disposal capacity. The preliminary candidate locations for an ocean outfall are Nantucket Sound, Cape Cod Bay and the Cape Cod Canal. There are many tasks required in order to successfully site an ocean outfall in accordance with the Massachusetts Ocean Sanctuaries Act (MGL Ch.132A, Sec.16G). This initial assignment is preliminary in nature and intended to identify the general vicinity where an effluent outfall could potentially be sited based on physical parameters and other general considerations.

PLANNING SCENARIOS

The Town of Barnstable is one of the largest Towns in Massachusetts and consists of seven distinct villages. The Town owns, operates and maintains a municipal wastewater collection and treatment system for its downtown and other areas of town. The Town has approximately 55 miles of sewer piping and 27 pumping stations (with one being constructed) and collects flows from approximately 2,300 acres of land area.

The Barnstable Water Pollution Control Facility (WPCF) includes septage handling, pretreatment, primary treatment, secondary treatment with nitrogen removal, disinfection, rapid infiltration basin disposal facilities, and solids processing. The WPCF has a current maximum daily discharge limitation of 2.70 million gallons per day (mgd) and a treatment capacity of 4.20-mgd at maximum daily flow. From 2013 to 2018, the WPCF has treated an annual average flow of 1.55-mgd and a maximum-month flow of 1.93-mgd.

Based on the CWMP, a significant increase in the number of sewered properties will be required to address water quality concerns in sensitive embayments that are adversely impacted by groundwater nitrogen loadings. As a part of the CWMP, the Town has been actively working on regional approaches to solve its water quality problems in order to determine if there are cost savings and environmental benefits. Potential regional approaches include: 1) working with Yarmouth; 2) working with Sandwich/Mashpee; and/or 3) working with all of the Upper Cape towns at Joint Base Cape Cod (JBCC).

The Town identified three potential flow scenarios for consideration in this review:

1) Barnstable CWMP: Total flow of 4.5-mgd annual average flow with **2.5-mgd** going to the ocean outfall and 2.0-mgd going to the existing land-based disposal system at the Barnstable WPCF site.
2) Barnstable CWMP plus the "Yarmouth Lewis Bay Scenario": Total flow of 5.0-mgd annual average flow with **3.0-mgd** going to the ocean outfall and 2.0-mgd going to land-based disposal system at the Barnstable WPCF site.
3) Barnstable CWMP plus the "Yarmouth Lewis Bay Scenario" plus the "Sandwich/Mashpee Three Town Regional Scenario": Total flow of 5.54-mgd annual average flow with **3.54-mgd** going to the ocean outfall and 2.0-mgd going to the land-based disposal system at the Barnstable WPCF.

A description of the Yarmouth Lewis Bay Scenario and the Sandwich/Mashpee This evaluation purposely omitted the "logistics" associated with transport/treatment and focused solely on effluent disposal. Three Town Regional Scenario are beyond the scope of this memorandum. We will utilize 3.54-mgd average daily flow as the basis for this preliminary feasibility review.

BASIS FOR FLOWS

Different components of a wastewater system are designed based on different process conditions (e.g., minimum day, annual average, maximum month, maximum multi-day, maximum day and peak instantaneous, etc.). For the purposes of this study, we established sewage peaking factors using the TR-16 Guides for the Design of Wastewater Treatment Works curves entitled "Relation of Extreme Discharges on Maximum and Minimum Days to the Average Daily Discharge of Domestic Sewage" (New England Interstate Water Pollution Control Commission, 2016) and the maximum month, maximum day and peak instantaneous values were adjusted upward by 0.2 to account for unique seasonal population/flow variations on Cape Cod. **Table 1** summarizes the peaking factors which have been used for this project as well as the flow rates for the various process conditions.

TABLE 1 - PEAKING FACTORS AND EFFLUENT FLOWS

Condition	Peaking Factor (Ratio from Annual Average)			Flow
	TR-16	Seasonal Adj.	Peak Factor	
Minimum Day	0.50	0.0	0.50	1.7-mgd
Minimum Month	0.75	0.0	0.75	2.6-mgd
Annual Average	1.0	0.0	1.00	3.54-mgd
Maximum Month	1.25	0.2	1.45	5.1-mgd
Maximum Day	1.9	0.2	2.10	7.4-mgd
Peak Instantaneous	3.0	0.2	3.20	11.3-mgd

POTENTIAL RECEIVING WATERS

Three potential receiving waters have been identified: Nantucket Sound, Cape Cod Bay and the Cape Cod Canal. Based on a review of National Pollutant Discharge Elimination System (NPDES) permits issued by EPA for ocean outfalls for facilities of similar size in Massachusetts and Maine, the minimum off shore distance was set at 3,000 feet for this analysis. Each are described below.

Nantucket Sound

Nantucket Sound off-shore waters are designated as a Class SA waterway by the DEP (SWQ Standards), not designated as an Outstanding Resource Water, and not designated as an Area of Critical Environmental Concern. Numerous tidal estuaries and embayments in Nantucket Sound are designated as an Outstanding Resource Water but we have limited our potential outfall location consideration to areas that are at least 3,000 feet off shore. Nantucket Sound is located within the Cape and Islands Ocean Sanctuary as designated under the Massachusetts Ocean Sanctuaries Act (M.G.L. c. 132A, 301 CMR 27.00). It provides habitat to a number of sensitive and/or endangered species including five species of turtles (Loggerhead, Leatherback, Kemp's Ridley, Green and Hawkbill), numerous whale species including endangered North Atlantic Right Whales, and several species of seals and porpoises including the gray seal, harbor seal and harbor porpoise.

Cape Cod Bay

Cape Cod Bay off-shore waters are designated as a Class SA waterway by the DEP (SWQ Standards), not designated as an Outstanding Resource Water, and not designated as an Area of Critical Environmental Concern. Similar to Nantucket Sound, numerous near shore waters (including Barnstable Harbor) are designated as Outstanding Resource Waters, but areas we considered for potential outfall locations were at least 3,000 feet off shore. The Cape Cod Bay area of interest is located within the Cape Cod Bay Ocean Sanctuary per the Ocean Sanctuaries Act. The entire north coast of the Town of Barnstable on Cape Cod Bay is within the Sandy Neck Barrier Beach System, which is designated as an Area of Critical Environmental Concern. The area includes Significant Resource Areas (SRAs) in the Massachusetts Coastal Zone Management (CZM) program. This area encompasses a 7-mile barrier beach, several thousand acres of salt marsh, productive shellfish beds and numerous other sensitive environmental resources. A new or increased discharge to an Outstanding Resource Water is prohibited unless it is necessary to accommodate important and economic or social development, no less environmentally damaging alternative site is reasonably available or feasible, and the discharge is designed to minimize adverse water quality impacts and still meet all criteria for the class. Therefore, we would not include this area for consideration of a new outfall unless all other areas are found not feasible. We also anticipate that crossing this area for installation of a new outfall would be challenging from an environmental permitting perspective, so it may be preferable to consider locations near the Barnstable/Sandwich town boundary or the Barnstable/Yarmouth town boundary to limit the impact to the ACEC zone. The majority of the targeted off-shore area (i.e. beyond 3,000 feet off shore) meet the target depth of greater than 40 feet, so relocation of the potential outfall location in Cape Cod Bay is feasible. Since the ACEC zone extends across the entire north shore of the

Town, it might be necessary to install some of the over land outfall piping outside of the Town of Barnstable in either Sandwich or Yarmouth.

The Cape Cod Bay is habitat to sensitive and/or endangered species including the North Atlantic Right Whale, Humpback Whale, Roseate Tern and Piping Plover. The shoreline provides habitat for other sensitive species, which would need to be addressed and accommodated in the construction of a new outfall but would not be expected to be impacted by the operation of a new ocean outfall.

The Cape Cod Bay is subject to strong tides that move water in and out of the bay exchanging about 9.3% of the total bay water volume and maintaining a well-mixed marine environment. The larger Gulf of Maine system is generally subject to counterclockwise currents influenced by a number of systems including the Gulf Stream, Labrador Current, Eastern Maine Coastal Current (EMCC) and Western Maine Coastal Current (WMCC). Hydrodynamics of the Bay are also influenced by the Cape Cod Canal with a net westward flow out of Cape Cod Bay to Buzzards Bay of approximately 3 billion gallons per tide change.

Cape Cod Canal

The Cape Cod Canal is designated as a Class SB waterway by the DEP (SWQ Standards), is not designated as an Outstanding Resource Water and is not an Area of Critical Environmental Concern. The Canal is a man-made waterbody that interconnects Buzzards Bay (west side) and Cape Cod Bay (east side) which is managed and operated by the Army Corps of Engineers (ACOE). It is a trapezoidal land cut that is approximately 700 feet wide at the top and approximately 500 feet wide at bottom with 3:1 riprap side-slopes. The land cut is approximately 6.9 nautical miles long from the Sandwich beach entrance to the Massachusetts Maritime Academy docks. The ACOE Navigation Channel dimensions are 480 feet minimum wide and 32 feet minimum deep envelope below mean low-low water. Channel depth minimum dimensions are maintained by periodic dredging.

The flow of seawater in the Canal is governed by the tide water levels in Buzzards Bay and Cape Cod Bay. Each bay's tidal water levels are governed by different branches of the main cyclic tidal wave in the Atlantic Ocean. When the head on the Cape Cod Bay side is higher than the Buzzards Bay side the flow is from east to the west, called the ebb. When the head on the Buzzard Bay side is higher, the flow is from west to east and is the flood tide. The driving head is also impacted by storm and wind factors. The flow reverses direction about every 6.2 hours with the shift in water surface profile. As outlined in the EPA 1981 Draft Environmental Impact Statement (EIS), the Canal volume is an estimated 8.5 billion gallons. The westward tidal flow totals an estimated 22 billion gallons per tide change and the eastward flow totals an estimated 19 billion gallons per tide change. The Draft EIS indicates that the hydrodynamics for the Cape Cod Bay end of the Canal are relatively straight-forward but that the hydrodynamics associated with Buzzards Bay are relatively complex.

Wright-Pierce previously completed a preliminary feasibility evaluation of a new outfall in the Cape Cod Canal (May 17, 2019). Based on this evaluation, it was concluded that it is potentially

feasible to install a new outfall in the Cape Cod Canal for 13.5-mgd annual average flow, with a 100 foot long diffuser in 40 feet of water within 200 feet of shore, and achieve a minimum dilution factor of 50:1 during slack tide minimum current velocity conditions.

POTENTIAL OUTFALLS TO SURFACE WATER

Any new effluent discharge to surface water in Massachusetts must meet the requirements of Massachusetts Ocean Sanctuaries Act MGL Ch.132A, Sec.16G (OSA).The OSA requires that the following 10 items must be met (*italics indicate text from MGL*):

1) *The new or modified discharge shall be consistent with the intent and purpose of the act. Any discharge shall meet the water quality standards of the receiving water body and the standards of the act to protect the appearance, ecology, and marine resources of the waters of the sanctuary.*
2) *The new or modified discharge shall meet the United States Environmental Protection Agency's approved TMDL, if any, on the receiving water body.*
3) *The applicant shall have adopted and implemented a plan approved by the department requiring the pretreatment of all commercial and industrial wastes discharged to the POTW.*
4) *The applicant shall have adopted and implemented a program for water conservation according to the guidelines established by the water resources commission.*
5) *The applicant shall have adopted and implemented a plan, approved by the department, to control and minimize inflow and infiltration.*
6) *The applicant shall have adopted and implemented a plan, approved by the department, to control any combined sewer overflows.*
7) *The new or modified discharge shall not significantly affect the quality or quantity of existing or proposed water supplies by reducing ground or surface water replenishment.*
8) *The new or modified discharge is consistent with the policies and plans of the Massachusetts coastal zone management program.*
9) *The new or modified discharge and treatment plans are consistent with all applicable federal, state, and local laws, ordinances, by-laws, rules, and regulations protecting the environment, including but not limited to, the requirements of chapters 21, 91, 130, and 131.*
10) *The proposed discharge and outfall structure will not adversely impact marine fisheries or interfere with fishing grounds or the normal operation of fishing vessels.*

The OSA Regulations stipulate that an application for a new or modified discharge must include the following *(italics indicate text from 301 CMR 27.00)*:

1) *The Department's application form for a new or modified discharge to an ocean sanctuary.*
2) *A description, coordinates, and maps of the proposed modified or new discharge, including location(s), average daily flow, proposed level of treatment, design capacity, existing and proposed outfall locations and alignment of discharge pipes and other related structures, a summary of any proposed changes to existing discharge conditions, effluent quality or*

characteristics. Maps shall show the boundaries of the affected ocean sanctuary and demarcate the following: Areas of Critical Environmental Concern; Special, Sensitive or Unique Resources from the Ocean Management Plan; marine life and natural resources, including but not limited to wetland resource areas, shellfish beds, eelgrass beds, habitats of endangered and threatened species, species of special concern; fisheries resources, including but not limited to commercial and recreational fishing areas, spawning sites, nursery and forage areas, and migratory pathways or areas necessary for other functions or critical stages in the life cycle of economically or recreationally important species; Concentrations of Water Dependent Uses from the Ocean Management Plan; recreational resources including, but not limited to, bathing beaches, boating areas and scenic areas; and water quality classification(s) of affected waters.

3) *A final CWMP, targeted watershed management plan, or other appropriate substitute as may be required, and has been approved by the department.*
4) *A final environmental impact report and certificate with the Secretary's findings and determinations.*
5) *A detailed evaluation of the receiving water body, including the data, information, results and conclusions from the following surveys and investigations establishing, at a minimum, a two year baseline: Ocean Sanctuaries Act Regulations Revisions: Final Version 9 (a) water quality monitoring, including nutrients, temperature, pH, dissolved oxygen, water clarity; (b) fisheries survey, including finfish and shellfish; (c) benthic sediments and infauna; and (d) fisheries habitat including eelgrass.*
6) *Data, information, results and conclusions from the development of a site-specific hydrodynamic model illustrating tides, bathymetry, mixing zones and seasonal variations that estimate dilution and dispersion of nutrients, pathogens, and other relevant contaminants within the wastewater discharge.*
7) *A hydrologic evaluation of any affected aquifer(s), including evaluation of the effects of the new or modified discharge, and any planned and potential sewering, on the recharge of the affected aquifer, and how those changes may affect drinking water supplies or natural resources.*
8) *An evaluation of the commercial and recreational fisheries at the project site, in the embayment and estuary, and in the affected ocean sanctuary, including the specific existing and potential fisheries, and the value of the fisheries. The evaluation must include an analysis of potential closures due to public health requirements including the potential extent of the mandatory shellfish bed closures to meet prescribed standards in the U.S. Food and Drug Administration's National Shellfish Sanitation Program Guide for the Control of Molluscan Shellfish. The evaluation shall also include potential impacts from the proposed outfall structure on normal operation of fishing vessels or equipment.*
9) *A proposed long-term monitoring plan to document that any new or modified discharge would continue to meet the intent of the Act, the standards of 301 CMR 27.07(3), and other applicable laws and regulations.*
10) *Documentation, detailed analysis, and supporting evidence demonstrating how the new or modified discharge meets the requirements and standards in 301 CMR 27.07(3).*

If the above can be met, then a surface water discharge could be permitted by the Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (DEP). The Barnstable WPCF effluent discharge would need to meet permit limits set forth in a new National Pollutant Discharge Elimination System (NPDES) permit issued by the EPA in accordance with Section 402 of the Clean Water Act. The Barnstable WPCF would also need to continue to meet the permit limits set forth in its existing (or future modified) DEP Groundwater Discharge Permit.

Table 2 summarizes the anticipated effluent limits for discharge into SA and SB marine waters, based on the current permitting approaches used by EPA and DEP. Table 2 also summarizes the current Groundwater Discharge Permit limits for the Barnstable WPCF. The Barnstable WPCF would require upgrades to achieve the anticipated NPDES permit limits.

TABLE 2 - ANTICIPATED WPCF PERMIT LIMITS

Parameter	**GWDP Existing Limits Rapid Infiltration [(1)]**	**NPDES Anticipated Limits Outfall (Class SA)**	**NPDES Anticipated Limits Outfall (Class SB)**
BOD_5, mg/l	30	30	30
TSS, mg/l	30	30	30
Total Dissolved Solids, mg/l	1,000	n/a	n/a
Total Nitrogen, mg/l	10 [(2)]	3 [(3)]	3 [(3)]
Nitrate-Nitrogen, mg/l	10	n/a	n/a
Ammonia-Nitrogen, mg/l	n/a	n/a[(4)]	n/a[(4)]
Oil & Grease, mg/l	15	n/a	n/a
Fecal Coliform (geo mean), #/100 ml	200	14	88
Enterococci (geo mean), #/100 ml	n/a	35	35
Total Residual Chorine, mg/l	1	0.65 [(5)]	0.65 [(5)]
Total Recoverable Metals, mg/l	n/a	n/a [(4)]	n/a [(4)]
Total Phosphorus, mg/l	n/a	n/a	n/a
Total Organic Carbon, mg/l	n/a	n/a	n/a
Turbidity, NTU	n/a	n/a	n/a
Virus Removal, log removal	n/a	n/a	n/a

Notes:
1.) GWD Permit #21-1.
2.) TN not to exceed 49,315 lbs per calendar year (equivalent to 6 mg/l at 2.7 mgd)
3.) Presumed based on input from EPA and Buzzards Bay Coalition.

4.) Assume dilution factors of greater than 50:1 can be obtained which would preclude the need for metals or other toxics limits. Ammonia limits not needed since TN limit governs.
5.) Max day limit based on acute criteria of 13 ug/l and 50:1 acute dilution. Not applicable if ultraviolet disinfection implemented.

MIXING, DILUTION AND DESIGN CONSIDERATIONS

The DEP Implementation Policy for Mixing Zone (January 1993) defines how a mixing zone is established for a surface water outfall. A "mixing zone" is an area or volume of a waterbody in the immediate vicinity of a discharge where the initial dilution of the discharge occurs. This mixing zone is also called a Zone of Initial Dilution (ZID) where dilution is rapid, driven by the intentionally high velocity and momentum of the effluent discharge. Within a mixing zone, excursions from certain water quality criteria may be tolerable, provided this does not interfere with the existing or designated uses of the segment. Water quality criteria apply at the boundary of the mixing zone. The mixing zone is a function of the proposed outfall flow rate versus the minimum flow or current velocity of the receiving water. In the case where there is tidal flow, there is a significant amount of judgement used by the permit writer in calculating the appropriate dilution factor and sizing the mixing zone.

EPA has established ambient water quality standards which indicate the maximum concentration limits which are protective of aquatic life for both short-term (acute) exposure and long-term (chronic) exposure. WWTF effluent is allowed to be thoroughly mixed with receiving water to dilute the concentrations to below acute water quality standards within the Zone of Initial Dilution. However, the mixing and resulting dilution must occur as fast as possible and in as small an area as possible. Mixing zones are limited in size as defined in the regulations. At the outer boundary of the acute mixing zone, the effluent must be sufficiently diluted to meet the acute water quality criteria. Mixing zones must be small enough to allow free passageways for aquatic life to bypass the zone. According to the EPA *Technical Support Document for Water Quality-Based Toxics Control*, organisms are not to be exposed to concentrations greater than the acute criteria when concentrations are time-weighted over one hour of exposure time in the plume.

There is also a secondary mixing zone for chronic water quality criteria, that is larger than the initial acute mixing zone, where dilution processes are much slower than the acute mixing zone. In the chronic zone, dilution occurs by wind driven waves and currents and concentration dispersion. Chronic zone dilution requires computer models to estimate the dilution and size of the mixing zone. Detailed hydraulic and hydrodynamic modeling is needed to provide more refined results (e.g., computational fluid dynamics, CORMIX, Visual Plumes/ UM3).

For this preliminary feasibility and planning study, we performed simplified spreadsheet analysis for various diffuser lengths and design current velocities. For each trial, the cross-sectional area of the water above the diffusers (length of diffuser section times water depth) was calculated and then multiplied by the velocity to calculate the bulk receiving water flow. The ZID dilution factor was then calculated by dividing the sum of the receiving water and WWTF flows by the WWTF flow. This dilution factor is used for comparison to the acute water quality criteria.

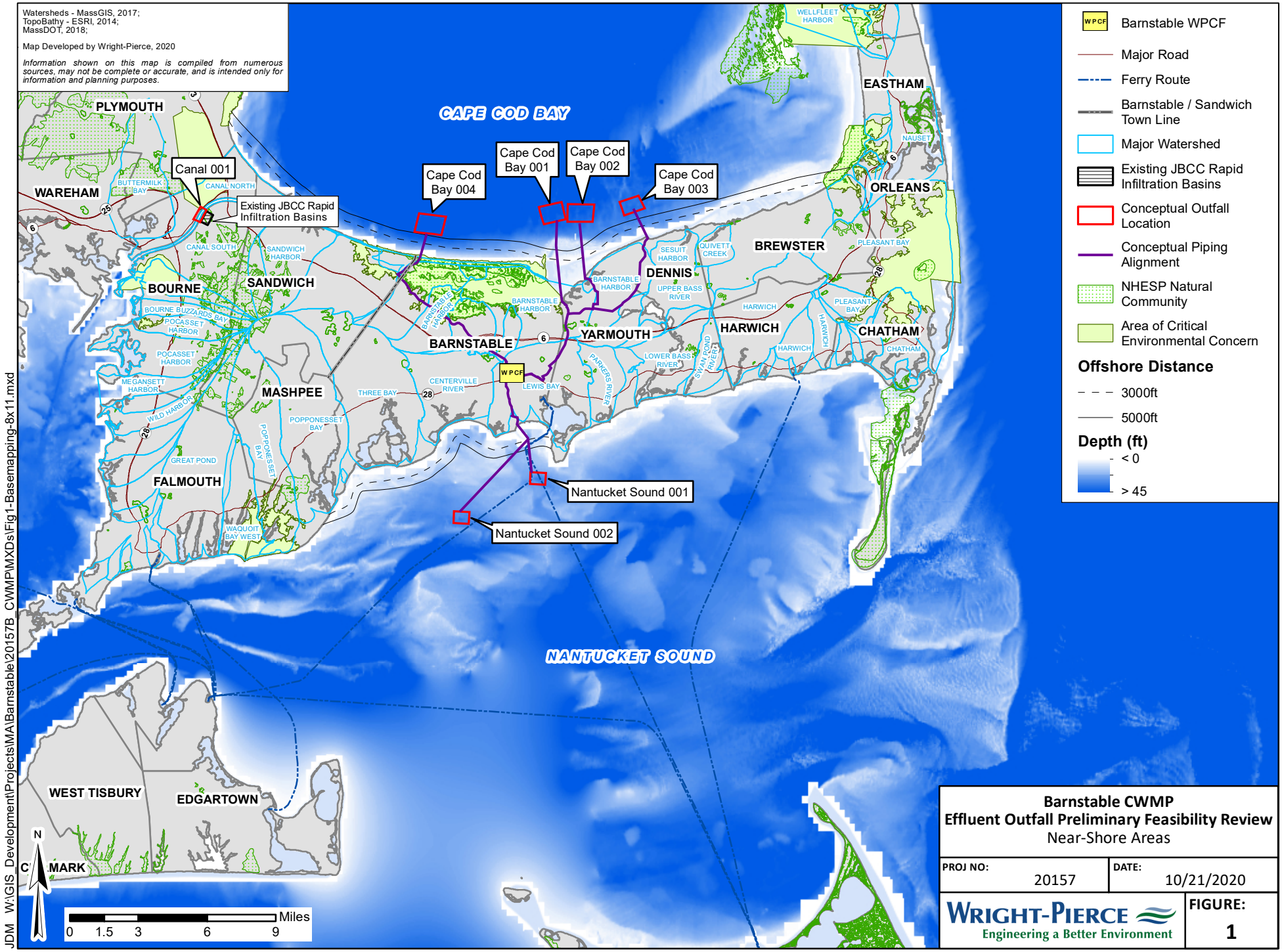
The most significant variables that influence dilution of an ocean outfall are diffuser depth and current velocity. Near shore ocean currents are most often dominated by tidal dynamics resulting in reversing currents. For outfall design, the most conservative design condition is the average current velocity that occur immediately before and after slack tide. This particular current condition is not commonly included in most publicly available ocean current studies and can vary widely based on numerous factors including bathymetric conditions around the outfall. Therefore, site-specific current monitoring would be required prior to final design of a new outfall. For this evaluation, we have assumed conservatively low design current speeds based on a review of outfall evaluations and designs at other similar locations including Marshfield, MA NPDES permit (0.05 f/s) and Sanford Sewerage District, Sanford, ME outfall evaluation study (0.033 f/s). The following physical parameters and assumptions were used in our potential site identification and simple dilution evaluation:

- Target water depth: 40 feet
- Current Velocity Design Basis:
  - Minimum (acute dilution): 0.033 ft/sec (slack tide conditions)
  - Average (low): 0.33 ft/sec
  - Average (normal): 1.0 ft/sec
- The use of multi-port diffusers oriented perpendicular to receiving water flow, with a discharge velocity of approximately 10 fps per port, in order to maximize dispersion and mixing of effluent with the receiving water. Alternating at 45 degrees either side of vertical and 10-foot spacing (20-foot on each side).

The Cape Cod Bay waters are consistently deeper than 40 feet beyond 3,000 feet off-shore. The Nantucket Sound waters are much shallower in the near-shore area; waters with greater than 40 foot depth are at least 12,000 feet off-shore. Approximate outfall locations are designated on Figure 1 with red rectangles. These locations were selected using publicly available bathymetric data and based on the target water depth noted above and a minimum off-shore distance of 3,000 feet. The potential locations are summarized as follows:

- Cape Cod Bay:
  - Approximately 40 foot depth and 3,500 to 4,000 feet off shore
  - Extensive area at the target depth to install outfall diffuser section
- Nantucket Sound:
  - Approximately 38 to 40 foot depth and 12,000 to 15,000 feet off shore
  - Two small areas at the target depth to install outfall diffuser section (~200 feet x 150 feet and 400 feet x 1200 feet)
- Cape Cod Canal:
  - Approximately 40 foot depth and 200 feet off shore
  - Small area at target depth beneath the Army Corps of Engineers navigation channel

None of these locations have any published TMDLs that we are aware of.


Watersheds - MassGIS, 2017;
TopoBathy - ESRI, 2014;
MassDOT, 2018;
Map Developed by Wright-Pierce, 2020
Information shown on this map is compiled from numerous sources, may not be complete or accurate, and is intended only for information and planning purposes.
CAPE COD BAY
NANTUCKET SOUND
Canal 001
Existing JBCC Rapid Infiltration Basins
Cape Cod Bay 004
Cape Cod Bay 001
Cape Cod Bay 002
Cape Cod Bay 003
Nantucket Sound 001
Nantucket Sound 002
PLYMOUTH
WAREHAM
BOURNE
SANDWICH
MASHPEE
FALMOUTH
BARNSTABLE
YARMOUTH
DENNIS
BREWSTER
ORLEANS
EASTHAM
HARWICH
CHATHAM
WEST TISBURY
EDGARTOWN
MARK
WPCF
Barnstable WPCF
Major Road
Ferry Route
Barnstable / Sandwich Town Line
Major Watershed
Existing JBCC Rapid Infiltration Basins
Conceptual Outfall Location
Conceptual Piping Alignment
NHESP Natural Community
Area of Critical Environmental Concern
Offshore Distance
3000ft
5000ft
Depth (ft)
< 0
> 45
N
Miles
0 1.5 3 6 9
Barnstable CWMP
Effluent Outfall Preliminary Feasibility Review
Near-Shore Areas
PROJ NO: 20157
DATE: 10/21/2020
WRIGHT-PIERCE
Engineering a Better Environment
FIGURE: 1
JDM W:\GIS Development\Projects\MA\Barnstable\20157B CWMP\MXDs\Fig1-Basemapping-8x11.mxd

We recommend a minimum near field dilution factor of 50:1 in order to avoid the acute toxics criteria. Based on the above stated assumptions, we calculated the worst case simple near field dilution based on the minimum current velocity, design flow, and diffusers depth and length.

The dilution calculations for the Cape Cod Bay 001 and Nantucket Sound 002 were the same because we assumed the same depth (40 feet). The Nantucket Sound 001 location resulted in slightly lower dilution due to shallower depth (38 feet). The Canal location results were summarized in the May 2019 memorandum and not reiterated herein. The minimum current velocity condition results are summarized in Tables 3 and 4 and these results would be the most limiting for feasibility consideration.

TABLE 3 – DILUTION AT MINIMUM CURRENT VELOCITY

LOCATION CAPE COD BAY 001 AND NANTUCKET SOUND 002

Diffuser Depth	Diffuser Length	Mixing Area	Current Velocity	Current Flow	Design Effluent Flow	Design Effluent Flow	Simple Dilution
Feet	Feet	Sq-Ft	FPS	CFS	MGD	CFS	Ratio
40	220	8,800	0.033	290	3.54	5.48	54
40	200	8,000	0.033	264	3.54	5.48	49
40	100	4,000	0.033	132	3.54	5.48	25
40	50	2,000	0.033	66	3.54	5.48	13

TABLE 4 – DILUTION AT MINIMUM CURRENT VELOCITY

LOCATION NANTUCKET SOUND 001

Diffuser Depth	Diffuser Length	Mixing Area	Current Velocity	Current Flow	Design Effluent Flow	Design Effluent Flow	Simple Dilution
Feet	Feet	Sq-Ft	FPS	CFS	MGD	CFS	Ratio
38	220	8,360	0.033	276	3.54	5.48	51
38	200	7,600	0.033	251	3.54	5.48	47
38	100	3,800	0.033	125	3.54	5.48	24
38	50	1,900	0.033	63	3.54	5.48	12

Based on these simplified calculation results, we anticipate that it would be possible to design an ocean outfall at these locations and achieve worst case slack tide acute dilution factor of 50:1 or greater. The ZID values at higher ambient current velocities for the conceptual outfall configuration would range from 500:1 to 1,600:1.

The outfall would be designed to distribute effluent longitudinally to mix with the desired cross sectional receiving water area with the size and number of diffusers to result in a peak flow jet velocity 10 feet per second (fps) in order to optimize turbulence and initial mixing with the receiving water. A 24-inch to 30-inch outfall pipe would be utilized to convey effluent to the diffuser location.. Twenty 4-inch diffusers would be provided at 11-foot spacing along the final 220-foot section of the outfall, which would be installed at the target water depth.

As noted previously, we attempted to make conservative assumptions for this preliminary evaluation. Additional more detailed site-specific data and use of more sophisticated hydrodynamic computer models would be necessary to confirm outfall feasibility and refine the conceptual configuration. These models would also be necessary to analyze far-field mixing and dilution to assess the impact of effluent pollutant loading to ensure that water quality impairments would not occur. After an outfall location is selected, significant more detailed environmental review would also be required.

OTHER OUTFALLS

There are several existing outfalls with individual NPDES permits on Cape Cod or the immediate vicinity:

1) a large cooling water outfall to Cape Cod Bay from the Pilgrim Nuclear Power Plant;
2) a wastewater effluent outfall to Plymouth Harbor from the Plymouth WWTP;
3) a large cooling water outfall to the Cape Cod Canal from the Canal Station in Sandwich;
4) a small wastewater effluent outfall to the Cape Cod Canal from the Massachusetts Maritime Academy in Bourne; and
5) a wastewater effluent outfall to the Agawam River from the Wareham WPCF.

In addition, there are several additional outfalls we are aware of that are under consideration by municipalities for wastewater effluent on Cape Cod or the immediately vicinity:

1) a new regional outfall to the Cape Cod Canal from expanded JBCC wastewater treatment facilities potentially for Bourne, Falmouth, Mashpee, Sandwich, Barnstable and JBCC;
2) a new outfall to Buzzards Bay or Vineyard sound from the Falmouth wastewater treatment facilities for Falmouth; and
3) a significant expansion of the MMA outfall to the Cape Cod Canal from expanded Wareham wastewater treatment facilities potentially for Wareham, Marion, Plymouth, Bourne and MMA.

None of these outfalls are assured to move forward, but the Town should be mindful of how these efforts may impact the regulatory and public perception of effluent outfalls (positively or negatively).

PIPING ALIGNMENT ALTERNATIVES

A new effluent pump station would be sited at the WPCF to convey effluent to the outfall. For the purposes of this analysis, 24-inch force main and outfall piping has been assumed. Six potential alignment and outfall location alternatives were considered for this evaluation. Three general force main alignments were identified to reach the coastline: 1) the "eastern Cape Cod Bay route" terminates with three possible outfall locations to the east of Barnstable Harbor; 2) the "western Cape Cod Bay route" runs northwesterly to the Sandy Neck area at the Barnstable/Sandwich boundary to the west of Barnstable Harbor; and 3) the "southerly route to Nantucket Sound" includes two possible outfall locations, as noted previously. The route/outfall alternatives are generally described as follows:

Cape Cod Bay Outfall 001

- WPCF site – 340 LF
- Bearses Way (south) – 660 LF
- Route 28 (east) – 3,700 LF
- Airport roads (enter at Airport Rotary, exit at end of Runway 24) – 10,300 LF
- Railroad crossing (airport to Yarmouth Road) – 250 LF
- Yarmouth Road/Willow Street (north) – 10,800 LF
- Route 6A (east) – 180 LF
- Wharf Lane (north) – 2,400 LF
- Beach crossing/subaqueous outfall – 19,900 LF ***(Note: this is very close to the ACEC)***

Cape Cod Bay Outfall 002

- Same as CCB Outfall 001 Through Route 6A (east) – 26,230 LF
- Route 6A (east) – 5,920 LF
- Winter Street (north) – 2,140 LF
- Center Street (north) – 5,400 LF
- Beach crossing/subaqueous outfall – 14,800 LF

Cape Cod Bay Outfall 003

- Same as CCB Outfall 002 Through Route 6A (east) – 32,150 LF
- Route 6A (east) – 20,450 LF
- Corporation Road (north) – 4,500 LF
- Beach crossing/subaqueous outfall – 8,000 LF

Cape Cod Bay Outfall 004

- WPCF site – 3,100 LF
- Pitchers Way (north) – 1,100 LF
- Bearses Way (north) – 700 LF

- Route 132 (northwest) – 12,400 LF
- Route 6A (west) – 20,500 LF
- Sandy Neck Road (north) – 6,500 LF
- Beach crossing/subaqueous outfall – 5,000 LF ***(NOTE: this is through the ACEC)***

Nantucket Sound Outfall 001

- WPCF site – 2,260 LF
- Pitchers Way – 9,300 LF
- Marston Ave./Hyannis Ave. – 3,000 LF
- Beach crossing/subaqueous outfall – 12,200 LF

Nantucket Sound Outfall 002

- Same as NS Outfall 001 through Marston Ave./Hyannis Ave. – 14,560 LF
- Beach crossing/subaqueous outfall – 27,200 LF

CAPITAL COSTS

The necessary facilities would include an effluent pump station, 24-inch diameter force main piping from the pump station to the shore, 24-inch outfall piping and a diffuser assembly. For each of the force main and outfall route alternatives, quantities were estimated for 24-inch Force Main (WPCF site, local roads, state roads, airport roads, railroad crossings) and beach crossing/ subaqueous outfall piping. No costs are included for WPCF upgrades related to effluent quality. The following references were used as the basis for estimating unit costs for each item with cost information adjusted to current dollar values using the ENR Construction Cost Index:

- Wright-Pierce, "Shared Wastewater Management Study Towns of Bourne, Falmouth, Mashpee, Sandwich, and Joint Base Cape Cod", November 2017 Revised August 2019
- City of Rehoboth Beach, DE Ocean Outfall Bid Form and Total Bid Tabulation, August 2017. The Rehoboth Beach outfall project is similar to the conceptual outfall facilities for the Barnstable project. The outfall size is 24-inch with a diffuser assembly located approximately 6,000 feet offshore, in 40-feet deep water. We utilized the median bid item values (i.e., not the low bidder values). No adjustment was made based on project location.

Planning-level project costs have been prepared for the recommended facilities and are presented in Table 1. These planning-level costs were developed using standard cost estimating procedures consistent with industry standards utilizing concept layouts, unit cost information, and planning-level cost curves, as necessary. Total project capital costs include allowances for contingency, technical services, as well as fiscal, legal and administrative expenses. The project cost information presented herein is in current dollars and is based on ENR Index 11540 (October 2020). This is considered a "Class 4" estimate (AACE International), with an accuracy of -25% to +50%. While this is broad accuracy range, the relative cost differential among the options will remain consistent.

TABLE 1 – PIPE LENGTH (FEET) AND CAPITAL COSTS SUMMARY ($MILLION)

ENR CCI 11540 (OCTOBER 2020)

Item	Cape Cod Bay Outfall 001	Cape Cod Bay Outfall 002	Cape Cod Bay Outfall 003	Cape Cod Bay Outfall 004	Nantucket Sound Outfall 001	Nantucket Sound Outfall 002
Pipe Length (Feet)						
Force Main Length	28,630	39,690	57,100	44,300	14,560	14,560
Subaqueous Length	19,900	14,800	8,000	5,000	12,200	27,200
Total Length	48,530	54,490	65,100	49,300	26,750	41,760
Capital Costs ($M)						
Effluent Pump Station	5	5	5	5	5	5
Force Main	12	17	26	21	6	6
Subaqueous Pipe	132	93	42	19	74	188
General & Project Management	6	6	6	6	6	6
Construction Total	155	122	79	51	91	205
Project Development & Contingency	94	72	48	31	55	122
Total	**249**	**194**	**127**	**82**	**146**	**327**

Notes and Assumptions:

1) Project Development & Contingency includes technical services (including environmental studies, public consultation) estimated at 25% of construction cost, fiscal/legal/administrative estimated at 5% of the construction cost, and construction contingency estimated at 30% of the construction cost.
2) The force main unit costs include all appurtenant work including traffic control
3) Railroad crossing would be completed using horizontal directional drilling (HDD) or pipe jacking.
4) The beach crossing and initial subaqueous piping sections would be completed using HDD. For the purposes of this analysis, the maximum HDD length is assumed to be 3,800 feet, so the remainder of the subaqueous piping and diffuser assembly would be constructed using open cut trench similar to the Rehoboth Beach project.
5) Outfall general expenses, including mobilization, staging areas, and indeterminate quantity items would be similar for all the alternatives.

CONCLUSIONS

1) This preliminary feasibility review indicates that an ocean outfall is potentially feasible in either Cape Cod Bay or Nantucket Sound with respect to the principal physical parameters described herein. A previous preliminary feasibility review indicated a similar conclusion for the Cape Cod Canal location at a higher flow rate than identified herein. This review used annual average flow in the computations; this will need to be reviewed with the ultimately permitting agency (EPA).
2) Water depth is one of the key considerations for siting of an ocean outfall in order to achieve high initial dilution with the receiving water. The bathymetry of Cape Cod Bay is more conducive to an outfall location within a closer distance to shore than the bathymetry of Nantucket Sound. Locations with suitable water depth can be reached within 4,000 feet of the shore, whereas, similar water depths in Nantucket Sound are at least 12,000 feet off shore.
3) The Barnstable WPCF is closer to the Nantucket Sound shore than the Cape Cod Bay shore. The total land-based and water-based outfall piping length as well as the land-based and water-based environmental permitting will need to be considered.
4) The Town should consider moving forward in a step-wise manner, gaining incremental consensus along the way, and advancing/finalizing the regional planning decisions regarding other communities participation and future wastewater flows. Prior to conducting much more additional study it would be appropriate to consider a meeting with DEP, Massachusetts Coastal Zone Management, Massachusetts Natural Heritage and Endangered Species Program and Massachusetts Division of Marine Fisheries staff.
5) Significant additional study will be required in order to successfully site an ocean outfall including: regulatory outreach; field survey; habitat review; subaqueous siting; potential piping alignments; hydrodynamic, particulate and pollutant modeling; long-term water quality data collection; precipitation recharge and water balance analysis; cost evaluations; NPDES permit applications; and public consultation program.
6) It would be our expectation that the public consultation process will be extensive and intensive and will focus on questions routinely raised at wastewater-related public meetings (e.g., water balance, growth impacts, inadvertent discharge of partially treated wastewater to surface water, water quality impacts, habitat impacts, beach impacts, etc.). In the context of the potential JBCC regional discharge to the Cape Cod Canal, the Buzzards Bay Coalition has gone on record stating that they would not support a net increase in nitrogen loading to Buzzards Bay.
7) EPA, DEP and CZM will require site-specific data and detailed environmental monitoring/modeling of the fate of conservative and non-conservative contaminates as well as detailed hydraulic/hydrodynamic modeling (e.g., computational fluid dynamics, CORMIX, Visual Plumes/ UM3, etc.) in order to determine actual dilution factor at any of these locations.
8) Long-term water quality monitoring will be needed to establish existing conditions for MADEP to make an anti-degradation determination.
9) The application and review process for a new surface water discharges should be expected to take at least 5 to 7 years and the successful conclusion is not assured. Since the OSA

was amended in 2014 to allow consideration of new or expanded ocean outfalls, there have been no new outfalls implemented, and we are not aware of any completed application yet submitted to the MADEP for consideration. There is no precedent to provide a basis for expectations of the regulatory success of this process.

10) If the Town desires to keep a potential outfall among its potential options, it would be appropriate to incorporate alternatives analyses that will be required to meet the OSA regulations into the on-going CWMP process.
11) There is a wide range of costs for the evaluated alternatives with a range of $82M to $327M. The Cape Cod Bay Outfall 004 is the lowest cost alternative. The most significant cost factor is the length of the subaqueous piping. There are many site-specific characteristics that will influence the capital cost of the various elements of the project; however, the length of the subaqueous piping is the most significant cost factor because it has the highest unit cost and because there is paucity of recent relevant bid data. Relatively few effluent outfalls get constructed and the characteristics of each outfall are usually unique.
12) Depending on the regional scenarios being considered with other towns as a part of the CWMP, it is conceivable that an outfall could be shared among towns with shared implementation costs.

REFERENCES

1) *Technical Support Document for Water Quality-Based Toxics Control*, U.S. EPA, 1992.
2) *Implementation Policy for Mixing Zone*, DEP, 1993.
3) *Draft Environmental Impact Statement, Wastewater Collection and Treatment Facilities, Sandwich, Massachusetts*, U.S. EPA, 1982.
4) Marshfield MA NPDES Permit, EPA Region 1, December 2014.
5) Scituate MA NPDES Permit, EPA Region 1, September 2012.
6) Ogunquit, ME MEPDES Permit, Maine DEP, November 2018
7) Old Orchard Beach, ME, MEPDES Permit Renewal, Maine DEP, June 2015
8) *Sanford Sewerage District, Ocean Outfall Dilution Estimates*, Wright-Pierce, March 1999
9) Mass GIS, TopoBathy – ESRI 2014
10) Center for Coastal Studies, internet site
11) *JBCC SWMS – Conceptual Cape Cod Canal Outfall Alternative*, Wright-Pierce, May 2019.
12) Others as noted within text of this memorandum

Appendix ZZ

Barnstable CWMP EENF

The Town of Barnstable
Department of Public Works
382 Falmouth Road, Hyannis, MA 02601
508.790.6400

Daniel W. Santos, P.E.
Director

Robert R. Steen, P.E.
Assistant Director

January 14, 2020

Secretary Kathleen A Theoharides
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
100 Cambridge Street, Suite 900
Boston, MA 02114

RE: Town of Barnstable Comprehensive Wastewater Management Plan
Expanded Environmental Notification Form

Dear Secretary Theoharides:

On behalf of the Town of Barnstable we are pleased to submit the attached Comprehensive Wastewater Management Plan (CWMP) and Expanded Environmental Notification Form (EENF) with a request for a Single Environmental Impact Report (SEIR) in accordance with MEPA regulations.

This CWMP is the culmination of years of wastewater planning efforts within the Town. The Town undertook this effort in order to address the multiple wastewater needs of the community. The recommended plan is a three-phase, 30-year plan, which includes substantial sewer expansion throughout the Town as well as non-traditional projects (which are anticipated to be submitted as a Notice of Project Change), in order to reduce nutrient loading to coastal waters and meet total maximum daily loads (TMDLs) for embayments. The plan also provides for fresh water pond and drinking water source protection, and supports sustainable growth.

Attached please find two copies of the CWMP and EENF. The appendices and an electronic copy of the CWMP have been provided on a flash drive, which can be found in the inside cover of the CWMP report. We look forward to continued coordination with MEPA on this important project. Please feel free to contact me with any questions regarding this document.

Sincerely,

Daniel W. Santos, P.E.

Commonwealth of Massachusetts

Executive Office of Energy and Environmental Affairs
Massachusetts Environmental Policy Act (MEPA) Office

Environmental Notification Form

For Office Use Only

EEA#: _____

MEPA Analyst: _____

The information requested on this form must be completed in order to submit a document electronically for review under the Massachusetts Environmental Policy Act, 301 CMR 11.00.

Project Name: Barnstable Comprehensive Wastewater Management Plan (CWMP)		
Street Address: Town-Wide		
Municipality: Barnstable	Watershed: Multiple (see report)	
Universal Transverse Mercator Coordinate:	Latitude: Town-wide Longitude: Town-wide	
Estimated commencement date: 7/1/2020	Estimated completion date: 7/1/2050	
Project Type: Town-wide CWMP	Status of project design: 10 %complete	
Proponent: Town of Barnstable		
Street Address: 367 Main Street		
Municipality: Barnstable (Hyannis)	State: MA	Zip Code: 02601
Name of Contact Person: Daniel W. Santos, P.E.		
Firm/Agency: Barnstable DPW	Street Address: 382 Falmouth Road	
Municipality: Barnstable (Hyannis)	State: MA	Zip Code: 02601
Phone: 508-790-6400	Fax: 508-790-6406	E-mail: daniel.santos@town.barnstable.ma.us

Does this project meet or exceed a mandatory EIR threshold (see 301 CMR 11.03)?
☒Yes ☐No

If this is an Expanded Environmental Notification Form (ENF) (see 301 CMR 11.05(7)) or a Notice of Project Change (NPC), are you requesting:

a Single EIR? (see 301 CMR 11.06(8))	☒Yes ☐No
a Special Review Procedure? (see 301CMR 11.09)	☐Yes ☒No
a Waiver of mandatory EIR? (see 301 CMR 11.11)	☐Yes ☒No
a Phase I Waiver? (see 301 CMR 11.11)	☐Yes ☒No

(Note: Greenhouse Gas Emissions analysis must be included in the Expanded ENF.)

Which MEPA review threshold(s) does the project meet or exceed (see 301 CMR 11.03)?
11.03(5)(a)(2) & 11.03(5)(a)(3)
Which State Agency Permits will the project require?
See Section 8.4 of Report
Identify any financial assistance or land transfer from an Agency of the Commonwealth, including the Agency name and the amount of funding or land area in acres:
Unknown at this time. Anticipate future applications for Clean Water SRF assistance.

Summary of Project Size & Environmental Impacts	Existing	Change	Total
LAND			
Total site acreage	N/A		
New acres of land altered		0	
Acres of impervious area	N/A	N/A	N/A
Square feet of new bordering vegetated wetlands alteration		0	
Square feet of new other wetland alteration		0	
Acres of new non-water dependent use of tidelands or waterways		0	
STRUCTURES			
Gross square footage	N/A	N/A	N/A
Number of housing units	N/A	N/A	N/A
Maximum height (feet)	N/A	N/A	N/A
TRANSPORTATION			
Vehicle trips per day	N/A	N/A	N/A
Parking spaces	N/A	N/A	N/A
WASTEWATER			
Water Use (Gallons per day)	N/A	N/A	N/A
Water withdrawal (GPD)	N/A	N/A	N/A
Wastewater generation/treatment (GPD)	1,670,000 (average daily flow to BWPCF)	1,914,500 (existing average daily flow of parcels to be sewered)	3,584,500
Length of water mains (miles)	N/A	N/A	N/A
Length of sewer mains (miles)	85	190	275

Has this project been filed with MEPA before?
☐ Yes (EEA #_____) ☒No

Has any project on this site been filed with MEPA before?
☐ Yes (EEA #_____) ☒No

GENERAL PROJECT INFORMATION – all proponents must fill out this section

PROJECT DESCRIPTION:

Describe the existing conditions and land uses on the project site: *The project site is the Town of Barnstable which is includes residential, commercial and limited industrial and agricultural land uses. The attached Comprehensive Wastewater Management Plan provides extensive detail on the Town's wastewater needs.*

Describe the proposed project and its programmatic and physical elements: *Project is a Town-wide Comprehensive Wastewater Management Plan. The details of the plan are explained in extensive detail in the attached Comprehensive Wastewater Management Plan, specifically in Section 5.*

Describe the on-site project alternatives (and alternative off-site locations, if applicable), considered by the proponent, including at least one feasible alternative that is allowed under current zoning, and the reasons(s) that they were not selected as the preferred alternative:
Section 8 of the attached Comprehensive Wastewater Management Plan describes the project alternative, which would be a "No Action" alternative. The Town considers the "No Action" alternative to be highly undesirable, irresponsible and inconsistent with the Local Comprehensive Plan of the Town and the Cape Cod community at large. In addition, the "No Action" alternative would result in regulatory issues for the Town as well as potential legal challenges.

Summarize the mitigation measures proposed to offset the impacts of the preferred alternative:
These mitigation measures are discussed in Section 8 of the attached Comprehensive Wastewater Management Plan.

If the project is proposed to be constructed in phases, please describe each phase:
The project is proposed to be constructed in phases. This is described in detail in Section 5 of the attached Comprehensive Wastewater Management Plan.

AREAS OF CRITICAL ENVIRONMENTAL CONCERN:

Is the project within or adjacent to an Area of Critical Environmental Concern?

☐ Yes (Specify_____)
☒ No

if yes, does the ACEC have an approved Resource Management Plan? ___ Yes ___ No;
If yes, describe how the project complies with this plan.

_____

Will there be stormwater runoff or discharge to the designated ACEC? ___ Yes ___ No;
If yes, describe and assess the potential impacts of such stormwater runoff/discharge to the designated ACEC.

_____

RARE SPECIES:

Does the project site include Estimated and/or Priority Habitat of State-Listed Rare Species? (see http://www.mass.gov/dfwele/dfw/nhesp/regulatory_review/priority_habitat/priority_habitat_home.htm)

☒ Yes (Specify_____) ☐ No

The project involves multiple projects that include the installation of sewer infrastructure, generally within right-of-ways, some of which are adjacent to mapped habitats.

HISTORICAL /ARCHAEOLOGICAL RESOURCES:

Does the project site include any structure, site or district listed in the State Register of Historic Place or the inventory of Historic and Archaeological Assets of the Commonwealth?

☒ Yes (Specify_____) ☐ No

The project is a Town-wide wastewater plan involving the installation of sewer infrastructure throughout the Town of Barnstable, which has numerous historic areas. When in historic districts, above ground components of the

projects (pump stations, etc.) may be subject to review, which is anticipated to be handled on a project by project basis. Candidate sites for these facilities will be reviewed against available mapping during preliminary design to determine if there are any anticipated historical / archaeological impacts.

If yes, does the project involve any demolition or destruction of any listed or inventoried historic or archaeological resources? ☐Yes (Specify_____) ☒No

The Town does not anticipate the project to involve any demolition or destruction of inventoried historic or archaeological resources.

WATER RESOURCES:

Is there an Outstanding Resource Water (ORW) on or within a half-mile radius of the project site? ___Yes _X__No;
if yes, identify the ORW and its location. _____

(NOTE: Outstanding Resource Waters include Class A public water supplies, their tributaries, and bordering wetlands; active and inactive reservoirs approved by MassDEP; certain waters within Areas of Critical Environmental Concern, and certified vernal pools. Outstanding resource waters are listed in the Surface Water Quality Standards, 314 CMR 4.00.)

Are there any impaired water bodies on or within a half-mile radius of the project site? _X__Yes ___No; if yes, identify the water body and pollutant(s) causing the impairment: *See attached list.*

Is the project within a medium or high stress basin, as established by the Massachusetts Water Resources Commission? ___Yes _X__No

STORMWATER MANAGEMENT:

Generally describe the project's stormwater impacts and measures that the project will take to comply with the standards found in MassDEP's Stormwater Management Regulations: *The project will have create minimal new impervious areas. Stormwater management BMPs will be incorporated as necessary for any new impervious surfaces.*

MASSACHUSETTS CONTINGENCY PLAN:

Has the project site been, or is it currently being, regulated under M.G.L.c.21E or the Massachusetts Contingency Plan? Yes ___ No _X__ ; if yes, please describe the current status of the site (including Release Tracking Number (RTN), cleanup phase, and Response Action Outcome classification):_____

The project involves multiple projects that include the installation of sewer infrastructure, generally within right-of-ways. Any properties that work is proposed on will be screened during the preliminary design process.

Is there an Activity and Use Limitation (AUL) on any portion of the project site? Yes ___ No ___;
if yes, describe which portion of the site and how the project will be consistent with the AUL:
_____.

Are you aware of any Reportable Conditions at the property that have not yet been assigned an RTN? Yes ___ No ___ ; if yes, please describe:_____

SOLID AND HAZARDOUS WASTE:

If the project will generate solid waste during demolition or construction, describe alternatives considered for re-use, recycling, and disposal of, e.g., asphalt, brick, concrete, gypsum, metal, wood: *Refer to Section 8.3.16 of the attached Comprehensive Wastewater Management Plan.*

Will your project disturb asbestos containing materials? Yes ___ No _X__ ;
if yes, please consult state asbestos requirements at http://mass.gov/MassDEP/air/asbhom01.htm

Describe anti-idling and other measures to limit emissions from construction equipment: *Refer to Section 8.3.16 of the attached Comprehensive Wastewater Management Plan.*

DESIGNATED WILD AND SCENIC RIVER:

Is this project site located wholly or partially within a defined river corridor of a federally designated Wild and Scenic River or a state designated Scenic River? Yes ___ No _X__ ;
if yes, specify name of river and designation:

If yes, does the project have the potential to impact any of the "outstandingly remarkable" resources of a federally Wild and Scenic River or the stated purpose of a state designated Scenic River?
Yes ___ No ___ ; if yes, specify name of river and designation: _____;
if yes, will the project will result in any impacts to any of the designated "outstandingly remarkable" resources of the Wild and Scenic River or the stated purposes of a Scenic River.
Yes ___ No ___ ;
if yes,describe the potential impacts to one or more of the "outstandingly remarkable" resources or stated purposes and mitigation measures proposed.

ATTACHMENTS:

1. List of all attachments to this document.
   Town of Barnstable Comprehensive Wastewater Management Plan (CWMP)
2. U.S.G.S. map (good quality color copy, 8-½ x 11 inches or larger, at a scale of 1:24,000) indicating the project location and boundaries.
   Locus Map provided in CWMP(Figure 1-1)
3.. Plan, at an appropriate scale, of existing conditions on the project site and its immediate environs, showing all known structures, roadways and parking lots, railroad rights-of-way, wetlands and water bodies, wooded areas, farmland, steep slopes, public open spaces, and major utilities.
   Numerous figures provided in CWMP
4 Plan, at an appropriate scale, depicting environmental constraints on or adjacent to the project site such as Priority and/or Estimated Habitat of state-listed rare species, Areas of Critical Environmental Concern, Chapter 91 jurisdictional areas, Article 97 lands, wetland resource area delineations, water supply protection areas, and historic resources and/or districts.
   Numerous figures provided in CWMP
5. Plan, at an appropriate scale, of proposed conditions upon completion of project (if construction of the project is proposed to be phased, there should be a site plan showing conditions upon the completion of each phase).
   Numerous figures provided in CWMP
6. List of all agencies and persons to whom the proponent circulated the ENF, in accordance with 301 CMR 11.16(2).
   List provided in CWMP.
7. List of municipal and federal permits and reviews required by the project, as applicable.
   List provided in Section 8.4 of CWMP.
8. *List of Impaired Waters in Town of Barnstable*

LAND SECTION – all proponents must fill out this section

I. Thresholds / Permits

A. Does the project meet or exceed any review thresholds related to **land** (see 301 CMR 11.03(1)
___ Yes _X__ No; if yes, specify each threshold:

II. Impacts and Permits

A. Describe, in acres, the current and proposed character of the project site, as follows:

	Existing	Change	Total
Footprint of buildings	_____	_____	_____
Internal roadways	_____	_____	_____
Parking and other paved areas	_____	_____	_____
Other altered areas	_____	_____	_____
Undeveloped areas	_____	_____	_____
Total: Project Site Acreage	_____	_____	_____

Project is a Town-wide wastewater plan which will generate minimal new impervious surfaces.

B. Has any part of the project site been in active agricultural use in the last five years?
___ Yes _X__ No; if yes, how many acres of land in agricultural use (with prime state or locally important agricultural soils) will be converted to nonagricultural use?

C. Is any part of the project site currently or proposed to be in active forestry use?
___ Yes _X__ No; if yes, please describe current and proposed forestry activities and indicate whether any part of the site is the subject of a forest management plan approved by the Department of Conservation and Recreation:

D. Does any part of the project involve conversion of land held for natural resources purposes in accordance with Article 97 of the Amendments to the Constitution of the Commonwealth to any purpose not in accordance with Article 97? ___ Yes _X__ No; if yes, describe:

E. Is any part of the project site currently subject to a conservation restriction, preservation restriction, agricultural preservation restriction or watershed preservation restriction? ___ Yes__X_ No; if yes, does the project involve the release or modification of such restriction? ___ Yes ___ No; if yes, describe:

F. Does the project require approval of a new urban redevelopment project or a fundamental change in an existing urban redevelopment project under M.G.L.c.121A? ___ Yes __X_ No; if yes, describe:

G. Does the project require approval of a new urban renewal plan or a major modification of an existing urban renewal plan under M.G.L.c.121B? Yes ___ No __X_; if yes, describe:

III. Consistency

A. Identify the current municipal comprehensive land use plan
Title: Town of Barnstable Comprehensive Plan 2010 Date: 2010

B. Describe the project's consistency with that plan with regard to:
1) economic development : Project will promote targeted economic development
2) adequacy of infrastructure: Project will improve sewer infrastructure
3) open space impacts: Project will have minimal impact on open space.
4) compatibility with adjacent land uses: Not applicable

C. Identify the current Regional Policy Plan of the applicable Regional Planning Agency (RPA)
RPA: Cape Cod Commission

Title: Cape Cod Regional Policy Plan Date: February 22, 2019

D. Describe the project's consistency with that plan with regard to:
1) economic development: Project will promote targeted economic development
2) adequacy of infrastructure: Project will improve sewer infrastructure
3) open space impacts: Project will have minimal impact on open space.

RARE SPECIES SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **rare species or habitat** (see 301 CMR 11.03(2))? ___ Yes __X_ No; if yes, specify, in quantitative terms:

(NOTE: If you are uncertain, it is recommended that you consult with the Natural Heritage and Endangered Species Program (NHESP) prior to submitting the ENF.)

B. Does the project require any state permits related to **rare species or habitat**? __ Yes _X__ No

C. Does the project site fall within mapped rare species habitat (Priority or Estimated Habitat?) in the current Massachusetts Natural Heritage Atlas (attach relevant page)? ___ Yes __X_ No.

D. If you answered "No" to all questions A, B and C, proceed to the **Wetlands, Waterways, and Tidelands Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Rare Species section below.

II. Impacts and Permits

A. Does the project site fall within Priority or Estimated Habitat in the current Massachusetts Natural Heritage Atlas (attach relevant page)? ___ Yes ___ No. If yes,
1. Have you consulted with the Division of Fisheries and Wildlife Natural Heritage and Endangered Species Program (NHESP)? ___Yes ___No; if yes, have you received a determination as to whether the project will result in the "take" of a rare species? ___ Yes ___ No; if yes, attach the letter of determination to this submission.

2. Will the project "take" an endangered, threatened, and/or species of special concern in accordance with M.G.L. c.131A (see also 321 CMR 10.04)? ___ Yes ___ No; if yes, provide a summary of proposed measures to minimize and mitigate rare species impacts

3. Which rare species are known to occur within the Priority or Estimated Habitat?

4. Has the site been surveyed for rare species in accordance with the Massachusetts Endangered Species Act? ___ Yes ___ No

4. If your project is within Estimated Habitat, have you filed a Notice of Intent or received an Order of Conditions for this project? ___ Yes ___ No; if yes, did you send a copy of the Notice of Intent to the Natural Heritage and Endangered Species Program, in accordance with the Wetlands Protection Act regulations? ___ Yes ___ No

B. Will the project "take" an endangered, threatened, and/or species of special concern in accordance with M.G.L. c.131A (see also 321 CMR 10.04)? ___ Yes ___ No; if yes, provide a summary of proposed measures to minimize and mitigate impacts to significant habitat:

WETLANDS, WATERWAYS, AND TIDELANDS SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **wetlands, waterways, and tidelands** (see 301 CMR 11.03(3))? ___ Yes _X__ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits (or a local Order of Conditions) related to **wetlands, waterways, or tidelands**? ___ Yes _X__ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Water Supply Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Wetlands, Waterways, and Tidelands Section below.

II. Wetlands Impacts and Permits

A. Does the project require a new or amended Order of Conditions under the Wetlands Protection Act (M.G.L. c.131A)? ___ Yes ___ No; if yes, has a Notice of Intent been filed? ___ Yes ___ No; if yes, list the date and MassDEP file number: _____; if yes, has a local Order of Conditions been issued? ___ Yes ___ No; Was the Order of Conditions appealed? ___ Yes ___ No. Will the project require a Variance from the Wetlands regulations? ___ Yes ___ No.

B. Describe any proposed permanent or temporary impacts to wetland resource areas located on the project site:

C. Estimate the extent and type of impact that the project will have on wetland resources, and indicate whether the impacts are temporary or permanent:

Coastal Wetlands	Area (square feet) or Length (linear feet)	Temporary or Permanent Impact?
Land Under the Ocean		
Designated Port Areas		
Coastal Beaches		
Coastal Dunes		
Barrier Beaches		
Coastal Banks		
Rocky Intertidal Shores		
Salt Marshes		
Land Under Salt Ponds		
Land Containing Shellfish		
Fish Runs		
Land Subject to Coastal Storm Flowage		
Inland Wetlands		
Bank (If)		
Bordering Vegetated Wetlands		
Isolated Vegetated Wetlands		
Land under Water		
Isolated Land Subject to Flooding		
Borderi ng Land Subject to Flooding		
Riverfront Area		

D. Is any part of the project:

1. proposed as a **limited project**? ___ Yes ___ No; if yes, what is the area (in sf)?____
2. the construction or alteration of a **dam**? ___ Yes ___ No; if yes, describe:
3. fill or structure in a **velocity zone** or **regulatory floodway**? ___ Yes ___ No

4. dredging or disposal of dredged material? ___ Yes ___ No; if yes, describe the volume of dredged material and the proposed disposal site:
5. a discharge to an **Outstanding Resource Water (ORW)** or an **Area of Critical Environmental Concern (ACEC)**? ___ Yes ___ No
6. subject to a wetlands restriction order? ___ Yes ___ No; if yes, identify the area (in sf):
7. located in buffer zones? ___Yes ___No; if yes, how much (in sf) _____

E. Will the project:
1. be subject to a local wetlands ordinance or bylaw? ___ Yes ___ No
2. alter any federally-protected wetlands not regulated under state law? ___ Yes ___ No; if yes, what is the area (sf)?

III. Waterways and Tidelands Impacts and Permits

A. Does the project site contain waterways or tidelands (including filled former tidelands) that are subject to the Waterways Act, M.G.L.c.91? ___ Yes ___ No; if yes, is there a current Chapter 91 License or Permit affecting the project site? ___ Yes ___ No; if yes, list the date and license or permit number and provide a copy of the historic map used to determine extent of filled tidelands:

B. Does the project require a new or modified license or permit under M.G.L.c.91? ___ Yes ___ No; if yes, how many acres of the project site subject to M.G.L.c.91 will be for non-water-dependent use? Current ___ Change ___ Total ___
If yes, how many square feet of solid fill or pile-supported structures (in sf)?

C. For non-water-dependent use projects, indicate the following:
Area of filled tidelands on the site:_____
Area of filled tidelands covered by buildings:_____
For portions of site on filled tidelands, list ground floor uses and area of each use:
_____
Does the project include new non-water-dependent uses located over flowed tidelands? Yes ___ No ___
Height of building on filled tidelands_____

Also show the following on a site plan: Mean High Water, Mean Low Water, Water-dependent Use Zone, location of uses within buildings on tidelands, and interior and exterior areas and facilities dedicated for public use, and historic high and historic low water marks.

D. Is the project located on landlocked tidelands? ___ Yes ___ No; if yes, describe the project's impact on the public's right to access, use and enjoy jurisdictional tidelands and describe measures the project will implement to avoid, minimize or mitigate any adverse impact:

E. Is the project located in an area where low groundwater levels have been identified by a municipality or by a state or federal agency as a threat to building foundations? ___Yes ___ No; if yes, describe the project's impact on groundwater levels and describe measures the project will implement to avoid, minimize or mitigate any adverse impact:

F. Is the project non-water-dependent **and** located on landlocked tidelands **or** waterways or tidelands subject to the Waterways Act **and** subject to a mandatory EIR? ___ Yes ___ No;
(NOTE: If yes, then the project will be subject to Public Benefit Review and Determination.)

G. Does the project include dredging? ___ Yes ___ No; if yes, answer the following questions:
What type of dredging? Improvement ___ Maintenance ___ Both ____

What is the proposed dredge volume, in cubic yards (cys) _____
What is the proposed dredge footprint ____length (ft) ___width (ft)____depth (ft);
Will dredging impact the following resource areas?

Intertidal Yes__ No__; if yes, ___ sq ft
Outstanding Resource Waters Yes__ No__; if yes, ___ sq ft
Other resource area (i.e. shellfish beds, eel grass beds) Yes__ No__; if yes __ sq ft
If yes to any of the above, have you evaluated appropriate and practicable steps to: 1) avoidance; 2) if avoidance is not possible, minimization; 3) if either avoidance or minimize is not possible, mitigation?
If no to any of the above, what information or documentation was used to support this determination?

Provide a comprehensive analysis of practicable alternatives for improvement dredging in accordance with 314 CMR 9.07(1)(b). Physical and chemical data of the sediment shall be included in the comprehensive analysis.
Sediment Characterization

Existing gradation analysis results? __Yes ___No: if yes, provide results.
Existing chemical results for parameters listed in 314 CMR 9.07(2)(b)6? ___Yes ____No; if yes, provide results.

Do you have sufficient information to evaluate feasibility of the following management options for dredged sediment? If yes, check the appropriate option.

Beach Nourishment ___
Unconfined Ocean Disposal ___
Confined Disposal:
Confined Aquatic Disposal (CAD) ___
Confined Disposal Facility (CDF) ___
Landfill Reuse in accordance with COMM-97-001 ___
Shoreline Placement ___
Upland Material Reuse____
In-State landfill disposal____
Out-of-state landfill disposal ____
(NOTE: This information is required for a 401 Water Quality Certification.)

IV. Consistency:

A. Does the project have effects on the coastal resources or uses, and/or is the project located within the Coastal Zone? ___ Yes ___ No; if yes, describe these effects and the projects consistency with the policies of the Office of Coastal Zone Management:

B. Is the project located within an area subject to a Municipal Harbor Plan? ___ Yes ___ No; if yes, identify the Municipal Harbor Plan and describe the project's consistency with that plan:

WATER SUPPLY SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **water supply** (see 301 CMR 11.03(4))? ___ Yes __X_ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **water supply**? ___ Yes _X__ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Wastewater Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Water Supply Section below.

II. Impacts and Permits

A. Describe, in gallons per day (gpd), the volume and source of water use for existing and proposed activities at the project site:

	Existing	Change	Total
Municipal or regional water supply	_____	_____	_____
Withdrawal from groundwater	_____	_____	_____
Withdrawal from surface water	_____	_____	_____
Interbasin transfer	_____	_____	_____

(NOTE: Interbasin Transfer approval will be required if the basin and community where the proposed water supply source is located is different from the basin and community where the wastewater from the source will be discharged.)

B. If the source is a municipal or regional supply, has the municipality or region indicated that there is adequate capacity in the system to accommodate the project? ___ Yes ___ No

C. If the project involves a new or expanded withdrawal from a groundwater or surface water source, has a pumping test been conducted? ___ Yes ___ No; if yes, attach a map of the drilling sites and a summary of the alternatives considered and the results. _____

D. What is the currently permitted withdrawal at the proposed water supply source (in gallons per day)? _____Will the project require an increase in that withdrawal? ___Yes ___No; if yes, then how much of an increase (gpd)? _____

E. Does the project site currently contain a water supply well, a drinking water treatment facility, water main, or other water supply facility, or will the project involve construction of a new facility? ___ Yes ___No. If yes, describe existing and proposed water supply facilities at the project site:

	Permitted Flow	Existing Avg Daily Flow	Project Flow	Total
Capacity of water supply well(s) (gpd)	_____	_____	_____	_____
Capacity of water treatment plant (gpd)	_____	_____	_____	_____

F. If the project involves a new interbasin transfer of water, which basins are involved, what is the direction of the transfer, and is the interbasin transfer existing or proposed?

G. Does the project involve:

1. new water service by the Massachusetts Water Resources Authority or other agency of the Commonwealth to a municipality or water district? ___ Yes ___ No
2. a Watershed Protection Act variance? ___ Yes ___ No; if yes, how many acres of alteration?
3. a non-bridged stream crossing 1,000 or less feet upstream of a public surface drinking

water supply for purpose of forest harvesting activities? ___ Yes ___ No

III. Consistency

Describe the project's consistency with water conservation plans or other plans to enhance water resources, quality, facilities and services:

WASTEWATER SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **wastewater** (see 301 CMR 11.03(5))? _X__ Yes ___ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **wastewater**? _X__ Yes ___ No; if yes, specify which permit: *See section 8.4 of CWMP*

C. If you answered "No" to both questions A and B, proceed to the **Transportation -- Traffic Generation Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Wastewater Section below.

II. Impacts and Permits

A. Describe the volume (in gallons per day) and type of disposal of wastewater generation for existing and proposed activities at the project site (calculate according to 310 CMR 15.00 for septic systems or 314 CMR 7.00 for sewer systems):

	Existing	Change	Total
Discharge of sanitary wastewater	1,670,000	1,914,500	3,584,500
Discharge of industrial wastewater			
TOTAL	1,670,000	1,914,500	3,584,500

	Existing	Change	Total
Discharge to groundwater			
Discharge to outstanding resource water			
Discharge to surface water			
Discharge to municipal or regional wastewater facility	1,670,000	1,914,500	3,584,500
TOTAL	1,670,000	1,914,500	3,584,500

ABOVE FLOWS ARE AVERAGE DAILY FLOWS

B. Is the existing collection system at or near its capacity? ___ Yes _X__ No; if yes, then describe the measures to be undertaken to accommodate the project's wastewater flows:

C. Is the existing wastewater disposal facility at or near its permitted capacity? _X__ Yes___ No; if yes, then describe the measures to be undertaken to accommodate the project's wastewater flows: *Discussed at length in CWMP.*

D. Does the project site currently contain a wastewater treatment facility, sewer main, or other wastewater disposal facility, or will the project involve construction of a new facility? _X__ Yes ___ No; if yes, describe as follows:

	Permitted	Existing Avg Daily Flow	Project Flow	Total
Wastewater treatment plant capacity (in gallons per day)	2,700,000	1,670,000	1,914,500	3,584,500

ABOVE FLOWS ARE AVERAGE DAILY FLOWS

E. If the project requires an interbasin transfer of wastewater, which basins are involved, what is the direction of the transfer, and is the interbasin transfer existing or new?

The project will involve interbasin transfer of wastewater and treated effluent. Wastewater will be collected from the Halls Creek, Centerville River, Three Bays, Popponesset Bay, and Barnstable Harbor Watersheds will be treated at the Barnstable Water Pollution Control Facility (BWPCF) in Lewis Bay Watershed. Treated effluent will be disposed of at the BWPCF and likely at a yet to be determined supplemental disposal location (watershed undetermined at this time).

F. Does the project involve new sewer service by the Massachusetts Water Resources Authority (MWRA) or other Agency of the Commonwealth to a municipality or sewer district? ___ Yes _X_ No

G. Is there an existing facility, or is a new facility proposed at the project site for the storage, treatment, processing, combustion or disposal of sewage sludge, sludge ash, grit, screenings, wastewater reuse (gray water) or other sewage residual materials? _X__ Yes ___ No; if yes, what is the capacity (tons per day):

	Existing	Change	Total
Storage			
Treatment			
Processing			
Combustion			
Disposal			

H. Describe the water conservation measures to be undertaken by the project, and other wastewater mitigation, such as infiltration and inflow removal.

III. Consistency

A. Describe measures that the proponent will take to comply with applicable state, regional, and local plans and policies related to wastewater management: *This project is the Town's Comprehensive Wastewater Management Plan and is intended to be an effort to comply with federal, state, and regional plans/policies related to wastewater management.*

B. If the project requires a sewer extension permit, is that extension included in a comprehensive wastewater management plan? ___ Yes ___ No; if yes, indicate the EEA number for the plan and whether the project site is within a sewer service area recommended or approved in that plan: *Project is a comprehensive wastewater management plan.*

TRANSPORTATION SECTION (TRAFFIC GENERATION)

I. Thresholds / Permit

A. Will the project meet or exceed any review thresholds related to **traffic generation** (see 301 CMR 11.03(6))? ___ Yes __X_ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **state-controlled roadways**? __X_ Yes ___ No; if yes, specify which permit: *Portions of the project will require access permits to install infrastructure within state highways.*

C. If you answered "No" to both questions A and B, proceed to the **Roadways and Other Transportation Facilities Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Traffic Generation Section below.

II. Traffic Impacts and Permits

A. Describe existing and proposed vehicular traffic generated by activities at the project site:

	Existing	Change	Total
Number of parking spaces	_____	_____	_____
Number of vehicle trips per day	_____	_____	_____
ITE Land Use Code(s):	_____	_____	_____

B. What is the estimated average daily traffic on roadways serving the site?

Roadway	Existing	Change	Total
1. _____	_____	_____	_____
2. _____	_____	_____	_____
3. _____	_____	_____	_____

C. If applicable, describe proposed mitigation measures on state-controlled roadways that the project proponent will implement:

D. How will the project implement and/or promote the use of transit, pedestrian and bicycle facilities and services to provide access to and from the project site?

C. Is there a Transportation Management Association (TMA) that provides transportation demand management (TDM) services in the area of the project site? ____ Yes ____ No; if yes, describe if and how will the project will participate in the TMA:

D. Will the project use (or occur in the immediate vicinity of) water, rail, or air transportation facilities? ____ Yes ____ No; if yes, generally describe:

E. If the project will penetrate approach airspace of a nearby airport, has the proponent filed a Massachusetts Aeronautics Commission Airspace Review Form (780 CMR 111.7) and a Notice of Proposed Construction or Alteration with the Federal Aviation Administration (FAA) (CFR Title 14 Part 77.13, forms 7460-1 and 7460-2)?

III. Consistency

Describe measures that the proponent will take to comply with municipal, regional, state, and federal plans and policies related to traffic, transit, pedestrian and bicycle transportation facilities and services:

TRANSPORTATION SECTION (ROADWAYS AND OTHER TRANSPORTATION FACILITIES)

I. Thresholds

A. Will the project meet or exceed any review thresholds related to **roadways or other transportation facilities** (see 301 CMR 11.03(6))? ___ Yes _X__ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **roadways or other transportation facilities**? __X_ Yes ___ No; if yes, specify which permit: *Portions of the project will require access permits to install infrastructure within state highways.*

C. If you answered "No" to both questions A and B, proceed to the **Energy Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Roadways Section below.

II. Transportation Facility Impacts

A. Describe existing and proposed transportation facilities in the immediate vicinity of the project site:

B. Will the project involve any

1. Alteration of bank or terrain (in linear feet)? _____
2. Cutting of living public shade trees (number)? _____
3. Elimination of stone wall (in linear feet)? _____

III. Consistency -- Describe the project's consistency with other federal, state, regional, and local plans and policies related to traffic, transit, pedestrian and bicycle transportation facilities and services, including consistency with the applicable regional transportation plan and the Transportation Improvements Plan (TIP), the State Bicycle Plan, and the State Pedestrian Plan:

ENERGY SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **energy** (see 301 CMR 11.03(7))? ___ Yes _X__ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **energy**? ___ Yes _X__ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Air Quality Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Energy Section below.

II. Impacts and Permits

A. Describe existing and proposed energy generation and transmission facilities at the project site:

	Existing	Change	Total
Capacity of electric generating facility (megawatts)	_____	_____	_____
Length of fuel line (in miles)	_____	_____	_____
Length of transmission lines (in miles)	_____	_____	_____
Capacity of transmission lines (in kilovolts)	_____	_____	_____

B. If the project involves construction or expansion of an electric generating facility, what are:

1. the facility's current and proposed fuel source(s)?
2. the facility's current and proposed cooling source(s)?

C. If the project involves construction of an electrical transmission line, will it be located on a new, unused, or abandoned right of way? ___Yes ___No; if yes, please describe:

D. Describe the project's other impacts on energy facilities and services:

III. Consistency

Describe the project's consistency with state, municipal, regional, and federal plans and policies for enhancing energy facilities and services:

AIR QUALITY SECTION

I. Thresholds

A. Will the project meet or exceed any review thresholds related to **air quality** (see 301 CMR 11.03(8))? ___ Yes _X__ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **air quality**? ___ Yes _X__ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Solid and Hazardous Waste Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Air Quality Section below.

II. Impacts and Permits

A. Does the project involve construction or modification of a major stationary source (see 310 CMR 7.00, Appendix A)? ___ Yes ___ No; if yes, describe existing and proposed emissions (in tons per day) of:

	Existing	Change	Total
Particulate matter			
Carbon monoxide			
Sulfur dioxide			
Volatile organic compounds			
Oxides of nitrogen			
Lead			
Any hazardous air pollutant			
Carbon dioxide			

B. Describe the project's other impacts on air resources and air quality, including noise impacts:

III. Consistency

A. Describe the project's consistency with the State Implementation Plan:

B. Describe measures that the proponent will take to comply with other federal, state, regional, and local plans and policies related to air resources and air quality:

SOLID AND HAZARDOUS WASTE SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **solid or hazardous waste** (see 301 CMR 11.03(9))? ___ Yes _X__ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **solid and hazardous waste**? ___ Yes _X__ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Historical and Archaeological Resources Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Solid and Hazardous Waste Section below.

II. Impacts and Permits

A. Is there any current or proposed facility at the project site for the storage, treatment, processing, combustion or disposal of solid waste? ___ Yes ___ No; if yes, what is the volume (in tons per day) of the capacity:

	Existing	Change	Total
Storage			
Treatment, processing			
Combustion			
Disposal			

B. Is there any current or proposed facility at the project site for the storage, recycling, treatment or disposal of hazardous waste? ___ Yes ___ No; if yes, what is the volume (in tons or gallons per day) of the capacity:

	Existing	Change	Total
Storage			
Recycling			
Treatment			
Disposal			

C. If the project will generate solid waste (for example, during demolition or construction), describe alternatives considered for re-use, recycling, and disposal:

D. If the project involves demolition, do any buildings to be demolished contain asbestos? ___ Yes ___ No

E. Describe the project's other solid and hazardous waste impacts (including indirect impacts):

III. Consistency

Describe measures that the proponent will take to comply with the State Solid Waste Master Plan:

HISTORICAL AND ARCHAEOLOGICAL RESOURCES SECTION

I. Thresholds / Impacts

A. Have you consulted with the Massachusetts Historical Commission? ___ Yes _X__ No; if yes, attach correspondence. For project sites involving lands under water, have you consulted with the Massachusetts Board of Underwater Archaeological Resources? ____Yes ____ No; if yes, attach correspondence

B. Is any part of the project site a historic structure, or a structure within a historic district, in either case listed in the State Register of Historic Places or the Inventory of Historic and Archaeological Assets of the Commonwealth? ___ Yes ___ No; if yes, does the project involve the demolition of all or any exterior part of such historic structure? ___ Yes ___ No; if yes, please describe:

C. Is any part of the project site an archaeological site listed in the State Register of Historic Places or the Inventory of Historic and Archaeological Assets of the Commonwealth? ___ Yes ___ No; if yes, does the project involve the destruction of all or any part of such archaeological site? ___ Yes ___ No; if yes, please describe:

D. If you answered "No" to all parts of both questions A, B and C, proceed to the **Attachments and Certifications** Sections. If you answered "Yes" to any part of either question A or question B, fill out the remainder of the Historical and Archaeological Resources Section below.

II. Impacts

Describe and assess the project's impacts, direct and indirect, on listed or inventoried historical and archaeological resources:
The project is a Town-wide wastewater plan involving the installation of sewer infrastructure throughout the Town of Barnstable, which has numerous historic areas. When in historic districts, above ground components of the projects (pump stations, etc.) may be subject to review, which is anticipated to be handled on a project by project basis. Candidate sites for these facilities will be reviewed against available mapping during preliminary design to determine if there are any anticipated historical / archaeological impacts.

III. Consistency

Describe measures that the proponent will take to comply with federal, state, regional, and local plans and policies related to preserving historical and archaeological resources: *Candidate sites for these facilities will be reviewed against available mapping during preliminary design to determine if there are any anticipated historical / archaeological impacts.*

CERTIFICATIONS:

1. The Public Notice of Environmental Review has been/will be published in the following newspapers in accordance with 301 CMR 11.15(1):

   (Name) Cape Cod Times (Date) January 17, 2020

2. This form has been circulated to Agencies and Persons in accordance with 301 CMR 11.16(2).

Signatures:

1/14/20 Daniel W. Santos P.E.

Date Signature of Responsible Officer or Proponent

Date Signature of person preparing ENF (if different from above)

Daniel W. Santos, P.E.
Name (print or type)

Name (print or type)

Barnstable Department of Public Works
Firm/Agency

Firm/Agency

382 Falmouth Road
Street

Street

Hyannis/MA/02601
Municipality/State/Zip

Municipality/State/Zip

508-790-6400
Phone

Phone

Attachment: Town of Barnstable Impaired Waters*

Location	Category	Pollutants addressed by TMDL
Bearses Pond	4a	Mercury in Fish Tissue
Bumps River	4a	Fecal Coliform
Centerville River	4a	Estuarine Bioassessments
		Fecal Coliform
		Nitrogen (Total)
Cotuit Bay	4a	Fecal Coliform
		Nitrogen (Total)
Halls Creek	4a	Fecal Coliform
Hyannis Harbor	4a	Fecal Coliform
Maraspin Creek	4a	Fecal Coliform
Mill Creek	4a	Fecal Coliform
North Bay	4a	Estuarine Bioassessments
		Fecal Coliform
Popponesset Bay	4a	Estuarine Bioassessments
Prince Cove	4a	Estuarine Bioassessments
		Fecal Coliform
Santuit River	4a	Fecal Coliform
Seapuit River	4a	Fecal Coliform
Shoestring Bay	4a	Estuarine Bioassessments
		Fecal Coliform
Snows Creek	4a	Fecal Coliform
Stewarts Creek	4a	Fecal Coliform
Wequaquet Lake	4a	Mercury in Fish Tissue
West Bay	4a	Estuarine Bioassessments
Barnstable Harbor	5	Estuarine Bioassessments
		Fecal Coliform
Hamblin Pond	5	Mercury in Fish Tissue
		Dissolved Oxygen
Hyannis Inner Harbor	5	Fecal Coliform
		Nitrogen (Total)
Lewis Bay	5	Estuarine Bioassessments
		Fecal Coliform
Lovells Pond	5	Chlorophyll-a
		Excess Algal Growth
		Oxygen Dissolved
		Phosphorus (Total)
		Secchi disk transparancy
Middle Pond	5	Oxygen Dissolved
Mystic Lake	5	Oxygen Dissolved
Red Lily Pond	5	Fecal Coliform
		Nutrient/Eutrophication Biological Indicators

*Compiled from Massachusetts Year 2014 Integrated List of Waters

Town of Barnstable Comprehensive Wastewater Management Plan

Distribution List

A copy of the CWMP/EENF has been sent to the following:

Secretary of Energy and Environmental Affairs
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
100 Cambridge Street, Suite 900
Boston MA 02114

Mass DEP- Boston
Commissioner's Office
One Winter Street, 2nd Floor
Boston, MA 02108

MassDEP Southeastern Regional Office
20 Riverside Drive Lakeville, MA 02347
Attention: MEPA Unit

Massachusetts Department of Transportation
Public/Private Development Unit 10 Park Plaza, Suite #4150 Boston, MA 02116

Massachusetts Department of Transportation
District #5
Box 111
1000 County Street
Taunton, MA 02780
Attn: MEPA Coordinator

Cape Cod Commission
3225 Main Street
P.O. Box 226
Barnstable, MA 02630

Massachusetts Historical Commission
The MA Archives Building
220 Morrissey Boulevard
Boston, MA 02125
Attn: Ms. Brona Simon

Coastal Zone Management
Attn: Project Review Coordinator
251 Causeway Street, Suite 800
Boston, MA 02114

Division of Marine Fisheries (South Shore)
Attn: Environmental Reviewer
836 South Rodney French BLVD
New Bedford, MA, 02744

Department of Agricultural Resources
Attn: MEPA Coordinator
138 Memorial Avenue, Suite 42
West Springfield, MA 01089

Natural Heritage and Endangered Species Program
Massachusetts Division of Fisheries & Wildlife
1 Rabbit Hill Road
Westborough, MA 01581

Energy Facilities Siting Board
Attn: MEPA Coordinator
One South Station
Boston, MA 02110

Department of Energy Resources
Attn: MEPA Coordinator
100 Cambridge Street, 10th floor
Boston, MA 02114

Department of Public Health
Director of Environmental Health
250 Washington Street
Boston, MA 02115

DCR
Attn: MEPA Coordinator
251 Causeway St. Suite 600
Boston MA 02114

Town of Mashpee
Board of Selectmen
Mashpee Town Hall
16 Great Neck Road North
Mashpee, MA 02649

Town of Mashpee
Conservation
16 Great Neck Road North
Mashpee, MA 02649

Town of Mashpee
Board of Health
16 Great Neck Road North
Mashpee, MA 02649

Town of Mashpee
Planning Board
16 Great Neck Road North
Mashpee, MA 0264

Town of Sandwich
Planning and Development
16 Jan Sebastian Drive
Sandwich, MA 02563

Town of Sandwich
Conservation Commission
16 Jan Sebastian Drive
Sandwich, MA 02563

Town of Sandwich
Health Department
16 Jan Sebastian Drive
Sandwich, MA 02563

Town of Sandwich
Board of Selectman
130 Main Street
Sandwich, MA 02563

Town of Yarmouth
Board of Selectman
1146 Route 28
South Yarmouth, MA 02664

Town of Yarmouth
Planning Division
1146 Route 28
South Yarmouth, MA 02664

Town of Yarmouth
Conservation
1146 Route 28
South Yarmouth, MA 02664

Town of Yarmouth
Health Department
1146 Route 28
South Yarmouth, MA 02664

Town of Yarmouth
Department of Public Works
1146 Route 28
South Yarmouth, MA 02664

Town of Yarmouth
Town Administrator
1146 Route 28
South Yarmouth, MA 02664

Town of Barnstable
Town Council
367 Main St
Hyannis, MA 02601

Town of Barnstable
Planning and Development
367 Main St
Hyannis, MA 02601

Town of Barnstable
Conservation
200 Main St
Hyannis, MA 02601

Town of Barnstable
Health Division
200 Main St
Hyannis, MA 02601

Commonwealth of Massachusetts
Executive Office of Energy and Environmental Affairs

MEPA Office

100 Cambridge St., Suite 900
Boston, MA 02114
Telephone 617-626-1020

The following should be completed and submitted to a local newspaper:

PUBLIC NOTICE OF ENVIRONMENTAL REVIEW

PROJECT: Town of Barnstable Comprehensive Wastewater Management Plan

LOCATION: Town of Barnstable, Town-wide

PROPONENT: Town of Barnstable

The undersigned is submitting an Expanded Environmental Notification Form ("EENF") to the Secretary of Energy & Environmental Affairs on or before January 12, 2020

This will initiate review of the above project pursuant to the Massachusetts Environmental Policy Act ("MEPA", M.G.L. c. 30, s.s. 61-62I). Copies of the EENF may be obtained from:
Town of Barnstable Department of Public Works
Attn: Griffin Beaudoin, P.E., Town Engineer
382 Falmouth Road, Hyannis, MA 02601
(508)-790-6400

Copies of the EENF are also being sent to the Conservation Commission and Planning Board of The Town of Barnstable **where they may be inspected.**

The Secretary of Energy & Environmental Affairs will publish notice of the EENF in the Environmental Monitor, will receive public comments on the project for 30 days, and will then decide, within seven days, if an Environmental Impact Report is needed. A site visit and consultation session on the project may also be scheduled. All persons wishing to comment on the project, or to be notified of a site visit or consultation session, should write to the Secretary of Energy & Environmental Affairs, 100 Cambridge St., Suite 900, Boston, Massachusetts 02114, Attention: MEPA Office, referencing the above project.

By: Town of Barnstable Department of Public Works

Appendix AAA

Secretary Certificate, April 3, 2020

The Commonwealth of Massachusetts
Executive Office of Energy and Environmental Affairs
100 Cambridge Street, Suite 900
Boston, MA 02114

Charles D. Baker
GOVERNOR

Karyn E. Polito
LIEUTENANT GOVERNOR

Kathleen A. Theoharides
SECRETARY

Tel: (617) 626-1000
Fax: (617) 626-1081
http://www.mass.gov/eea

April 3, 2020

CERTIFICATE OF THE SECRETARY OF ENERGY AND ENVIRONMENTAL AFFAIRS
ON THE
EXPANDED ENVIRONMENTAL NOTIFICATION FORM

PROJECT NAME	: Barnstable Comprehensive Wastewater Management Plan
PROJECT MUNICIPALITY	: Barnstable
PROJECT WATERSHED	: Cape Cod
EEA NUMBER	: 16148
PROJECT PROPONENT	: Town of Barnstable
DATE NOTICED IN MONITOR	: February 10, 2020

Pursuant to the Massachusetts Environmental Policy Act (MEPA; M.G. L. c. 30, ss. 61-62I) and Section 11.06 of the MEPA regulations (301 CMR 11.00), I have reviewed the Expanded Environmental Notification Form (EENF) and hereby determine that this project **requires** the submission of an Environmental Impact Report (EIR). The EENF was submitted to support the Proponent's request to file a Single EIR, rather than a Draft and Final EIR, pursuant to Section 11.06(8) of the MEPA regulations. The Proponent should submit a Single EIR in accordance with the Scope included in this Certificate.

Project Description

The EENF/Comprehensive Wastewater Management Plan (CWMP) described the Town of Barnstable's plan to address water quality management concerns resulting from population growth and increased development. The CWMP is a 30-year plan focused on traditional sewering solutions to replace the current dependence on septic systems; these solutions will be implemented in three 10-year phases. The plan has been designed to address multiple goals and needs of the community, specifically: nutrient removal, pond protection, drinking water protection, economic development and other related concerns regarding wastewater management.

Project Site

The Town of Barnstable is located in the central section of Cape Cod. Its year-round population is 45,193 (US Census 2010) while seasonal population can grow to more than three times that amount. The Town is organized into seven villages, and contains eight watersheds (no geographic relationship to the villages) including the Popponesset Bay Watershed, Rushy Marsh Watershed, Three Bays System Watershed, Centerville River System Watershed, Halls Creek Watershed, Lewis Bay Watershed, Barnstable Harbor Watershed and a very small portion of the Scorton Creek Watershed. Of these watersheds, three are contained solely within the Town's borders (Centerville River System Watershed, Halls Creek Watershed and Rushy Marsh Watershed), while the rest are shared with neighboring communities. Five of the eight watersheds have a Total Maximum Daily Load (TMDL) for nitrogen.

A TMDL is the maximum pollutant load a water body can receive and still meet water quality standards. TMDLs are created through a cooperative process involving multiple agencies. In the example of establishing TMDLs for nitrogen on Cape Cod, the process began with the Massachusetts Estuaries Project (MEP), a collaborative effort among MassDEP, University of Massachusetts School of Marine Science and Technology (SMAST), and the United States Geological Survey (USGS). The MEP developed nitrogen thresholds for 70 estuaries in Southeast Massachusetts using a water quality model that predicts water quality changes resulting from land use decisions. The model is run with different watershed loading values to demonstrate that the "nitrogen threshold" can be met, which is the upper limit of nitrogen loading that can enter the estuary and still meet water quality goals. Once MEP has established the nitrogen thresholds, MassDEP takes those numbers and prepares a draft TMDL for the water body. The draft TMDLs are then sent to the United States Environmental Protection Agency (USEPA) for approval; after such approval, the TMDLs become enforceable. As of the submittal date of the EENF/CWMP, TMDLs are in place for Popponesset Bay, Scorton Creek, the Three Bays System, the Centerville River System, Halls Creek, and Lewis Bay.

The Town's existing wastewater infrastructure includes the Barnstable Water Pollution Control Facility (BWPCF) located in Hyannis and a smaller wastewater plant in Marstons Mills referred to as the Marstons Mills Wastewater Treatment Plant (MMWWTP). The BWPCF treats an average daily flow of 1.67 million gallons per day (mgd) and has a maximum-month average daily flow of 1.97 mgd (2018 flow data). The BWPCF is permitted for a treatment capacity of 4.2 MGD and an effluent disposal capacity of 2.7 mgd.

The Federal Emergency Management Agency (FEMA) prepared a series of Flood Insurance Rate Maps (FIRM), effective July 16, 2014, that depict flood zones across the town. Coastal Flood Zones with Velocity Hazard (VE zone) are located along the Town's northern and southern coasts and the 100-year flood plain extends landward from the coasts with varying Base Flood Elevations (BFE).

Permitting and Jurisdiction

The project is undergoing MEPA review and is subject to preparation of a mandatory EIR pursuant to 301 CMR 11.03(5)(a)(3) of the MEPA regulations because it requires State Agency

Actions and involves the construction of one or more new sewer mains of ten or more miles in length. The project also exceeds the ENF threshold at 301 CMR 11.03(3)(b)(1)(f) because it involves the alteration of one half or more acres of any other wetlands. The project requires a Sewer Connection/Extension Permit and Groundwater Discharge Permit from Massachusetts Department of Environmental Protection (MassDEP) and a State Highway Access Permit from the Massachusetts Department of Transportation (MassDOT).

The project also requires review under the Massachusetts Endangered Species Act (MESA) by the Natural Heritage Endangered Species Program (NHESP) and review by the Massachusetts Historical Commission under Section 106 of the National Historic Preservation Act of 1966 and M.G.L. Chapter 9, sections 26-27C (950 CMR 70-71). The project may require Federal Consistency Review with the Massachusetts Coastal Zone Management Office. It is subject to review under the May 2010 MEPA Greenhouse Gas (GHG) Emissions Policy and Protocol ("the Policy").

The project will require an Order of Conditions (OC) from the Barnstable Conservation Commission (or in the case of an appeal, a Superseding Order of Conditions (SOC) from MassDEP). The project is subject to review by the Cape Cod Commission (CCC) to determine its consistency with the Section 208 Area-wide Water Quality Management Plan. The project will also require a National Pollutant Discharge Elimination System (NPDES) Construction Activities Permit from the U.S. Environmental Protection Agency (EPA) and authorizations from the U.S. Army Corps of Engineers (ACOE) under the General Permits for Massachusetts.

The Town will receive Financial Assistance from the Commonwealth through the State Revolving Fund (SRF). Therefore, MEPA jurisdiction is broad and extends to all aspects of the project with the potential to cause Damage to the Environment as defined in the MEPA regulations.

Environmental Impacts

As described in the EENF, implementation of the CWMP Recommended Plan will add one acre of impervious area and impact 390,000 sf (8.95 acres) of Land Subject to Coastal Storm Flowage (LSCSF) and 10,000 sf (0.22 acres) of Bordering Land Subject to Flooding (BLSF) for the proposed sewer infrastructure installation.

The project is intended to improve aquatic health and water quality by providing more effective wastewater treatment. Measures to avoid minimize, and mitigate project impacts include the use of erosion and sediment control measures during construction, and limiting areas of disturbance by locating work within previously disturbed areas where possible. Additional mitigation commitments should be identified in the Single EIR.

Single EIR Request

The Town requested that it be allowed to file a Single EIR in lieu of a Draft and Final EIR. The MEPA regulations indicate a Single EIR may be allowed, provided I find that the EENF:

a) describes and analyzes all aspects of the project and all feasible alternatives, regardless of any jurisdictional or other limitation that may apply to the Scope;

b) provides a detailed baseline in relation to which potential environmental impacts and mitigation measures can be assessed; and,

c) demonstrates that the planning and design of the Project use all feasible means to avoid potential environmental impacts.

The Proponent submitted an EENF to satisfy the requirements for a Single EIR and, as required, the EENF was subject to an extended comment period. In addition, a two-week extension of the 30-day comment period was granted at the request of the Town to prepare and distribute supplemental information.[1] The comment period closed on March 27, 2020. The EENF provided a detailed project description, a baseline for evaluating environmental impacts and a comprehensive alternatives analysis. The EENF identified how the project is designed to achieve consistency with regulatory standards, including water quality standards and measures to avoid, minimize and mitigate project impacts. Comments from MassDEP, NHESP and the Cape Cod Commission (CCC) identify issues that can be addressed in a Single EIR.

Special Review Procedure

While the Town's initial CWMP may be reviewed at a master planning level through a Single EIR, the plan sets forth a 30-year buildout scenario with varying levels of details for future phases. In particular, it is not yet clear, among other issues, whether specific phases will have unique or different impacts on natural resource areas from those currently known, whether the Town will choose to formally amend its CWMP to include non-traditional methods of water quality management for purposes of TMDL compliance, and whether regional solutions will become more viable and eventually obviate the need for a Town-specific CWMP. To outline the parameters for future reviews based on these and other similar circumstances, a Special Review Procedure (SRP) is warranted.

The Town has agreed to work with the MEPA Office to develop a SRP and submit a proposed framework prior to or together with the Single EIR. [2] The proposed SRP framework should address the methods for MEPA review in the circumstances outlined above, as well as other anticipated factors that may warrant special consideration. The SRP should also address the types of project changes that will require Notice of Project Change filings.

Review of the EENF

The CWMP included a comprehensive review of existing water quality in the Town's coastal waters, freshwater ponds, and groundwater sources of drinking water. The Town has continued to participate in the Massachusetts Estuaries Project (MEP) to conduct water quality

[1] Supplemental information entitled EENF Addendum dated March 12, 2020 from Griffin Beaudoin on behalf of the Town.
[2] Email stating that the Town is willing to work with the MEPA office to develop special review procedures for the Barnstable CMWP project prior to submission of the EIR dated March 24, 2020 from Griffin Beaudoin on behalf of the Town.

sampling and identify nutrient loading problems for the Town's coastal embayments. As stated above, the Technical Reports produced by the MEP are used by MassDEP and EPA to establish TMDLs for nitrogen loading to these coastal embayments and their tributaries.

CWMP

The CWMP documented that wastewater discharges from septic systems are the most significant source of nitrogen loading to coastal embayments. It outlined a long-term, three-phase approach to reducing nitrogen by managing wastewater through a variety of traditional means, such as sewering, expansion and improvements of the current wastewater treatment facility, and construction of new effluent disposal sites. It also outlined non-traditional methods including the control of fertilizer use and stormwater, public education, implementation of innovative and alternative (I/A) technologies, use of permeable reactive barriers (PRB), and wetland restoration.

The CWMP documented how the Town plans to address the water quality and wastewater needs of the community in each of three phases (Phase 1, Phase 2 and Phase 3) of the 30-year plan. The 30-year plan consists of primarily a conventional approach of sewer expansion, but the Town has designed the plan with the ability to integrate non-traditional projects in the last phase (Phase 3) based on demonstration projects. Based on data generated from future potential demonstration projects, the Town will assess how the CWMP can be modified to implement traditional strategies with the incorporation of nontraditional approaches. The focus area of the future non-traditional strategy will be located in the Three Bays Watershed.

A key component of the CWMP is an Adaptive Management Plan (AMP) that will include the reassessment and adjustment of the CWMP as phases of the plan are implemented. The AMP will be informed by the findings of a Wastewater Implementation Committee (WIC) that will monitor the progress of the CWMP, the results of on-going water quality monitoring in the watersheds, WWTF water quality reports, and population growth data. The AMP will assist the Town in evaluating its progress in attaining water quality goals, including compliance with the TMDLs, and adjusting the design or phasing of structural and non-structural components of the CWMP. It will also enable the Town to modify the Preferred Alternative's phasing, timing, or the specific areas to be sewered based on the results of the earlier implementation phases to comply with the anticipated nitrogen TMDLs.

The CWMP provided a summary of wastewater planning that has occurred to date, described existing conditions and land uses in the project area, identified future needs, and evaluated system alternatives to meet identified wastewater treatment demand and water quality objectives.

Needs Assessment

The CWMP included a needs assessment that identified Areas of Concern (AOC). The Town of Barnstable is currently exceeding the TMDL for nitrogen in its coastal embayments. The primary source of the problem is stormwater discharges, septic system failures, boat waste discharges, wildlife and other sources. Hydrographic modeling by MEP identified the needs assessment presented in the CWMP. The needs assessment was based on updated data related to

the original criteria and new information on I/A septic systems, rare species habitat, and areas with established TMDLs.

The Town completed a needs assessment in 2011 that was based on the presence of water supply protection zones, soil characteristics, density of lots, high groundwater, location within flood zones, septic system failures, shellfish closure areas, industrial land uses and filled wetlands. The assessment was completed to determine the nutrient loads generated by existing and future build-out of residential and commercial development in Barnstable. In developing the analysis, the Town reviewed the total number of parcels located within each of the watersheds for the marine embayments surrounding Barnstable and freshwater pond watersheds, and estimated the water use, wastewater flows and nutrient loading to be generated. Existing and future development parcels were evaluated to determine the need for sewers to address the water quality requirements and TMDLs of the Town's marine and freshwater water resources.

Development of an CWMP is an important step toward meeting TMDLs and restoring impaired waters. However, the plans to meet TMDL requirements for nutrient loading must always consider source reduction as the primary means of long-term nutrient control. Source reduction usually focuses on controlling watershed land use loads generated from human activity. Source reduction can include, but are not limited to, constructing new sewer systems, upgrading existing sewer systems (e.g. providing higher levels of treatment and eliminating combined sewer outflows), eliminating fertilizers, reducing runoff from impervious surfaces, reducing impervious surfaces, and tightening standards for new and upgraded septic systems.

In addition to source controls, successful nutrient management plans may include alternative nutrient control strategies to achieve the desired nitrogen concentrations specified in the TMDL and MEP reports. The EENF provided a detailed discussion of the source controls proposed.

Alternatives Analysis

The CWMP developed multiple water quality management scenarios to meet nitrogen removal goals identified in the needs assessment and the MEP studies. The scenarios reflect a broad array of options, including combinations of sewering, treatment facilities (including regional treatment facilities), effluent recharge sites, discharge of treated wastewater outside the watershed, and various levels of non-structural components such as I/A septic systems and permeable reactive barriers (PRB). The scenarios were intended to provide a screening-level analysis from which a subset would be selected, refined, and further analyzed. The Town determined that five of these scenarios warranted further analysis. Three additional scenarios were developed to evaluate regional wastewater alternatives.

The alternatives were evaluated and compared on the basis of cost, design requirements and reliability of technology, and construction impacts. The Town selected the Preferred Alternative (as presented previously in the Project Description section) because it will collect wastewater from a sufficient number of developed parcels throughout the Town and Popponesset Bay Watershed and the Cotuit Bay Subwatershed of the Three Bays Watershed to meet nitrogen removal requirements and provide sewer infrastructure to economic growth districts. It will meet

MEP and TMDL nitrogen reduction thresholds and can be phased in a manner that provides implementation flexibility.

Preferred Alternative

The Preferred Alternative has been designed to treat an average daily flow of 1.77 million gallons expected from the areas to be sewered, remove 176 kilograms per day (kg/day) of nitrogen after all three phases have been completed. Phase 1 in the first ten years is designed to treat an average daily flow of 782 thousand gallons per day and remove 78 kg/day of nitrogen, which is 44% of the total proposed of nitrogen removal for the project. Phase 2 in years ten to twenty years is designed to treat an average daily flow of 653 thousand gallons per day and remove 65 kg/day of nitrogen, which is 37% of the total proposed of nitrogen removal for the project. Phase 3 in years twenty to thirty years is designed to treat an average daily flow of 782 thousand gallons per day and remove 33 kg/day of nitrogen, which is 19% of the total proposed of nitrogen removal for the project. Please see Phasing Plan Statistics table below:

Phasing Plan Statistics Table

	Phase 1 (0-10 Years)	Phase 2 (10-20 Years)	Phase 3 (20-30 Years)	Total
WW Captured (gpd)	782,000	653,000	335,000	**1,770,000**
Load N Removed (kg/day)	78	65	33	**176**
Number of Parcels Affected	4,610	3,130	2,100	**9,870**
Approximate Road Miles	90	60	40	**190**
% of N Removed by Plan	44%	37%	19%	**100%**

****(wasterwater: WW; nitrogen: N)*

The Preferred Alternative identified in the CWMP will be implemented in following three phases:

PHASE 1 (0-10 Years)

- Construction of sewer infrastructure along Route 28 to address nutrient related issues within the Three Bays watershed. The Route 28 sewer infrastructure will be the major infrastructure to convey flow from westerly portions of the Town to the Barnstable Water Pollution Control Facility (BWPCF) located in Hyannis.
- Sewer expansion adjacent to Wequaquet Lake, Bearses Pond, Shallow Pond, Long Pond, Red Lily Pond, Lake Elizabeth, and Filenes Pond to address deteriorating water quality.
- Sewer expansion to accommodate identified economic development areas including along the Route 28, Old Yarmouth Road, Attuck's Lane/Route 132, Kidd's Hill, Independence Park, and Hyannis Harbor.
- Sewer expansion within the flood zones in the Craigville and Long Beach region to address septic system issues in the area.
- Sewer expansion adjacent to Prince Cove and Warren's Cove (most impaired waterbodies in the Three Bays Watershed) and the Marstons Mills River.
- Modifications at BWPCF including upgrades to aeration, denitrification upgrades, and upgrades to solids handling.
- Identification, permitting and construction of new effluent disposal site(s).

- Pursuit of a regional sewer option at Joint Base Cape Cod (JBCC).
- Implementation of non-traditional demonstration projects along the Marstons Mills River System (Mill Pond Dredging to cranberry bogs), together with monitoring and analysis of results.
- Continued embayment monitoring.

PHASE 2 (10-20 Years)

- Continued westerly sewer expansion along Route 28.
- Continued sewer expansion within the Centerville River Watershed, specifically the Centerville River East subwatershed and expansion adjacent to Bumps River.
- Sewer expansion into the Nye's Neck region to complete sewer expansion surrounding all of Wequaquet Lake.
- Sewer Expansion to areas south of Craigville Beach Road east of Covell's Beach.
- Sewer expansion into the Millway subwatershed (the one sub-watershed within the Barnstable Harbor Watershed requiring septic load removal per the MEP report).
- Sewer expansion within the Lewis Bay Watershed in the General Patton area and northern Hyannis Port.
- Continued sewer expansion within the Three Bays Watershed, directly adjacent to subembayments requiring septic load removal (Prince Cove and North Bay), to address areas with shortest groundwater travel times.
- Continued monitoring and analysis of non-traditional demonstration projects.
    1. During this phase, it is the Town's intention to present the monitoring and analysis of the non-traditional approaches to the regulatory agencies.
    2. If, as anticipated, the analysis of the monitoring program determines that the nontraditional approaches have improved conditions within the Three Bays Watershed, the Town would then enter discussions with regulatory agencies to pursue non-traditional "credits" in an effort to minimize the required sewer expansion proposed in Phase 3. The Town is not proposing any non-traditional "credits" at this time and has designed the sewer expansion plan to achieve the required septic load removals by traditional approaches only.
- Continued embayment monitoring.

PHASE 3 (20-30 Years)

- Continued sewer expansion into the northerly portion of the Three Bays Watershed.
- Continued sewer expansion within the Lewis Bay/Halls Creek Watershed.
- Continued monitoring and analysis of non-traditional projects and follow-up with regulatory agencies.
- Continued embayment monitoring.

In addition to the three phases of the 30-year plan, the CWMP also documented how the Town will conduct a parallel "3-stage" sewer expansion plan to address the wastewater needs in the Popponesset Bay Watershed and the Cotuit Bay Subwatershed of the Three Bays Watershed. The timing and execution of the 3-stage sewer expansion plan is subject to the involvement and collaboration of adjacent communities who also contribute nitrogen loads into these watersheds. The term "stages" was used for these sewer expansion areas because they do not have a

determined schedule as it is assumed that these areas would be served by a western treatment and disposal solution to accommodate the sewer expansion. The original plan developed by the Water Resources Advisory Committee (WRAC), recommended approaching these areas via an inter-municipal agreement (IMA). However, in order to address water quality concerns in Shoestring Bay and Cotuit Bay that would not be addressed via nitrogen sharing in an IMA, there is a desire for traditional wastewater solution in these areas. If a westerly solution becomes a reality, the Town intends to pursue sewer expansion the areas identified in the stages.

Conclusion

I recognize that the impacts caused by the discharge of nitrogen through both private septic and municipal sewer systems to surrounding water bodies can be severe and that this is a significant issue for towns on Cape Cod. The EENF describes a thorough evaluation of Barnstable's needs for wastewater and nutrient management. Specifically, much of the recommended plan is driven by the findings of the MEP which documented resource impairment from excess nitrogen loads. I support the comprehensive planning for wastewater management and applaud the effort that has gone into the development of this CWMP. In addition, the adaptive management approach proposed in this plan provides a flexible management framework that allows for changes to the planned implementation schedule, based upon future unknown variables, such as changes in water quality, future build-out rates in different watersheds, and economics.

Comments from State agencies and environmental groups are generally supportive of the Town's effort in preparing the CWMP. Based on review of the EENF, consultation with State Agencies and review of comment letters, I have determined that the Proponent may submit a Single EIR. This decision to allow a Single EIR is conditioned upon the Town's agreement to establish a SRP to allow for additional public review and input on future phases of the CWMP as information and plans are developed. The Single EIR should be prepared in accordance with the following Scope.

SCOPE

General

The Single EIR should follow Section 11.07 of the MEPA regulations for outline and content, as modified by this Scope. The Single EIR should identify and describe any changes to the project since the filing of the EENF and provide an update on State, local and federal permitting.

Project Description

The Single EIR should include an executive summary, it should identify significant environmental benefits and impacts, and measures that will be taken to avoid, minimize and mitigate adverse impacts. The Single EIR should describe the planning process that has occurred to date, and the proposed schedule for the remaining phases of planning, design, environmental permitting and review, and construction. Information should be provided for each area where

construction is proposed, including maps that show where sewer lines, cross-country easements, pumping stations, and other facilities will be located, to the extent it is available when the Single EIR is submitted.

The Single EIR should discuss the state permitting process for this project and describe how it will meet all applicable performance standards. I encourage early coordination with MassDEP during preparation of the Single EIR as requested in the agency's comments.

CWMP

The Single EIR should include the following supplemental information as related to the CWMP:

Alternatives Analysis

The Preferred Alternative presented in the EENF does not rely on any percent nitrogen removal credit for the non-traditional components of the CWMP, including dredging, aquaculture, land use controls and open space acquisition, and stormwater management and fertilizer use reduction programs and provided little detail on these non-traditional components of the CWMP. Regardless of the fact that the Town is not seeking any percent nitrogen removal credit, the Single EIR should provide a conceptual description of non-traditional nitrogen reduction measures that it intends to implement through demonstration projects assist to achieve the nitrogen removal, including, in addition to water quality benefits, a conceptual description of environmental impacts and mitigation measures to the extent this can be identified at this stage. The proposed SRP framework should include procedures to review non-traditional methods of nitrogen removal, either together with the CWMP or outside any review procedures applicable to the CWMP and/or any subsequent amendments.

In addition, the Single EIR should provide more detail about the water quality embayment monitoring program described under the Preferred Alternative, including the general approach to be used, how it will be implemented, monitoring locations, and water quality parameters to be measured. It should address how the monitoring program will be designed to evaluate the effectiveness of non-traditional treatment options.

Regional Planning

The Town is investigating several opportunities for regional cooperation with neighboring towns. Many local studies have shown that economies of scale from a cost savings and sustainability perspective offer significant advantages to regional solutions. Barnstable shares several watersheds with neighboring communities and is investigating community partnerships with them. The Town shares the Popponesset Bay Watershed with Sandwich and Mashpee. The Towns have executed an inter-municipal agreement (IMA) to establish a work group. The objective of the work group is to come to agreement on a formula for allocation of responsibilities and costs, establish a municipal fiscal agent lead. The EENF also discusses that there are water quality concerns in the Shoestring Bay Subwatershed of Popponesset Bay and the Cotuit Bay Subwatershed of the Three Bays Watershed that would not be addressed via nitrogen

trading in the IMA. As aforementioned, a potential "westerly solution" would allow Barnstable to carry out the 3-stage sewer expansion plan addressing those concerns.

The Town of Barnstable has also been participating in discussions with the Upper Cape Communities in an effort to form an Upper Cape regional treatment and disposal solution at Joint Base Cape Cod (JBCC). The EENF states that Barnstable, Bourne, Falmouth, Mashpee and Sandwich are conducting a regional evaluation of wastewater discharge options on Joint Base Cape Cod JBCC. Specifically, the EENF also states that the Towns are discussing the possibility of utilizing the existing wastewater treatment facility at JBCC, which currently consists of a treatment plant and four infiltration basins northwest near the Cape Cod Canal, as a regional facility. Comments from MassDEP express support for the regional efforts of the Upper Cape Communities and Barnstable and will continue provide regulatory guidance.

The Single EIR should provide updates on opportunities for wastewater planning on a regional scale identified in the EENF, including its coordination with Bourne, Falmouth, Mashpee and Sandwich to establish nutrient loadings and discussions related to the potential use of the JBCC wastewater facility. In addition, the NHESP notes that the four existing infiltration basins at JBCC near the Cape Cod Canal are located within the Camp Edwards Wildlife Management Area. Chapter 47 of the Acts of 2002 transferred the care, custody and control of the northern 15,000 acres of JBCC to the Division as the Camp Edwards Wildlife Management Area to conserve fish and wildlife resources for the benefit of the citizens of the Commonwealth. I remind the Town that any projects or activities within the Camp Edwards Wildlife Management Area, including but not limited to any potential upgrades to or expansion of existing wastewater treatment facilities, would require review and approval by the NHESP. To the extent these planning efforts result in regional wastewater management solutions that obviate the need for town-specific CWMPs, the SRP framework should propose a mechanism for conducting appropriate MEPA reviews.

Adaptive Management Plan

The EENF discusses how an Adaptive Management Plan (AMP) will allow for a systematic and prescribed process to report on the Town's activities and to incorporate new technical information and potential agreements among the towns in the shared watersheds. The AMP will assist the Town to evaluate the Town's compliance with established TDMLs and identify the need for adjustments or mid-course corrections to subsequent phases of the structural and non-structural components of the Preferred Alternative program.

Comments from MassDEP recognize that this the AMP is subject to modification based on partnerships with towns that share common watersheds and the advancement of nutrient management strategies and technologies. The Single EIR should provide a detailed description of the Town's proposed AMP and its water quality monitoring program in the Town of Barnstable.

<u>Land Use and Alteration</u>

The Single EIR should provide an estimate of the total amount of alteration associated with the proposed project in greater detail than what was provided in the EENF (including areas

to be altered for sewer mains, pump station impacts, and other project components). The Single EIR should include a breakdown showing the amount of alteration for different project elements. The Single EIR should clarify the location, type and amount of alteration in previously undisturbed areas.

The Single EIR should clarify the amount of new impervious area associated with the construction of the components of the Town's CWMP. The Single EIR should describe how the Town's proposed stormwater management system will be designed and constructed to be consistent with MassDEP's stormwater management regulations and policy standards and avoid and minimize adverse impacts associated with any new impervious area. The Single EIR should describe proposed measures to manage stormwater during project construction.

Growth Management

Executive Order #385 requires that State and local agencies engage in protective and coordinated planning oriented towards resource protection and sustainable economic development. For reasons of both environmental protection and fiscal prudence, investments in public infrastructure should be carefully targeted toward those areas for which clear existing needs have been established and for areas where denser development is appropriate, thereby relieving development pressures on open space, agricultural lands, and other valuable natural resources.

The Single EIR should identify parcels located within the proposed sewer service areas that are undeveloped or that have development constraints due to the lack of sewers, and compare the potential secondary growth impacts that may be induced by public sewers with local and regional growth management policies and zoning. It should examine what regulatory or physical constraints would remain on home expansions after sewers are constructed, and whether such expansions might have unanticipated impacts on estimated wastewater flows and water use.

Wetlands and Waterways

According to the EENF, the project will impact LSCSF and BLSF. Although not indicated in the EENF, the project may qualify as a limited project pursuant to 310 CMR 10.53(3)(d) for the construction of underground public utilities (sewer lines). In addition, construction of wastewater treatment plants' related structures are exempt from the requirements for Riverfront Area pursuant to 310 CMR 10.58(6)(h). According to the EENF, the majority of work within these areas will occur within paved right-of-way, will be temporary in nature, and will be restored to original conditions following completion of construction. The Single EIR should identify areas of impacts to wetland resource areas and describe mitigation measures. It should address the project's compliance with appropriate standards of the Wetlands Regulations (310 CMR 10.00).

The Single EIR should also delineate on a plan of reasonable scale all environmental resources areas located within areas proposed for sewering, including wetlands, drinking water supplies, sensitive habitats, fisheries, designated Areas of Critical Environmental Concern (ACEC), Article 97 lands, historic resources, and agricultural lands. Where it has been

demonstrated that impacts are unavoidable, the Single EIR should demonstrate that the impacts have been minimized, and that adequate mitigation will be pursued.

I note that any proposed sewer lines that cross over or under tidelands or tidal rivers and streams will likely require a Chapter 91 License from MassDEP. The Single EIR should include information on which future phases of the CWMP are located in Chapter 91 jurisdictional areas or landlocked tidelands subject to a Public Benefits Determination by the Secretary of EEA.

Rare Species

The Town of Barnstable's ponds, bays and estuarine waters provide critical foraging, breeding, migration and over-wintering habitats for a suite of state-listed rare species. Portions of Barnstable are mapped as Priority Habitat for state-listed rare species. All projects proposed within Priority Habitat, which are not otherwise exempt from review pursuant to 321 CMR 10.14, require review through a direct filing with the Natural Heritage and Endangered Species Program (NHESP) within the Division of Fisheries and Wildlife pursuant to the Massachusetts Endangered Species Act (M.G.L. c. 131A) and its implementing regulations (MESA; 321 CMR 10.00).

As described in the EENF, a portion of the phased sewer main installations is located near or within Priority Habitat for state-listed rare species. According to comments from NHESP, based on its review of the EENF it appears that the proposed work is exempt from MESA review (321 CMR 10.14). However, if proposed activities do not meet the MESA exemptions, a checklist for these activities must be filed with NHESP. The Town should submit detailed construction plans to NHESP to confirm the exempt status.

If NHESP should subsequently find that the project will require a Conservation and Management Permit pursuant to MESA, the Single EIR should analyze the impacts to rare or endangered species and evaluate avoidance/mitigation strategies. I ask that the Town continue to work closely with NHESP and consult with the Barnstable Conservation Commission during the preparation of this section of the Single EIR. The Single EIR should identify necessary project construction and post-construction conditions and commitments to avoid an adverse impact to resource area habitats of state-listed species located within and adjacent to the project areas. The Single EIR should report on the results of the Town's consultations with NHESP. If sufficient detail is not available to conduct a full evaluation of all phases, the Town should propose procedures in the SRP to enable a review of rare species impacts as appropriate during future phases of the CWMP buildout plan.

NHESP's comments indicate that, in addition to the proposed sewering, any proposed upgrades to or expansions of the wastewater treatment facilities would require review by the NHESP for compliance with the MESA that because they are located within Priority Habitat. The Single EIR should address applicability of any permitting requirements by NHESP in the manner described above.

Wastewater / Facility Upgrades

The EENF describes that the Barnstable Water Pollution Control Facility (BWPCF) discharges all of its treated wastewater effluent to disposal sites at the treatment facility. The Town is planning to invest in maintenance and improvement of existing infrastructure, including pump stations, collection system upgrades, and infrastructure to minimize infiltration and inflow (I/I). The Town is planning to upgrade and expand the facility's treatment capacity throughout Phase 1 of the CWMP with improvements to the reactor trains, modifications of the secondary clarifier and expansion of the aeration system. The goal is to reduce the annual effluent nitrogen concentration while accommodating the anticipated new flow from sewer expansion projects.

In 2017, MassDEP conservatively lowered the disposal capacity in the Town's groundwater discharge permit to allow time to study the disposal capacity and understand the potential downgradient hydrogeological impacts that may result from increased sewer flows. Where soil and groundwater conditions are favorable for recharge of groundwater, treated sewage effluent can infiltrate into the soil and move down to the groundwater creating a recharge cappacity. The lower level of soils then act as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses, and other microorganisms. Significant reductions in nitrogen, phosphorus, and heavy metals concentrations can also be achieved. The preliminary findings presented in the EENF indicate that the estimated average annual recharge capacity of the BWPCF is 2 mgd when the depth to groundwater is less than 8 feet at a downgradient receptor. The CWMP states that the annual average flow is not expected to reach 2 mgd until 2027. MassDEP supports the Town's current plan to maintain flows below 2 mgd until the Town designs, permits and constructs the new disposal effluent sites.

MassDEP supports the Town's current plan to maintain flows below 2 mgd until the Town designs, permits and constructs the new disposal sites. The Single EIR should present the proposed locations and preliminary designs for the proposed new disposal sites. As requested by MassDEP. MassDEP also requests that the Town investigate and permit additional wastewater sites in parallel with the wastewater treatment upgrades planned Phase 1. The Town should continue consulting with MassDEP and present the results of the discussion in the Single EIR.

In addition, the Single EIR should include any identified upgrades and or modifications of the wastewater treatment facilities through Phase 1, and, to the extent future upgrades are anticipated, either provide details on those upgrades or a process by which they could be reviewed through the SRP if relevant thresholds are met or exceeded.

Climate Change

Governor Baker's Executive Order 569: Establishing an Integrated Climate Change Strategy for the Commonwealth (EO 569; the Order) was issued on September 16, 2016. The Order recognizes the serious threat presented by climate change and directs agencies within the administration to develop and implement an integrated strategy that leverages state resources to combat climate change and prepare for its impacts. The Order seeks to ensure that Massachusetts will meet greenhouse gas (GHG) emissions reduction limits established under the Global Warming Solution Act of 2008 (GWSA) and will work to prepare state government and cities

and towns for the impacts of climate change. Review of these issues through the GHG Policy and requirements to analyze the effects of climate change through EIR review is an important part of this statewide strategy. These analyses inform State Agencies and proponents' understanding of a project's GHG emissions and a project's vulnerability to the effects of climate change.

Adaptation and Resiliency

The Town is a participant in the Commonwealth's Municipal Vulnerability Preparedness (MVP) program. The MVP program is a community-driven process to define natural and climate-related hazards, identify existing and future vulnerabilities and strengths of infrastructure, environmental resources and vulnerable populations, and develop, prioritize and implement specific actions the Town can take to reduce risk and build resilience.

Components of the wastewater collection infrastructure, such as proposed pump station sites, appear to be located within coastal flood zones. The Town should consider alternative locations for the infrastructure proposed to be sited in these locations, or to otherwise implement climate change adaptation measures to protect the pump stations. The Single EIR should review alternative locations for system components, such as pump stations, including locations outside the floodplain. It should identify design features that could increase the resiliency of the proposed infrastructure under future sea level conditions. The Town should consult the best available data on climate change predictions, including data available on the resilientMA.org website, to develop climate change scenarios for the project and identify potential adaptation measures for the appropriate design life of the project. EEA's Climate Change Adaptation Report (September 2011) and the Town's Climate Change Vulnerability Assessment (dated December, 2019) provide additional resources to assist in this analysis. The Single EIR should discuss climate resiliency considerations made in designing and implementing other components of the CWMP, including the siting and construction of new sewer mains.

Greenhouse Gas Emissions

This project is subject to review under the May 5, 2010 MEPA GHG Policy. The Policy requires Proponents to quantify carbon dioxide (CO_2) emissions and identify measures to avoid, minimize or mitigate such emissions. The analysis should quantify the direct and indirect CO_2 emissions of the project's energy use. Direct emissions include on-site stationary sources, which typically emit GHGs by burning fossil fuel for heat, hot water, steam and other processes. Indirect emissions result from the consumption of energy, such as electricity, that is generated off-site by burning of fossil fuels, and from emissions from vehicles used by employees, vendors, customers and others. The Policy directs proponents to use applicable building codes to establish a project emissions baseline that is "code-compliant." However, there is no building energy code equivalent that applies specifically to WWTFs or energy use models (such as eQUEST) designed to estimate the projected energy use of the WWTF processing energy loads.

The Single EIR should include a more project-specific GHG evaluation of emissions associated with modification to the WWTF and any other facilities, such as pump stations, that may emit GHG. It should establish a Base Case and an as-proposed Preferred Alternative Case along with providing the other information required by the Policy. Both the projected energy

consumption and related GHG emission should be quantified for both cases. Design assumptions for the base case should be based on a typical WWTF and pump station design that meets the requirements of TR-16, *Guides for the Design of Wastewater Treatment Works*, 2016 Edition, which is commonly used as a guide for wastewater facility design in Massachusetts. The as-proposed Preferred Alternative design should include features and measures that would result in a significant reduction from the Base Case in both the consumption of grid electricity and the related GHG emissions. Measures that should be evaluated include: increasing piping sizes to reduce friction loss; use of premium efficiency pumps and motors; and use of variable frequency pump drives (VFD).

The Town should consult MassDEP's "Energy Efficiency and Renewable Energy Opportunities at Water and Wastewater Facilities" webpage[3], the Water Environment Research Foundation's *Utilities of the Future Energy Findings*[4] report published in 2014, the EPA's *Evaluation of Energy Conservation Measures for Wastewater Facilities*[5] (2010), the *Water and Wastewater Energy Management Best Practices Handbook*[6] (2010) prepared by the New York State Energy Research and Development Authority, and other resources to identify energy efficiency practices at WWTFs. The Single EIR should review energy-efficient alternatives identified in the reports cited above and indicate whether the Town will adopt the measure or not, and provide a rationale for the decision. The Single EIR should review opportunities for on-site energy generation, including biogas and solar photovoltaic (PV) systems. The Town should consult with MEPA staff before completing this analysis.

Historical/Archaeological Resources

The Town should provide MHC with a US Geological Survey topographical map that clearly locates the phased project areas and scaled project plans showing existing and proposed conditions. These plans should be submitted to MHC as early as possible during the design phase corresponding to each of the proposed project development phases. The Town should continue to coordinate with MHC to ensure review of any potential historic impacts from the project and the Single EIR should provide an update on the status of these discussions. If MHC deems the project to have an "adverse effect" on historic or archaeological resources, the Single EIR should include a discussion of mitigation measures that the Town will undertake to address the adverse effect.

Construction Impacts

The EENF indicated that the project will require a Access Permit from MassDOT to address work within State-controlled roadways. The Town should consult with MassDOT to confirm what elements of the project will require approval. The Single EIR should identify areas

[3] http://www.mass.gov/eea/agencies/massdep/climate-energy/energy/water-utilities/energy-efficiency-at-water-and-wastewater-facilities.html
[4] Available online at https://www.werf.org/a/ka/Search/ResearchProfile.aspx?ReportId=ENER6C13
[5] Available online at https://nepis.epa.gov/Exe/ZyPDF.cgi/P1008SBM.PDF?Dockey=P1008SBM.PDF
[6] Available online at https://www.nyserda.ny.gov/-/media/Files/Programs/Clean-Energy-Communities/NYSERDA-Water-Wastewater-Energy-Management-Best-Practices-Handbook.pdf

subject to MassDOT review, describe potential project impacts in those areas, and identify mitigation measures.

Construction period impacts and mitigation measures should be described in the Single EIR, including impacts from noise and dust, impacts on trees and other vegetation, and traffic impacts. Measures that will be taken to minimize and mitigate construction period impacts (in particular impacts on sensitive receptors or exceptional resources) should be detailed.

While much of the project will occur within existing roadways, it will increase impervious area by approximately one acre due to the placement of pump stations and other system components. The Single EIR should describe impervious areas to be created by the project and review alternatives for minimizing new impervious surfaces. The Single EIR should identify sedimentation and erosion control measures to be used during construction. A Stormwater Pollution Prevention Plan will be developed for the project in accordance with MassDEP's Stormwater Management Standards. The Single EIR should describe any stormwater best management practices (BMPs) to be constructed to offset new impervious area.

All construction and demolition activities should be managed in accordance with applicable MassDEP's regulations regarding Air Pollution Control (310 CMR 7.01, 7.09-7.10), and Solid Waste Facilities (310 CMR 16.00 and 310 CMR 19.00, including the waste ban provision at 310 CMR 19.017). The project should include measures to reduce construction period impacts (e.g., noise, dust, odor, solid waste management) and emissions of air pollutants from equipment, including anti-idling measures in accordance with the Air Quality regulations (310 CMR 7.11). I encourage the Town to require that its contractors use construction equipment with engines manufactured to Tier 4 federal emission standards, or select project contractors that have installed retrofit emissions control devices or vehicles that use alternative fuels to reduce emissions of volatile organic compounds (VOCs), carbon monoxide (CO) and particulate matter (PM) from diesel-powered equipment. Off-road vehicles are required to use ultra-low sulfur diesel fuel (ULSD). If oil and/or hazardous materials are found during construction, the Proponent should notify MassDEP in accordance with the Massachusetts Contingency Plan (310 CMR 40.00). All construction activities should be undertaken in compliance with the conditions of all State and local permits. I encourage the Townto reuse or recycle construction and demolition (C&D) debris to the maximum extent.

Mitigation Measures/Section 61 Findings

The Single EIR should include a separate chapter summarizing proposed mitigation measures. This chapter should also include draft Section 61 Findings for each permit or other approval to be issued by State Agencies. The Single EIR should contain clear commitments to implement these mitigation measures, estimate the individual costs of each proposed measure, identify the parties responsible for implementation, and a schedule for implementation. The Single EIR should clearly indicate which mitigation measures will be constructed or implemented based upon project phasing to ensure that adequate measures are in place to mitigate impacts associated with each phase.

Response to Comments

The Single EIR should contain a copy of this Certificate and a copy of each comment letter received. In order to ensure that the issues raised by commenters are addressed, the Single EIR should include direct responses to comments to the extent that they are within MEPA jurisdiction. This directive is not intended to, and shall not be construed to, enlarge the Scope of the Single EIR beyond what has been expressly identified in this certificate.

Circulation

The Proponent should circulate the Single EIR to those parties who commented on the EENF, to any State Agencies from which the Proponent will seek permits or approvals, and to any parties specified in section 11.16 of the MEPA regulations. Per 301 CMR 11.16(5), the Proponent may circulate copies of the Single EIR to commenters in CD-ROM format or by directing commenters to a project website address. However, the Proponent must make a reasonable number of hard copies available to accommodate those without convenient access to a computer and distribute these upon request on a first-come, first-served basis. The Proponent should send correspondence accompanying the CD-ROM or website address indicating that hard copies are available upon request, noting relevant comment deadlines, and appropriate addresses for submission of comments. The Single EIR submitted to the MEPA office should include a digital copy of the complete document. A copy of the Single EIR should be made available for review at the Barnstable public library.[7]

April 3, 2020
Date

K. Theoharides
Kathleen A.Theoharides

Comments received:

03/12/2020	Natural Heritage and Endangered Species Program (NHESP)
03/12/2020	Massachusetts Department of Environmental Protection (MassDEP– Southeast Regional Office (SERO)
03/12/2020	Cape Cod Commission (CCC)
03/27/2020	Massachusetts Department of Transportation (MassDOT)
03/30/2020	Division of Marine Fisheries (DMF)

KAT/ACC/acc

[7] Requirements for hard copy distribution or mailings will be suspended during the Commonwealth's COVID-19 response. Please consult the MEPA website for further details on interim procedures during this emergency period: https://www.mass.gov/orgs/massachusetts-environmental-policy-act-office.

Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection
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Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Kathleen A. Theoharides
Secretary

Martin Suuberg
Commissioner

March 12, 2020

Kathleen A. Theoharides
Secretary of Environment and Energy
Executive Office of Energy and Environmental Affairs
ATTN: MEPA Office
100 Cambridge Street, Suite 900
Boston, MA 02114

RE: ENF Review. EOEEA 16148
BARNSTABLE. Comprehensive Waste Water Management Plan – Town Wide

Dear Secretary Theoharides,

The Southeast Regional Office of the Department of Environmental Protection (MassDEP) has reviewed the Environmental Notification Form (ENF) for the Comprehensive Waste Water Management Plan – Town Wide, Barnstable, Massachusetts (EOEEA 16148). The Project Proponent provides the following information for the Project:

Describe the proposed project and its programmatic and physical elements: ***The Project is a Town-wide Comprehensive Wastewater Management Plan which will expand wastewater infrastructure throughout the Town. The project is a thirty year plan, comprised of three, 10-year phases, predominantly focused on sewer expansion to achieve reduction in nutrients and address TMDL's in embayments, while also addressing water quality in ponds, drinking water source protection, targeted economic development and other wastewater needs of the community. The phases will be further broken up into individual projects, during which the Town anticipates that project specific permitting requirements (such as wetland resources, habitat, historical, etc.) will be reviewed in consultation with the appropriate agencies. The details of the plan are explained in extensive detail in the attached Comprehensive Wastewater Management Plan, specifically in Sections 5 and 6.***

Bureau of Water Resources Comments:
Wetlands and Waterways. The Wetlands and Waterways Program has reviewed the EENF for the Barnstable Comprehensive Wastewater Management Plan and offers the following comments.

Wetlands
The Project Proponent provides very little detail on the locations of the proposed facilities. It is therefore not possible for the Program to provide detailed comments on the potential Project

impacts on wetland resource areas, or the Projects ability to meet the regulatory performance standards and protect the interests of the Act.
However, the Program would like to comment on some of the information included in the EENF. The EENF indicates that the Project is not considered a Limited Project under the Wetlands Protection Act Regulations. The Project Proponent may wish to review 310 CMR 10.24(7)(b) regarding the Limited Project status of the proposed activities. Additionally, portions of the Project may meet the regulatory requirements to be considered a Minor Exempt Activity. The Project Proponent should review 310 CMR 10.02(2)(b) 1. & 2.j. prior to preparing and submitting any Notices of Intent.

Waterways.
The CWMP primarily focuses on future sewer system expansion, upgrading the wastewater treatment facility, water quality improvements and a variety of non-traditional nitrogen management methods. The ENNF does not provide information on which components of these future Projects will be constructed within area subject to Chapter 91 jurisdiction. Proposed sewer lines which cross over or under tidelands or tidal rivers and streams will likely require a Chapter 91 License. The conceptual non-traditional nitrogen management methods which include targeted dredging, cranberry bog conversion and bivalve aquaculture will also likely require Chapter 91 permitting. The Waterways Program recommends that the EIR include information on which future Projects of the CWMP are located in Chapter 91 jurisdictional areas.

Wastewater Management. MassDEP's Southeast Regional Office is pleased to have the opportunity to comment on the Town of Barnstable's Draft Comprehensive Wastewater Management Plan and Expanded Environmental Notification Form (EENF). MassDEP commends the Town on its efforts to restore the coastal embayments impacted by nutrient enrichment with an accelerated timeline.

Introduction
The Town has submitted an Expanded Environmental Notification Form for the Town's Draft Comprehensive Wastewater Management Plan (DCWMP). The DCWMP provides a summary of the evaluations and activities the Town has completed since 2003, the 2011 needs assessment report, and the activities anticipated through 2050. The Town plans to utilize a variety of strategies including sewering, wetland restoration, innovative alternative septic systems (I/A Systems), permeable reactive barriers (PRBs), and aquaculture to achieve nitrogen reduction targets necessary to meet the Total Maximum Daily Load (TMDL) in each of the watersheds linked to an identified impaired embayment. At the same time, the planning efforts account for wastewater needs other than nitrogen mitigation.

The EENF/DCWMP states that the Town plans to address the various wastewater needs of the community in a 30-year plan (3 phases of ten years). The Town also has parallel 3-stage sewer expansion plan to address needs in the Popponesset Bay Watershed and the Cotuit Bay Subwatershed of the Three Bays Watershed. The timing and execution of the 3-stage plan is subject to a "westerly solution" involving the collaboration of multiple communities. The 30-year plan consists of primarily a conventional approach of sewer expansion, but the Town has designed the plan with the ability to integrate non-traditional Projects in the last phase based on demonstration Projects. Based on the results of the demonstration Project data, the Town will assess how the Town can modify the existing plan to implement traditional strategies with the incorporation of non-traditional approaches. The focus of non-traditional strategy application is within the Three Bays Watershed.

The Barnstable DCWMP provides a clear schedule toward resource restoration with allowances for adaptive management and economic development. MassDEP recognizes that this is a plan subject to modification based on partnerships with towns that share common watersheds and the advancement of nutrient management strategies and technologies. As such, MassDEP supports the Town of Barnstable's plan to submit a 2025 Adaptive Management Report as an update to the 2020 DCWMP and Notice of Project Change filings (NPCs) for future non-traditional Projects.

Wastewater Treatment

The Town has diligently maintained and improved the existing Barnstable Water Pollution Control Facility (BWPCF) and associated infrastructure and plans to do so through Phase 1 of the 30-year plan. The Town is planning to invest in maintenance and improvement of existing infrastructure, including pumping stations, collection system evaluation studies and to address infiltration and inflow. The Town is planning to upgrade and expand the facility's treatment capacity throughout Phase 1 with improvements to the reactor trains, modifications of the secondary clarifier and expansion of the aeration system. The goal is to reduce the annual effluent nitrogen concentration from 6 mg/l to 3 mg/l while accommodating the anticipated new flow from sewer expansion Projects. In Phase 1, Barnstable will also upgrade the solids handling facility in years 2 through 4; upgrade the headworks in years 3 through 8; and install additional emergency generators in years 4 and 5.

The proposed changes are consistent with demands that will be placed on the facility and all design issues will be addressed during plan and/or permitting review. The treatment facility and associated infrastructure are regulated under MassDEP's groundwater discharge permit GW# 021-1. The permit expires in November 2023. The permit states the following in Section D. Supplemental Conditions 10:

> "Simultaneously with the permit renewal application in 2023, the permittee shall submit and engineering report prepared by a registered professional engineer to the Department for its review and approval that outlines in sufficient detail what modification (if any) to the facility or other changes are required to insure that the facility can remain in compliance with its GWDP and other applicable requirements through the next 5 year permit term (year 2028) and beyond".

For the engineering report, rather than Projecting required upgrades through the next 5-year permit term, MassDEP advises the Town to include any identified upgrades and or modifications of the facility through Phase 1 in accordance with Barnstable's DCWMP. Depending on the timing of the design and permitting of critical upgrades or modifications that could expand discharge capacity, the Town should consider submission of a WP11 in lieu of a WP12 permit application. MassDEP can be flexible with the submission date of the permit renewal, within reason, to simplify permit renewal and potential plan approval reviews.

Wastewater Disposal

The DCWMP acknowledges limitations in wastewater recharge at the BWPCF. The Barnstable Water Pollution Control Facility (BWPCF) discharges all of its treated wastewater effluent to disposal sites at the treatment facility. As a result of a planning level analysis conducted in 2017, MassDEP conservatively lowered the disposal capacity in the groundwater discharge permit to allow time to study the disposal capacity and understand the potential downgradient hydrogeological impacts. The Town has retained a consultant to investigate and model the hydrogeological impacts of different discharge capacities at the facility. The current Project seeks to discover the actual maximum disposal volume that would cause issues; further define the issues,

locate the properties where the issues would be observed; and assess the gravity and extent of those defined issues in the identified locations. Initial modeling indicates that depth to groundwater in low lying areas is the limiting factor, and that capacity varies depending on the amount of recharge from precipitation over the preceding three months. The preliminary Project findings indicate that the estimated average annual recharge capacity of the BWPCF is 2 MGD when the depth to groundwater is less than 8 feet at a downgradient receptor. The DCWMP states that the annual average flow is not expected to reach 2 MGD until 2027.

With potential complications at 2 MGD, based on the current on-going study, MassDEP supports the Town's current plan to maintain flows below 2 MGD until the Town designs, permits and constructs the new disposal sites. The disposal limitation is a significant obstacle in Barnstable's wastewater plan. MassDEP considers it imperative that the Town's plan prioritize its stated intent to investigate and permit additional wastewater sites in parallel with the wastewater treatment upgrades planned Phase 1.

Opportunities for Regional Cooperation

The Town is investigating several opportunities for regional cooperation with neighboring towns. Many local studies have shown that economies of scale from a cost savings and sustainability perspective offer significant advantages to regional solutions. Barnstable shares several watersheds with neighboring communities and is investigating community partnerships with them. Barnstable retained the University of Massachusetts School for Marine Science and Technology (SMAST) to conduct a Massachusetts Estuaries Project (MEP) model run for TMDL compliance of the Lewis Bay Watershed using the proposed plans of the two towns (Barnstable and Yarmouth) sharing this watershed. The model indicates that the Towns will meet the TMDL if the Towns execute their proposed plans. Additionally, the Towns are discussing and have studied options centered on Barnstable providing treatment for Yarmouth's raw wastewater and Yarmouth providing disposal capacity for some of Barnstable's wastewater in addition to the treated effluent from Yarmouth's wastewater. MassDEP supports the potential partnership and believes that a Watershed Permit can organize the expectations the Towns have of each other to carry out proposed plans for the restoration of Lewis Bay.

The Town shares the Popponesset Bay Watershed with Sandwich and Mashpee. The Towns have executed an inter-municipal agreement (IMA) to establish a work group. The objective of the work group is to apply for a Watershed Permit, come to agreement on a formula for allocation of responsibilities and costs, establish a municipal fiscal agent lead, and "to provide assurance that each town will take affirmative steps toward water quality improvement". Barnstable believes there are water quality concerns in the Shoestring Bay Subwatershed of Popponesset Bay and the Cotuit Bay Subwatershed of the Three Bays Watershed that would not be addressed via nitrogen trading in the IMA. As aforementioned, a potential "westerly solution" would allow Barnstable to carry out the 3-stage sewer expansion plan addressing those concerns. Barnstable has also been participating in discussions with the Upper Cape Communities (Bourne, Falmouth Mashpee and Sandwich) in an effort to form an Upper Cape regional treatment and disposal solution at Joint Base Cape Cod (JBCC). Barnstable is also discussing alternative "western solutions" with different permutations of Upper Cape Community partnerships outside of utilizing the facility on JBCC. MassDEP supports the regional efforts of the Upper Cape Communities and Barnstable and will continue provide regulatory guidance.

Lastly, the Town has formed a collaborative relationship with the Barnstable Clean Water Coalition (BCWC), a 501 (c) (3) non-profit organization. The Town and BCWC are working towards assessment of non-traditional technologies in the Three Bays Watershed.

TMDL Compliance. The Town retained SMAST to conduct a MEP model run with updated land use and water use data which demonstrated that the 30-year plan, once executed, will meet all of the nutrient removal targets to achieve the TMDLs in all of the embayments that are primarily in Barnstable: Three Bays, Centerville River, Lewis Bay and Barnstable Harbor. Barnstable designed the DCWMP with solely traditional strategies; the Town will apply adaptive management if necessary to adjust the plan with non-traditional strategies in the future. The Town not only considered MEP nitrogen target thresholds for choosing sewer expansion areas, but also considered areas with traditional Title 5 concerns, pond protection needs, flood zone considerations and economic development. The Town's DCWMP has a detailed breakdown of the Phase 1 sewer expansion in Barnstable Harbor, Centerville, Lewis Bay, Hall Creek and Three Bays Watersheds, with the expectation to submit a similar detailed plan for Phase 2 with the 2025 adaptive management update.

The Town of Barnstable implemented its own fertilizer regulation and continually invests in stormwater upgrades. The Town believes fertilizer regulations and stormwater upgrades are difficult to quantify for nitrogen reduction purposes and have decided not to rely or include those efforts towards TMDL compliance. MassDEP supports the implementation of fertilizer regulations and stormwater upgrades, but agree that they are hard to quantify towards TMDL compliance. Additionally, Barnstable's fertilizer regulation appears to overall provide best management practices and performance standards rather than prohibit fertilizer use, making it even more difficult to quantify the actual reduction.

The Town should continue to work towards a "western solution" to address the respective needs of Popponesset Bay and the Three Bays embayments. The Town should continue to consider alternative partnerships and solutions to assure the Town meets the TMDLs and water quality needs in those embayments.

Lewis Bay
The Town plans to expand sewer collection through 1,081 parcels in the Lewis Bay Watershed. The BWPCF treats and discharges within the Lewis Bay watershed and the Town plans to decrease annual total nitrogen from 6 mg/l to 3 mg/l. As discussed in the Opportunities for Regional Cooperation section, the Town is collaborating with Yarmouth on wastewater solutions for the shared embayment; however, the CWMPs for each Town anticipate meeting the TMDL on their own should a partnership not develop.

Centerville River
The Town plans to expand sewer collection through 55% of the watershed's parcels. The watershed septic reduction equivalency of the Centerville River Watershed sewer expansion will exceed the MEP nitrogen reduction target. The Town plans to execute the majority of this sewering in Phase 1.

Three Bays
The Town plans to expand sewer collection into 66% of the watershed's parcels. The watershed septic reduction equivalency of the Three Bays Watershed sewer expansion will not meet the MEP nitrogen reduction target. The Town is proposing several non-traditional demonstration Projects in the watershed with a focus of a reduction of the nitrogen load to the Marston's Mills River. The DCWMP includes six (6) non-traditional demonstration initiatives: Cranberry Bog Restoration Project, Mill Pond Dredging Project, Warren's Cove Dredging and Aquaculture Project, Sampson's Island Dredging Project, Horse Farm Permeable Reactive Barrier (PRB) Project, and the Innovative Alternative Technologies (I/A Systems) Project. With the exception of Sampson's Island Dredging

Project, all non-traditional initiatives are in the feasibility and Project design stage. The DCWMP acknowledges that the conventional approach does not meet the target nitrogen reduction (even accounting for Sandwich's portion of the load). The DCWMP states that the remaining load can be addressed through these non-traditional approaches; however, there should be a conventional contingency plan provided in the event that the non-traditional approaches do not produce the desired results.

The BCWC is assisting the Town with the Cranberry Bog Restoration Project, I/A Systems Project, and the Horse Farm PRB Project. The BCWC is currently working with the cranberry bog farmers to frame a demonstration Project that would restore wetlands in certain areas of the bogs for enhanced nitrogen attenuation without adversely affecting the ability to farm the bogs. Based on an SMAST study, the Town believes that a dredging Project would increase the residence time of an on-site pond, which would improve nitrogen attenuation. The Town would like to dredge Warren's Cove back to its sandy layer. Hypothetically, this may remove the nitrogen contribution from the decayed benthic layer and create and environment for local aquaculture, leading to enhanced nitrogen removal. The Cranberry Bog Restoration Project, Mill Pond Dredging Project and Warren's Cove Dredging Project are ecological restoration Projects with potential water quality benefits. The Projects have several benefits with respect to different aquatic species and public health and safety. As such, the Town should assure to gain permitting approval from all applicable regulatory agencies. As the Town moves from planning to permitting, the Town should work with MassDEP to form a water quality-monitoring plan and discuss the sustainability of the proposed water quality effects. Adequate monitoring data before and after the implementation of theses interventions facilitates the assessment of potential enhanced nitrogen attenuation and water quality benefits. At the minimum, monitoring plans should consider use of nearby monitoring station locations used for the MEP, utilized an adequate number of upgradient and downgradient monitoring stations to capture the effect of the intervention, and the testing of the same parameters used in the MEP according to the existing MEP Quality Assurance Project Plan (QAPP).

The Sampson's Island Dredging Project is a three-phase, three-year ecological restoration Project that will widen the channel width by approximately 400 feet to improve flushing and navigation in Cotuit Bay. The Town plans to complete the Project in winter 2020. MassDEP will consider monitoring data taken before the start of the intervention conducted incongruent with MEP standards. The Town should develop a monitoring plan for MassDEP approval to estimate the nitrogen attenuation impact of the Project moving forward.

Barnstable and BCWC are in the planning and feasibility stage for a PRB demonstration Project to investigate the interception of groundwater from a horse farm that contributes high loads of nitrogen during rainfall events. The DCWMP did not mention aboveground stormwater management in the description of this Project; as the Project is formed, aboveground stormwater management should be considered in an effort to capture nitrogen loads from the farm above and below the ground surface. BCWC is also collaborating with the Massachusetts Alternative Septic System Test Center (MASSTC) to create a demonstration Project to install and monitor I/A systems in a residential neighborhood. BCWC has teamed with the Nature Conservancy in this effort to develop a financing plan in creating a roadmap for widespread replacement of standard Title 5 septic systems with I/A septic systems. MassDEP will continue to work with BCWC and the Town as the demonstration Project continues to take form. All demonstration Projects involving I/A systems without general approval must coordinate with MassDEP's I/A program as part of the MassDEP I/A approval process. As the Town, BCWC, and the Nature Conservancy develop a financing plan, the Project team should factor in that the MassDEP expects any I/A initiative for

TMDL compliance and nitrogen reduction to be municipally managed. This will help assure that maintenance and required monitoring meets an acceptable quality standard.

Barnstable Harbor

Barnstable Harbor does not have a TMDL. The embayment has assimilative capacity for nitrogen with the exception of the Millway Subwatershed. The Draft MEP report indicates a 65% (4.7 kg/day-N) reduction in septic load for the Millway Subwatershed. The Town is planning to expand sewers into 370 parcels within the Millway Subwatershed. The watershed septic reduction equivalency of the Millway Subwatershed sewer expansion will exceed the MEP nitrogen reduction target.

Halls Creek Watershed

Halls Creek was evaluated as part of the Lewis Bay MEP report and TMDL. The MEP model shows the Halls Creek embayment system to have assimilative capacity for nitrogen. The Town plans to sewer a residential neighborhood located in the southwestern corner of the watershed to address pond protection considerations, water supply protection considerations, flood zone considerations, and economic development needs. The Town has already installed sewers in the uppermost section of the watershed.

Rushy Marsh Pond

Rushy Marsh Pond has a relatively low nitrogen load from its watershed. The watershed is small and has a large percentage of undeveloped area. According to the 2006 MEP report, its nitrogen enrichment may not be anthropogenic, but rather caused by the very low tidal exchange rate as the barrier beach restricts the inlet to Nantucket Sound. In 2012, the Town attempted to implement inlet widening to promote better flushing with a 10-foot wide box culvert in the southern portion of the basin, but the inlet did not maintain its width. Due to the tidal prism and the rate of littoral sand transport along the beach, a stable inlet is not feasible without extensive maintenance and hard structures such as jetties or extended pipe within the surf zone. MassDEP supports the Town's plan to focus restoration efforts towards other watersheds.

Popponesset Bay

As discussed in the Opportunities for Regional Cooperation section, the Town has an IMA with Mashpee and Sandwich to develop methodologies, strategies, and further agreements on nitrogen trading and monitoring responsibilities. The DCWMP relies on the formation of a "western solution" to address water quality and nitrogen reduction needs for the watershed. MassDEP will look to the 2025 Adaptive Management Report for a refinement of the plan for Popponesset Bay.

Adaptive Management

MassDEP views adaptive management as a certain amount of flexibility to recognize alternative approaches that allow for mid-course corrections in the implementation of a recommended plan. The Barnstable DCWMP is a plan Projected to meet TMDL compliance and the reliance on adaptive management is solely for the refinement of the existing plan amidst several variables that exist today. The Town plans to submit a 2025 Adaptive Management Report. MassDEP will look towards that report for further explanation of the plan for Phase 2 sewering, an update on non-traditional demonstration Projects, an update on disposal capacity expansion, and either materialization of a "western solution" or refinement of the plan for the Shoestring Bay Subwatershed of Popponesset Bay and the Cotuit Bay Subwatershed of the Three Bays Watershed.

Conclusion

The Barnstable DCWMP is a well-defined step forward. MassDEP commends Barnstable's efforts in addressing the Town's nitrogen management in a phased approach focusing not only on nutrient reduction but economic development, water supply protection, coastal resilience, and pond protection. MassDEP recognizes the effort of the Town to maintain existing infrastructure while expanding. MassDEP is supports the Town's approach to combine traditional approaches while engaging in demonstration Projects for non-traditional approaches and observing their effectiveness.

As the Town is aware, the disposal capacity limitation is a potential impediment to the Town's progress. MassDEP looks forward to the completion of the study of the existing disposal beds and the permitting and construction of new disposal sites. MassDEP will continue to provide regulatory guidance during the process. MassDEP recognizes that the DCWMP is clearly the result of hard work and thoughtful deliberation. Furthermore, MassDEP believes that the DCWMP will serve as the basis of a sound and innovative plan that will accommodate both the needs of the Town and MassDEP. MassDEP looks forward to working cooperatively with Barnstable, as both parties have in numerous past occasions, in order to achieve the goal of habitat restoration that we both ardently desire.

Miscellaneous Comments/Edits:

1. Table 2-3 indicates that Threshold TN Concentrations for the Barnstable Harbor Sentinel Station is "To Be Determined". The MEP Report indicates that the threshold concentration is the average of the bioactive nitrogen concentrations at Stations BM-11, BM-13, and BSH-4 and is set a 0.16 mg/L. The additional sentinel station in the Millway (as shown in Figure VIII-3 of the MEP Report) has a threshold concentration of 0.21 mg/L.

2. In Section 2.2.1.2, it mentions that the 208 Plan Update identifies stormwater contributing 23% of the controllable nitrogen load to the Three Bays watershed. This is a significantly higher figure than identified in the MEP report for this watershed. The difference in the numbers should be explained or reconciled.

3. In general, the discussion about stormwater should discuss how stormwater improvements, particularly in leaching catch basins, may or may not treat for total nitrogen.

4. The Town should consult with MassDEP's Air Quality section to determine if there are any permitting requirements for the proposed replacement and additional generators.

5. On Page 2-23 there is a typographical error in the last line of the first paragraph stating "Error! Reference Source not found".

6. On Figure 2-12: Nitrogen Hot Spots, most of the Town is not color coded. Perhaps this figure could be better described.

7. In Section 5.2.1.1.1 Nutrient Removal, the reference should be to Appendix QQ.

8. In Table 5-5, is there an update on the status of Mary Dunn, Campground and Aunt Betty's Ponds?

Bureau of Waste Site Cleanup Comments:

EENF #16148 – Based upon the information provided, the Bureau of Waste Site Cleanup (BWSC) searched its databases for disposal sites and release notifications that have occurred at or might impact the proposed Project area. A disposal site is a location where there has been a release to the environment of oil and/or hazardous material that is regulated under M.G.L. c. 21E, and the Massachusetts Contingency Plan [MCP – 310 CMR 40.0000].

The proposed Comprehensive Wastewater Management Plan is a three-phase Project spanning thirty years. There are many MCP sites located near and possibly within the proposed Project areas. Some of these sites have been closed, but other sites require on-going response actions and reporting until final closure under the MCP. A list of all MCP sites will not be presented here. Interested parties may view a map showing the location of BWSC disposal sites using the MassGIS data viewer (Oliver) at: http://maps.massgis.state.ma.us/map_ol/oliver.php Under "Available Data Layers" select "Regulated Areas", and then "DEP Tier Classified 21E Sites". MCP reports and the compliance status of specific disposal sites may be viewed using the BWSC Waste Sites/Reportable Release Lookup at: https://eeaonline.eea.state.ma.us/portal#!/search/wastesite

The Project Proponent is advised that if oil and/or hazardous material are identified during the implementation of this Project, notification pursuant to the Massachusetts Contingency Plan (310 CMR 40.0000) must be made to MassDEP, if necessary. A Licensed Site Professional (LSP) should be retained to determine if notification is required and, if need be, to render appropriate opinions. The LSP may evaluate whether risk reduction measures are necessary if contamination is present. The BWSC may be contacted for guidance if questions arise regarding cleanup.

Spills Prevention. A spills contingency plan addressing prevention and management of potential releases of oil and/or hazardous materials from pre- and post-construction activities should be presented to workers at the site and enforced. The plan should include but not be limited to, refueling of machinery, storage of fuels, and potential on-site activity releases. Information related to spills prevention best practices may be obtained at the following web page: https://www.mass.gov/files/spill_prevention.pdf?

Bureau of Air and Waste (BAW) Comments:

Air Quality. Construction and operation activities shall not cause or contribute to a condition of air pollution due to dust, odor or noise. To determine the appropriate requirements please refer to:

310 CMR 7.09 Dust, Odor, Construction, and Demolition
310 CMR 7.10 Noise

Construction-Related Measures

MassDEP requests that all non-road diesel equipment rated 50 horsepower or greater meet EPA's Tier 4 emission limits, which are the most stringent emission standards currently available for off-road engines. If a piece of equipment is not available in the Tier 4 configuration, then the Proponent should use construction equipment that has been retrofitted with appropriate emissions reduction equipment. Emission reduction equipment includes EPA-verified, CARB-verified, or MassDEP-approved diesel oxidation catalysts (DOCs) or Diesel Particulate Filters (DPFs). The Proponent should maintain a list of the engines, their emission tiers, and, if applicable, the best available control technology installed on each piece of equipment on file for Departmental review.

Massachusetts Idling Regulation
The ENF reports that the Project Proponent proposes simply to "minimize idling." MassDEP reminds the Proponent that unnecessary idling (i.e., in excess of five minutes), with limited exception, is not permitted during the construction and operations phase of the Project (Section 7.11 of **310 CMR 7.00**). With regard to construction period activity, typical methods of reducing idling include driver training, periodic inspections by site supervisors, and posting signage. In addition, to ensure compliance with this regulation once the Project is occupied, MassDEP requests that the Proponent install permanent signs limiting idling to five minutes or less on-site.

Climate Change Comments:
Climate Change – Greenhouse Gas Emissions**.** Pursuant to the Global Warming Solutions Act of 2008 (GWSA) (Chapter 298 of the Acts of 2008) and the Commonwealth's Clean Energy and Climate Plan the Commonwealth has established economy-wide greenhouse gas (GHG) emission reduction limits for Massachusetts that will achieve reductions of 25 percent below statewide 1990 GHG emission levels by 2020 and 80 percent below statewide 1990 GHG emission levels by 2050. Furthermore, Section 7 of the GWSA amended Section 61 of Chapter 30 of the Massachusetts General Laws by inserting, "in considering and issuing permits, licenses and other administrative approvals and decisions, the respective agency, department, board, commission or authority shall also consider reasonably foreseeable climate change impacts, including additional greenhouse gas emissions, and effects, such as predicted sea level rise."

The Proponent should consider potential GHG impacts (e.g., energy demand, use of renewable energy sources, transportation modes, etc.) of its Project in the context of furthering the Commonwealth's goals and recommended GHG mitigation policies in the *Clean Energy and Climate Plan for 2020*. Additional information on the Commonwealth's efforts to reduce GHG emissions can be found at: http://www.mass.gov/eea/air-water-climate-change/climate-change/massachusetts-global-warming-solutions-act/.

Sea Level Rise. The Project's location will subject it to the impacts of climate change-induced sea level rise. MassDEP recommends that the Proponent consider various scenarios and future conditions that are beyond the scope of the 100-year flood elevations designated in the Flood Insurance Rate Maps (FIRMs) to evaluate impacts such as sea level rise, shoreline change, and hurricane inundation. Recognizing the vulnerability of the coastline in the vicinity of the proposed Project site, the Proponent should be prepared to address the impacts of sea level rise and damage to property, businesses, and infrastructure over the lifespan of the Project. The potential risks to the Project should be evaluated based on sea level rise scenarios developed by known authorities, including the Massachusetts Coastal Zone Management Agency or community/localized studies.

One recommended resource is the Massachusetts Sea Level Rise and Coastal Flooding Viewer https://www.mass.gov/service-details/massachusetts-sea-level-rise-and-coastal-flooding-viewer. Please note that the viewer doesn't include all types of wastewater treatment and drinking water infrastructure.

Adaptation strategies should be considered to accommodate the effects of sea level rise and manage risk. Adding pre-disaster adaptation and post-disaster recovery measures will improve the Project resiliency to flooding and the impacts of extreme storm events. Please be aware that the Sea Level Rise and Coastal Flooding Viewer does not account for storm surge, waves, erosion and other dynamic factors, while FIRMs do not account for sea level rise, shoreline erosion, changes in the frequency and magnitude of storm events, etc. Therefore, it's important to review and consider

these combined with hurricane surge scenarios (which use current sea level) in order to plan for worst case scenarios and appropriate adaptation measures.

Climate Change – Adaptation. Section 7 of the Global Warming Solutions Act of 2008 (GWSA) (Chapter 298 of the Acts of 2008), amended Section 61 of Chapter 30 of the Massachusetts General Laws by inserting, "in considering and issuing permits, licenses and other administrative approvals and decisions, the respective agency, department, board, commission or authority shall also consider reasonably foreseeable climate change impacts, including additional greenhouse gas emissions, and effects, such as predicted sea level rise."

MassDEP recommends that the Proponent review and consider the data and recommendations identified in the 2011 Massachusetts Climate Change Adaptation Report issued by the Executive Office of Energy and Environmental Affairs (EEA) (http://www.mass.gov/eea/docs/eea/energy/cca/eea-climate-adaptation-report.pdf), the 2014 National Climate Assessment, specifically the Northeast region section, (https://nca2014.globalchange.gov/) and the 2017 U.S. Global Change Research Program Climate Science Special Report (https://science2017.globalchange.gov/) to address potential climate change impacts and adaptation measures feasible for implementation on the Project site. MassDEP also recommends that you check the following link for updates to the Massachusetts State Hazard Mitigation and Climate Adaptation Plan (https://resilientma.com/updates/) which is anticipated to be finalized in 2018. Once completed, this plan will include more usable data and information.

Wastewater & Drinking Water Treatment Facilities and Climate Change. The Proponent should consider the potential impacts of climate change as part of the planning, design and operation of the proposed expansion of the Headworks Facilities and upgrade of the WWTF. Wastewater treatment plants are among the largest energy consumers in many cities and towns across Massachusetts.

Therefore, minimizing the life-cycle operational costs and associated greenhouse gas emissions will have long-term economic and environmental benefits for the community and the Commonwealth.

MassDEP suggests review of the following resources, as well as any other governmental, industry, or research institute reports to identify GHG and energy reduction strategies, and climate resilience and adaptation measures that the Proponent, as feasible, should commit to implement or continue to explore upon completion of the MEPA review. The resources listed below under Implementation also include potential funding sources.

Planning and Design

- TR-16 – Guides for the Design of Wastewater Treatment Works (2011 Edition as Revised in 2016) issued by the New England Interstate Water Pollution Control Commission (NEIWPCC);
- BMP guidance documents (Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities EPA 832-R-10-005, September 2010) https://www.epa.gov/sites/production/files/2016-01/documents/p1008sbm.pdf;
- EPA's Emerging Technologies and for Wastewater Treatment and In-Plant Wet Weather Management (2013).

Assessment

- Energy Efficiency and Renewable Energy Opportunities at Water and Wastewater Facilities-http://www.mass.gov/eea/agencies/massdep/climate-energy/energy/water-utilities/energy-efficiency-at-water-and-wastewater-facilities.html

- EPA's Energy Efficiency in Water and Wastewater Facilities – 2013 https://www.epa.gov/sites/production/files/2017-06/documents/wastewater-guide.pdf;
- EPA's Climate Resilience Evaluation and Awareness Tool (CREAT) – 2016 https://www.epa.gov/crwu/creat-risk-assessment-application-water-utilities; and
- Massachusetts Municipal Vulnerability Preparedness Program - https://www.mass.gov/municipal-vulnerability-preparedness-program.

Implementation

- MassDEP's Clean Energy Results Program – Achieving Positive Cash Flow Through Energy Saving Upgrades at Water Infrastructure Facilities – 2014 http://www.mass.gov/eea/docs/dep/energy/cash-flow.pdf;
- Mass save® Municipal Energy Saving Program http://www.mass.gov/eea/docs/doer/green-communities/eap/mass-save-municipal-sector-sheet.pdf;
- Massachusetts Clean Energy Center http://www.masscec.com/get-clean-energy/government-and-non-profit;

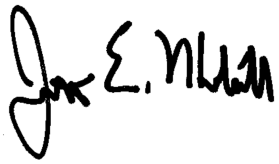
Proposed s.61 Findings

The "Certificate of the Secretary of Energy and Environmental Affairs on the Environmental Notification Form" may indicate that this Project requires further MEPA review and the preparation of an Environmental Impact Report. Pursuant to MEPA Regulations 301 CMR 11.12(5)(d), the Proponent will prepare Proposed Section 61 Findings to be included in the EIR in a separate chapter updating and summarizing proposed mitigation measures. In accordance with 301 CMR 11.07(6)(k), this chapter should also include separate updated draft Section 61 Findings for each State agency that will issue permits for the Project. The draft Section 61 Findings should contain clear commitments to implement mitigation measures, estimate the individual costs of each proposed measure, identify the parties responsible for implementation, and contain a schedule for implementation.

Other Comments/Guidance

The MassDEP Southeast Regional Office appreciates the opportunity to comment on this EENF. If you have any questions regarding these comments, please contact Jonathan Hobill at (508) 946-2870.

Very truly yours,



Jonathan E. Hobill,
Regional Engineer,
Bureau of Water Resources

JH/GZ

Cc: DEP/SERO

ATTN: Millie Garcia-Serrano, Regional Director
David Johnston, Deputy Regional Director, BWR
Gerard Martin, Deputy Regional Director, BWSC
Seth Pickering, Deputy Regional Director, BAW
Jennifer Viveiros, Deputy Regional Director, ADMIN

Brian Dudley, Chief, Wastewater Management, BWR
Andrew Osei, Wastewater Management, BWR
Dan Gilmore, Wetlands and Waterways, BWR
Mark Dakers, Solid Waste, BAW
Alison Cochrane, Solid Waste, BAW
Allen Hemberger, Site Management, BWSC

MASSWILDLIFE

DIVISION OF
FISHERIES & WILDLIFE

1 Rabbit Hill Road, Westborough, MA 01581
p: (508) 389-6300 | f: (508) 389-7890
MASS.GOV/MASSWILDLIFE

March 12, 2020

Kathleen A. Theoharides, Secretary
Executive Office of Environmental Affairs
Attention: MEPA Office
Anne Canaday, EEA No. 16148
100 Cambridge Street
Boston, Massachusetts 02114

Project Name:	*Comprehensive Wastewater Management Plan*
Proponent:	*Town of Barnstable*
Location:	*Town-Wide*
Document Reviewed:	*Environmental Notification Form*
EEA No.:	*16148*
NHESP No.:	*12-30930*

Dear Secretary Theoharides:

The Natural Heritage & Endangered Species Program of the Massachusetts Division of Fisheries & Wildlife (the "Division") has reviewed the *Environmental Notification Form* (dated January 2020) for the Town of Barnstable's Comprehensive Wastewater Management Plan (CWMP; the Project) and would like to offer the following comments regarding state-listed species and their habitats.

The Town of Barnstable's ponds, bays and estuarine waters provide critical foraging, breeding, migration and over-wintering habitats for a suite of state-listed rare species. We commend the Town for its efforts to improve water quality within these critical habitats, and for its consideration of both traditional and non-traditional approaches to wastewater and nutrient management.

Portions of Barnstable are mapped as Priority Habitat for state-listed rare species. All projects proposed within Priority Habitat, which are not otherwise exempt from review pursuant to 321 CMR 10.14, require review through a direct filing with the Division pursuant to the Massachusetts Endangered Species Act (M.G.L. c. 131A) and its implementing regulations (MESA; 321 CMR 10.00). The MESA is administered by the Division and prohibits the Take of state-listed species, which is defined as "in reference to animals…harm…kill…disrupt the nesting, breeding, feeding or migratory activity…and in reference to plants…collect, pick, kill, transplant, cut or process…Disruption of nesting, breeding, feeding, or migratory activity may result from, but is not limited to, the modification, degradation, or destruction of Habitat" of state-listed species (321 CMR 10.02).

To the extent possible, the Division has evaluated and provided comments below on the recommended Phase 1 actions outlined within the ENF (Sections 5.1.2 and 5.2.4.2). For many of the proposed actions,

the Division has not yet received a direct filing pursuant to the MESA; therefore, the comments provided below should be considered preliminary in nature.

Construction of New Sewer Infrastructure

The Division notes that wastewater collection systems proposed within Priority Habitat may be exempt from MESA review pursuant to 321 CMR 10.14 (6) and or (10), which state that "[t]he following Projects and Activities shall be exempt from the requirements of 321 CMR 10.18 through 10.23…"

> *[6] construction, repair, replacement or maintenance of septic systems, private sewage treatment facilities, utility lines, sewer lines, or residential water supply wells within existing paved areas and lawfully developed and maintained lawns or landscaped areas, provided there is no expansion of such existing paved, lawn and landscaped areas;*
>
> *[10] installation, repair, replacement, and maintenance of utility lines (gas, water, sewer, phone, electrical) for which all associated work is within ten feet from the edge of existing paved roads…;*

The complete list of MESA filing exemptions may be found on the Division's website. We would encourage the Town to examine design alternatives which avoid and minimize impacts to Priority Habitat, including re-use of existing paved, developed and or landscaped areas wherever possible. For any proposed work within Priority Habitat, the Town should proactively consult with the Division to confirm whether proposed work is exempt from MESA review or will require review through a direct filing with the Division.

Modifications to Existing Barnstable Water Pollution Control Facility (BWPCF)

The Division notes that the Town's existing wastewater treatment facility does not appear to be located within the Priority Habitat of state-listed rare species, as indicated in the Massachusetts Natural Heritage Atlas (14th Edition). Therefore, the Division anticipates that any proposed upgrades to the BWPCF would not require review for compliance with the MESA.

New Discharge Site

The ENF states that a new effluent disposal site(s) will need to be identified, permitted and constructed to accommodate flows from proposed sewer areas. As provided above, any new effluent disposal site(s) proposed within Priority Habitat would require review for compliance with the MESA. The Division encourages the Town to examine alternative locations for the proposed disposal site(s) that are located outside of, or that otherwise avoid and minimize disturbance within, Priority Habitat. For any proposed work within Priority Habitat, the Division would encourage the Town to contact the Division in advance of a formal filing to proactively address any rare species concerns and discuss potential MESA permitting pathways.

Joint Base Cape Cod

The ENF states that Barnstable, Bourne, Falmouth, Mashpee and Sandwich are conducting a regional evaluation of wastewater discharge options on Joint Base Cape Cod (JBCC). Specifically, the ENF also states that the Towns are discussing the possibility of utilizing the existing wastewater treatment facility at JBCC – which currently consists of a treatment plant and four infiltration basins northwest near the Cape Cod Canal – as a regional facility.

The Division notes that, with the exception of the treatment plant itself, the existing JBCC wastewater treatment facilities and their surrounds appear to be located within Priority Habitat. Any proposed upgrades to or expansions of these facilities would require review by the Division for compliance with the MESA.

In addition, the Division notes that the four existing infiltration basins at JBCC near the Cape Cod Canal are located within the Camp Edwards Wildlife Management Area. Chapter 47 of the Acts of 2002 transferred the care, custody and control of the northern 15,000 acres of JBCC to the Division as the Camp Edwards Wildlife Management Area to conserve fish and wildlife resources for the benefit of the citizens of the Commonwealth. Any proposed projects or activities within the Camp Edwards Wildlife Management Area, including but not limited to any potential upgrades to or expansion of existing wastewater treatment facilities, would require review and approval by the Division.

The Town should contact the Division as soon as possible to discuss this proposal. In advance, we request that the Town provide more detailed information about this proposal to the Division for review, including but not limited to whether it would include upgrades to or expansion of existing JBCC effluent disposal facilities. In advance, we request that the Towns evaluate alternative locations for this proposal that avoid and minimize work within Priority Habitat.

Cotuit Cut / Sampson's Island Dredging

The Division reviewed and determined (October 6, 2009) that this project, as proposed, would not result in a Take of state-listed species. Therefore, the Division has no additional comments on this project at this time.

Non-Traditional Approaches for Marstons Mills River System: Mill Pond Dredging

The ENF states that the Town will pursue dredging of Mill Pond as a component of its non-traditional approaches to nutrient management. The Division notes that Mill Pond is mapped as Priority Habitat for a state-listed fish species. Based on a review of information submitted to the Division to date and information currently contained in our database, the Division anticipates that this project, as proposed, **will likely result in a Take (321 CMR 10.18 (2)(b))** of state-listed species. Projects resulting in a Take of state-listed species may only be permitted if they meet the performance standards for a Conservation and Management Permit (CMP; 321 CMR 10.23). In order for a project to qualify for a CMP, the applicant must demonstrate that the project has avoided, minimized and mitigated impacts to state-listed species consistent with the following performance standards: (a) adequately assess alternatives to both temporary and permanent impacts to the state-listed species; (b) demonstrate that an insignificant portion of the local population will be impacted; and (c) develop and agree to carry out a conservation and management plan that provides a long-term net benefit to the conservation of the state-listed species.

The Town has been consulting with the Division to proactively address state-listed species concerns and MESA permitting associated with this project. Coordination and consultation with the Division remain ongoing at this time. As the MESA review process for this project remains ongoing, no work or activities associated with this project may occur until the Division has made a final decision relative to the CMP.

We appreciate the opportunity to comment on this project. If you have any questions about components of this letter related to MESA, please contact Jesse Leddick, Chief of Regulatory Review, at jesse.leddick@mass.gov or 508-389-6386. If you have any questions about the components of this letter

related to the Camp Edwards Wildlife Management Area, please contact Jason Zimmer, Southeast District Manager, at jason.zimmer@mass.gov or 508-759-3406. We look forward to working with the Town to address the comments provided herein and further its efforts to improve water quality in the Town of Barnstable's ponds, bays and estuarine waters.

Sincerely,

Everose Schlüter, Ph.D.
Assistant Director

cc: Daniel Santos, Barnstable Department of Public Works
Town of Barnstable Board of Selectmen
Town of Barnstable Planning Board
Town of Barnstable Conservation Commission
Jason Zimmer, MassWildlife Southeast District Manager

Charles D. Baker, Governor
Karyn E. Polito, Lieutenant Governor
Stephanie Pollack, MassDOT Secretary & CEO

massDOT
Massachusetts Department of Transportation

March 27, 2020

Kathleen Theoharides, Secretary
Executive Office of Energy and Environmental Affairs
100 Cambridge Street, Suite 900
Boston, MA 02114-2150

RE: Barnstable: Barnstable Comprehensive Wastewater Management Plan – EENF
(EEA #16148)

ATTN: MEPA Unit
Anne Canaday

Dear Secretary Theoharides:

On behalf of the Massachusetts Department of Transportation, I am submitting comments regarding the Expanded Environmental Notification Form for the Barnstable Comprehensive Wastewater Management Plan project in Barnstable, as prepared by the Office of Transportation Planning. If you have any questions regarding these comments, please contact J. Lionel Lucien, P.E., Manager of the Public/Private Development Unit, at (857) 368-8862.

Sincerely,

David J. Mohler
Executive Director
Office of Transportation Planning

DJM/jll

Ten Park Plaza, Suite 4150, Boston, MA 02116
Tel: 857-368-4636, TTY: 857-368-0655
www.mass.gov/massdot

cc: Jonathan Gulliver, Administrator, Highway Division
Patricia Leavenworth, P.E., Chief Engineer, Highway Division
Mary Joe Perry, District 5 Highway Director
Neil Boudreau, Assistant Administrator of Traffic and Highway Safety
Planning Board, Town of Barnstable
Cape Cod Commission

Charles D. Baker, Governor
Karyn E. Polito, Lieutenant Governor
Stephanie Pollack, MassDOT Secretary & CEO

massDOT
Massachusetts Department of Transportation

MEMORANDUM

TO: David Mohler, Executive Director
Office of Transportation Planning

FROM: J. Lionel Lucien, P.E, Manager
Public/Private Development Unit

DATE: March 27, 2020

RE: Barnstable Comprehensive Wastewater Management Plan – EENF
(EEA #16148)

The Public/Private Development Unit (PPDU) has reviewed the Expanded Environmental Notification Form (EENF) for the Barnstable Comprehensive Wastewater Management Plan in Barnstable. The town-wide sewer expansion project consists of adding 190 miles of new sewer main and several above-ground pump station structures.

The project will require a Non-Vehicular Access Permit from MassDOT. The new sewer lines will run along and cross state highways Route 132 and Route 28, and the state jurisdictional portions of Route 6A and Phinney's Lane. Though the new sewer lines will not generate traffic, temporary traffic impacts related to the construction of the project may occur. Accordingly, the proponent should develop a Traffic Management Plan (TMP) to be reviewed and approved by MassDOT. The proponent may also wish to adopt a Temporary Traffic Control Plan (TTCP), to be developed consistent with FHWA and MassDOT guidelines.

MassDOT recommends that no further environmental review be required based on transportation issues. The details of the above and any other access-related issues can be addressed during the permitting process for the project. If you have any questions regarding these comments, please contact me at (857) 368-8862 or Nicholas Zavolas at (857) 368-8856.

Ten Park Plaza, Suite 4150, Boston, MA 02116
Tel: 857-368-4636, TTY: 857-368-0655
www.mass.gov/massdot

March 30, 2020

Secretary Kathleen Theoharides
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Anne Canaday, EEA No. 11333
100 Cambridge Street, Suite 900
Boston, MA 02114

Dear Secretary Theoharides:

The Division of Marine Fisheries (MA DMF) has reviewed the Notice of Project Change (NPC) for the Town of Bourne's Integrated Solid Waste Management Facility.
The project was reviewed with respect to potential impacts to marine fisheries resources and habitat.

Based on the information provided, MA DMF has no recommendation for sequencing, timing, or methods that would avoid or minimize impact at this time.

Questions regarding this review may be directed to John Logan in our New Bedford office at (508) 742-9722.

_____

John Logan, Ph.D.
MA Division of Marine Fisheries
836 South Rodney French Boulevard
New Bedford, MA 02744
(508) 742-9722
http://www.mass.gov/eea/agencies/dfg/dmf/

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BARNSTABLE, MASSACHUSETTS 02630

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CAPE COD COMMISSION

Via Email

March 12, 2020
Kathleen A. Theoharides, Secretary of Energy and Environmental Affairs
Executive Office of Energy and Environmental Affairs
Attn: MEPA Office, Eva Anne Canaday, MEPA Analyst
100 Cambridge Street, Suite 900, Boston, MA 02114

Re: Environmental Notification Form — EEA No. 16148 (CCC File No. 20037)
Barnstable Comprehensive Wastewater Management Plan

Dear Secretary Theoharides:

Thank you for the opportunity to comment on the above-referenced ENF.

Commission staff believe the ENF sufficiently details the scope of the Town's Plan and addresses the appropriate environmental issues that will be addressed through subsequent MEPA review. Further, staff support the Town's request for and the Secretary's grant of a Single EIR, as the ENF describes and analyzes a wide variety of alternatives, provides sufficient environmental baseline information, and includes planning and design to avoid environmental impacts. The overall purpose of the Plan is to protect or improve a variety of natural resources from environmental degradation: coastal waters, freshwater ponds and drinking water supplies.

The Cape Cod Commission reserves further substantive comment for later stages of MEPA review. Commission staff have consulted with and provided comments to the Town as the Town has developed the Plan. Ultimately, after MEPA review concludes, the Cape Cod Commission will review the Plan to determine its consistency with the Section 208 Area-wide Water Quality Plan for Cape Cod.

Commission staff are available to discuss any questions you might have about these comments.

Sincerely,

Kristy Senatori

Kristy Senatori
Executive Director

Cc: Project File
Mark Ells, Barnstable Town Manager, via email
Dan Santos, Barnstable DPW Director, via email
Barnstable Cape Cod Commission Representative via email
Cape Cod Commission Chair via email
Cape Cod Commission Committee on Planning and Regulation Chair via email